Department of Computing Sciences

Interactive Visualisation of Electricity Usage in Smart Environments

by

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Abstract

Saving electricity is a trending topic due to the electricity challenges that are being faced globally. Smart environments are environments that are equipped with physical objects, which include computers, sensors, actuators, smartphones, and wearable devices interconnected together through the Internet of Things. The Internet of Things provides a network to achieve communication, and computation abilities to provide individuals with smart services anytime, and anywhere. Rapid developments in information technology have increased the number of smart appliances being used, leading to increased electricity usage. Devices and appliances in Smart Environments continue to consume electricity even when not in use, because of the standby function. The problems arise as the electricity consumption of the standby function accumulates to large amounts. Effective communication through visualisation of the electricity consumption in a Smart Environment provides a viable solution to reducing the consumption of electricity.

This research aimed to design and develop a visualisation system that successfully communicates electricity consumption to the user using a variety of visualisation techniques. The Design Science Research Methodology was used to address the research questions and was used to iteratively design and develop an energy usage visualisation system. The visualisation system was created for the Smart Lab at the Nelson Mandela University's Department of Computing Sciences. A usability study was conducted to assess the usability and efficacy of the system. The system was found to be usable and effective in communicating power usage to potential customers, since the participants were able to complete the tasks in a short amount of time. The positive results show that visualisation can aid in communicating electricity usage to customers, resulting in a possible reduction in electricity consumption and improved decision-making.

Keywords: *Human-centred computing, Human-Computer Interaction (HCI), HCI design and evaluation methods, Visualisation, Interaction Design*

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"...And as we let our own light shine, we unconsciously give other people permission to do the same. As we are liberated from our own fear, our presence automatically liberates others " - Marianne Williamson

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Glossary

AOI	Areas of interest
CNN	Convolutional Neural Network
DSRM	Design Science Research Methodology
DSR	Design Science Research
EVDSL	Electricity Visualisation Dashboard for a Smart Lab
HEMS	Home energy management systems
ICT	Information Communication Technology
IV	Information Visualisation
kWh	kilowatt/hour
LoRaWAN	Low Power Wine Area Networking
InfoQual	Information Quality
IntQual	Interface Quality
IoT	Internet of Things
PSSUQ	Post Study Usability Questionnaire
UPS	Uninterruptible power supply
RFID	Radio Frequency Identification
RQ	Research Question
SE	Smart environment
SysUse	System Usefulness
WLAN	Wireless Local Area Network
Wi-Fi	Wireless Fidelity

Chapter 1: Introduction

1.1. Background

Electricity costs continue to increase. In South Africa, a 5.23% average price increase of electricity was implemented from April 2018, and a 7.32% increase for municipalities effective as of 1 July 2018 was approved by the National Energy Regulator of South Africa (Eskom.co.za, 2019). As a result, there has been an increased interest in finding ways to monitor and control electricity usage.

A Smart Environment (SE) can be defined as an environment that can acquire and apply knowledge about an environment and modify it to improve the users' experience in the environment (Balandin & Waris, 2009). A SE is an integrated environment where sensor-enabled technologies work together to make the life of the inhabitant more comfortable (Ahmed et al., 2016). Smart refers to the advanced technologies that have some degree of artificial intelligence (Marikyan et al., 2019a), which includes the ability to obtain and apply knowledge (Ahmed et al., 2016). Ahmed et al. (2016) concluded that a SE is an environment that can obtain and apply knowledge about its inhabitants and adapt to the environment according to their needs. SEs include Smart Homes, Smart Buildings, Smart Offices, Smart Farms, Smart Hospitals, and Smart Meeting Rooms.

Rajguru et al., (2015) stated that SEs can be viewed as an application of the Internet of Things (IoT) technologies in the home environment. IoT refers to the network of physical objects interconnected; these physical objects include computers, sensors, buildings, actuators, smartphones, structures, wearable devices, homes, vehicles, and energy systems. IoT guarantees communication between different types of systems and applications to provide increasingly smart, dependable, and secure services (Mohanty et al., 2016).

The environment becomes smart because of the IoT technology included in it, making it possible to monitor and manage electricity usage in the home (Alur et al., 2015). Large amounts of data are collected by the IoT end nodes with unique sensors, such as temperature sensors, light sensors, and humidity sensors that can be used to monitor electricity consumption (Wei et al., 2018). If the data collected from the sensors can be visualised, it helps users gain an understanding of the data. Previous research has shown that comprehensive and real-time visualisation of electricity is vital for users, as they can see when there is a wastage in their electricity usage (Fan et al., 2017).

Connectivity is possible anywhere and anytime in a SE but comes at the cost of increased electricity consumption (Li et al., 2014). Continuous developments in data communication technology ensure the connectivity of devices, however, continuous connectivity contributes to a large portion of electricity consumption (Carroll & Heiser, 2010). This consumption continues to increase as more developments occur (Li et al., 2014).

The role of SE technologies to improve energy efficiencies is becoming increasingly important (Bhati et al., 2017). SE provides several advantages; some of which include increased comfort, quality of life, reduction in operating costs, and motivating users to use resources, including energy usage, more efficiently (Desai & Upadhyay, 2014). This study will focus on energy usage in the form of electricity usage in a SE.

Idle networked and connected smart devices in a SE contribute to electricity usage. The continuous connections, as is the case of smart devices, cause an increase in electricity usage, even when the devices are in standby mode (IEA, 2014). Monitoring electricity consumption, therefore, becomes essential to understand the sources of electricity usage and take the appropriate action to save electricity (Hertzog & Swart, 2018).

Previous research was conducted by (Paetz et al., 2012) on understanding peoples' insights and reactions to electricity saving using SE technology and concepts, which included smart meters and devices. Several systems have been developed to address monitoring and communication of the increase in electricity usage in SEs, however, the effectiveness of the communication of the electricity usage to the user could be improved. This research found positive reactions on SEs, which could help reduce electricity usage and eventually reduce electricity costs. Thu et al. (2017) stated in their research that when appropriate visualisation methods were applied, they could effectively motivate and improve behavioral-specific abilities to change users' behaviours. Developing a visual tool with suitable visualisation methods to inform users of their electricity usage and motivate them to make changes in their electricity consumption, could effectively reduce electricity usage. Visualisation of data plays a vital role, as it can communicate findings in a way that is easily and quickly understood by the user (Ambrose & James, 2017). Users need to understand their electricity usage, to know where they are wasting electricity, and what their consumption is in real-time (Fan et al., 2017).

1.2. Problem Statement

Based on the problem descriptions, the problem statement for this research study is:

"*Systems have been developed to assist in monitoring and communicating the electricity usage in smart environments, but these systems lack effectiveness in the communication of the electricity usage, as well as increasing user engagement with the system for longer periods*".

1.3. Research Aim and Contribution

The purpose of this research study is defined as follows:

"*To design and develop an effective information visualisation tool that can be used to effectively communicate the electricity usage in smart environments and subsequently lead to a reduction in electricity wastage*".

The research study aimed to contribute to visualisation technology that can assist users to become more conservative in their electricity consumption in SEs. Visualisation has demonstrated that it can be used as an incentive to encourage electricity conservation as well as be utilised as a mechanism to reduce the excessive use of electricity (Stinson et al., 2015). Visualisation will keep users informed of their detailed electricity usage. This study makes a theoretical contribution by looking at the most effective visualisation techniques for visualizing power usage.

1.4. Research Questions

The main research question that will be addressed in this study is:

RQ_m: How should electricity usage in a SE be effectively visualised?

The following subsidiary questions were formulated to answer the main research question:

RQ_1. How does a SE impact electricity usage?

RQ_2. How is the electricity usage in a SE currently visualised?

RQ_3. Which are the most effective techniques for visualising electricity usage in a SE?

RQ_4. How should a tool be designed to effectively support visualisation of electricity usage in a SE?

RQ_5. How usable is the proposed visualisation tool?

1.5. Scope, Constraints, and Ethics

This research aimed to investigate how various visualisation techniques can be combined to effectively communicate electricity usage to SE users. The various visualisation techniques were used to encourage users to conserve or reduce electricity wastage in a SE.

The research was restricted to a dedicated computer lab, currently being converted into a Smart Lab. The Smart Lab will be the "Smart environment" mentioned throughout the study. The equipment and technology used in the Smart Lab are not all "smart", hence the electricity usage of not all appliances will be monitored.

The author followed the Nelson Mandela University ethical considerations and policies for conducting a research study. Ethical clearance was received from the University in accordance with the research ethics and policies, and the ethics clearance reference number is **H21-SCI-CSS-003** (Appendix 6). More details on the ethical procedures are provided in Chapter 5.

1.6. Research Methodology and Chapter Structure

The Design Science Research Methodology (DSRM) was used for this research. The various activities are included in the DSRM and are discussed in the following sections.

Explicate Problem: The DSRM process begins with identifying the problem, and at this stage, the problem is thoroughly investigated and analysed (Johannesson & Perjons, 2014). This step aims to answer RQ_1 and RQ_2, which are *"How does a SE impact electricity usage?",* and *"How is the electricity usage in a SE currently visualised?"*. To understand the problem, a literature review was conducted to cover topics such as SEs, visualisation, and existing systems in this domain. The advantages and shortfalls of the existing systems were reviewed, and the results of this step led to gathering requirements for the proposed tool.

Define Requirements: The Define Requirements activity highlights a solution to the problem identified in the first activity. The solution can be in the form of an artefact, and requirements for the artefact are gathered from the literature review and review of existing systems done in activity one (Johannesson & Perjons, 2014). This activity aimed to answer the third research question RQ_3: *"Which are the most effective techniques for visualising electricity usage in a smart environment?"*

Design and Develop Artefact: The Design and Develop Artefact activity aims to develop the artefact, which addresses the problems identified and meets the specified requirements. The design of the artefact included determining its functionality and structure (Johannesson & Perjons, 2014). This activity was achieved through the application of different technologies, methods, and theories to solve the problem (Geerts, 2011). The design of the proposed tool was done several times to refine the design of the tool to increase its effectiveness with each iteration. This activity aimed to answer the fourth research question RQ_4: "*How should a tool be designed to effectively support the visualisation of electricity usage in a SE?*"

Demonstrate Artefact: The Demonstrate Artefact involved using the developed artefact in an illustration or real-life case (proof of concept), to show the feasibility of the artefact. The demonstration showed whether or not the artefact could solve the problem identified (Johannesson & Perjons, 2014). This activity aimed to answer the fifth research question RQ_5: *"How usable is the proposed tool?"*. This activity involved showing how the artefact is used to solve the explicated problem (Geerts, 2011).

Evaluate: The evaluate activity determined the extent to which the developed artefact met the specified requirements and solved the problem motivated by the research (Johannesson & Perjons, 2014). This activity aimed to answer the main research question (RQ_m): "*How should electricity usage be effectively visualised in a SE?".* This activity included the use of relevant metrics and evaluation techniques (Geerts, 2011), to measure how well it provided a solution to the problem (Peffers et al., 2008). The usefulness of the tool was measured by the user's ability to reduce or conserve energy based on predefined goals (for example "I want to reduce energy wastage by 2% this week"). Figure 1.1 illustrates the mapping of the DSRM activities to the chapters of this dissertation. The structure of the chapters is briefly mentioned in this section.

Chapter 1 – Introduction

This chapter provides a background to the problems of electricity usage and the problems in effectively communicating the electricity usage in a SE. In addition, the chapter provides an overview of the research study. The DSRM activity that is partially reported is the Explicate Problem activity.

Chapter 2 – Impact of Smart Environments on Electricity Usage

The second chapter provides a detailed discussion on SEs and electricity usage and reports and extends on the DSRM, Explicate Problem activity.

Chapter 3 – Visualisation of Electricity Usage in Smart Environments

Chapter 3 presents a discussion on visualisation techniques, reviewing the generally used techniques, and reviewing alternative visualisation techniques. This chapter extends on the DSRM, Explicate Problem activity, and Define Requirements activity.

Chapter 4 – Design and Development of Electricity Usage Information Visualisation Tool

The fourth chapter focuses on the design and development of the proposed information visualisation tool. This chapter reports on the Design and Develop Activity of the DSRM activity.

Chapter 5 – Evaluation of Electricity Usage Information Visualisation Tool

Chapter 5 discusses the results from the evaluations performed on the developed Information Visualisation tool. This chapter reports on the Demonstration and Evaluate activity of the DSRM.

Chapter 6 – Conclusion and Future Work

Chapter 6 provides a summary of the results obtained and conclusions, which can be drawn from the results. Possible contributions and future work are also described, as well as limitations encountered throughout the study.

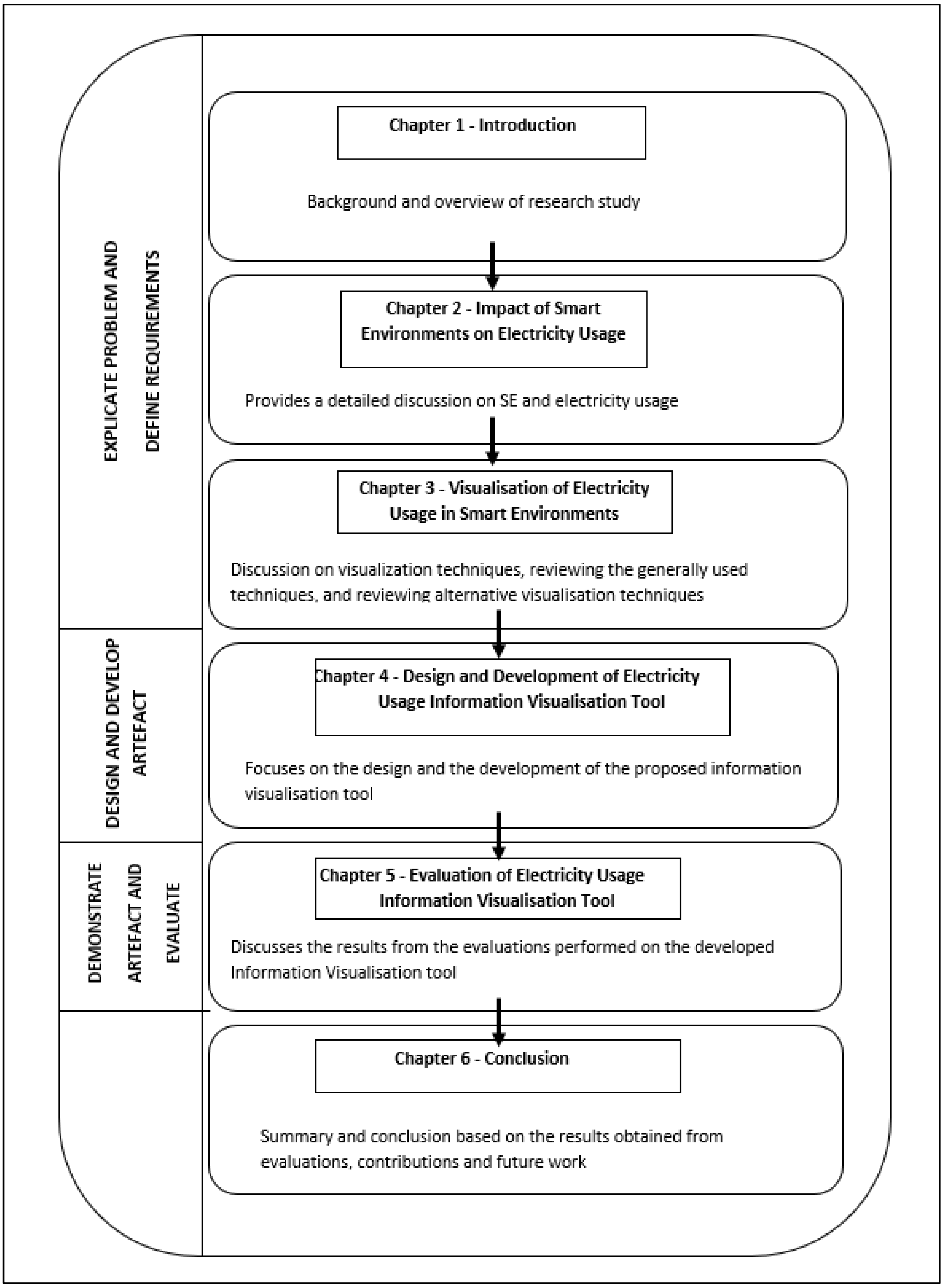


Figure 1.1: DSRM activities mapped to research chapters

Chapter 2: Impact of Smart Environments on Electricity Usage

2.1. Introduction

Chapter 1 introduced the main elements of this research study and outlined an overview of the structure of the dissertation. Chapter 2 aimed to answer research question one (RQ_1), *"How does a SE impact on electricity usage?"*. This chapter provides a context of SEs and electricity usage based on existing literature to answer RQ_1. In addressing RQ_1, it is important to gain an understanding of SEs and their related concepts. This chapter will begin by briefly discussing the Internet of Things, which facilitates SEs. Section 2.2 provides an overview of the Internet of Things and how it relates to SEs. Section 2.3 discusses SEs in detail, including the architecture of SEs. Electricity usage in SEs is investigated in Section 2.4, providing an understanding of the sources of electricity usage in SEs. A summary of the literature review on how SEs impact electricity usage in SEs is provided in Section 2.5.

2.2. Internet of Things

The Internet of Things (IoT) is a computing paradigm where everyday physical objects are amplified by using computational and wireless communication capabilities. This is heightened through the implementation of resource-constrained devices, which include actuators and sensors that enable connection to the Internet. The IoT provides open possibilities and flexibility to enable unified and remote control of modern and old devices alike (Idongesit Efaemiode & Andrew, 2019). The IoT is viewed as a necessary ingredient in developing SEs (Gomez et al., 2019). Gubbi et al., (2013) described the IoT in the context of SEs, as when sensors and actuators are interconnected to provide the following:

- Sharing of information across multiple platforms through a unified framework (Gomez et al., 2019; Idongesit Efaemiode & Andrew, 2019), and
- Developing a common operating vision to enable innovative applications. This is achieved by seamless large-scale sensing, which refers to the way information is presented by using cloud computing and ubiquitous sensing and data analytics (Gomez et al., 2019; Idongesit Efaemiode & Andrew, 2019).

The IoT is, therefore, a fundamental enabler of SEs (Gomez et al., 2019), and due to the IoT, the world is becoming smart (Rathinam Devi Kala et al., 2018). Examples of SEs include smart buildings, smart objects, smart cars, sensor technology, and buildings (Gomez et al., 2019; Pourzolfaghar & Helfert, 2016). Section 2.3 discusses SEs.

2.3. Smart Environments

In this research, we define a smart environment (SE) as an integrated small world where sensor-enabled technologies work together to make inhabitants' lives more comfortable (Ahmed et al., 2016). Smart refers to advanced technologies that have some degree of artificial intelligence (Marikyan et al., 2019b), which is its ability to obtain and apply knowledge (Ahmed et al., 2016). Environment refers to the surroundings (Ahmed et al., 2016). Ahmed et al. (2016) concluded that a SE is an environment that can obtain and apply knowledge about its inhabitants and adapt to the environment according to their needs.

As the development of mobile data communication and smart devices increases, so does the number of possible devices that can be found in a SE (Li et al., 2014). The devices in a SE come with limited capabilities, such as a wireless link of 25 kilobytes per second (kBps) throughput. These devices are meant to provide increased quality comfortability to their inhabitants, as well as ensure environmental sustainability. SEs are known to be energy-efficient systems (Murad Khan et al., 2016). However, energy efficiency is still a problem due to several issues, which include the continuous development of applications for SEs, and the coordination of devices within a SE, which is still a complex task (Rust et al., 2016).

Connectivity anywhere and anytime that is made available in a SE comes at a cost of increased energy consumption (Li et al., 2014). A problem that arises due to the developments in data communication, is that it contributes to a large portion of energy consumption, as determined in a study by Carroll & Heiser (2010). This consumption continues to increase as more SE developments occur, which are likely to do so (J. Li et al., 2014).

To address the problems affecting energy efficiency in SEs, it is important to first understand the concept of a SE as well as related concepts. Firstly, we discuss the architecture of SEs in Section 2.4.

2.4. Smart Environment Architecture

Over the past years, several architectures for SEs have been developed using different techniques (Miraoui et al., 2016). The SE architecture presented in this research is a breakdown of the various technologies separated into four layers. An in-depth description of each layer is given in the following sections. The derived architecture, as shown in Figure 2.1, is generic enough to cover the various requirements of a SE as addressed in previous research (Moreno et al., 2014; Khalid, 2016; M. Li et al., 2018; Mokhtari et al., 2019).

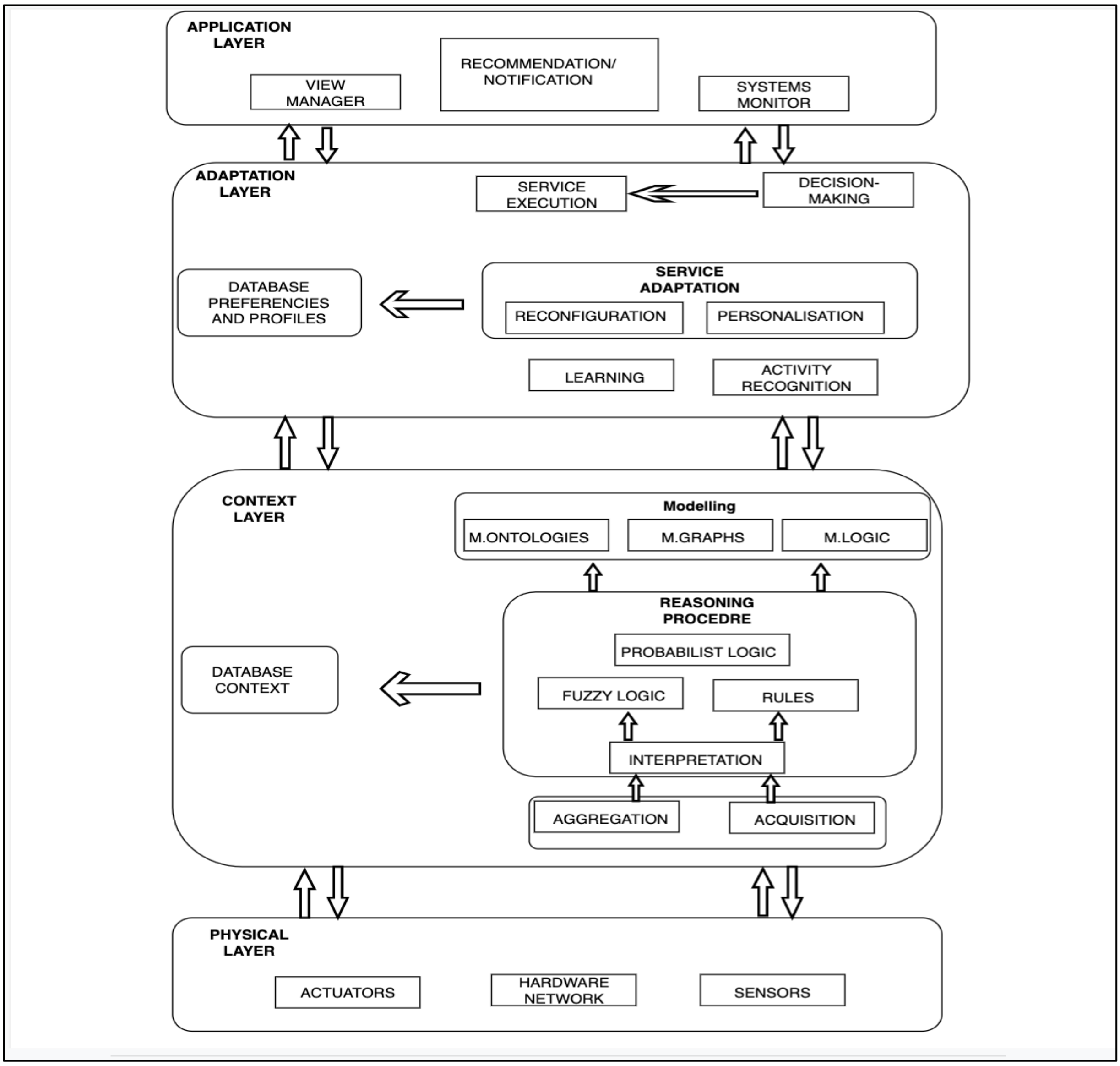


Figure 2.1: Smart Environment architecture (Belaidouni et al., 2016)

2.4.1. Physical Layer

The first layer of a general SE has many alternative names, which include the sensor layer (Liu et al., 2019), which will be referred to as the physical layer in this research. The physical layer contains sensors (health sensors, security sensors, energy sensors), physical hardware devices (e.g. smart plugs) (Felicetti et al., 2015; Liu et al., 2019), actuators, network interface, microcontroller, and sensing technologies (Zigbee, Bluetooth, Wi-Fi) (Aziz, 2013; Moreno et al., 2014; Khalid, 2016; Mokhtari et al., 2019). This layer manages data sensing, and intelligent sensing of its inhabitants, and can manage vast data sources as well as various technologies found in this layer (Moreno et al., 2014; Liu et al., 2019).

The physical layer (Belaidouni et al., 2016) can be viewed as a network of smart objects. The physical layer, as seen in Figure 2.2, contains elements that include sensors, either wireless or wired, actuators equipped with their infrastructure, and the hardware network, which was referred to as all the hardware parts that make up the system (Belaidouni et al., 2016). Wi-Fi routers, microphones, and cameras are examples of hardware network components. Motion, door, and smoke sensors are examples of sensors. In the context of this research, this is where smart plugs and appliances, i.e., devices that collect data from the environment, would be located. The primary objective of this layer is to capture and gather outside information about the environment and transmit it to the context layer, which is the next layer.

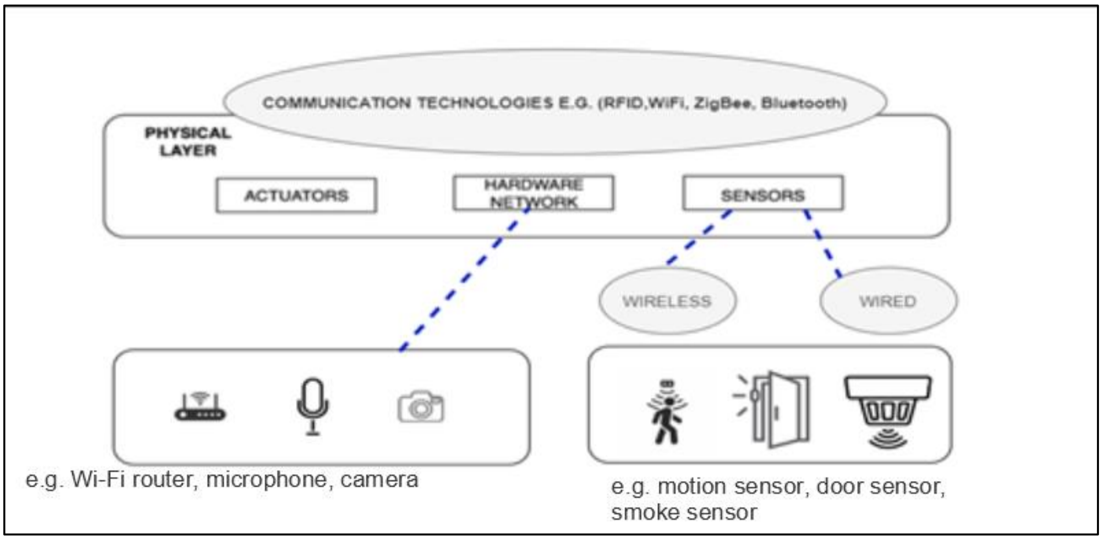


Figure 2.2: Derived physical layer from Belaidouni et al., (2016)

2.4.2. Context Layer

The second layer is the context layer, which is the backbone of the entire architecture. It is the major support of the system and it contains multiple components, each having unique responsibilities related to the context (Belaidouni et al., 2016; Miraoui et al., 2016). Context is referred to as any information, which can be used to characterize any situation of an entity. An entity is a place, person, or object, which is considered applicable to the interaction between the application and the user (Vahdat-Nejad et al., 2013; Yang & Cho, 2017).

Context-aware applications (context-awareness) are based on the *presence* notion, which refers to where a user can be located at a particular time, the activities they are doing, the services they may require in that situation (context), and the location of the services concerning the user (Donohoe et al., 2015; Yang & Cho, 2017). Context awareness can be viewed as a fundamental part of SEs (Humayun Kabir et al., 2015), and thus researching this layer will be vital in finding areas that may consume energy. The devices in the physical layer mentioned above, are aimed at providing information that is passed to the context layer. Data from 'virtual sensors', such as data gathered from software application sources are frequently used by users (Donohoe et al., 2015). In the context layer of the reasoning procedure, the interpretation process is performed by the context interpreter which is made up of a context knowledge base. The context knowledge base is made up of data collected. from various sources is stored in a knowledge base and can be queried and used for context modelling and reasoning (Donohoe et al., 2015).

The context layer is based on the internet and deals with broadcasting networks and telecommunication. This layer aims to provide reliable, convenient, large-capacity, and complete infrastructure to enable the sharing of data between devices and users (Liu et al., 2019). This layer can be further split into essential modules that reside in every SE in one form or another (Miraoui et al., 2016). These modules include the knowledge base, the context module, aggregators, the interpreter, the reasoning procedure, and modelling (Belaidouni et al., 2016).

i. Knowledge base

The knowledge base is the foundation of any information, which is related to the system and its components (Humayun Kabir et al., 2015; Belaidouni et al., 2016). In Figure 2.1 the knowledge base can be illustrated as the information coming from the various connected devices in the physical layer. The information can include static information on appliances, devices, and users such as information on configuration, or dynamic information caused by regular changes, such as devices in the environment and location of users (Belaidouni et al., 2016). Knowledge base information can include a description of the services provided (Humayun Kabir et al., 2015).

ii. Context module

The context module is aimed at transforming low-level data collected from the physical layer, which is in the knowledge base, into high-level information. This module gathers data from sensors and interprets it to find the meaning and gain an understanding of the data to be used by the reasoning module (Belaidouni et al., 2016). In Figure 2.1 the knowledge base and context module comprise the acquisition process.

iii. Aggregators

Aggregators are aimed at gathering unique pieces of context information that are logically connected to a logical depot and are shown as the aggregation process in Figure 2.1. A context is usually received from distributed and unique sensors, hence aggregators decompose and gather context information in clear groups for consistency checking, context inference, and knowledge sharing (Belaidouni et al., 2016).

iv. Interpreter

After the content information is combined into logical groups, the interpreter is responsible for recognizing the meaning of the context before the context can be used (Belaidouni et al., 2016).

v. Reasoning procedure

Context reasoning, which is also referred to as context inference, is one of the most vital elements of context-aware systems and involves a unique process, which includes: verifying the consistency of the context and understanding the high-level, implicit context from the low-level, explicit context. To achieve these goals, the reasoning process is founded on certain reasoning methods, which include decision trees, fuzzy logic, and ontology mechanisms (Belaidouni et al., 2016).

vi. Modelling

Context modelling is an important element to handle contexts and manage their collection, organization, and representation, while context-awareness highlights reasoning about the context. In a SE context, modelling defines how context information for reasoning and the adaptation process is presented. Models in the presenting context include graphical models, ontology-based models, and logical models (Belaidouni et al., 2016).

The different module operations that take place in the context layer make the environment “smart” by being able to, for example, identify a user’s location in an environment and switch on the light, which is making use of artificial intelligence to obtain and apply knowledge (Marikyan et al., 2019b). These activities taking place in the context layer, are happening and invisible to the user, and consequently, the energy usage, which is the focus of this research, to make visible through visualisation of the ‘invisible’ energy usage.

2.4.3. Adaptation Layer

Adaptation refers to the ability to alter service and provide another corresponding environment (Belaidouni et al., 2016). The adaptation layer is comprised mostly of the domain-level logic of the system. This layer is aimed at adapting services according to a detected context by the context layer. The adaptation layer is responsible for analysing context and determining which actions to execute in response (Belaidouni et al., 2016). The adaptation layer as seen in Figure 2.1 can be further divided into four main processes, namely machine learning, decision-making, adaptation services, and activity recognition.

Adaptation is a very important characteristic of SEs, as research in the past has been conducted on how to ensure the environment adapts to the user's behaviour, in a way that does not disturb the user's way of living (Gomez et al., 2019).

Research conducted by Garzotto et al., (2016), which was centred on monitoring and adaptation in SEs for disabled children, described adaptation as the ability of a SE to address different characteristics of each child. Garzotto et al, (2016) highlighted two types of adaptation, used. Firstly, a manual adaptation, which was achieved through the manual operation of a therapist, then secondly, the developed dynamic automatic adaptation, which was more effective as the manual option had the drawback of children becoming easily distracted as the therapist made changes.

2.4.4. Application Layer

The application layer aims at supporting the business needs of the SE (Liu et al., 2019). The application layer includes all the applications, which are subscribed to the use or exchange of data-driven services of a SE (Mokhtari et al., 2019). This layer is responsible for communication between the user and the system. It allows users to perform their required tasks such as turning the television on or off, or turning the lights on or off (Paredes-Valverde et al., 2020).

According to (Belaidouni et al., 2016) the application layer consists of three elements:

i. **The View Manager** has the function of specifying mechanisms that are responsible for the management of diverse views. It is also responsible for the supervision of the numerous interfaces that obtain external context, displaying user interfaces, and management of the users' interaction.

ii. **Notification/Recommendation** is referred to as an adaptive application behaviour, which defines the process of reasoning and adaptation for all the actions, which have been executed to comprehend the situation and the corresponding services. It is vital to note that all the information from the adaptation layer is received by this component.

iii. **System Monitors,** which are where information related to systems and their performance indicators, detected errors from inside the system or environmental devices, and the status of components are monitored by the system.

This research will be focused on the application layer of the architecture as the application layers allow users to interact with the system. In this research, we will focus on the electricity consumption of the SE and visualise it and present it to the user at the application layer.

The investigation into the architecture provides a deeper understanding of what a SE comprises and how it functions. In doing so we can identify the sources of electricity usage in an SE. The following section discusses electricity and the sources of electricity usage in a SE.

2.5. Electricity Usage in Smart Environments

Recent research has shown that there has been an increase in electricity prices, which have been due to several factors, which include demand, supply, and weather forecasts (Paredes-Valverde et al., 2020). This becomes a strong motivation for this research as we try to visualise and examine the power consumption for the user. The following section will discuss vampire power, which is important in understanding why it can be useful to visualise the electricity usage in a SE as it is not always visible.

First, we will need to get some understanding of what electricity is. The following section aims to discuss electricity further.

2.5.1. Electricity

Energy is a universal currency that must be transformed to get anything done (Smil, 2019). Energy refers to the ability to perform work (Dincer & Abu-Rayash, 2020). Energy is often intangible to us but present in daily activities. Energy has multiple forms (Figure 2.3), electrical energy, however, will be the focus of this research. Electrical energy refers to the kinetic energy of moving electrons. For this research, energy, and electricity may be used interchangeably as the researchers focused on an electrical type of energy.

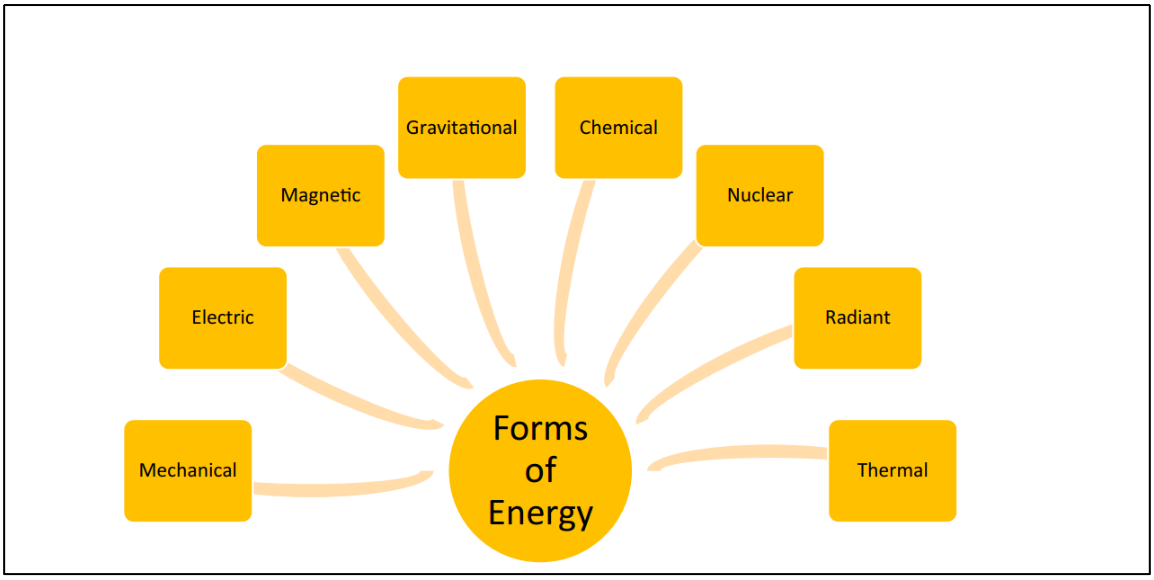


Figure 2.3: Forms of energy emerging from potential and kinetic energy (Dincer & Abu-Rayash, 2020)

The main aspects of energy are shown in Table 2.1 below.

Table 2-1: Summary of basic energy properties (Dincer & Abu-Rayash, 2020)

Term	**Unit**
(International System of Units) SI unit	Joule (J=kg m^2/s^2)
Other Units	Calorie, kWh, kcal, BTU

The SI unit for energy is the joule, which measures work done when a force of 1 newton acts over a distance of 1 meter (Smil, 2019). Power (Smil, 2019) refers to the rate of energy flow, and the first standard unit is horsepower, which was set by James Watt. The basic scientific unit of power today is approximately 1 watt (1 joule/second), which is equal to the flow of 1 joule per second. For example, one horsepower equals approximately 750 watts (Smil, 2019). Total consumption has been used as a method of measuring the consumption of energy usage (Spengler & Wilmsmeier, 2018). The most common metrics used to communicate electricity usage include price and kilowatt/hour (kWh) (Murugesan, 2017).

As global trends such as technology evolution, integration, technology transfer, and utilization continue to progress, it also puts a high demand on energy availability (Okakwu et al., 2019). Economic metrics and per capita index are therefore highly dependent on the efficacy of the electric power industry in any country as everything seems to rise and fall depending on its efficacy (Okakwu et al., 2019). Electricity consumption has therefore become one of the major problems in industry (Vani Sri et al., 2018). The consumption of power plays an important role in electricity consumption. This is due to various reasons, which include leaving the air conditioner on, lights on, fan on, etc. (Vani Sri et al., 2018). Electricity alone accounts for approximately 30% of global energy consumed (Floris et al., 2015), and as a result, it is vital to research how it can be reduced.

Buildings are responsible for a large portion of the world's energy consumption, as the building sector alone caters to approximately 40% of the energy consumption (Amasyali & El-Gohary, 2018). Residential housing accounts for most of the building energy consumption, about ¾ of the total energy consumption of buildings. Residential energy consumption is expected to continue to rise. The emergence of innovative and new technology and the utilisation of electronics decreases energy consumption (Peng & Qian, 2014). Coupled with technological developments leading to the development of smart homes (Xia et al., 2018), it is necessary to plan and investigate electrical usage in SEs. Since energy usage in the residential sector contributes to a large part of total energy consumption, reducing energy usage will provide a positive impact on energy saving (Kim et al., 2019). Monitoring electricity usage is important to understand the sources of consumption in an environment and to know the necessary measures required to save energy (Peng & Qian, 2014).

Monitoring electricity usage is important as it helps in understanding the electricity consumption sources in an environment and taking appropriate action to save electricity (Hertzog & Swart, 2018). Comprehending the source of electricity usage can lead to finding ways to reduce electricity usage (Hertzog & Swart, 2018). Section 2.5.2 investigates the various sources of electricity in a SE.

2.5.2. Sources of Electricity Usage in a SE

To answer RQ_1, it is crucial to identify the source of electricity usage in a SE. The following section investigates the sources of electricity consumption found in a SE.

2.5.2.1. Vampire Power

The IoT offers multiple opportunities with objects being interconnected and consequently means they will use electricity (López-De-Armentia et al., 2012). López-De-Armentia et al, (2012) highlighted in their research that before the technological advancement made by IoT, the electricity used by ICT alone was already significantly high.

Smart meters have been used recently to capture vampire power, as meters can only monitor the functioning of devices and measure the power but do not control it, unlike energy-saving systems that monitor and control the function of devices. Electricity is consumed in maintaining an internal clock and receiving remote signals in a device (Kumar et al., 2017).

Kumar et al., (2017) highlighted in their research that the power used to maintain and control one device may be small, however, the electricity usage increases as more devices are connected (López-De-Armentia et al., 2012), which can be estimated to be 32 to 87W and about 10% of the total residential consumption (López-De-Armentia et al., 2012).

It is vital to control vampire energy as it accumulates in the electricity usage for which a user will pay (Kumar et al., 2017). Most devices are affected by vampire power. Vampire power can be found in the following devices that can be turned on instantly with the assistance of a timer device, remote control, UPS, security systems, motion sensors, and fire alarms (Kumar et al., 2017). There are different ways of controlling vampire power, which include the use of energy star products, power strips, and unplugging the device. However, these methods can result in electrical fires and electrical shocks (Fernández-Caramés, 2015). This research aims to provide a way to communicate the power usage of appliances including the vampire power used by these devices, to create awareness among the users.

As vampire power affects most devices, we must discuss the various types of common devices, components, and functionality performed by SEs to understand how each operates and consequently impacts electricity usage. The following sections aim to describe the various components and functionalities common in SEs and how each can impact overall electricity usage.

2.5.2.2. SE Devices and Appliances

The Internet of Things (IoT) contains things that are connected to the Internet anywhere and anytime. IoT, in a technical sense, refers to how sensors and devices are integrated into everyday objects, which are connected to the internet either through wireless or wired networks (Chin et al., 2019). There has been a stable increase in the number of devices being connected to the internet, (Zyrianoff et al., 2020), and, as a result, more devices can be included in a SE. The continuous development of ICT continues to increase the total household electricity consumption (Pothitou et al., 2017). The increase in ICT is because more users can afford the higher-performing ICT devices, which include televisions, computers, and their peripheral devices. Most of these devices are powered by the internet. The development of smartphones and tablets provide portability for the user, and daily practices of life have become dependent on having an active data connection, which is referred to as “always on” society.

i. Sensors

Efficient energy scheduling involves sensing and monitoring the status of devices, which is essential for Smart Home Energy Management Systems (Mokhtari et al., 2019). In SEs sensors are embedded in the environment or interact with the environment via a mobile phone or other devices collecting data that can be carried by a user. Microphones and cameras are either placed on wearable devices or equipped in the SE (Belapurkar et al., 2018). A sensor can be viewed as a device that can change a physical dimension into a digital signal; an example includes detecting the presence of light (Augusto et al., 2020). The information that is detected by the sensors is passed onto the upper layers in the SE architecture (Mokhtari et al., 2019). Various types of sensors can be equipped in a SE, as shown in Table 2.2.

These devices are meant to provide information on the users and the environment (Belapurkar et al., 2018). Other devices that could be found in a common SE include data processors, multimodal systems, and consumer electronics (Korzun et al., 2017).

ii. Actuators

Actuators have the responsibility of transforming a digital signal into a physical dimension (Augusto et al., 2020), which includes a light being turned off. Actuators can convert energy into motion (Madakam et al., 2015), meaning they can drive motions into mechanical systems.

iii. Smart plugs

A smart plug can be referred to as an electric plug with an internet connection that can control the plug remotely, to turn it on or off via a smartphone (A. Wang & Nirjon, 2019). Smart plugs measure the energy usage of home appliances and then send the information to the upper layers of the SE, where a decision can be made on the appliances, such as whether to turn the appliance on or off (Paredes-Valverde et al., 2020). Most smart plugs that are currently sold in the market (Wang & Nirjon, 2019) have an ‘away’ mode feature, which gives users the ability to specify times when a device should be on or off. Having the ‘away’ mode feature gives rise to vampire power, as discussed in the previous section. The ‘away’ mode comes at the cost of an increase in energy consumption, as this increases the devices’ up-time and consequently the amount of electricity used (Wang & Nirjon, 2019).

Table 2-2: Sensors that can be found in a SE (Alam et al., 2012; Mokhtari et al., 2019)

Type	**Name**	**Purpose**
Sensor	Pressure	Identifies a user's location
	Temperature	Measures the temperature of the environment as well as the user's body temperature
	Light	Measures the lights' intensity
	RFID	Is used to identify objects and people
	Water	Measures the volume of water usage
	Power	Is used to calculate the power usage of a SE
	Current	Measures the current usage
	Ultrasonic	Is used for location tracking
	Switch senor	Is used to detect the status of a door as open or closed
	Fire	Detecting fire in the SE
	Access	Used to differentiate between residents and visitors

iv. Energy meters

Energy meters deal with the measuring and monitoring of electricity consumption in a SE. Sensing of energy usage in a SE can either be done at a single point or can be distributed. Single point sensing is when one single smart meter monitors all the electricity consumption, while distributed sensing involves multiple smart meters connected around the SE (Mokhtari et al., 2019).

v. Smart appliances

Information Communication Technology (ICT) is responsible for about 15% of the world's domestic electricity usage (Pothitou et al., 2017); this also includes waste energy produced by devices left on standby. The electricity consumption regarding ICT and consumer electronics has continued to significantly increase over the years as cheaper ICT devices are made available, and hence more accessible to users (Pothitou et al., 2017).

Electrical appliances that consume electricity impact the overall household electricity usage through the electric power consumed by each device over the amount of time the appliance is being used, and in which consumption mode it is in (Pothitou et al., 2017).

Research by Pothitou et al. (2017) categorised household appliances based on previous research, which categorised appliances into either:

- **Continuous appliances**, use a constant amount of electricity.
- **Standby appliances**, refer to appliances, which still consume electricity when they are not being actively used. Examples include televisions, which have three statuses, namely in use, standby, and turned off; and laptops, which can operate in either sleep mode or idle. More modes are shown in Table 2.3.
- **Cold appliances** are continuously in use, but their electricity consumption is variable.
- **Active appliances** are appliances without the standby mode and can be switched off to prevent them from consuming electricity.

Table 2-3: Electrical appliances power state (Pothitou et al., 2017)

Active	**Idle**	**Sleep**	**Standby**	**Disconnect**
The power button is in the *on* position	The operation at a low speed disengaged from the load	The lowest power level between *on* and *off*	The power button is in the *off* position and the unit is plugged in (powered)	The power button is in the *off* position and the unit is unplugged (not powered)

The research conducted by Pothitou et al. (2017) was based on studies conducted in Australia and the UK with samples of 14 and 72 households in the UK and 150 households in Australia respectively, highlighted that the *active* and *standby* appliances consume the most electricity (see Table 2.4).

Table 2-4: Category of household appliances and their examples, derived from (Pothitou et al., 2017)

Category	**Examples**
Continuous	Alarm, clock, wireless routers, broadband modems
Standby	Television, audio Hi-Fi, smart phone (charging), desktop computer, laptop computer, tablet (charging), printer, games console.
Cold	Fridges, freezer
Active	Kettles, washing machine, electric showers

A SE can also be equipped with various types of smart appliances, which can include dishwashing and laundry machines. Data that can be collected from these devices include their status as being either ON or OFF (Mokhtari et al., 2019). These appliances are a vital part of the electricity bill (Paredes-Valverde et al., 2020), and need to be studied closely to reduce energy consumption.

2.5.2.3. Smart Environment Sensing Technologies

Multiple communication technologies can be used in a SE, but for this research, we will focus on a few of the most common technologies and look at how the different technologies may impact energy usage in a SE.

The following selection will discuss some common technologies:

i. Zigbee technology

Zigbee is considered to be designed for mesh wireless technologies (Ahuja & Khosla, 2019), which enable it to carry small amounts of data over short to medium distances (10-75m) (Mazzara et al., 2019) while utilising low-power ZigBee's additional benefits, which include sound security, robustness with a large node count and high scalability. Due to its low power utilisation, it is common in energy-saving management systems, or where the researcher has energy conservation in mind (Ahuja & Khosla, 2019).

Zigbee technology's main benefits include it being an efficient and easy method to reduce power loss (Ali et al., 2014; Zungeru et al., 2019). Zigbee is commonly used in SEs due to its low-power and low-cost benefits (Zaidan et al., 2018) when it comes to energy efficiency in higher bandwidth WIFI applications in a SE. Zigbee is utilized to reduce standby energy consumption (Zungeru et al., 2019)). Zigbee sensor networks enable multi-hopping, which increases the effective transmission range.

ii. Bluetooth

Bluetooth wireless technology is an economical and short-range radio technology that reduces the need for exclusive cabling between devices, such as handheld PCs, printers, and PDAs. Bluetooth has an effective range of 10 – 100 meters and communicates at less than 1Mbps. The benefits of Bluetooth technology include less operating expenses, offering a wide range, and using less energy (Ali et al., 2014). Bluetooth is common when considering point-to-point communication (Ahuja & Khosla, 2019).

iii. WIFI

Wireless Fidelity (Wi-Fi) refers to a networking technology that enables computers and other devices to communicate with each other using a wireless signal (Madakam et al., 2015). The major benefit of Wi-Fi is the existing broad approach; Wi-Fi technology is enabled in almost every new electronic device (Mazzara et al., 2019).

iv. RFID

RFID is the first technology that makes use of an RFID tag and reader. The RFID tag represents a simple label or a chip that is connected to provide the object's identity. The reader transmits a query signal to the tag and receives the tag's reflected signal (Al-Fuqaha et al., 2015), and then passes it to the database. Different types of RFID tags exist based on the power supply method (Madakam et al., 2015), namely passive, active, and semi-active/passive tags. The active tags are battery-powered, and the passive ones do not require a battery. The semi-active/passive tags make use of board power when needed (Al-Fuqaha et al., 2015).

v. WLAN

Wireless Local Area Network (WLAN) is also referred to as Wireless Ethernet. WLAN can provide reliable communication between low latency for both point-to-point and point-to-multi-point transmission of up to 250m.

vi. LoRaWAN

LoRaWAN is referred to as a Media Access Control (MAC) protocol meant for wide area coverage, which utilizes low power and has a high data rate (Ahuja & Khosla, 2019). LoRaWAN technology is specifically built for low-powered devices that have internet-connected applications.

Information and communication technology (ICT) (Tsaurai, 2020) refers to the usage of computers to store, retrieve, transmit, and manipulate information or data. The growth of ICT has resulted in a related increase in energy consumption (Gelenbe & Caseau, 2015).

Despite the strong improvements in the electricity efficiency of the devices, electricity usage is increasing (Andrae & Edler, 2015). ICT increases the amount of electricity used due to more electrical gadgets being used, which consume a lot of electricity (Zhang & Liu, 2015). It is therefore important to understand what ICT devices are in the environment as they contribute to overall energy consumption.

Table 2-5: Technologies that are common in SEs and their attributes (Ahuja & Khosla, 2019; Madakam et al., 2015; Mazzara et al., 2019; Merhej et al., 2019; Santos & Ferreira, 2019)

Technology	**Coverage Area/ Communication Range**	**Data Rate**	**Power Consumption**
Bluetooth 5	Up to 200m +200m (BLE)	255 Bytes	15mW
ZigBee	-10-200m Direct Line Sight -75-100m Indoor	250Kbps	52.22mW
Wi-Fi	1-100m	Top 1Gb/s – IEEE 802.11ac	2-24 W
RFID	Depends on the type of tag	Depends on the type of tag	Depends on the type of tag
WLAN	50- up to 250m	11.54 -108Mbps	19.95mW
LoRaWAN	-5km Urban -15-20km Rural	290 bps-50Kbps	25mW

Research conducted by (Ahuja & Khosla, 2019) provided a table containing information on technologies that were classified based on different factors, including coverage area range, data rate, range, and power consumption. This research supports that energy consumption will vary depending on the type of communication technology that will be selected in Table 2.5. It is important to know the technology that is used to know the energy usage and if the technology could be what is affecting the overall energy usage. The communication technology in a SE is used continuously to allow for automation, equating to notable energy consumption (Alaa et al., 2017).

2.5.2.4. *Smart Environment Functions*

The following sections aim to describe the main functions performed in SEs. These functions define how the components described in the sensor layer are used in the main functions of SEs.

- **Alert:** A SE possesses the ability to sense its environment and send the necessary alerts to the user (Malche & Maheshwary, 2017). The alerts are sent out with information on fault locations in the environment (Zhou et al., 2016).
- **Monitor:** The monitor function in a SE is vital, as it keeps track of activities occurring in the environment. Monitoring is important as it is a base need for any decision-making, such as monitoring temperature readings and sending alerts to the user to switch on the heater (Malche & Maheshwary, 2017). Easy access to real-time information on energy usage in a SE is made possible through monitoring. Monitoring makes use of display services for operational nodes and the status of the energy usage in the SE (Zhou et al., 2016).
- **Control:** The control function allows the user to control various activities in the environment. The user can control the environment either locally or remotely, as well as allow for automation of activities such as switching on/off of lights when the room is dark/light (Malche & Maheshwary, 2017). Control can be broadly classified into two types: direct and remote control. Direct control is when implementation is done on both the control system and equipment and remote control is when users can access the usage patterns of the devices in the SE through a computer or smartphone from anywhere (Zhou et al., 2016).
- **Intelligence/Management:** The Intelligence function is the most significant in a SE and refers to the intelligent behaviour of the SE. This function involves automatic decision-making on the occurrence of actions (Malche & Maheshwary, 2017).

Functions in a SE are continuously working, and as SEs are automated, the continuous work of the functions leads to a significant amount of energy being used.

2.5.2.5. *Smart Environment Services*

Services offered by SEs are widely classified as assistive and management services and these services are often found at the application level of a contextually aware system (Gomez et al., 2019), such as a SE. As shown in Figure 2.4, assistive services are aimed at the provision of direct support to users' interests and in daily activities and actions, which can take place in the SE. Management services include services that address specific functionalities in a SE (Gomez et al., 2019).

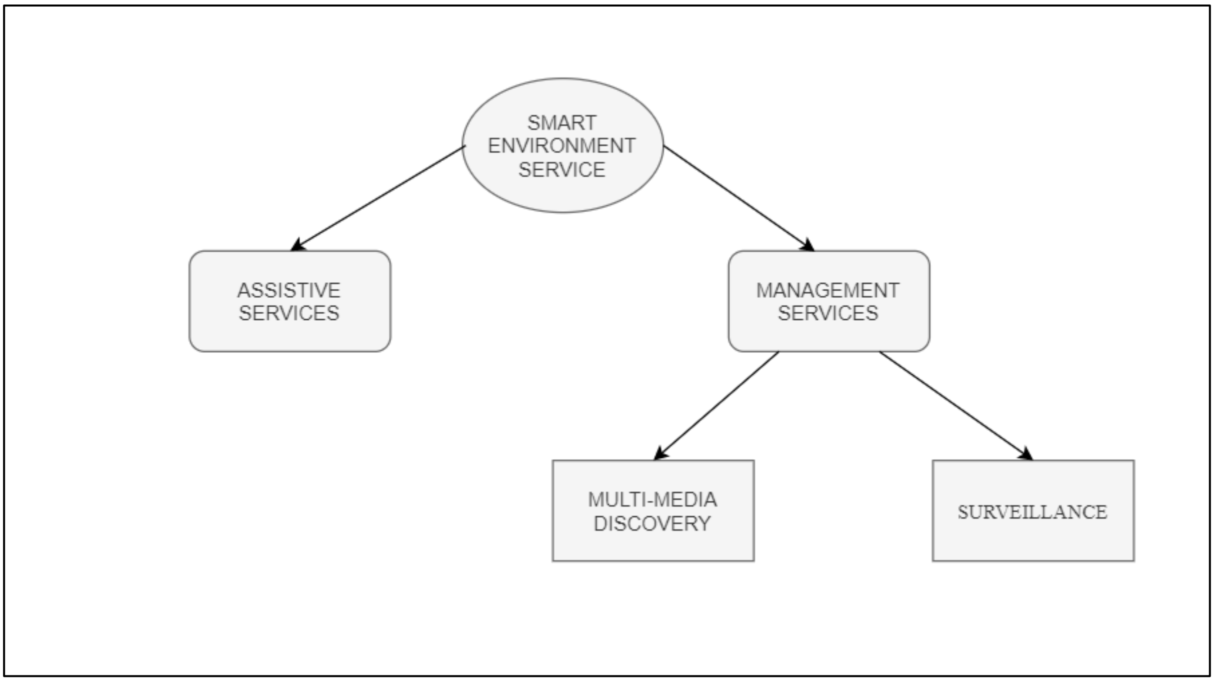


Figure 2.4: Derived SE services (Gomez et al., 2019, Marikyan et al., 2019b)

The assistive services, as shown in Figure 2.5, aim at providing its users or occupants with help by identifying their actions. The well-being of the occupants is the major aim of the service. Examples of such include healthcare, the ageing population, and assisting in childcare (Marikyan et al., 2019b). Management services, as shown in Figure 2.6, can be further split into two categories: the discovery of multi-media information in the form of videos and photos of the occupants' day-to-day living activities, and "surveillance of the environment", which has the main objective of processing data to predict and alert occupants of security intrusions or in event of future natural disasters (Marikyan et al., 2019b).

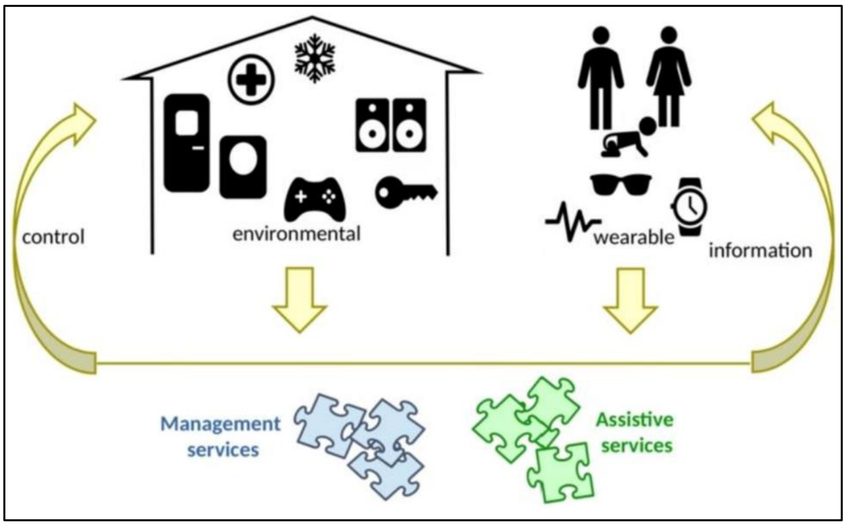


Figure 2.5: Assistive services and management services (Gomez et al., 2019)

2.5.2.6. Other Factors Impacting Electricity Usage in Smart Environments

Problems in electricity usage continue to increase as the number of demands of users rises (Zaidan et al., 2018). These challenges can be summarised as follows:

i. **Network traffic data:** transmission based on home network traffic, which is considered a major issue due to its electricity consumption and environmental effects (Zaidan et al., 2018).
ii. **A variety of devices:** CNN technology faces a lot of challenges due to the presence of various devices and the availability of service updates (Zaidan et al., 2018). A study conducted by (Agate et al., 2018) found that as the number of devices passing through the SE increases, so does the electricity consumption.
iii. **Technical challenges:** such as the Wahab system faced challenges in reliability, power consumption, and low complexities (Zaidan et al., 2018). Technical challenges also include a lack of device maintenance, electrical fires due to power overloads and short circuits, and device irregularities and inefficiencies (Alaa et al., 2017).

The impact of one of these factors might not cause a significant negative effect on the overall energy usage of a SE, but the combination of all the various factors may impact the energy greatly. Figure 2.6 provides an overall vision of the various factors that impact energy usage.

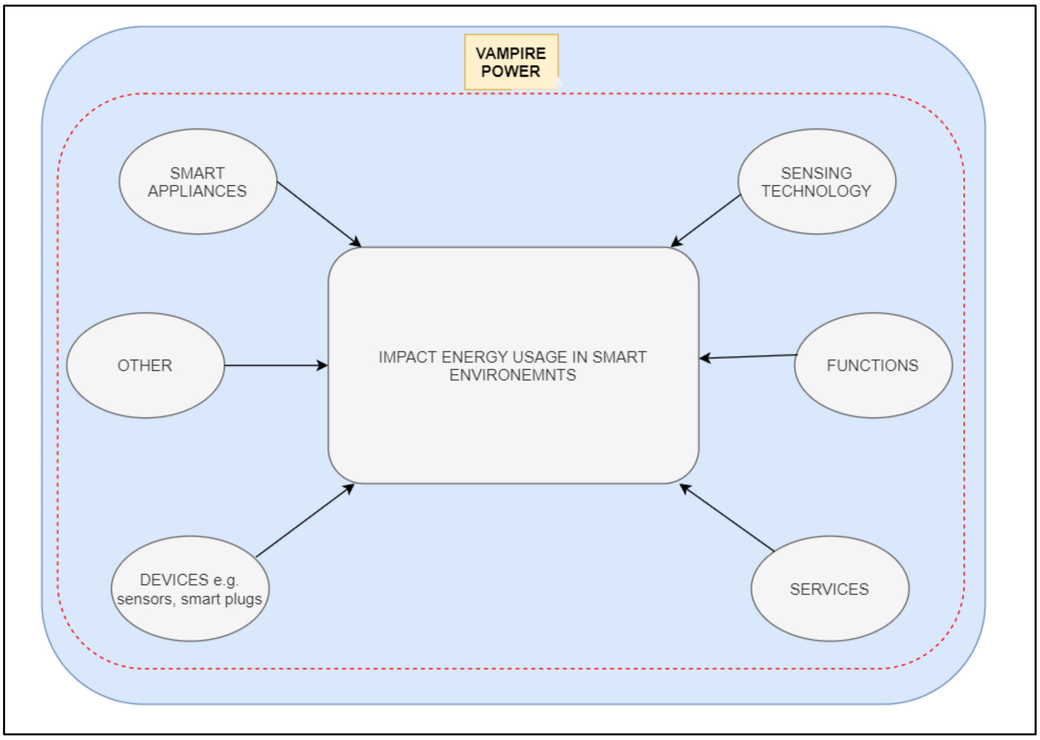


Figure 2.6: Factors impacting energy usage in a SE

2.6. Conclusion

This chapter set out to provide a discussion on SEs. To understand how a SE impacts energy usage, a literature review on SEs is important as this helps in understanding what components use energy. Doing so allowed us to focus on these areas that consume energy, which is a more focused approach. RQ_1 "*How does a SE impact electricity usage*" was addressed by exploring the components of a SE, which included its architecture (Section 2.3.1) to understand how a SE is structured, the various components that could be found in a SE, and their relative impact on electricity usage (Section 2.4). Figure 2.6 provides an overview of the answers to RQ_1: "*How does a SE impact energy usage?".* Various factors in a SE may cause issues in energy usage in SE systems, which include misuse of services, inadequate maintenance, and mismanagement of applications by the user (Alaa et al., 2017). As shown by the architecture of a SE, interlinked with communication technologies, as a SE is automated it is required to constantly work, which leads to significant energy usage (Alaa et al., 2017).

This chapter highlighted that IoT plays a significant role in SEs and how they function. The ability for objects to be interconnected is important for SEs because it allows the SE to quickly adapt to different user needs. For example, different devices in a SE may be required to meet a user's needs, and these devices must communicate with one another to do so, which is made possible by IoT, which provides connectivity everywhere. However, increasing electricity usage comes at the cost of increased and continuous connection, as most devices must be powered or in standby power mode to ensure that they are always connected. Standby power mode causes vampire power, in which devices consume electricity even when they are not in use. This discovery, along with the other sources of electricity usage in the SE, helps to answer RQ_1.

The next chapter is a continuation of the literature review conducted in Chapter 2, as it investigates visualisation and how it can be used to communicate SE electricity usage.

Chapter 3: Visualisation of Electricity Usage in Smart Environments

3.1. Introduction

Chapter 3 provides a literature review on visualisation techniques by reviewing the commonly used visualisation techniques for electricity usage. This chapter aims to answer RQ_2 and RQ_3, which are "*How is the electricity usage in a smart environment currently visualised?",* and "*Which are the most effective techniques for visualising electricity usage in a smart environment?*", respectively. This chapter is organised as follows: Section 3.2 provides an insight into electricity management in smart environments (SEs). Section 3.3 discusses visualisation of electricity usage in SEs to further answer RQ_1 and RQ_2 through an investigation into existing systems that have been developed to visualise electricity usage in SEs. Section 3.4 provides a discussion based on the literature on how to best visualise electricity usage in a SE in terms of which visualisation techniques can be incorporated into a visualisation tool. Section 3.5 provides a summary and conclusion for the chapter.

As discussed in Chapter 2, electricity is essential in daily human activities, and electricity usage awareness has the potential to significantly reduce electricity consumption (Floris et al., 2015; Srinivasan et al., 2019). The current chapter aims to support the decision on the use of visualisation as a communication tool for electricity usage data to solve the research problem. For this research, energy, and electricity may be used interchangeably as the researchers focused on an electrical type of energy, as discussed in Chapter 2 (Section 2.5).

Climate change is a global issue. Human activities directly cause changes in the global climate, which caused an increase in greenhouse gas (GHG) emissions, making them the highest in human history (Bhati et al., 2017). At a global level, buildings are responsible for the largest consumption of energy (Ruiz et al., 2020). Worldwide, the shortage of electricity has become a critical issue, and electricity-saving strategies have become an increasing cause for concern (Chen & Lin, 2019). It is therefore important to attempt to improve the monitoring and effective communication of electrical energy usage.

The Internet of Things (IoT) continues to gain traction, which means that more electronic devices will be connected (Andrae & Edler, 2015). In SEs where IoT plays an important role, this inadvertently affects SE electricity usage. Processing and storage improvements have been made to improve electricity efficiency. Despite these improvements, electricity consumption continues to rise (Andrae & Edler, 2015).

Electricity consumption can be ‘invisible’ as it is silent, cannot be touched, and is paid for through automated payment and billing systems (Nilsson et al., 2018). As a result, electricity is not seen as a unified sector of consumption, but rather as an integral component of daily human activity, with energy, consumed indirectly through services and appliances (Nilsson et al., 2018).

Energy usage can be shown in energy units or power that is kWh or kW, environmental units (kilogram of CO2), and monetary units (de Moura et al., 2019). However, electricity or power units are considered too difficult or abstract for users to relate to their day-to-day activities (de Moura et al., 2019), and alternatively, monetary units are used (Murugesan et al., 2014; de Moura et al., 2019). Users find the monetary unit is the most appropriate and understandable measure of energy (Murugesan et al., 2014). It is therefore important to find ways to make electrical energy ‘visible’ by using ways that users can understand the electricity usage information and be informed. This research aims to find ways to effectively communicate electricity usage to people in SE using visualisation.

The following section provides insight into the electricity management systems in SEs and how they operate to communicate electricity usage to their users.

3.2. Electricity Management in Smart Environments

Energy management and energy efficiency are becoming increasingly important issues worldwide (Elma & Selamogullari, 2015). The electrical energy consumed in buildings, both residential and commercial, makes up a large percentage of total electricity generated. It is, therefore, important to attempt to reduce electricity usage, especially in these environments (Elma & Selamogullari, 2015). Energy or electricity awareness has been raised due to environmental and economic aspects (Pelliccia et al., 2016). Energy monitoring enables the possibility of understanding the consumption of energy and has thus become one of the most important research topics (Ruiz et al., 2020). This research aims to contribute to researching ways to monitor and communicate electricity usage to users.

To achieve energy efficiency, smart environments (SEs) are equipped with home energy management systems (HEMS) to assist in managing and controlling energy usage. This section further discusses HEMS and how they work to manage energy usage.

Advancements in IoT, together with developments in communication technology, have affected a vast range of domains that enable the development of SEs (Celik et al., 2017; Xia et al., 2018). Home energy management systems (HEMS) have been implemented to manage energy generation, storage needs, and consumption SEs, specifically smart homes and home energy management systems (Celik et al., 2017). HEMS have been investigated concerning their components, structure, and advantages. HEMS have been considered a vital component in a SE for efficient energy usage (Elma & Selamogullari, 2015).

HEMS provide smart features and energy feedback, using in-home displays, giving users support in making sustainable decisions concerning energy usage (Nilsson et al., 2018). HEMS manage energy usage through adequate scheduling of the use of resources and still maintaining the user's economic and comfort needs (Celik et al., 2017). HEMS also provide the benefit of increasing users' understanding of their energy consumption levels, and unnecessary energy usage, whilst still providing comfort to the user (Nilsson et al., 2018).

HEMS can control and manage smart home appliances, renewable energy resources, and the home energy storage system to save electricity (Liu et al., 2016; Zhou et al., 2016). HEMS also provides real-time information on the amounts of energy consumption, active control services, and pricing of the energy used by the user (Liu et al., 2016; Zhou et al., 2016). HEMS aims to enhance the energy utilisation efficiency of devices by allowing users to schedule a service time for multiple appliances via a user interface (Zhou et al., 2016). Figure 3.1 shows a representation of the functionalities of a smart HEMS, which includes five modules, monitoring, logging, control, alarm, and management.

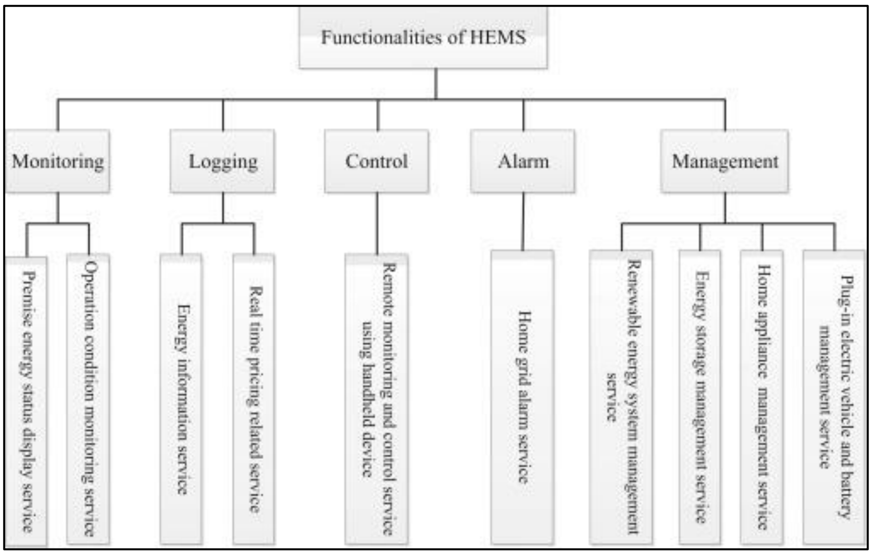


Figure 3.1: Functionalities of representative smart HEMSs (Zhou et al., 2016)

i. Monitoring enables users to easily access real-time information on their energy usage and lets users engage in saving electricity. Display services can be provided for the operational modes and energy status of every home appliance (Zhou et al., 2016).

ii. Logging involves gathering and saving the data information on the electricity usage amounts from multiple sources, which includes home appliances (Zhou et al., 2016).
iii. There are two types of **control**, namely remote and direct control. Direct control is applied to the control system and equipment; remote control is when users have online access to control and monitor the consumption patterns of their in-home devices using a smart device (McIlvennie et al., 2020; Zhou et al., 2016).
iv. Management is the most vital function in increasing efficiency and optimisation of electrical power usage in SE. The services covered in management include energy storage management, renewable energy system management service, battery management service, Plug-in EVs, and home appliance services (McIlvennie et al., 2020; Zhou et al., 2016).
v. The alarm - the smart HEMS centre receives alerts with information on where faults exist in the environment (Zhou et al., 2016).

HEMS is not considered to be a straightforward approach that leads to saving energy (Nilsson et al., 2018). The resident's cultural and social practices should be considered (Nilsson et al., 2018). Based on research conducted by (Nilsson et al., 2018), the effectiveness of HEMS also depends on the users' ability and willingness to absorb the information and features offered by the system. An example of an in-home display is shown in Figure 3.2. Users were able to turn eleven appliances on and off, adjust the settings on thermostats for several appliances, and change the duration of each appliance's operation (in 30 min increments). Figure 3.2 depicts the electricity usage and the manipulations available to the user, which included the user setting the time, in hours, for how long they wanted to switch an appliance on or off, resetting the time and setting for an appliance or all appliances, and turning an appliance on or off.

Figure 3.2: Screenshot of an In-Home Display (Krishnamurti et al., 2013)

Based on the functionalities of HEMS and how they operate, the major disadvantage of HEMS is that they require continuous monitoring and management to obtain the optimum benefit, which consumes a lot of time. The effectiveness of the HEMS will depend on how the user interprets the information based on the interface provided. It is therefore important to research into improving how information should be presented to the user.

3.3. Visualisation

Ware (2012) highlighted that vision allows us to obtain more information compared to all other sensors combined. Visualisation refers to the graphical representation of concepts or data (Ware, 2012); this enables users to make use of their user perception to achieve better analysis and understanding (Ferreira et al., 2019). Visualisation can also lead to an increase in awareness for the user and can motivate users to respond (Grainger et al., 2016).

Data visualisation involves the illustration of data in a manner that allows the data to be easily understood by the user, without having to go into statistical details (Grainger et al., 2016; Shen et al., 2019). Creating a data visualisation involves multiple decisions to be made in the process. These decisions include which data should be collected, which data is presented, how to present it, and where to present it (Boehnert, 2016).

For this research, "data visualisation", "information visualisation", and "visualisation" will refer to the same thing, as we will be focusing on the communication aspect of their definitions. The main difference between the three terms tends to be shaped by one's emphasis in focus towards either the input material (data) or the nature of the output form (information) (Kirk, 2019). Information visualisation deals with information that is usually structured in a complex format and is highly dimensional, as well as other qualitative data (Muzammil Khan & Khan, 2011; Kirk, 2019).

The main objective of visualisation involves using a human visual perception of information to improve reasoning abilities (Hrabovskyi et al., 2020). Comprehending the data or turning data into knowledge can mean different things for different individuals, however, visualisation in all such cases (including rules, constraints, and patterns), provides an essential tool in this effort (Godfrey et al., 2016).

The basic goal of visualisation is to increase a person's reasoning abilities by employing their visual perception of information (Hrabovskyi et al., 2020). Understanding data or turning data into knowledge might mean different things to different people, but visualisation is a critical tool in all these circumstances (including rules, limitations, and patterns) (Godfrey et al., 2016).

McCormick (1988) acknowledged the importance of research in visualisation and stated that the main drive for research in the field of energy visualisation is that energy flows are invisible to the human eye. Visualisation plays a critical role in communicating information to the user, and this can be achieved through the use of pictures (Al-Kassab et al., 2014). The main benefit of visualisation is the sheer amount of information that can be quickly understood if presented well (Ware, 2012).

The benefits of general visualisation (Ware, 2012) include:

i. The visualisation provides a platform for users to easily understand large amounts of data (Al-Kassab et al., 2014; Hrabovskyi et al., 2020; Ware, 2012).
ii. The perception of emergent properties is allowed through visualisation (Hrabovskyi et al., 2020; Ware, 2012).
iii. Problems in the data can be quickly identified when using visualisation (Hrabovskyi et al., 2020; Ware, 2012). Visualisation not only reveals problems in the data but also issues in the way the data was collected (Ware, 2012).
iv. The visualisation provides an understanding of both small- and large-scale features of data (Ware, 2012).

The visualisation process has four stages; these stages are illustrated in Figure 3.3. The stages include the following:

- Collecting and storing data (Batch & Elmqvist, 2018; Ware, 2012).
- Pre-processing of data collected involves transforming data into something easier to manipulate. Data reduction is usually involved to reveal selected aspects, and data exploration refers to the process of altering the subset currently being used (Ware, 2012).
- Mapping of data from a visual representation can be accomplished through computer algorithms that can produce images on screens (Ware, 2012).
- Individuals' perceptual and cognitive systems (Ware, 2012), communicate the results to stakeholders in presentations, charts, and reports (Batch & Elmqvist, 2018).

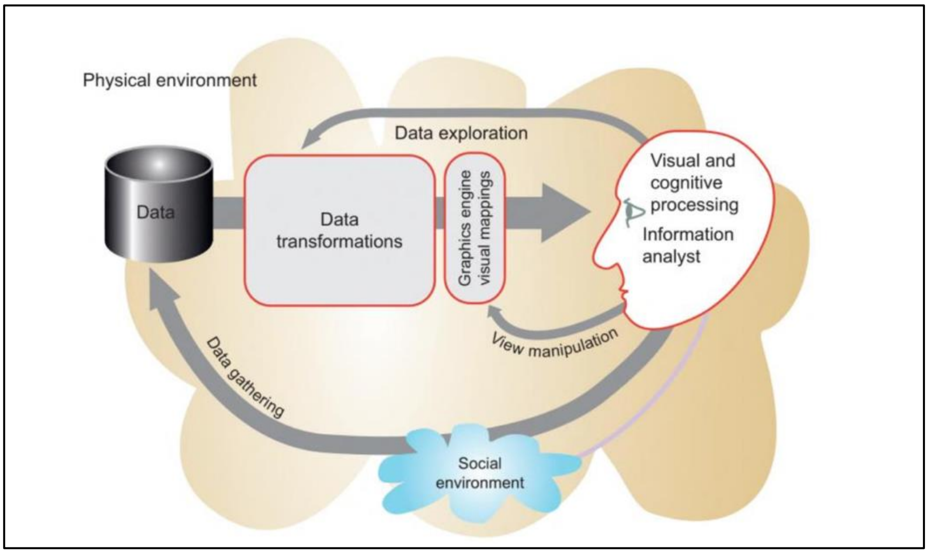


Figure 3.3: Visualisation stages (Ware, 2012)

Visualisation acts as a tool to communicate energy usage and share information with the users to provide them with more knowledge of their sources of energy usage (Murugesan et al., 2014), Enabling users to view and understand their electricity consumption provides great potential for users to reduce the waste of electricity usage (Stinson et al., 2015).

An important feature for a visualisation to have is interactivity, meaning the user can interact with the visualisation (Ali et al., 2016). A limited amount of data is presented on the screen with interactivity, but the user has the option to explore the entire data set. Allowing interactive features means giving the user power over the values and properties by altering them to their needs. Interactive visualization is an "*on-demand visualization technique that allows decision makers to browse to selected data and present it at various levels of detail and in numerous formats*" (Maria Perkhofer et al., 2019). The user or decision maker can choose the order in which they wish to look at the information.

Exploratory data analysis to detect patterns and generate hypotheses is aided by interactive information visualization. Furthermore, the review process might begin with Shneiderman's mantra: *"Overview first, zoom and filter, then details-on-demand,"* reducing issues related to information overload (Shneiderman, 1996).

3.3.1. Interactive Visualisation

Visualisation can be referred to as a cognitive tool. The interaction of visuals allows for a deeper level of cognition while also enhancing the human's ability to learn (Sandouka, 2019). The user can define what data they see and how they see it through interaction with the visualisation, which creates a dialogue between the user and the system. Designers must understand what tasks, visual representations, and interaction strategies are available, as well as how they function together to assist analytical thinking, as interactive visualizations become more common in information systems (Sandouka, 2019). Different interaction types of visualisations were summarised by (Sandouka, 2019), as shown in Table 3.1.

Users can change the date on display via interactive visualisation, which allows them to interact with graphs and tables in real-time (Shafik & Case, 2021). This enables users to go beyond the graphical information provided by static graphs and dig deeper into data to uncover previously hidden insights (Shafik & Case, 2021). Users may delve down into the data, sort it, and filter it. The goal of interactive visualisation is to increase the transparency and controllability of dynamic decision-making processes, allowing for suitable decisions based on real-time data (Shafik & Case, 2021).

In this research we aim to include interactivity in the visualisation of electricity usage to enable users to analyse the information available in more detail, enabling them to make more informed decisions to save electricity.

3.3.2. Visualisation of Electricity Usage

Research on electricity usage in households has become an important and vital topic of research in the energy consumption field (Herrmann, 2018). Managing electrical appliances has become more important due to the development of SEs, and makes the management of electricity in the environment easier (Herrmann, 2018). To achieve energy efficiency in buildings, it is necessary to comprehend how electricity is consumed in the building, and have an appropriate monitoring system to save electricity (Ruiz et al., 2020).

Table 3-1: Interaction Types (Sandouka, 2019)

Interaction	**Description**	**Source**
Overview	Birds-eye view; the entire collection	(Shneiderman, 1996; Yi et al., 2007; Few, 2009; Figueiras, 2015)
Zoom	Scale visualisation to see a specific subset of data points	(Shneiderman, 1996; Few, 2009; Figueiras, 2015)
Filter	Reduce the size of the search, hide data points conditionally	(Shneiderman, 1996; Yi et al., 2007; Few, 2009; Figueiras, 2015)
Details on Demand	Select an item to get details	(Shneiderman, 1996; Few, 2009)
Relate	View relationships among items	(Shneiderman, 1996; Yi et al., 2007; Figueiras, 2015)
History	Track exploratory steps, allow back-tracking	(Shneiderman, 1996)
Extract steps	Save results of exploratory	(Shneiderman, 1996)
Abstract / Elaborate	show more or less detail	(Yi et al., 2007; Figueiras, 2015)
Select	mark something as interesting	(Shneiderman, 1996; Yi et al., 2007; Few, 2009; Figueiras, 2015)
Reconfigure	change the arrangement, scale, or encoding	(Shneiderman, 1996; Yi et al., 2007; Few, 2009; Figueiras, 2015)

Energy is viewed as invisible, intangible, and abstract (Boomsma et al., 2016). This makes it difficult to understand how much energy is generally used (Boomsma et al., 2016), as well as how energy is linked to what an individual does in their day-to-day activities. Feedback has been viewed as a tool that 'makes invisible energy visible'. Feedback delivers information on energy consumption to users, often making use of devices such as in-home displays (Boomsma et al., 2016).

Several efforts have been done on IoT platforms to save energy. However, while using IoT, vast volumes of data are produced, and the IoT devices require a significant amount of electricity to run them and send data (Motlagh et al., 2020). Our research aims to contribute to the advancement of the visualisation aspect of communication systems for feedback on electricity usage. Visualisation can help with effectively conveying electricity usage since it allows consumers to quickly analyse data and make decisions (Benita et al., 2020; Loos et al., 2019).

The importance of visualising electricity usage is that it gives consumers intelligible and timely electricity usage statistics, allowing them to recognise when wastage occurs (Herrmann, 2018). This research intends to use visualisation to effectively communicate electricity usage to users, which could result in a reduction in electricity consumption. Visualisation has been considered a feasible approach to motivating users to save energy by providing them the capability to monitor, and eventually, control their consumption of energy (Murugesan et al., 2015a).

The type of information provided as feedback on electricity consumption involves near-real-time power data, such as total power consumed by all appliances, and historical electricity data such as past days, weeks, months, etc. (Murugesan et al., 2015a). This type of data can be referred to as time-series data, which is made up of a methodical sequence that uses time as an index, together with values of variables of interest at the corresponding time point (Ushakova & Jankin Mikhaylov, 2020). Section 3.3.3 discusses why it is important to visualise electricity usage in a SE.

3.3.3. Why Visualise Electricity Usage in a Smart Environment

SEs are making a shift from a research vision, but through the IoT, they have made a concrete manifestation in the real world (Curry et al., 2019). It is only fitting that in preparation for more SEs being developed, energy conservation in these environments will become necessary. The development of SEs, especially in the household environment, and the use of smart appliances, which include smart refrigerators, washing machines, ovens, and air-conditioners, increase comfort for the user (Xia et al., 2018). However, energy-hungry applications are created, leading to a rise in the electricity cost of a household (Xia et al., 2018).

SEs produce large amounts of low-level data that is collected, but fail in producing this data in a usable, meaningful, and accessible manner (Von Frankenberg und Ludwigsdorff et al., 2016). The multiple connected devices produce a lot of data, and this data can become challenging to understand (Benita et al., 2020). Therefore, appropriate, and adequate visualisation tools are necessary to get a full view of data, patterns, and major characteristics of the gathered datasets and discover structures (Benita et al., 2020).

To reduce electricity consumption, visualisation has been vital in helping energy managers and users in understanding the data and conserving electricity (Murugesan et al., 2014). Visualisation of data assists in transforming a problem into a perceptual task to understand the data (Fernandez & Fetais, 2017). Real-time and comprehensive visualisation of electricity is vital as it allows users to know whether there is a waste in electricity usage (Fan et al., 2017). Providing users with this data can be viewed as having the potential to encourage users to reduce their energy consumption (Stinson et al., 2015); as the data provides insight into users' behaviours and actions, and providing visualisation for this data enables its users to further understand their environment, themselves, and their habits (Castelli et al., 2017).

The SE system might have been developed for years but deficiencies still exist in the energy management aspect (Fan et al., 2017). Keeping the 'smartness' of the environment is key when dealing with the issue of energy usage reduction to maintain a positive user experience (Cottone et al., 2015).

IoT has brought about a significant increase in the capabilities of devices used in the environment daily (Wang et al., 2020). Smart devices provide improved convenience, remote control over the internet, and better energy management; however, this contributes to increasing standby energy consumption (Wang et al., 2020). Standby power (vampire energy) was discussed in Chapter 2 and is popular with multiple products. Standby power adds up. (Wang et al., 2020) highlighted a comparative study on standby energy between the Philips Hue on-off mode and leaving the present lights on and used 67 lights for their study. The results showed that a SE bulb uses similar consumption to 60 W LED bulbs switched on continuously. This resulted in the researchers concluding that smart devices consume more energy in comparison to legacy systems (Wang et al., 2020). Figure 3.4 below shows this comparison.

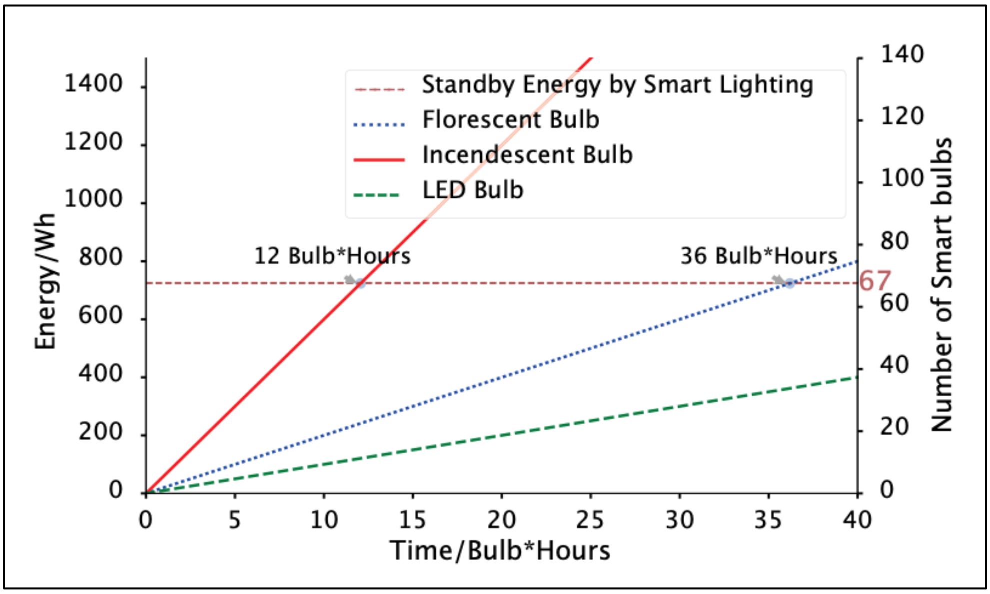


Figure 3.4: Visualisation process collected (Wang et al., 2020)

For this research, we selected visualisation as a tool that can be used to communicate electricity usage to the users. In motivation, we highlight the major benefits of using visualisation as a tool to communicate electricity usage to the user.

i. Communication and easier understanding of data:

Visualisation can be useful as it communicates information quickly, can evoke emotional responses, and can attract users' attention (Spence et al., 2018). Huge amounts of data are produced by a SE every day and visualisation can be used to understand the data easily (Lange et al., 2012)

ii. Motivation:

Visualising electricity consumption is a vital tool in assisting users in lowering electricity consumption and encouraging sustainable behaviour (Murugesan et al., 2014). Fan et al., (2017) and Thu et al., (2017) supported that visualisation can aid users in altering their behaviours to be more electricity conservative and practice best practices in energy consumption (Suppers & Apperley, 2014; Thu et al., 2017). Thu et al., (2017) presented an experiment where visualisation was used as a tool to raise awareness of their behaviours and their relative impact on electricity consumption. This technique was used in conjunction with positive motivational techniques, such as goal setting in facilitating behaviour change.

iii. Improve electricity usage awareness:

Visualisation can be a tool for creating electricity awareness and enabling users to better understand how to conserve electricity (Spence et al., 2018). Visualisation creates awareness by quickly communicating the user's electricity usage and attracting the user's attention (Murugesan et al., 2015a; Spence et al., 2018). Visualisation of electricity usage is vital in engaging the users in their electricity usage (Spence et al., 2018).

iv. Assist in reaching electricity saving goals and improving sustainability:

Some researchers (Spence et al., 2018) highlighted that due to the benefits that visualisation offers, it could potentially be effective in assisting users in remembering and enacting electricity-saving goals. Visualisation of electricity consumption also provides increased sustainability through saving electricity (Murugesan et al., 2015a).

This section motivated the selection of visualisation to effectively communicate electricity consumption information to users and solve the research problem. The various benefits discussed illustrate why visualisation can be beneficial to users in quickly and easily understanding their electricity usage and basing their decisions on this information to avoid wastage. Section 3.3.4 provides a review of visualisation techniques used to visualise electricity usage.

3.3.4. Visualisation Techniques Commonly used for Electricity Usage

To visualise data, a variety of ways can be used. However, because the focus of this study is on electricity, it's critical to look at visualization techniques that are both successful and appropriate for visualising electricity usage. Knowledge of the fundamental principles and theories of information visualization is required to select the proper visual encoding (Hoeber, 2018). To be effective, visualizations must be created for a specific goal rather than being generalized. Users will be better able to interpret the data if the visualisation is built with a specific objective in mind (Tripp, 2019).

The main objective of visualisation technologies is to assist users in identifying observations and patterns in the data to help them make informed decisions (Fernandez & Fetais, 2017). The following sections investigate the different techniques to select the most suitable visualisation technique to use to visualise electricity usage.

Data on electricity consumption is gathered over time, and thus most visualisation techniques implemented on existing systems fall under the time-oriented visualisation category (Masoodian et al., 2013; Herrmann et al., 2018). Most visualisations for electricity usage are usually in the form of graphical time series, such as line charts, silhouette graphs, and bar graphs (Masoodian et al., 2013; Herrmann et al., 2018). For this research, we will make use of the words graph and chart interchangeably.

i. Bar graph

The bar chart is one of the traditional techniques used to visualise data in multiple fields (Nga et al., 2012). A bar chart can display quantitative values for various category items (Kirk, 2019). The bar chart is made up of line marks (bars), as well as size attributes (height or length), which are used to show quantitative values for each item (Kirk, 2019). A bar graph (Slutsky, 2014) can consist of either a vertical or horizontal, the length of the bars, determines the value, the bigger the length the bigger the value. A bar graph can be used to compare a single variable between multiple groups (Slutsky, 2014) such as total energy usage between various months. Figure 3.5 shows an example of a horizontal bar chart. The x-axis represents the scale, and the y-axis shows the various categories being compared.

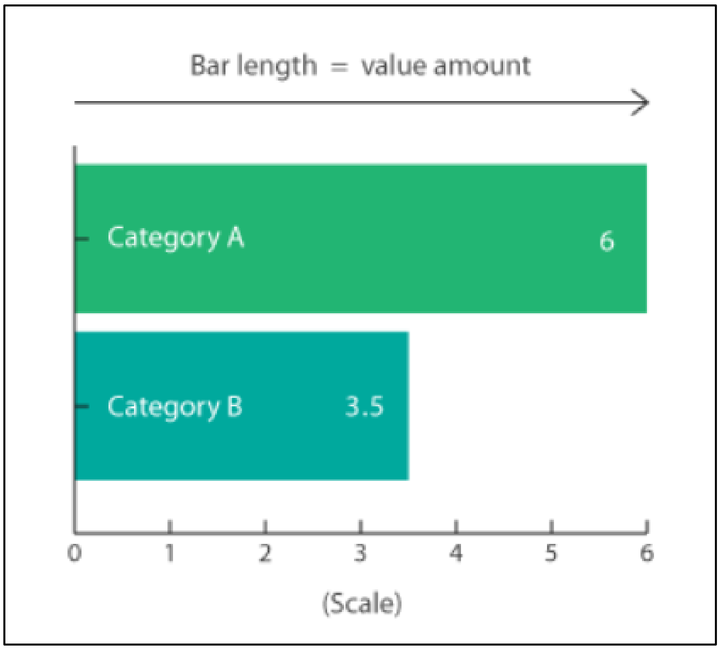


Figure 3.5: Bar graph (Ribecca, 2021)

ii. Grouped bar graph

A grouped bar graph is a variation of a bar graph and similar to a bar graph, the length of the bar shows the numerical, discrete comparisons between categories (Ribecca, 2021; Ferdio, 2021). To differentiate them, each data series is given a unique colour or different shade of the same colour. Each group of bars is separated from the others (Ribecca, 2021). It is mostly used to make comparisons between grouped variables or categories and other groups with the same variables or category types (Ribecca, 2021). Figure 3.6 shows an example of a grouped bar graph, comparing three different data sets in two different categories (A and B).

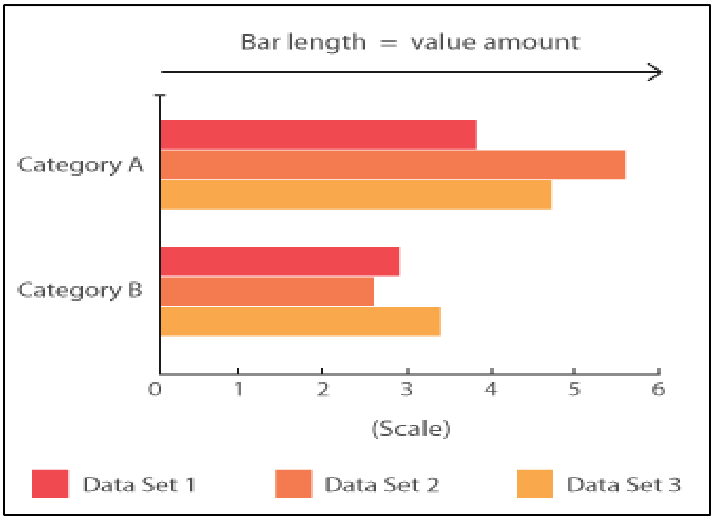


Figure 3.6: Grouped bar graph (Ribecca, 2021)

iii. Stacked bar graph

A stacked bar graph is a chart that makes use of bars to compare sums of categories of data (Vigo, 2019; In & Lee, 2017). The stacked bar graph in Figure 3.7 represents the compressed volume of each component of three operations (In & Lee, 2017). There are two types of stacked graphs, a simple and a 100 percent stacked bar graph (Ribecca, 2021) (Ferdio, 2021). The total value of the bar represents the sum of the segment values for simple stacked graphs. The cumulative values across each segment/group can be compared using a simple stacked bar graph (Ribecca, 2021; Ferdio, 2021), as shown in Figure 3.7. The 100 percent stacked bar graph (Figure 3.8) shows the percentage of the whole of each group and is plotted by the percentage of each value to the total sum of each group. This makes the relative differences between quantities in each category easier to see (Ribecca, 2021).

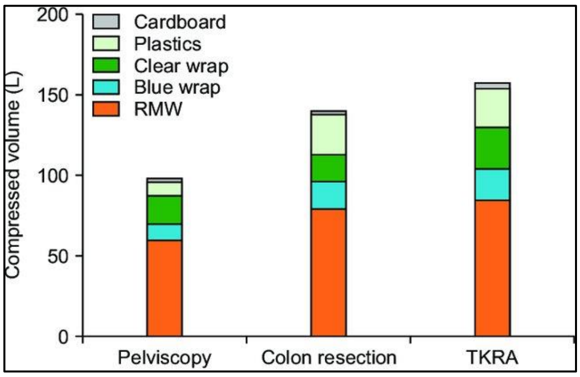


Figure 3.7: Stacked bar graph (In & Lee, 2017)

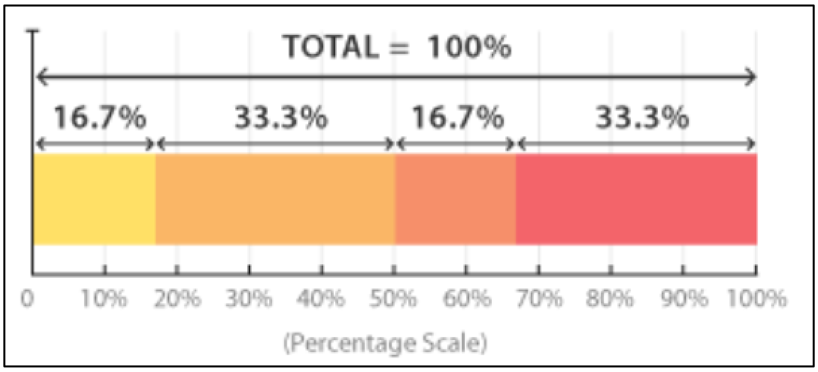


Figure 3.8: 100 percent stacked bar graph (Ribecca, 2021)

iv. Histogram

A histogram is also referred to as a frequency distribution graph. This is a special type of bar graph, which looks like a column graph but with no gaps between the columns. It is used to show data from a continuous variable (Slutsky, 2014). The single data points are grouped into classes to show the frequency of data in each class (Slutsky, 2014). Histograms are used to show where values are concentrated, the extreme values, and whether there are any gaps in values any unusual values (Ribecca, 2021). The histogram in Figure 3.9 shows a frequency distribution for time to respond to tickets sent into a fictional support system; each bar shows the time, and the height shows the number of tickets in each time range (Yi, 2021).

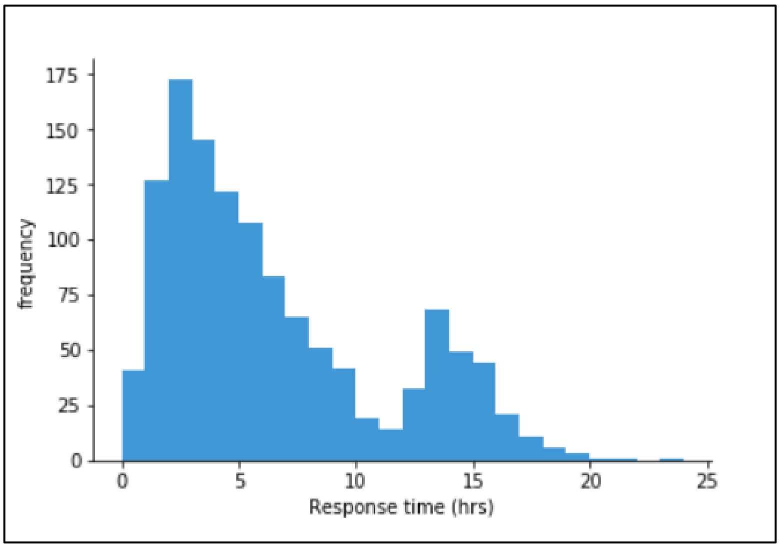


Figure 3.9: Example of a histogram (Yi,2021)

v. Donut chart

A donut (doughnut) chart is like a pie chart, the main difference being the blank centre (Ferdio, 2021). The use of pie charts is often criticised because it draws attention to the proportional areas of the slices in relation to one another and to the chart as a whole (Ribecca, 2021). By de-emphasizing the use of the area, the donut chart helps alleviates the problem with pie charts. Instead of focusing on the proportions between the slices, users can concentrate on reading the length of the arcs (Ribecca, 2021). Donut charts can be used for comparisons of different categories (Ribecca, 2021). Figure 3.10 shows an example of a donut chart comparing different categories A, B, C, and D.

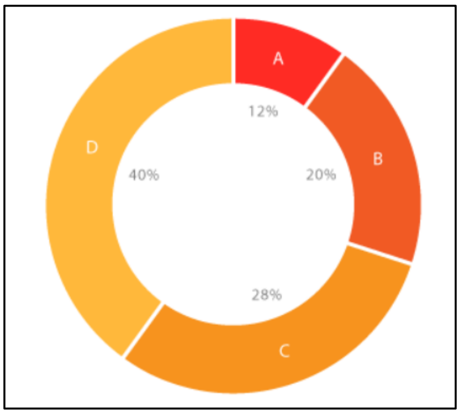


Figure 3.10: Donut chart (Ribecca, 2021)

vi. Scaled up number

A scaled up number is a technique used to highlight a single value (Ferdio, 2021). Figure 3.11 (left) shows an example of a scaled-up number showing the total number of users, (right) shows the use of scaled up numbers showing the number of emails sent, templates created by users, email addresses added to the system, and campaigns sent out.

Figure 3.11: Scaled up number (Ferdio, 2021)

vii. Line chart

A line chart shows the changes in the quantitative values over time for different group items (Kirk, 2019). Line charts are mostly organised around a continuous temporal x-axis and a quantitative y-axis with values mapped using point marks at applicable coordinates (Kirk, 2019). Figure 3.12 shows an example of a line chart x-axis showing intervals, and a y-axis showing a value scale. A variation of a line chart includes the multi-series line chart, which is like a line chart but shows multiple datasets' trends and relationships (FusionChart, 2021). Figure 3.13 shows a representation of a multi-series line chart showing energy consumption daily, each line representing a different month.

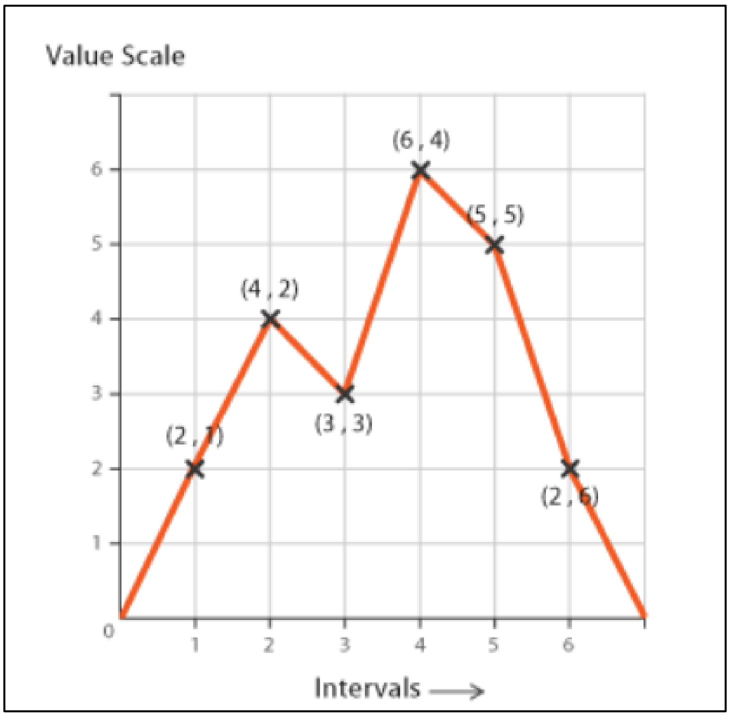


Figure 3.12: Line chart example (Ribecca, 2021)

Line charts are mostly used to show trends in data continuously varying over some time or range (Toasa et al., 2018). Line charts can therefore be used to show electricity consumption over a specified period. Figure 3.13 shows the average hourly electricity consumption of various households over the indicated months. Based on the trends provided, decisions can be made based on peak hours. Users can decide to alter their electricity usage behaviours, showing that electricity comparisons contribute to users projecting on their electricity usage, thus leading to electricity usage reductions (Evariste et al., 2016).

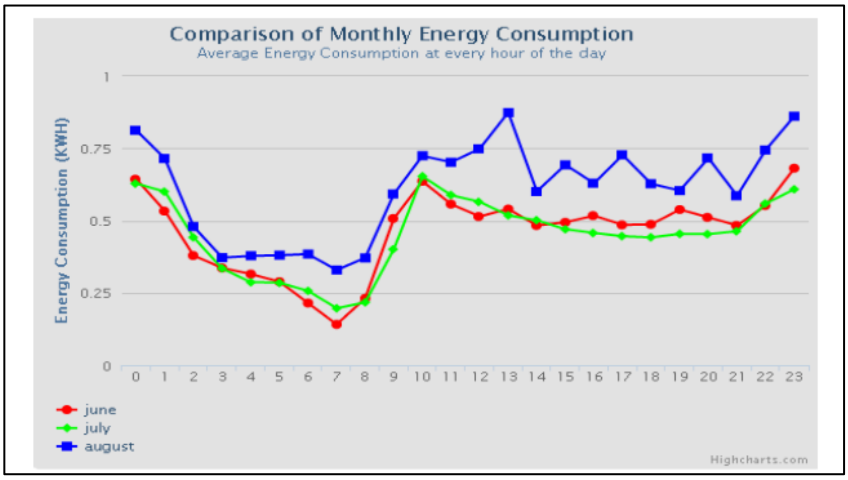


Figure 3.13: Multi-line chart (Evariste et al., 2016)

viii. Box plot

A box plot is used to show the distribution and shape of a series of quantitative values for unique categories. It shows five different summaries for the data, namely the first quartile, the second quartile, the median, the third quartile, and the maximum (Kirk, 2019). An example of a box plot is shown in Figure 3.14 which illustrates one individual's consumption and the variability around the central tendency visualised using boxplots. Horizontal lines within the boxes represent the median consumption at each half-hour band. The points outside the box represent less common usage behaviour (outside the second and fourth quantiles of data distribution). More variability outside the second and fourth quantiles at a given hourly time point indicates more instances of variation around typical energy usage by the user (Ushakova & Jankin Mikhaylov, 2020.

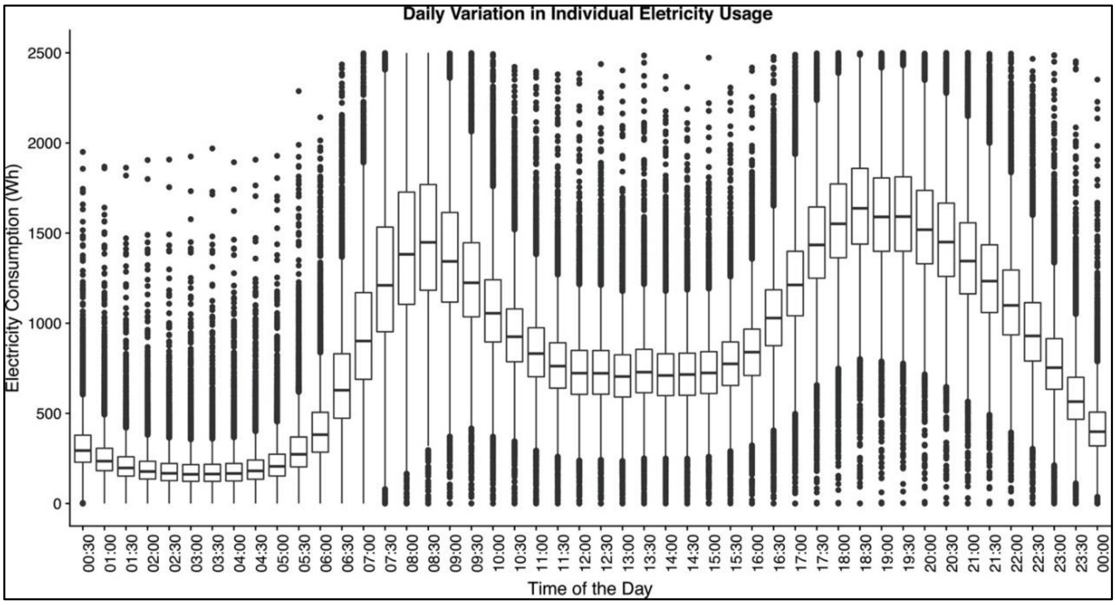


Figure 3.14: Box plot (Ushakova & Jankin Mikhaylov, 2020)

ix. Heat Map

A heat map can be referred to as a graphic illustration of data that shows the row and column hierarchical cluster structure in a data matrix (Guo et al., 2020). Unique colours are used to show the extent of a specific quantitative value (Kirk, 2019). Heat maps can transform data into a colour summary, making the distribution and characteristics of data clearer at a glance, and making it easier to differentiate and summarise abnormalities (Guo et al., 2020). An example of a heat map is given in Figure 3.15. Heat maps (Yi, 2021) show relationships between two variables, one on each axis.

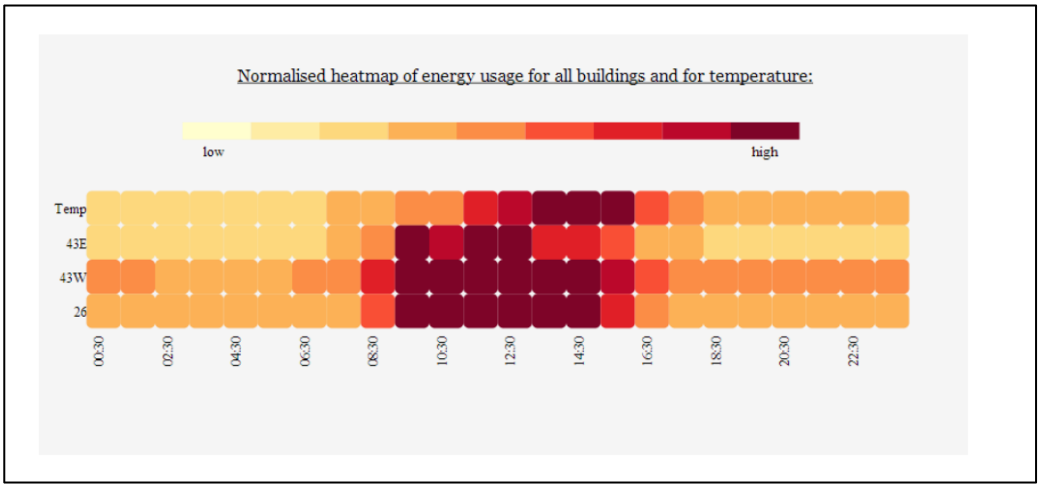


Figure 3.15: Heat map showing a building's energy use in comparison to environmental temperature data (Lunga et al., 2014).

x. Meter

A meter resembling a vehicle speedometer was used to visualise overall energy consumption (Evariste et al., 2016). This visualisation provides the benefit of improving the user's ability to identify and visualising the status of live power consumption (Evariste et al., 2016). An illustration of a meter being used to show real time display of power usage is shown in Figure 3.16.

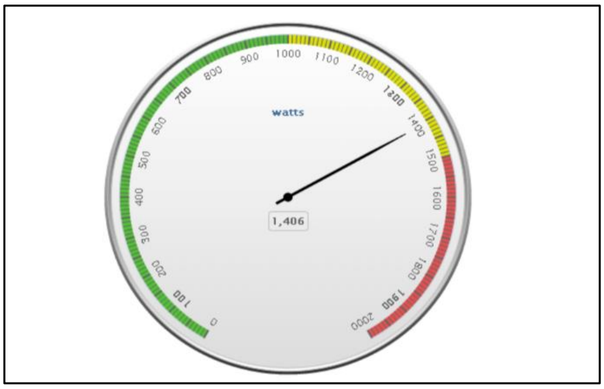


Figure 3.16: Real Time Power Data Displays (Evariste et al., 2016)

xi. Gauge

A gauge is mostly used to indicate whether an index is high/low, good/bad, etc. (Ferdio, 2021). The gauge in Figure 3.17, shows the current speed in miles per hour in the centre, the speed limit on the top left, and the current direction/position in the top right (Ferdio, 2021).

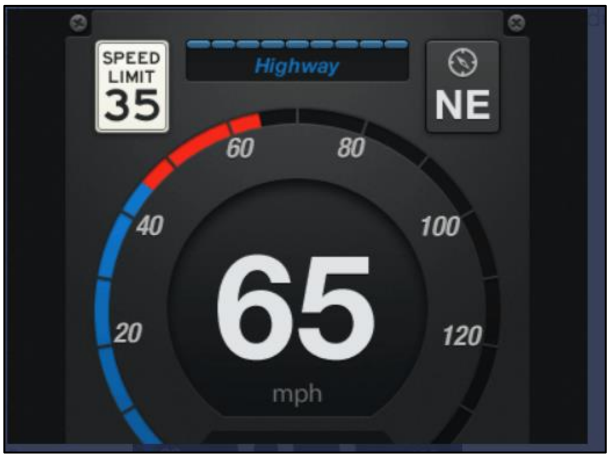


Figure 3.17: Gauge (Ferdio, 2021)

xii. Pie chart

A pie chart (Kirk, 2019) is used to represent how parts of quantities for unique categories make up a whole. Pie charts make use of a circular display separated into sections for each category, the angles of the chart represent percentage proportions, and colour can be used to differentiate attributes (Kirk, 2019). Figure 3.18 provides an example of a pie chart used to show electricity usage in real time (Johnson & Ropion, 2019). Pie charts are useful in comparing different proportions or shares of multiple items (Toasa et al., 2018).

Table 3.2 summarises the traditional techniques and provides a criterion to evaluate the different techniques; the criteria are based on characteristics that the various chart types need to meet for the development of the visualisation tool.

The literature review conducted on different visualisation techniques was an attempt to assist in answering RQ_3, "*Which are the most effective techniques for visualising energy usage in a Smart Environment?*".

The different roles of each chart type discussed above, assisted in deciding which chart should be used for a specific use case of the developed Information Visualisation (IV) tool. The charts discussed above all meet a similar criterion, which is they support the display of time series data, which is the basis of the selection of chart types discussed. Some charts have similar roles, for example, a pie chart and a bar graph can both be used to compare different categories to each other. The following section discusses existing systems that visualise electricity usage in SEs. The discussion will help in discovering which visualisation techniques are used to effectively communicate electricity usage information to users.

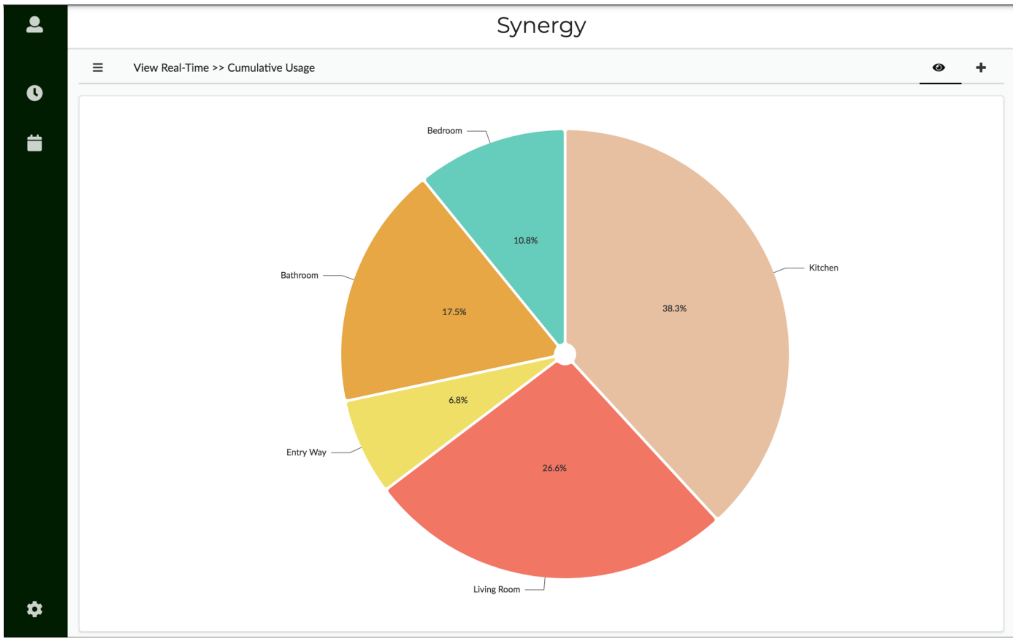


Figure 3.18: View of cumulative energy consumption in real time (Johnson & Ropion, 2019)

A formative evaluation of the proposed IV tool incorporating the different techniques (Chapter 4: Design and Development of IV tool) was conducted to determine which techniques are more effective for the user to assist them in easily understanding their electricity usage and answer RQ_3. Formative evaluation (Hartson & Pyla, 2012) includes identifying issues in the user experience and fixing the problems in the design.

3.3.5. Existing Systems Visualising Electricity Usage in Smart Environments

In this section, we investigate the various types of energy visualisation systems that have been developed for SEs and which have implemented different visualisation techniques. This section aims to answer RQ_2 which refers to "*How is the electricity usage in a SE currently visualized*?".

3.3.5.1. Efergy Pro

Consumers can use Efergy Pro (Efergy, 2021) to keep track of their home's power usage and solar energy generation daily. The program allows users to track their electricity usage so they can better understand their patterns and make more informed decisions about how to save money on electricity.

Table 3-2: Review summary of visualisation techniques researched

Technique	**Function**	**Easily Understood**	**Time series data supported**	**Scalable**	**Visually appealing**
Bar graph	Comparison	✔	✔	✔	✔
Grouped bar graph	Comparison	✔	✔	✔	✔
Stacked bar graph	Comparison; Composition	✔	✔	✔	✔
Histogram	Frequency distribution	✔	✔	✔	✔
Donut/ doughnut chart	Comparison composition	✔	x	✔	✔
Scaled up number	An indicator showing one value clearly	✔	x	✔	✔
Line chart	Shows trend	✔	✔	✔	✔
Box plot chart	Shows a five-number summary of data	x	✔	✔	x
Heat map	Summarizes data using colours	x	✔	✔	x
Meter	View live readings	✔	✔	✔	✔
Gauge	Shows proportions	✔	✔	✔	✔
Pie chart	Shows proportions	✔	x	✔	✔

Features of Efergy include (focusing on the visualisation aspect):

- Access to energy statistics from anywhere at any time via a mobile application.
- Allows consumers to see how much solar energy has been generated in real time, allowing them to track their solar system.
- View historical consumption and savings data; and
- Provide extensive and comprehensive views of consumption across the time specified.

Customer reviews (Amazon, 2021) indicated that visualisation of electricity consumption allowed users to easily track and monitor their electricity usage and identify which devices are consuming the most electricity.

Figures 3.19 and 3.20 provide screens from the Efergy application. Figure 3.19 (a) provides a screen showing energy usage in real time and a summary view of the data for the day, week, and month. A historic view of the screen is shown in Figure 3.19 (b), which shows a stacked bar chart of the historical energy usage to enable users to track the usage so that they can make changes based on their consumption. Figure 3.20 shows the screen view of detailed insights about the energy usage of the specified time.

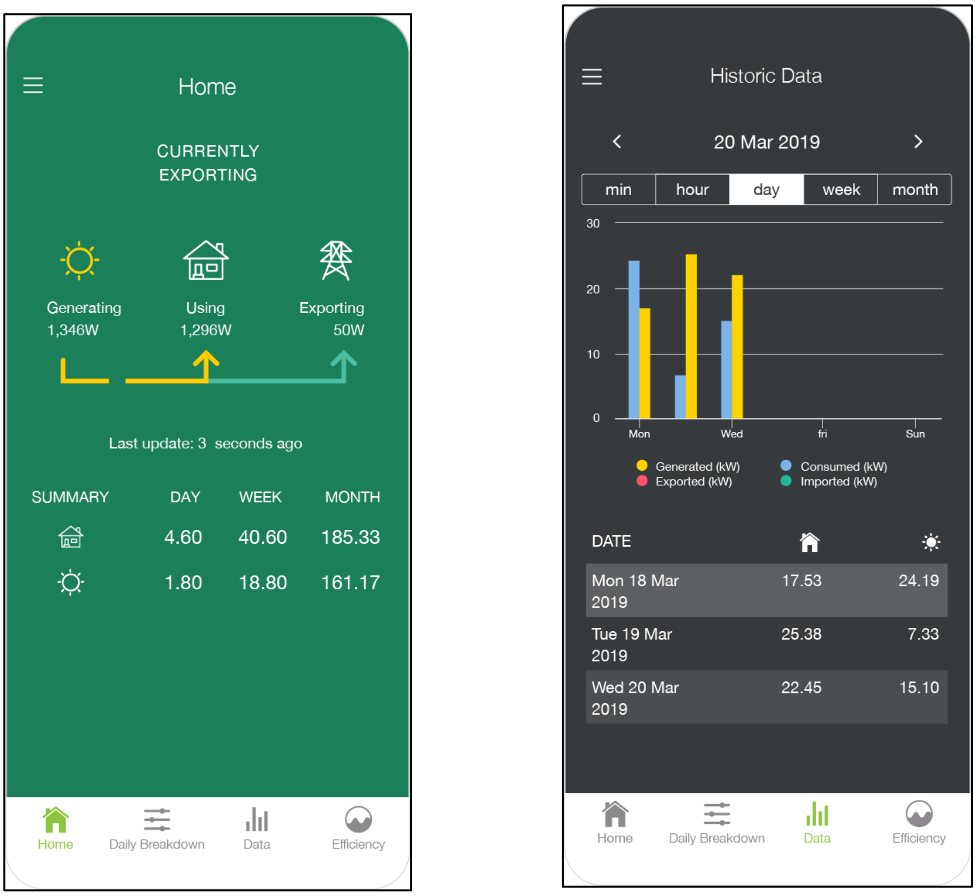


Figure 3.19: a) (left) Efergy Home screen, b) (right) Efergy historic data view (Efergy, 2021)

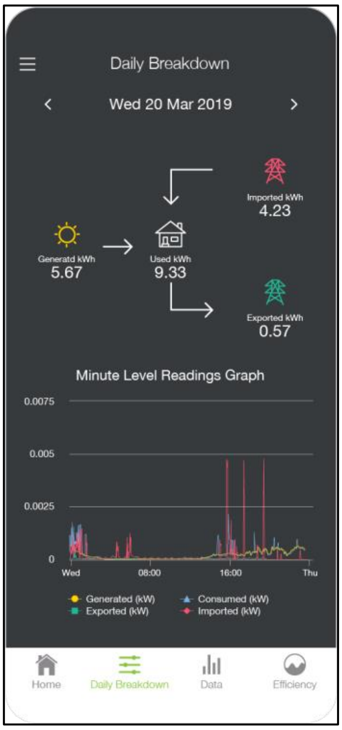


Figure 3.20: Efergy Daily breakdown (Efergy, 2021)

3.3.5.2. Sense

Sense (Sense, 2020) provides a tool that gives the user the ability to break down energy usage and take required actions to save energy. Sense provides usage in real time and in trends by week, day, and month to assist in understanding electricity usage patterns in the home, as shown in Figure 3.21 (a). Sense also provides goals for the user to help them improve their electricity usage. Sense provides an overall energy usage view of the home in Figure 3.21 (b); the user can view what appliances are on or receive a notification of when the washing machine has finished its wash cycle. Sense integrates with a few IoT devices to give the user more control using the Sense App.

3.3.5.3. Smappee

Smappee is an energy feedback system that allows users to monitor their consumption in historical, real time and drilled down to the specific device.

The Smappee dashboard provides its users with the ability to:

- View and analyse real time and historical electricity usage data.
- View appliances and their respective electricity usage data.
- Sort records on different parameters, which include highest consuming appliances with regards to their electricity usage,
- Interactivity with the systems, users can drill down on the detail of a graph, and
- View of always-on appliances, the appliances that have a standby feature.

Figure 3.22 shows a view of the Smappee dashboard; the screen shows total usage, the real time electricity usage, and always on energy usage, which is generated from appliances with the standby feature (Rosberg, 2016).

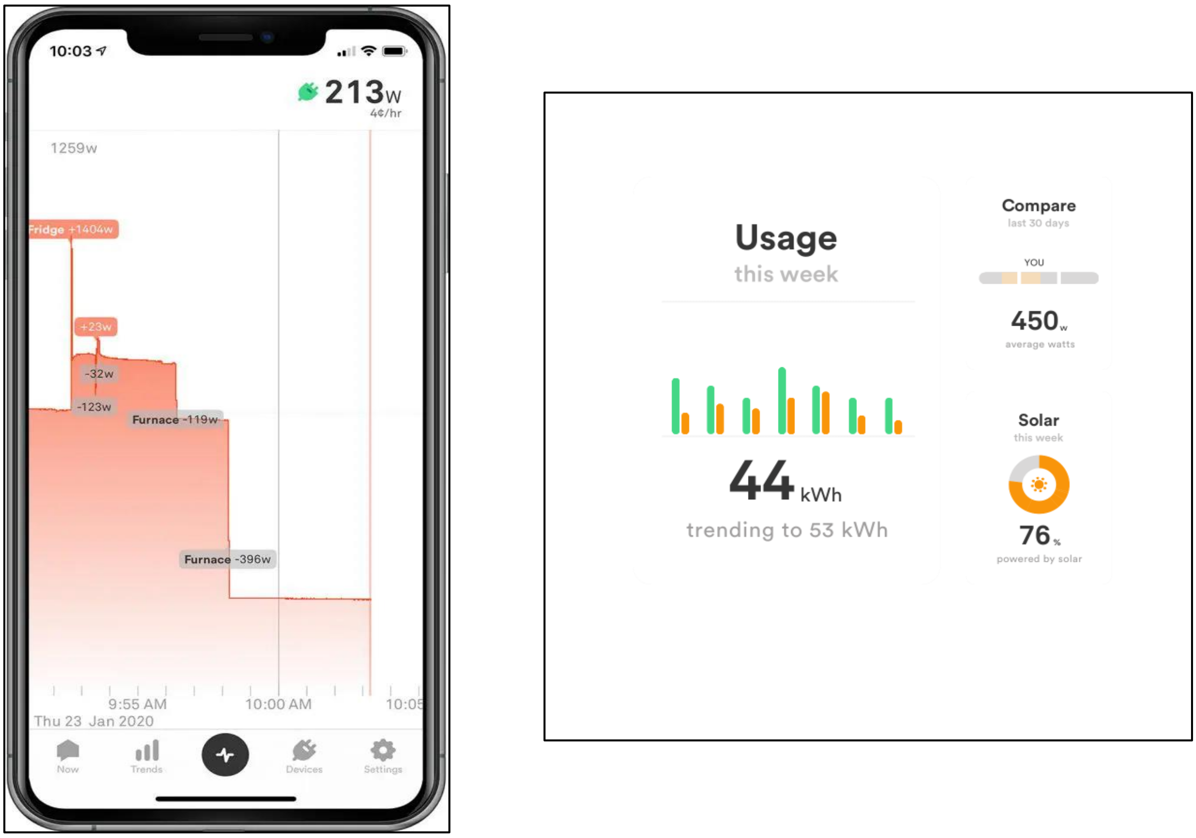


Figure 3.21: a) (left) Sense real time usage screen, b) Sense App usage summary

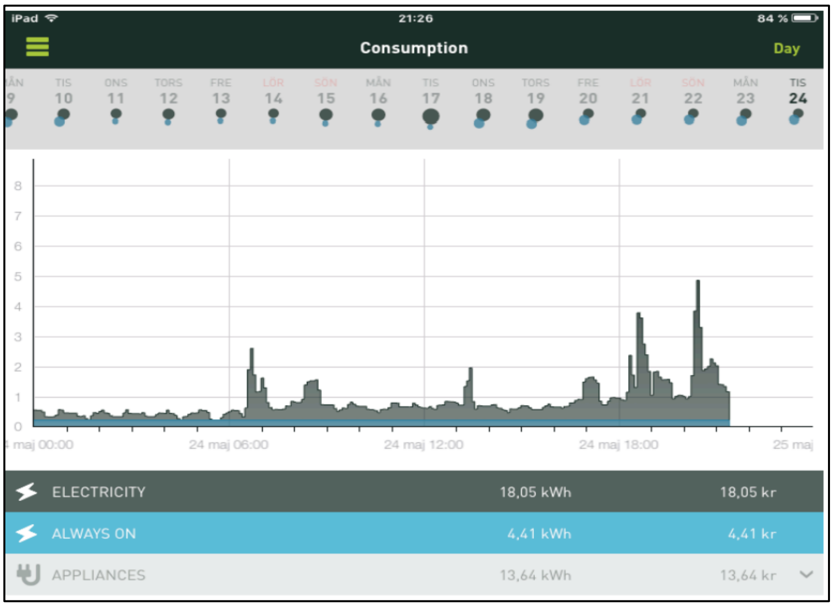


Figure 3.22: Energy usage of household consumption in Smappee (Rosberg, 2016)

Figure 3.23 shows a view of various readings of the specific appliance, which include the usage, the power usage in watts, the average time the device is on, the total consumption of the device, the total time the device is on, and the cost generated from the appliances' electricity consumption (Rosberg, 2016).

Research conducted by (Rosberg, 2016) on Smappee highlighted some issues that participants indicated while using the Smappee dashboard. The issues focusing on visualisation included making sure the graphs used are clearly labelled. Participants suggested the use of notifications on certain consumption levels.

By conducting this review of a few of the energy management tools currently being used in SEs focusing on the visualisation aspect of the applications, we discovered that most of the common features in Table 3.2, and most of the common visualisation techniques that were used as shown in Table 3.3.

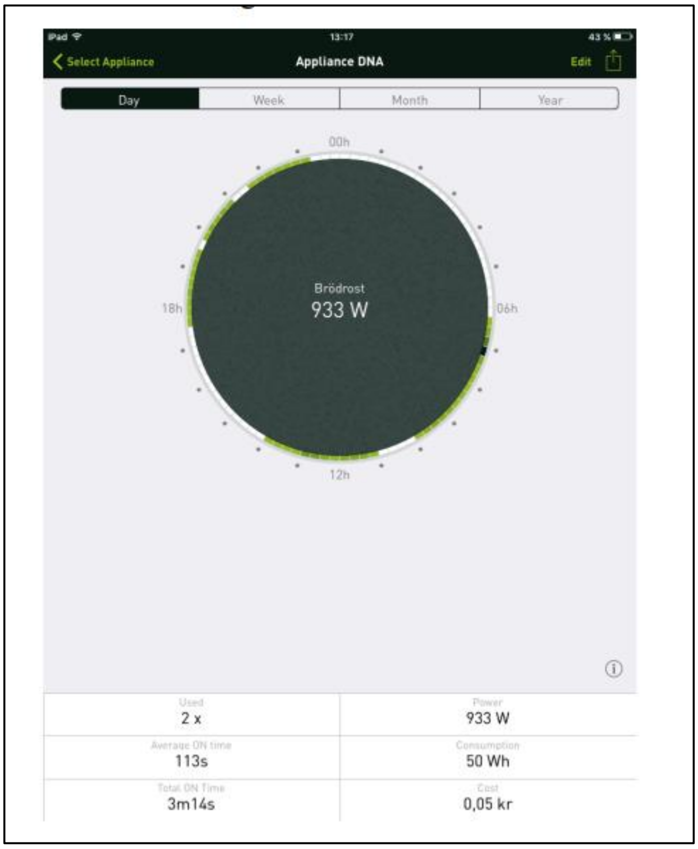


Figure 3.23: Drill down information about an appliance in Smappee (Rosberg, 2016)

Based on the review of existing systems, most applications currently developed a focus on energy, and not just on electricity usage, but rather energy, which includes solar, wind, and electrical types of energy. Existing systems reviewed made use of various chart types depending on the data being displayed. For example, when displaying energy usage over timeline charts were commonly used; when displaying comparisons of energy usage data pie charts and doughnut charts were used; bar charts were also used for showing energy usage in specified groups as well as the comparison of specified groups. The observation made from this review is that the selection of chart types depends on a few factors, which include the type of data being displayed, the type of users using the data, the purpose of displaying the information, and the relation of data to each other.

Table 3-3: Review of existing energy management systems

Feature	**Efergy**	**Sense**	**Smappee**
Real time information	✔	✔	✔
Detailed information - provide a breakdown of electricity usage information	✔	✔	✔
Historical information	✔	✔	✔
Filter: start and end date	×	×	×
Filter: period (day, week, month, year)	✔	✔	✔
Compare electricity usage	×	×	✔
Set target (energy saving goals)	×		×
Notification	×	✔	✔
Sole focus on electricity	×	×	×
Open Source			×

Table 3-4: Chart types used in review of energy management systems

	Efergy	**Sense**	**Smappee**
Chart type			
Line chart	✔	✔	✔
Scaled up number	✔		✔
Bar graph	✔		✔
Doughnut chart	✔		
Metaphor-based visualisations	×	✔	
Progress bar	×	✔	
Pulsing bubble chart			✔
Table			✔

This section discussed some visualisation tools developed in research and available on the market. This section aimed to provide insight into current electricity visualisation tools used in SEs and their strengths and weaknesses, focusing on the visualisation aspect of the tools. It should be noted that current existing tools are not limited to the ones discussed above, but can include and are not limited to Google Nest Hub (Google, 2023) and OpenEnergyMonitor (OpenEnergyMonitor, 2023).

3.3.6. Recommendations and Suggestions for Visualisation of Electricity Usage in Smart Environments

This section summarizes prior research findings on how to improve the visualisation of SE electricity usage in existing tools, which aids in the collecting of requirements for the proposed tool to answer the main research question. The following should be considered based on the literature review conducted on the design of an effective visualisation tool for electricity:

i. Suppers & Apperley (2014) and Stinson et al., (2015) highlighted that when designing an effective electricity visualisation, it is important to understand the type of user; doing so enables us to develop a visualisation that is best suited for the individual. They further stated that to motivate a change in electricity consumption behaviours, the visualisation needs to provide feedback that appeals to all types of users as this enables them to view their consumption from multiple perspectives (Suppers & Apperley, 2014; Stinson et al., 2015).

ii. Interactive visualisation (Koroleva et al., 2019) is best suited to motivate users to reduce their electricity consumption.

iii. Using electricity saving goals proved to be a useful feature in saving electricity. Koroleva et al., (2019) recommended the use of incentive-based mechanisms to motivate users to save electricity.

iv. Information given to the user should be how much energy a single device consumes, rather than only providing information on how much total energy is used (Herrmann, 2018).

v. Feedback should be shown in an appealing and clear manner (Herrmann, 2018).

vi. Users appreciate comparisons, both normative comparisons, which entail how a household performs in comparisons to the expected given family size and home size, and historical comparisons, which involve how a household performed in comparison to the past (Herrmann, 2018).

vii. Interaction between the user and the visualisation must be possible (Ali et al., 2016).

viii. Information on idle time and standby time of appliances should be included as well as the cause of energy consumption (Herrmann, 2018).

ix. Users found it more effective if they were provided with information immediately/in real time (Rodgers & Bartram, 2011; Murugesan et al., 2014) as well as providing actionable and practice-centred information (Herrmann, 2018).

x. Users find the monetary unit is the most appropriate and understandable measure of energy (Murugesan et al., 2014).

Table 4.5 shows the functional requirements for the proposed visualisation tool to assist in answering the main research question, and to incorporate the suggestions provided in the literature and the review of the existing systems.

3.4. Conclusion

This chapter synthesizes the body of knowledge about visualization techniques by reviewing the various types of visualization charts available, with a focus on electricity usage. RQ_2, *"How is electricity usage in a smart environment currently visualized?"* was answered successfully. HEMS was used to visualize energy usage in SE through an in-home display, assisting users to make sustainable energy decisions (Nilsson et al., 2018). However, according to the literature study, the efficiency of the HEMS is determined by the user's interpretation of the data based on the interface. Because the interpretation of information is dependent on visualisation, this research intends to contribute to the improvement of the design and development of the display of power usage.

To answer RQ_3" *What are the most effective ways for visualizing electricity usage in a smart environment?"* Designers find themselves in a difficult position when determining which visualisations to utilize, according to research done by (Sandouka, 2019). Without being able to evaluate each user's capacity to understand and interpret the visualisation, a judgment on the most effective visual representation was made. There are no clear standards for which chart types should be used, and chart type selection is based on the type of electricity usage statistics being supplied to the user, in addition to the examination of current systems.

Table 3-5: Functional requirements for the proposed visualisation tool

	User	**System**
1	Analyse the total electricity usage of all devices for a desired period.	Display the total electricity usage of all devices for the hour, day, week, month, and year.
2	View the current electricity of all devices.	Display the current electricity usage of all devices.
3	View historical electricity usage for different devices for a specific hour, day, week, month, and year.	Display historical electricity usage data for all devices for the hour, day, week, month, and year.
4	View the current electricity usage of a specific device.	Display the current electricity usage of selected devices.
5	View of historical electricity usage of selected devices.	Display historical electricity usage of the selected device for a specific previous period (hour, day, week, month, year).
6	Allow users to make comparisons of electricity usage among devices.	Enable the user to make comparisons of electricity usage among devices on selected dates.
7	Allow users to compare electricity usage between categories of devices on selected dates.	Enable the user to make comparisons of electricity usage among categories of devices on selected dates.
8	Get alerts on high electricity usage.	Alert the user on high electricity usage readings.
9	View the time with the most or least electricity usage for a specified period (hour, day, week, month, year).	Display the device with the most or least electricity usage for a specified period (hour, day, week, month, year).
10	View the category of devices with the most or least electricity usage for a specified period (hour, day, week, month, year).	Display the category of devices with the most or least electricity usage for a specified period (hour, day, week, month, year).
11	View the time of day when the most electricity is consumed.	Show the time of day when the most electricity is consumed.

However, we were able to determine that the type of data, the users for whom the visualisation is being created, the amount of data being displayed, the reason for displaying the data, and the relationships between the data all influence the visualisation of electricity usage or any other type of data. We determined that pie charts, doughnut charts, line charts, bar charts, progress bars, scaled up data, and tables were the most utilized chart formats for visualizing electricity usage in SEs after reviewing existing systems.

In addition to answering RQ_2 and RQ_3, the functional requirements for the proposed tool to be used to effectively communicate electricity usage to users were gathered, based on the literature review conducted.

The next chapter aims to demonstrate the usefulness of the visualisation tool developed by examining if users can easily understand the presented electricity usage data by studying the electricity usage data provided.

Chapter 4: Design and Development of Electricity Usage Information Visualisation Tool

The visualisation techniques that can be used to design an artefact that successfully communicates electricity usage were discussed in Chapter 3. The requirements that a system would need to fulfil to contribute to the solution of the primary research question were also generated by Chapter 3. To answer RQ_4, *"How should a system be developed to effectively allow visualisation of electricity usage in a SE?"*, this chapter focuses on the design and development artefact activity in the Design Science Research (DSR) methodology. The specifications and suggestions from Chapter 3 were used to design an artefact. The feasibility and effectiveness of the concepts used in the design were then evaluated using an artefact that was created to support the designs and test them on actual electricity usage data.

The design and develop activity involves creating an artefact that solves the problems identified (Benfell, 2020) in Chapter 1 using models, methods, or constructs, and the first activity of the DSRM. This activity includes ensuring the artefact addresses the defined requirements proposed (Johannesson & Perjons, 2014) in Chapter 3. The DSRM allows for cycling back on different processes (Venable et al., 2017). In this study, the author cycled back on the design process to improve the design of a visualisation to build an effective tool for communicating electricity usage. The artefact was used to address the requirements identified for this study. The goal was to use the designed artefact to implement several visualization techniques discussed in Chapter 3. Chapter 4 intends to respond to RQ_4 by incorporating various types of visualisation charts into the design artefact and evaluating the designs to determine the most effective approaches for visualizing electricity usage. Additionally, a prototype was developed using the feedback from the design evaluation.

The chapter was split into two major sections, namely the Design section (Section 4.1) and the Development section (Section 4.2).

4.1. Design

The design of the artefact is discussed in the sub sections to follow. In Section 4.1 the artefact that will be designed is discussed and the rationale behind the selection of the artefact to best meet the system requirements that were identified in Chapter 3.

Secondly, the design methodologies that were implemented in the design of the artefact are discussed, and how they were applied to the artefact design process in Section 4.1.2. Thirdly, the design of the artefact is then discussed, highlighting the data that was used and the process followed in the design process itself, and the result in the form of the artefact is shown in Section 4.1.3. The designs created were then evaluated and the evaluation process and results are discussed in Section 4.1.4.

4.1.1. Dashboards

A dashboard can be referred to as visually displaying vital information, which includes the graphics and text required to achieve one or more objectives; the information is combined and organized on a single screen so that it can be seen at a glance visually (Abduldaem & Gravell, 2019). A dashboard can be referred to as a cognitive tool, which helps in improving the "span of control" for the user (Toasa et al., 2018). These tools assist people in identifying patterns, trends, and anomalies, and subsequently guide users with effective decision making (Toasa et al., 2018). If designed properly, dashboards can effectively communicate information (Rahman, 2017). For these reasons, a dashboard was chosen as the artefact to be created to respond to RQ_4. In addition, the dashboard was selected as the artefact because a dashboard provides a way of visualising electricity usage and allows the use of various visualisation techniques to achieve this.

Information in dashboards can be organised in different layers. These different layers can be described as an onion, and as each layer is peeled off, more information is provided on the specific issue that is being investigated by the user, allowing the user to get to the root cause of the issue (Buttigieg et al., 2017). In the case of this research, a user can start by seeing that a specific category has high electricity usage. To investigate further, the user can drill down to see which specific device in the specified category has high electricity usage and why. In the process of designing dashboards, designers need to consider the literacy, cultural relevance of representations and visual language, and social framing (Sarikaya et al., 2019).

4.1.1.1. Benefits of Dashboards

Dashboards can have multiple benefits; information overload is a problem, which is related to the constant increase in data volumes and the resulting need to process it (Abduldaem & Gravell, 2019). Dashboards have been used to manage this overload. Dashboards can also act as a means of communication; to effectively deliver a message to the user, the message needs to be concise, goal-oriented, and clear (Abduldaem & Gravell, 2019; Ergasheva et al., 2020). Users can monitor and act on events as they occur using dashboards (Buttigieg et al., 2017; Abduldaem & Gravell, 2019).

4.1.1.2. Types of Dashboards

There are different dashboards, and for this research, we will look at dashboards categorised by their role, namely strategic, analytical, and operational (Rahman, 2017). Each dashboard is designed for specific use (UIPatterns, 2021).

i. Strategic Dashboards

Strategic dashboards aim to show vital key performance indicators of the organisation, which can either be daily, weekly, or monthly. This dashboard aims to show a high-level overview of the condition of the organisation (UIPatterns, 2021; Costa, 2021). Strategic dashboards are mostly used by top management to track the progress of strategic goals, with the main focus on management, rather than analysis and monitoring (Buttigieg et al., 2017).

ii. Analytical Dashboards

Analytical dashboards, also referred to as tactical dashboards, come with drill-down functionality, which enables users to explore the data in detail (UIPatterns, 2021; Costa, 2021). They can be used to show key data sets highlighted against previous data. Analytical dashboards are mostly used at the departmental management level and are focused on tracking processes and highlighting analysis (Buttigieg et al., 2017). They enable users to track performance against set targets (Buttigieg et al., 2017).

iii. Operational Dashboards

Operational dashboards show data facilitating the daily operations of a business. These dashboards mostly make use of real time or near real time data (UIPatterns, 2021; Buttigieg et al., 2017). Tracking information in real time enables the delivery of critical information at a glance (Buttigieg et al., 2017).

The different types of dashboards described above are summarised in Table 4.1. In this research, the type of dashboard designed and developed is a combination of all three types. It is a combination of all three as it will be showing key indicators of electricity usage, such as the highest consuming device or appliance; the drill down functionality is available as an overview of electricity usage is shown, and, individual device usage can be viewed in detail, seeing what makes up the overall usage, and real time electricity usage is also shown. Therefore, the designed dashboard shows different traits of the three types of dashboards discussed above.

Table 4-1: Summarised dashboard types, derived from (Rahman, 2017)

Type	Graphic Representation	Interactivity	Update Frequency
Strategic	Static	Low	Moderate
Operational	Static	Moderate	Low
Analytical	Dynamic	High	High

The type of dashboard that was designed and developed was identified as being a combination of the different types of dashboards, mainly because of the different type of data that is to be shown and the visualisation technique used. The type of data that was used for this dashboard is discussed further in Section 4.1.3.1. There are two key functions to designing dashboards that are deemed valuable, which include collecting the appropriate data and selecting the most appropriate visualisation techniques (Abduldaem & Gravell, 2019). The following section describes the design methodology that was followed in the design process for this research.

4.1.2. Design Methodology

In addition to following the iterative nature of the DSRM's design and development artefact activity, the visualisation tool was designed using a combination of two methodologies to produce an effective visualisation tool to be used to communicate electricity usage. The Agile Scrum methodology (Rai et al., 2018) and Shneiderman's Mantra (Shneiderman, 1996) were followed for the design of the artefact. The Scrum methodology was used as guidance to the design process, while Shneiderman's Mantra focused specifically on the design of the user interface to improve the usability of the tool.

4.1.2.1. Agile Scrum Methodology

The Agile methodology is focused on an iterative and incremental development concept, which allows for alterations to be made quickly (Rai et al., 2018). There are many different agile methodologies, but the Scrum method for this study was selected. Scrum was chosen because it best matches the nature of the design the author wants to implement and allows for several iterations. The Scrum life cycle consists mainly of three phases which are:

i. Initial Phase

The Initial phase (Alsaqqa et al., 2020) can be viewed as the planning or pre-sprint phase where the goals of the system being designed and developed are defined; this phase can also be referred to as iteration 0. This phase involves the following (Alsaqqa et al., 2020):

A product backlog is created and used to document customer requirements as features and user stories.

The **requirements** identified are analysed and given defined priorities and estimates on implementation efforts are carried out.

The product backlog can be **updated continuously** as user stories are created in increments and throughout the development process, as priorities may change.

ii. Development or Sprint phase

The Development or Sprint phase (Alsaqqa et al., 2020) consists of a succession of sprint cycles, each of which produces an increment value to be added to the system. Sprints are iterative fixed-length cycles that can last anywhere from two to four weeks. Every sprint will go through the standard software process phases, starting with requirements analysis and sprint planning based on the product backlog, and ending with the delivery phase following each sprint review.

iii. Project closure phase

The project closure phase (Alsaqqa et al., 2020) involves looking if the requirements are achieved, and if the goals obtained are identical to the agreed upon requirements of the product owner and team.

An illustration of the sprint life cycle is shown in Figure 4.1. The product backlog is a product of the sprint planning, and with each planning, updates can be made to the product backlog, either removing, updating, or removing a requirement. Each requirement is then taken up as a sprint, with the sprint length ranging from two to four weeks. After a sprint is complete, the result is analysed. If updates need to be made that is done, otherwise, if the requirements for the sprint are met, then the next sprint begins.

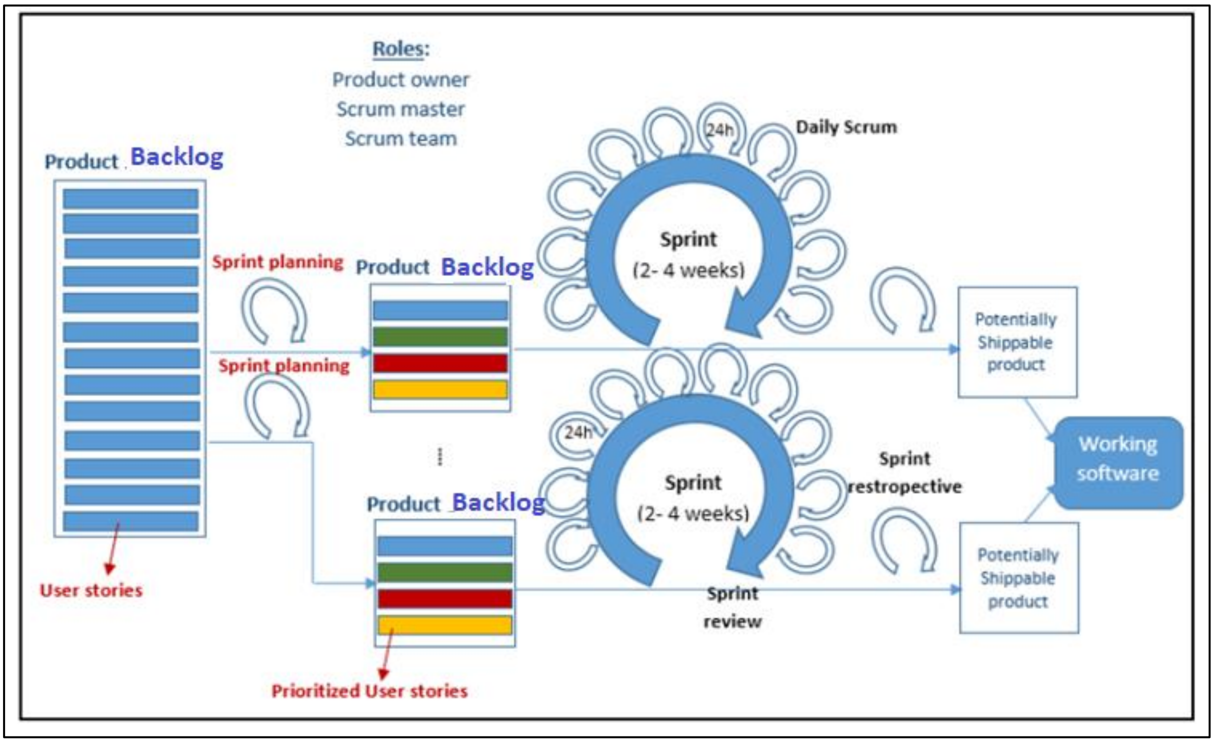


Figure 4.1: Derived scrum method life cycle (Alsaqqa et al., 2020

The main reason for selecting the Scrum methodology for this research was the ability to break down the design of the artefact into manageable tasks and allow for organisation of the design process (Alsaqqa et al., 2020). For this research, sprint planning involved breaking down different tasks of the design process into sprints. The sprints were broken down in terms of the different screens, which were involved in the design of the artefact, and each screen design was viewed as a sprint. The screens included the overall layout of artefact, navigation design, the home page, category page, device page, compare screen, and alerts screen. When the design of the screen met the requirements of the screen only, then did the authors move on to the next sprint (screen). In some cases, the authors iterated back to previous screens to update based on a change of requirements or layout of information.

4.1.2.2. *Shneiderman's Mantra*

Shneiderman (1996) proposed the Visual Information Seeking Mantra as a starting point for designing advanced graphical user interfaces, which states: ”Overview first, zoom and filter, then details on demand.” The artefact was designed to follow this mantra, with the user being able to drill down to specific data after seeing the overall data. This supports the idea proposed by (Koroleva et al., 2019) that visualisations should be interactive so that users may dig deeper into their electricity usage. Furthermore, it supports a previous study (Herrmann, 2018) that found that information on power usage offered to users should be specific, not just presenting the overall usage, but also the utilization of a single device or appliance.

The "Visual Information Seeking Mantra" and the "task-by-data-type taxonomy" are two contributions presented by Shneiderman (1996) to assist in understanding information visualisation methodology. The Visual Information Seeking Mantra referred to as the "Mantra" hereafter, guides users based on Shneiderman's vast experience in designing information visualisation software. The mantra highlights several tasks in its approach, which include:

- "Overview first, zoom and filter, then details-on-demand". This describes how data should be presented on the screen to be highly effective for users (Shneiderman, 1996).
- "Zoom", which allows items to be zoomed in, such as a pointer on a point of interest will request a detailed view of the specified item.
- "Filter" refers to filtering items out of interest such as the use of checkboxes and date pickers.
- "Details on demand" refers to the ability to select an item and get the details required, e.g., click on a category of devices and view the specific details of the category.
- "Relate" refers to viewing the relationship among different items, e.g., selecting a device to view related details of the device selected, or viewing similar attributes of the device with other devices.
- "History" refers to keeping a history of a series of actions, such as undoing or going back to a previous page.

For this research, we used this methodology to guide the overall design of the artefact, the dashboard. Following this methodology, the design of artefact was designed by showing the overview data first and then allowing the user to drill down to details on specific data.

A visual representation of the different methodologies applied in the design of this artefact is shown in Figure 4.2.

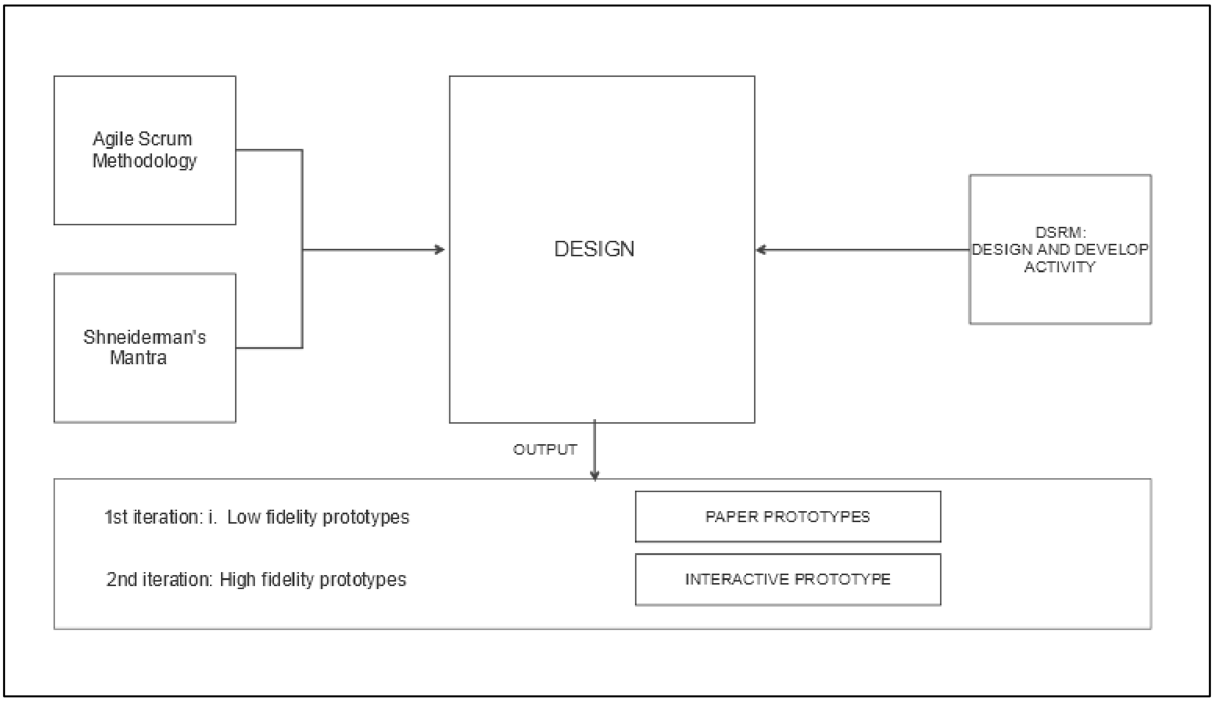


Figure 4.2: Overview of Design Process using selected Design Methodologies

4.1.3. Dashboard Design

The following section discusses the data that was used to design the dashboard and the design process of the dashboards following the design methodologies described in Section 4.1.2.

4.1.3.1. Data

The research was conducted in a Smart Lab created by the Department of Computing Sciences at Nelson Mandela University. The Smart Lab, as shown in Figure 4.3 below, shows the Smart Lab as a simulation of a room, which includes a kitchen, study, and lounge area.

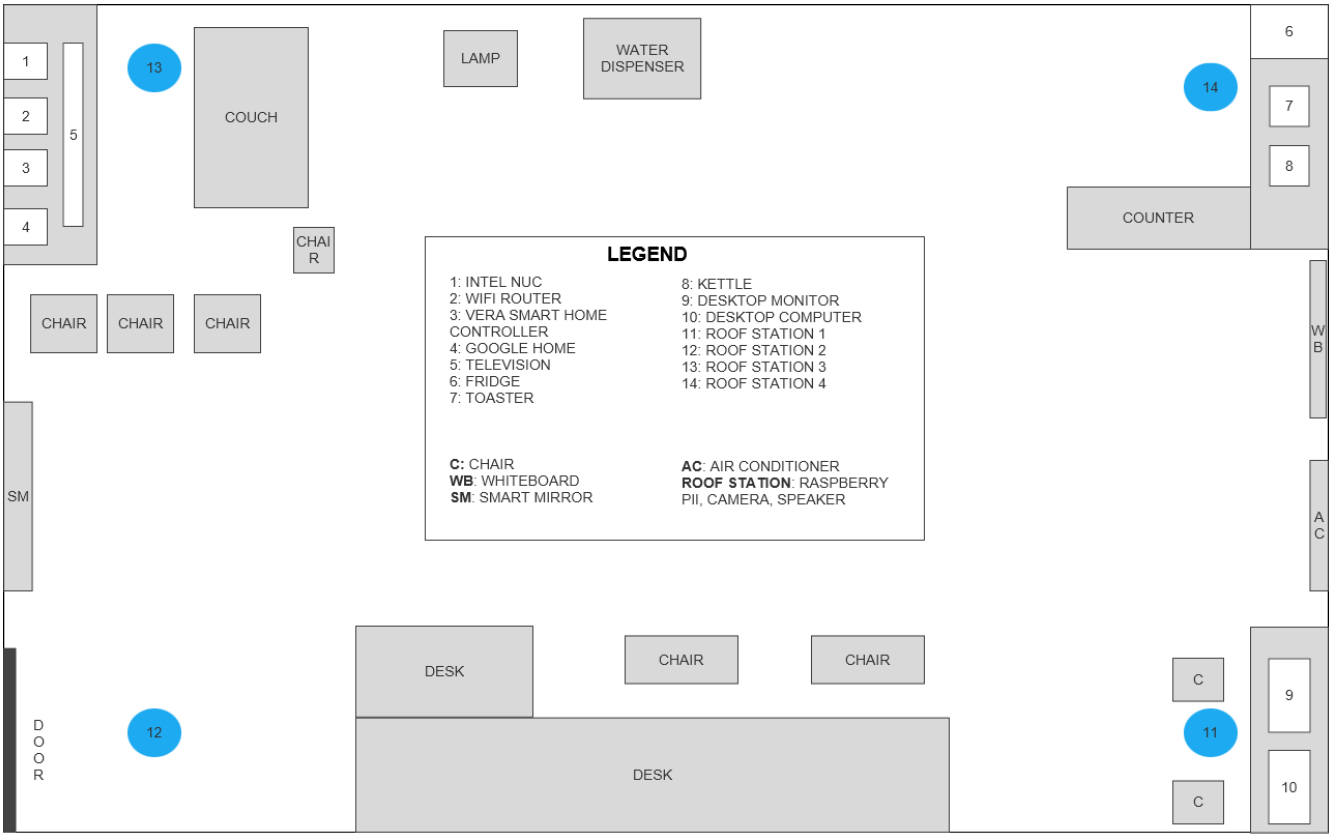


Figure 4.3: Model of Smart Lab at Nelson Mandela University

Table 4.3 categorises the devices and appliances for which we recorded the electricity usage in the Smart Lab, based on the location of the device in the room and its normal usage area.

Table 4-2: Category according to the location in the smart lab

Category	**Devices**	**Reference in model**
Kitchen	Kettle	7
	Refrigerator	6
	Toaster	8
Lounge	Television	5
	Google Home	4
	Wifi router	2
	Intel Nuc	1
	Vera Smart home controller	3
Study	Desktop Computer	10
	Monitor	9
Other	4 roof stations: Raspberry Pi, camera, speaker, microphone	11, 12, 13,14

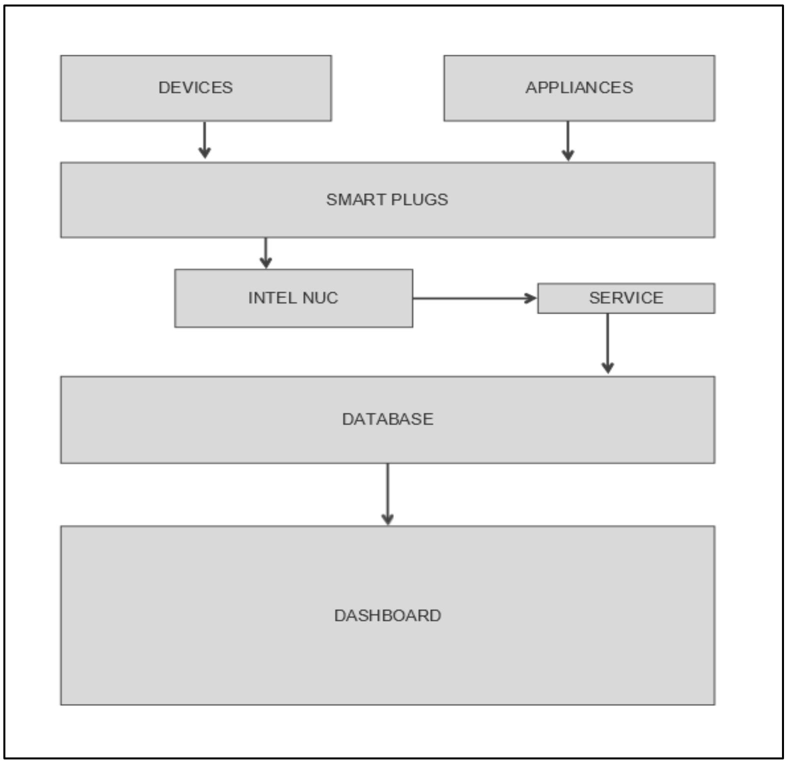


Figure 4.4: Smart Lab electricity usage data collection

Figure 4.4 illustrates how electricity usage data was collected in the Smart Lab and then shown to the user on the dashboard. The devices and appliances in Figure 4.4 refer to the devices and appliances shown in Table 4.2, which are connected to TP-Link HS100 Smart Wi-Fi plugs to capture their electricity usage data. An example of the smart plug is shown in Figure 4.5.

Figure 4.5: TP-Link HS100 Smart Wi-Fi plug (Takealot.com, 2022)

The smart plugs were plugged into the wall power socket and then connected to the Smart Lab's Wi-Fi network through the Kasa Smart app (Google Play, 2022) to immediately view the power readings. The Kasa Smart app allowed us to label the different smart plugs depending on the device or appliance connected to them to help in identifying the electricity readings provided. However, the Kasa Smart app (Google Play, 2022) didn't provide the ability to save the data readings directly to a database, which was required for this research.

Data that is provided by the smart plug include how long the device has been plugged into the smart plug, power, voltage, current (in amperes), voltage, schedules, runtime times, and timer information. Figure 4.3 illustrates the layout of the Smart Lab, showing the location of different appliances and devices connected to smart plugs. The choice of the TP-Link HS100 smart plug was because of its ability to monitor electricity usage as not all smart plugs have the capability to do so.

A script was written and run as a service on the Raspberry Pi using the tplink-smarthome-api (Tplink-Smarthome-Api - Npm, 2021) package to capture data from the smart plugs and save the data in a SQL database. This script is meant to run every time the operating system starts to ensure its collecting electricity data when electricity is being used. The importance of the smart plugs for this research was capturing the electricity usage data of the connected devices and appliances; it is evident that the electricity usage in a table format (Figure 4.5) with no insight is not as useful to a user. The goal of this research was to effectively communicate this electricity usage data to the user, by providing more insight to the user. The data saved in the database was processed and then displayed to the user through a combination of various visualisation techniques to help the user better understand their electricity usage data.

alias	deviceId	totalUsage	voltage	current	power	category	createdAt
kettle	80064F5E9DCC097D6814F2AF49B5…	0,00100	237	0	0	Kitchen	2021-12-03 17:30:07.2200000 …
Smart Lab Fridge	800615D2404C525CCCAC1664116B…	0,37700	236	1	55	Kitchen	2021-12-03 17:30:05.1270000 …
Smart Lab TV	8006FE673C69217643922F184EC9…	0,02300	235	0	0	Lounge	2021-12-03 17:30:04.5060000 …
Google home	800693A85800E1FA67311B81C5BD…	0,62900	237	0	2	Lounge	2021-12-03 17:30:04.4010000 …

Figure 4.6: Snippet of SQL database for electricity usage of devices in Smart Lab

Figure 4.6 shows a snapshot of values saved in the database, the details that were saved in the database for each device or appliance plugged into a smart plug included: the date and time of collection (createdAt), current (in kiloampere (kA), voltage (in kilovolts kV), total consumption (in kWh total usage), category of a device as shown in Table 4.6 (category), the label of the smart plug connected to the device/appliance (alias) and deviceId.

The following section discusses the design process used to develop a dashboard for visualising electricity usage in the Smart Lab using the data stored in the database.

4.1.3.2. Design Process

The design process was conducted in two iterations following the DSRM design activity, with each iteration aiming to improve the design of the dashboard. The design process started with paper prototypes, to show the structure and behaviour of the proposed user interface (Holtzblatt & Beyer, 2017). Paper prototyping is a way of conducting design, development, and testing through small representations of the final product (Geisen & Romano, 2017). After the paper prototypes were completed, the designs were then transferred to Justinmind where higher quality and more interactive prototypes were created.

Prototyping is a vital activity in product development (Lauff et al., 2018). Prototypes are viewed as a form of a design language that represents the design thought of the designer (Lauff et al., 2020). It entails a series of design steps that culminate in the maturity of the design (Suleri et al., 2019). It is a popular way of designing and evaluating user interfaces (Suleri et al., 2019). The roles of prototyping include learning, decision making, and communication (Lauff et al., 2020). Low, medium, and high are the three fidelities of prototypes. Each fidelity denotes the prototype's maturity level. Prototyping is an iterative process that takes time to reach a new degree of maturity (Lauff et al., 2020).

i. Low fidelity prototypes

As part of the low fidelity prototypes, basic drawings are made in the form of paper prototypes, which is a quick and inexpensive technique to test prototypes early in the design process, when modifications to the experience are simple to make (Gordon, 2021). Prototyping involves sketching out potential concepts, flows, or ideas on paper and testing the sketches with potential users (Gordon, 2021). Paper prototypes assist in allowing usability issues to be fixed much quicker without the actual implementation of a product that might not work (Nielsen, 2003; Geisen & Romano, 2017). An example of a paper prototype created is shown in Figure 4.7.

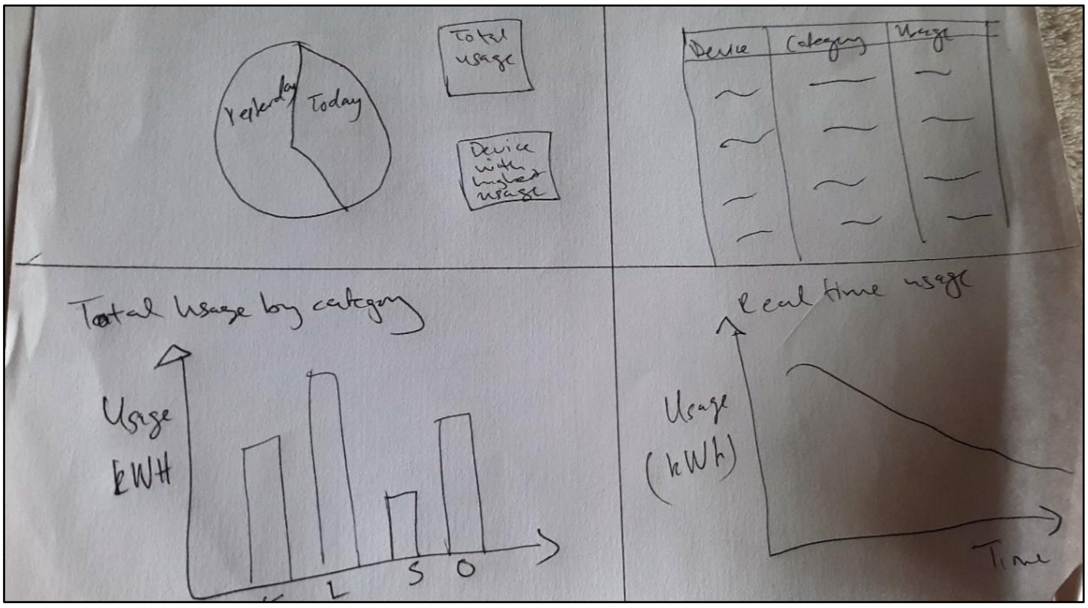


Figure 4.7: Prototype example 1

The paper prototypes were created because they helped make the design clear before implementing the designs, which would waste time. Prototypes help with guiding the structure of the dashboard. After the paper prototypes were created, Justinmind was used to create a more realistic version of the final product and improve the paper prototypes.

ii. High fidelity prototypes

Justinmind was used to develop highly interactive and functioning prototypes as part of the medium and high-fidelity prototypes. Medium-fidelity prototypes feature minimal functionality and represent the basic architecture of the dashboard, but include clickable regions that demonstrate the dashboard's interactivity and navigation (Pérez-Montoro & Codina, 2017). High fidelity prototypes look like the real program, which can be interactive or show some functionality. These prototypes include graphic elements and actual content (Pérez-Montoro & Codina, 2017). Justinmind has useful features, which include the capability to design fully interactive prototypes by providing web interactions such as clickable features. This feature was important in the selection of Justinmind as the prototype tool as it allowed for the simulation of the artefact and checking the feasibility of the design (Justinmind, 2021). The design process was done through two iterations, where each iteration the researchers conducted a review of the designs to see if the requirements were being met in the design and if the appropriate visualisation techniques were being used. After two iterations the designs shown in Figures 4.8-12 were the result, and the designs were created using

Justinmind. The following sections (A-F) show the different screen designs and the description of what the screens were displaying.

A. Home Screen

The home screen, displayed in Figure 4.8 shows a few features, which include the following:

- **Top left:** shows a pie chart comparing the total electricity usage of all devices of the current period and the previous period.
- **Top centre:** shows a bar chart comparing the total electricity usage of all devices of the current period and the previous period. In addition, it shows whether there was a reduction or increase in energy usage.
- **Top right:** shows a line chart displaying the real time electricity usage of all devices in the Smart Lab for every five minutes of data.
- **Bottom left:** shows a stacked bar graph comparing the electricity usage of categories in the Smart Lab, namely, kitchen, other, study, and lounge.
- **Bottom centre:** shows text displaying the device with the largest electricity usage in the Smart Lab.
- **Bottom right:** shows a progress bar, which shows the current usage in comparison with the set targeted usage.

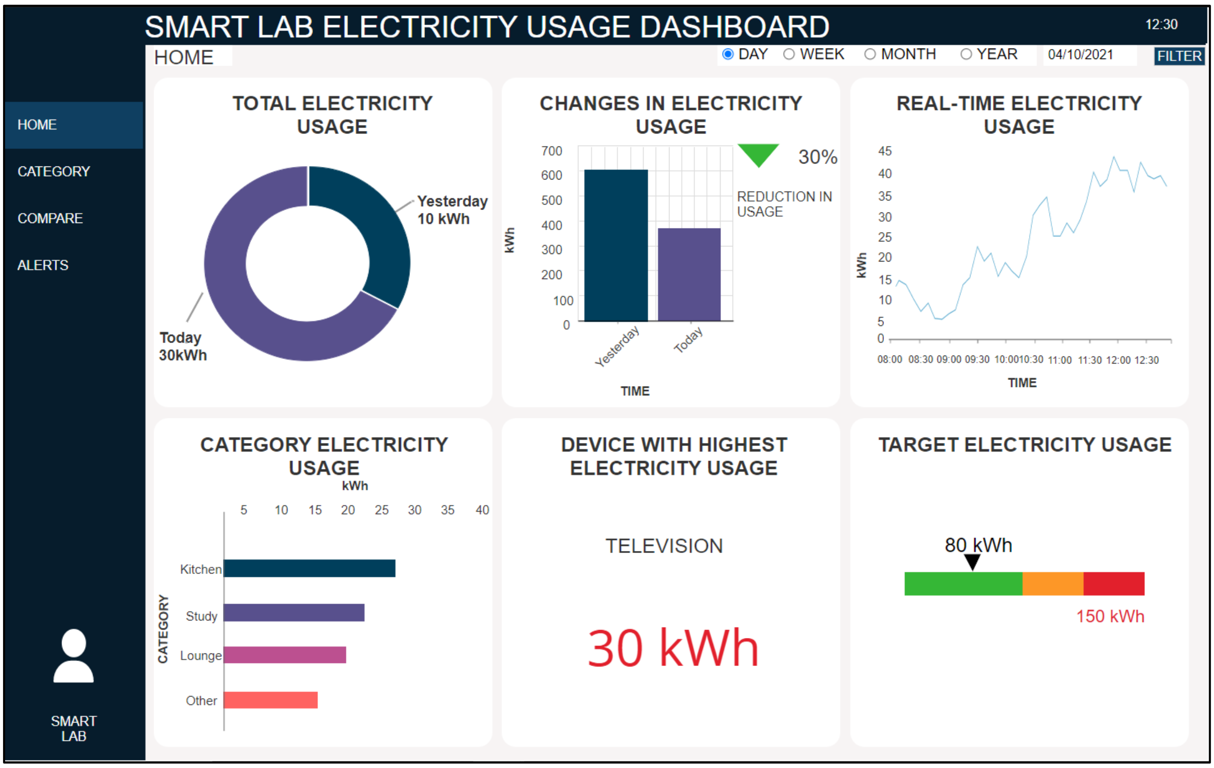


Figure 4.8: Home screen of Smart Lab electricity dashboard

B. Category Screen

The category screen, as shown in Figure 4.9, displays the following information:

- **Top left:** shows a pie chart comparing the total electricity usage of devices in the selected category (kitchen) of the current period and the previous period.
- **Top centre:** shows the device with the highest usage in the selected category.
- **Top right:** shows a progress bar of the targeted usage for the category and the current usage of the category.
- **Bottom left**: shows a multi-line graph with the real time usage of electricity of the devices in the category, together with the previous period's usage.
- **Bottom right**: shows a bar graph comparing the current and previous periods and showing either the reduction or increase in usage.

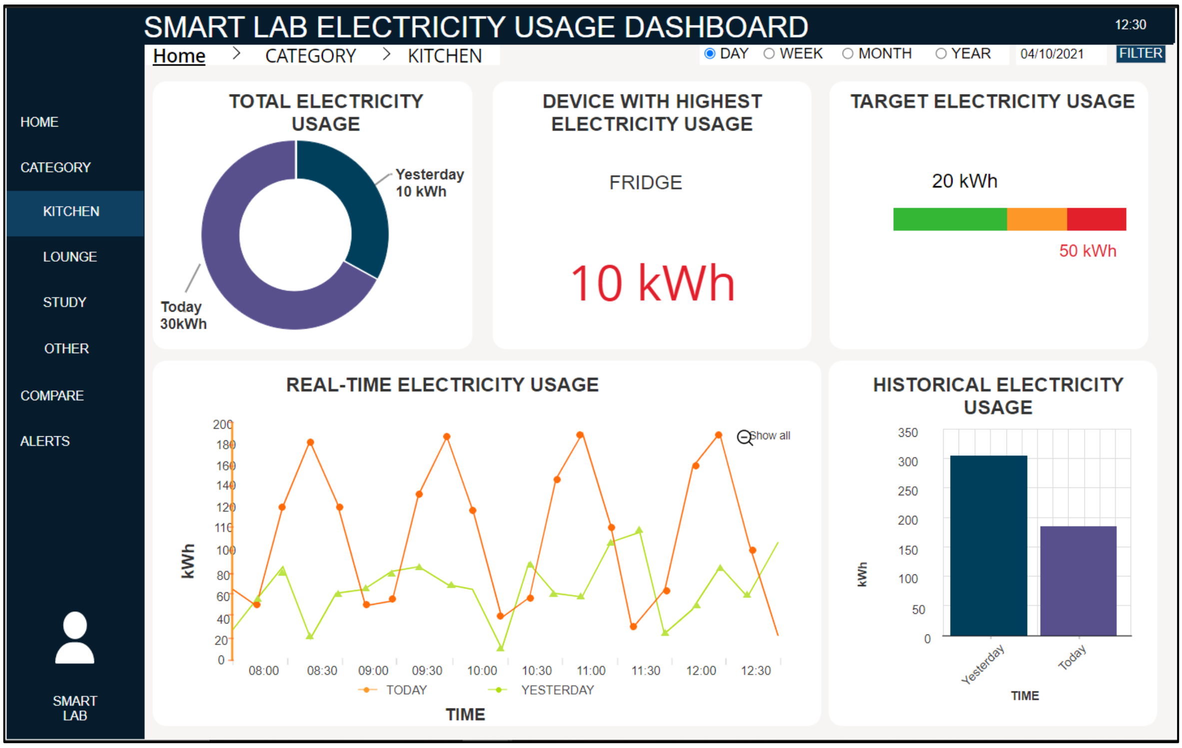


Figure 4.9: Category screen of smart lab electricity dashboard

C. Device Screen

The device screen, as shown in Figure 4.10, shows the following:

- **Top left:** shows a pie chart comparing the total electricity usage of devices in the selected device of the current period and the previous period.
- **Top centre:** shows text showing the time of highest usage for the selected device.

- **Top right:** shows a progress bar of the targeted usage for the device and the current usage of the device.
- **Bottom left:** shows a multi-line graph showing the real time usage of electricity of the selected device and the previous period's usage.
- **Bottom right:** shows a bar graph comparing the current and previous periods and showing either the reduction or increase in usage.

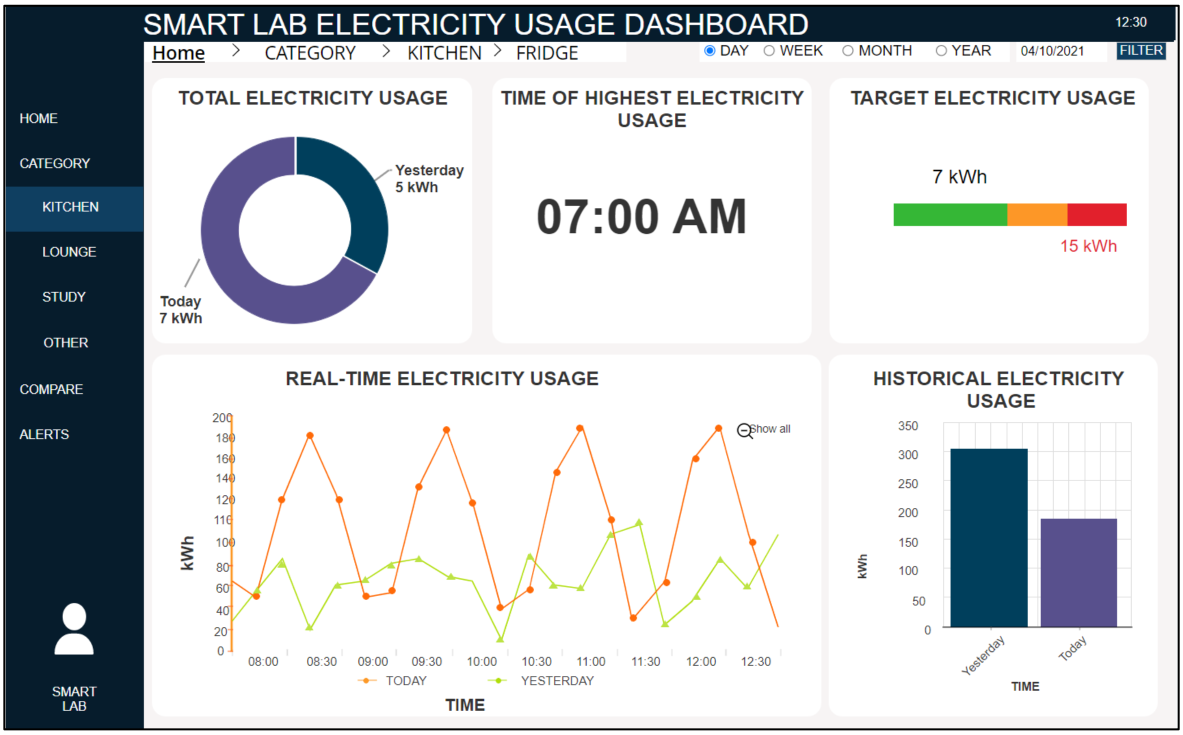


Figure 4.10: Device screen of smart lab electricity dashboard

D. Compare Screen

The Compare screen, as shown in Figure 4.11, allows the user to compare either devices or categories. The user can select either the devices or categories to compare and then the comparison is shown, which includes:

- The total electricity and average usage of each device/category is shown at the top, and then below a line chart is used to show the usage difference between the two devices/categories in real time.

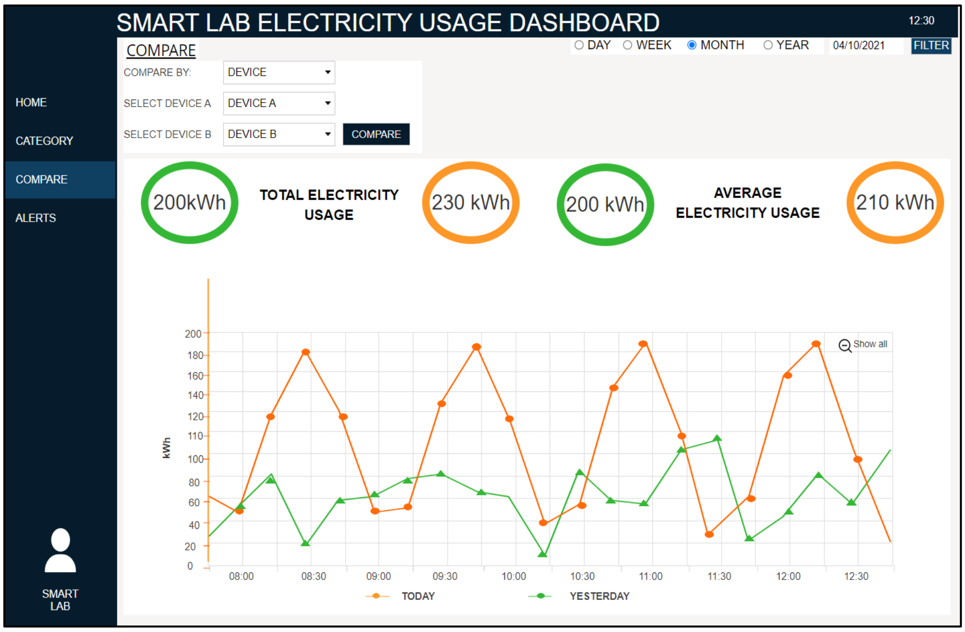


Figure 4.11: Compare the screen of the smart lab electricity dashboard

E. ALERTS SCREEN

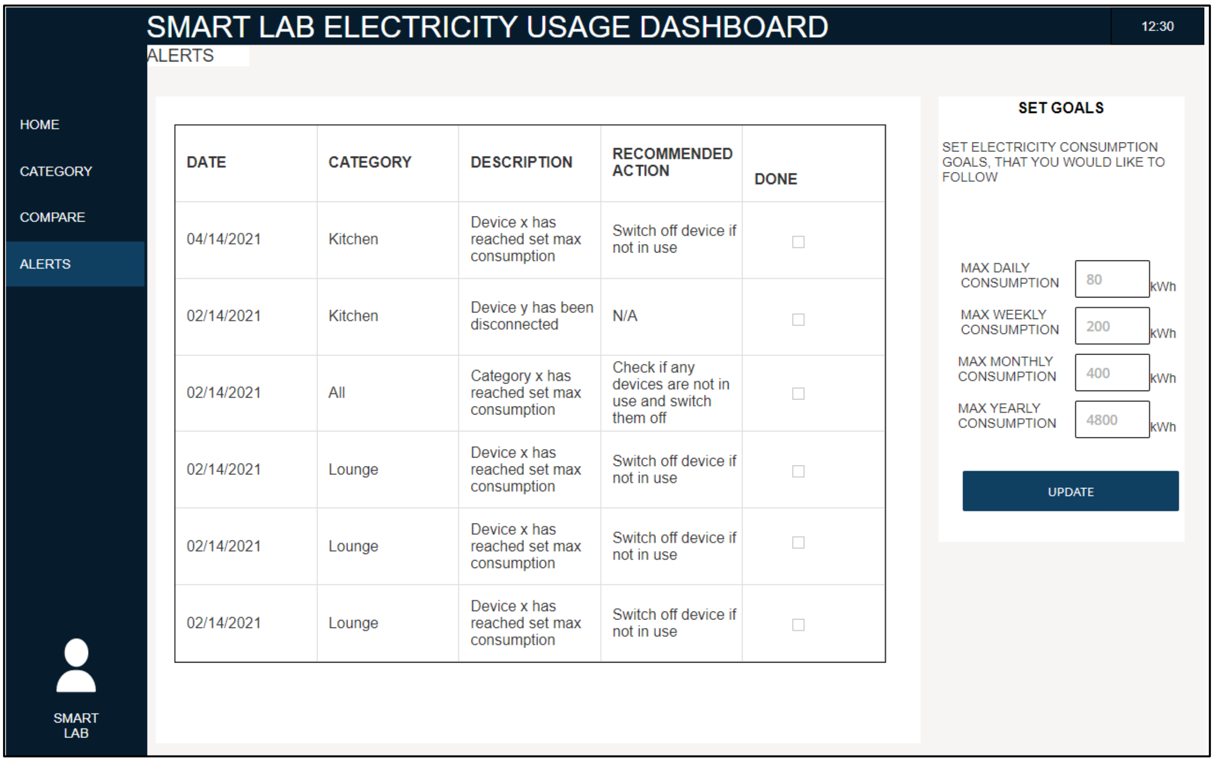


Figure 4.12: Alerts page of smart lab electricity dashboard

The Alerts screen, as shown in Figure 4.12, displays alerts to the user. These alerts include details on when a device and/or category reach the set target usage. The set targets can also be adjusted on this page.

F. Additional features on screens

Additional features included in the dashboard screens that were not discussed above include:

- **Navigation**: The menu of the dashboard has been placed on the left side of the screen, showing the different options offered to the user, namely the Home, Category, Compare, and Alerts pages. The menu provides the user with the ability to navigate easily through the different screens of the dashboards. In addition to the menu, vertical navigation and breadcrumbs were implemented.
- **Vertical Navigation:** Vertical navigation provides its users with the ability to efficiently scan through and find the available options (Nielsen, 2007).
- **Breadcrumbs:** Breadcrumbs provide users with the ability to view their current location on the dashboard, and the one click functionality can lead users straight to higher or lower site levels (Nielsen, 2007).
- **Filters**: At the top right of the home, category, compare, and device pages show the filters available to the users for them to select their desired output. The options include viewing the day, week, month, or year's view of data.

The following section discusses the evaluations that were conducted on the designs to test the usability and feasibility of the design.

4.1.4. Design evaluations

A formative evaluation was undertaken, which is normally done before finalizing the design, to test the usability of the product (Tullis & Albert, 2013). It is usually carried out to improve the design before execution, saving time in the event of errors. This research used a heuristic assessment, which is a type of formative evaluation. It was carried out to identify design flaws that might be rectified as part of the DSR methodology's iterative design activity. A heuristic evaluation entails a small group of evaluators, generally professionals, reviewing the user interface and determining whether it meets agreed usability standards (Nielsen, 1994).

The high-fidelity prototypes discussed in Section 4.1.3.2 were the designs used in the first evaluation, the heuristic evaluation, and the process described in the section that follows.

4.1.4.1. Evaluation Process

Dashboard designs were presented to evaluators, who were also instructed on the research, its goals, and the conditions that had to be followed for the IV tool's design.

Five participants were chosen for this evaluation because testing with five people enables the detection of almost as many usability issues as testing with more people (Nielsen, 1994).

Postgraduate students, graphic designers, and front-end designers served as evaluators. The evaluators were asked to rank the designs according to Nielsen's ten heuristics (Nielsen, 1994): visibility of system status, the match between system and real life, user control and freedom; consistency and standards; error prevention; recognition rather than recall; flexibility and efficiency of use; aesthetic and minimalist design; help users recognize, diagnose, and recover from errors; and help and documentation.

Following their review of the designs, the evaluators completed a questionnaire that contained the heuristic questionnaire as well as extra open-ended questions about design suggestions. An example of the heuristic evaluation is shown in Appendix 10.

4.1.4.2. Design Evaluation Results and Discussion

The results of the heuristic evaluation brought some insights into the interface of the dashboard. Figure 4.13 shows the results of the heuristic evaluation of the dashboard with five participants. Figure 4.13 shows that none of the ten heuristics were violated in the designs as their mean score for each heuristic was above 4, which indicates that the issues identified were minor.

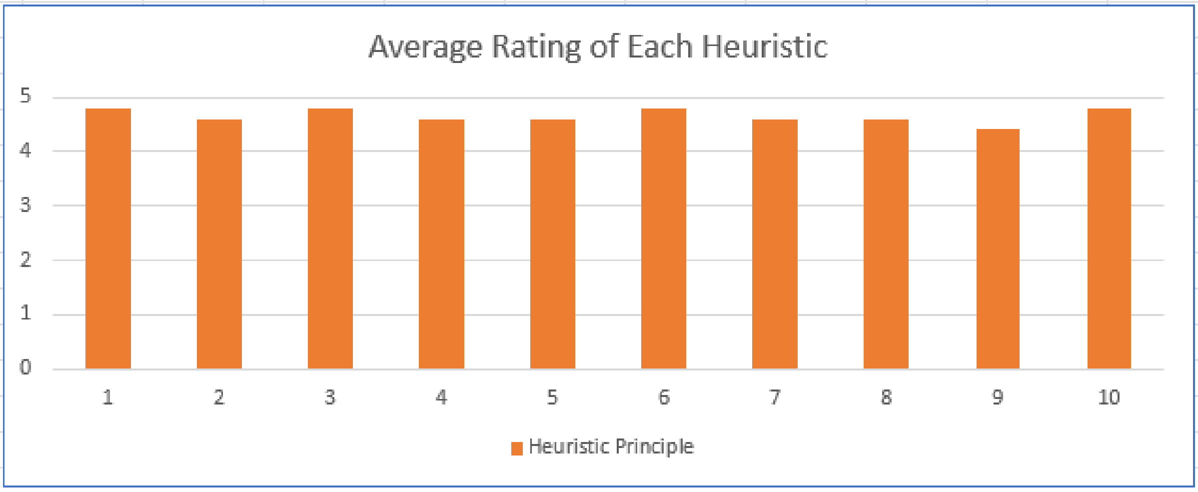


Figure 4.13: Average rating of each heuristic (n=5)

Table 4.3 lists the specific issues highlighted by the evaluators based on the questionnaire responses. "The design is simple and sleek, the infographics and data representation makes for a good dashboard," "Visuals are crisp and make sense," and "Could be useful if combined with ambient notification systems," were among the positive comments made on the dashboard's design, in addition to the results in Table 4.3.

Table 4-3: Heuristic report

Issue	Description	Recommendations
• Font • Colour scheme	• The font is not clear • Colours used make it hard to read some text (e.g., blue colour)	• Review and update the font • Review colour scheme • Use darker shades between grey and white cards • Review colour scheme
Filter	The filter labels (day, week, etc.) need to be more visible to make comparison easier	• Need to improve the labels, and make them clearer. • Use dropdown instead of radio button for filters (day, week, month, year) • Improve placement of filter options
Layout	White space and clarity of charts	• Line up grids with equal spacing • Stacking cards to show bigger graphs and remove white space. • Remove unnecessary all caps test
Menu	Menu breadcrumbs	Add icons and add hover function
Charts	• Replace the bar chart with a pie chart showing historical usage as this improves the clarity of reading	• Use a pie chart instead of a bar chart on historical electricity usage. • Show total electricity usage with a bar graph instead of a pie chart
Other	• Compare screen is unclear (which figures belong to which device) • Logo	• Need to improve the labels, make them clearer • Improve visualisations used in comparison screen • Add logo on top of the menu • Improve terminology used in designs e.g. word target • Use of a visual status indicator for the category menu and screen for better navigation • Remove repetitive visualisations such as showing historical usage on the same screen but with different visualisation charts.

The heuristic evaluation aimed to test the feasibility, usability, and effectiveness of the design in communicating electricity usage using the dashboard. The findings revealed that none of the issues were critical, implying that they would have little impact on the dashboard’s usability. The designs will be improved in the development of the dashboard including actual data on the electricity usage of the Smart Lab. Section 4.6 discusses the development of the dashboard. The development of the artefact supports the design of the artefact to test the feasibility of the design with actual electricity usage data.

4.2. Development

The following section describes the development process that was followed, and the output produced at the end of the process. The development methodology, which was applied in the development process is described in Section 4.2.1. The development process is discussed in Section 4.2.2, and the output of the development process is described in Section 4.2.3.

4.2.1. Development Methodology

For this research, the Agile methodology was followed for the development activity of the DSRM. SCRUM, as mentioned in Section 4.2, entails project management using the following stages/artefacts: a Product Backlog, a Sprint Backlog, a sprint, a daily scrum, and the Definition of Done when a feature is finished. The artefact’'s development was organized around the various features that needed to be produced, as shown in Figure 4.14 as the product backlog and a feature would be chosen for the current sprint, as indicated in the sprint backlog. During the sprint, the selected feature was developed, and once done, it was designated as complete, and a new feature was chosen to be produced.

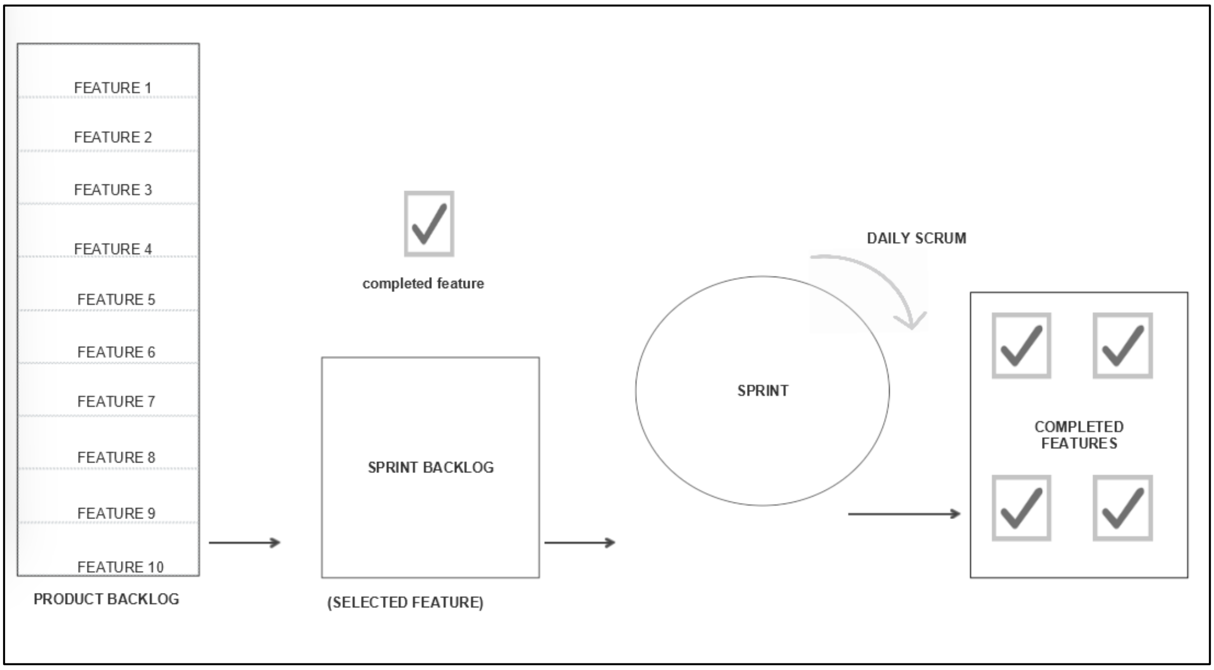


Figure 4.14: Dashboard development methodology implemented

In addition to the Agile methodology, the development process followed the iterative nature of the DSRM's design and development activity, refining the development process with each iteration to produce the most effective output. Section 4.7 discusses how the dashboard was developed and what tools were used.

4.2.2. Development Process

The development activity of the DSRM is discussed in this section. The dashboard creation process is depicted in Figure 4.15. The dashboard was built with Node.js on the back end and React.js on the front end, with a SQL database containing data from smart plug-connected gadgets and appliances in the Smart Lab.

The dashboard was developed using Visual Studio Code version 1.61.2 as the Integrated Development Environment (IDE). Visual Studio Code is a desktop-based source code editor that is both powerful and lightweight. Node.js, Typescript, and JavaScript are all supported (Visual Studio Code, 2021). The backend functionality of the dashboard was developed using Node.js version 14.16. In addition, the popular front-end framework React.js (React, 2021) was used.

Node.js (Node.js, 2021) is a cross platform, open-source, and backend JavaScript runtime environment, which is designed to create scalable network applications. React (React, 2021) is a JavaScript library for building user interfaces. React allows for the designing of simple views for different states of the application. It allows for applications to be efficiently updated and for the correct components to be updated when data changes. This is important for the Information Visualisation tool, which requires real time updates of data from the database.

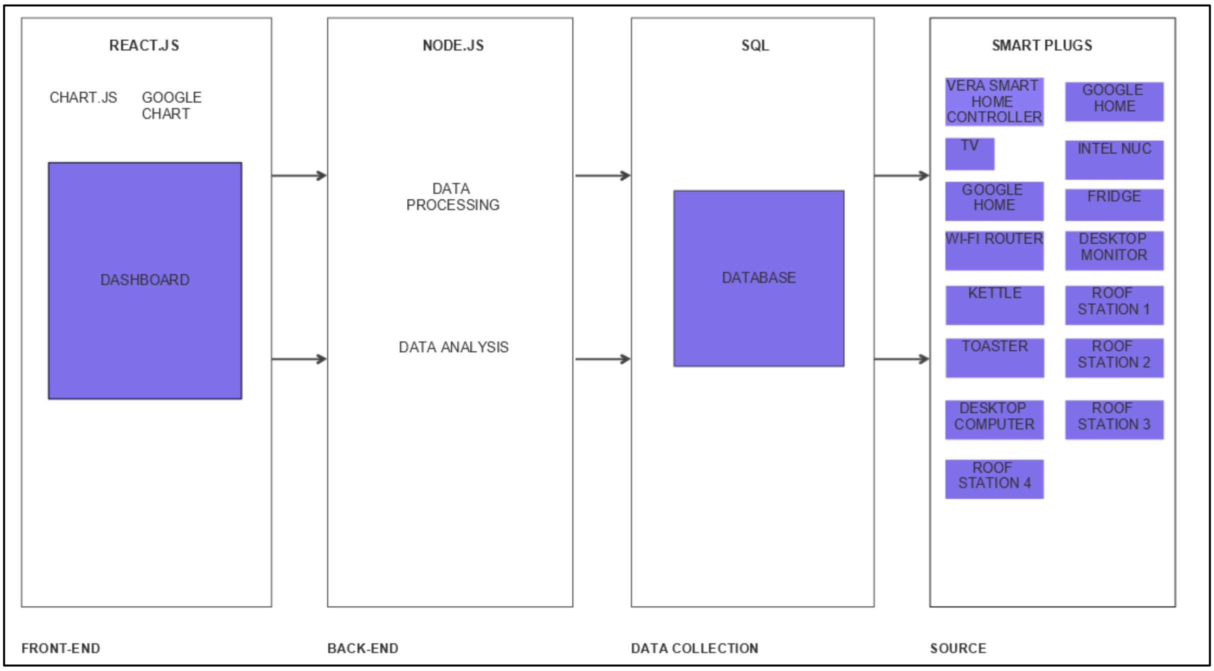


Figure 4.15: Dashboard flow diagram

The visualisation aspect of the dashboards required the use of charting libraries to fulfil the requirements of the dashboards. The charting libraries in Table 4.4, which were used, included Google Charts and Chart.js (Chart.js, 2021). These charting libraries were selected because of the chart types that were available and met the requirements of the dashboard, as described in Table 4.5.

Table 4-4: Charting libraries and chart types (Chart.js, 2021; Google, 2021)

Charting Library	**Chart types**
Chart.js	Line Chart
	Bar Chart (Horizontal, Vertical)
	Doughnut chart and Pie Chart
Google chart	Table
	Gauge

4.2.3. Development Output

The following section reports on the dashboard screens developed for the Smart Lab following the design guidelines from the literature review and the following requirements highlighted in Section 4.4.1. The dashboard serves as an artefact and an output in the design and development activity of the DSRM. The dashboard additionally assisted in partially answering RQ_4, "*How should a system be designed to effectively support visualisation of electricity usage in a SE".* The questions are only partially answered due to study limitations, most notably the fact that the study was conducted in a lab and over a short period of time. In retrospect, the researcher recognizes that conducting the study over a longer period of time and in an environment where users access the environment more frequently, rather than a lab, would be a more accurate way to measure the effectiveness of the visualisations used. In contrast, this study provides a tool that can be used in future studies to test its effectiveness in real life.

The development process was developed through multiple iterations. The first iteration of the development process produced the prototype, and the home screen of that prototype is shown in Figure 4.16. Additional screens for the prototype and descriptions of each screen are shown in Appendix 8. Figure 4.16 shows the home page screen developed in the first iteration, which showed the following details:

- **Top Left**: displays the total electricity usage of all devices for the selected period.
- **Top Centre**: displays the changes in electricity usage of all devices for the selected period and0 previous period such as current day and previous day.
- **Top Right**: displays the electricity usage in real time, showing the current reading for each minute.
- **Bottom Left**: displays the total electricity for each category namely kitchen, lounge, study, and other, for the selected period
- **Bottom Centre**: displays a table of all devices connected, the category the device is in, the total usage in kWh, the highest reading for that device, and the average usage in kWh, for the selected period.
- **Bottom Right**: at the top shows the target electricity usage set relative to the current total electricity usage recorded for the selected period in percentage. The bottom shows the device with the highest electricity usage.

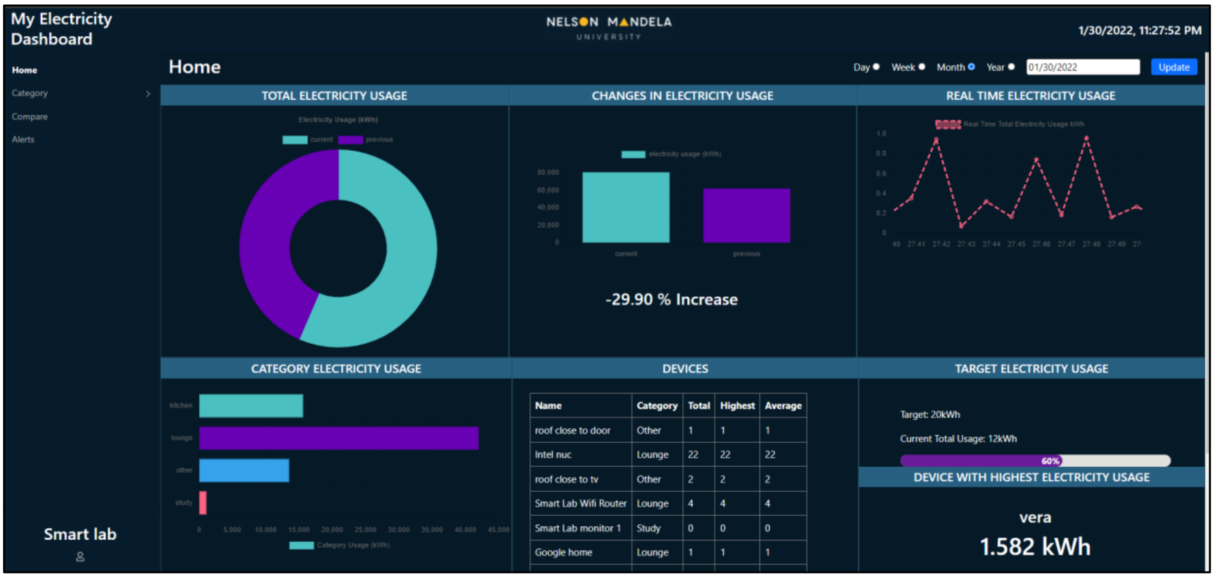


Figure 4.16: Home Screen of t first prototype

In the second iteration of the development process, the second prototype shows design updates to the prototype, also adjusting designs based on the actual data provided by devices connected.

The designs of the second iteration are shown in Figures 4.17 to 4.21. It is significant to note that electricity load shedding had an impact on the data in the screenshots, resulting in data being missing for a while.

i. Home Screen

When a user first opens the dashboard, the home screen is what they see. The following information is displayed in a weekly perspective on the home screen in Figure 4.17:

- **Top Left**: Uses a donut chart to show the total electricity used by all connected devices. It also breaks down usage into the current week, the week before, and the combined total for both weeks.
- **Top Centre**: Shows the breakdown of electricity use by category, namely kitchen, lounge, study, and other. This is demonstrated using a horizontal bar graph, and by selecting the "bar" for the relevant category, the user is directed to the relevant category page, such as the one in Figure 4.18.
- **Top Right**: A line graph, updated every five minutes, shows the periodic data usage while also displaying the current electricity usage.
- **Bottom Left**: Shows a vertical bar graph ranking the connected devices in the smart lab according to how much electricity they use. Additionally, when a user clicks a

device's "bar," they are directed to the device’s screen, showing the electricity usage screen for that device, as in Figure 4.19.

- **Bottom Right**: The progress bar displays the percentage of electricity consumed in proportion to the target set, and the top section shows the target use set in relation to the current usage. The device with the highest electricity usage for the chosen time period—in this case, the week—is shown in the bottom section.

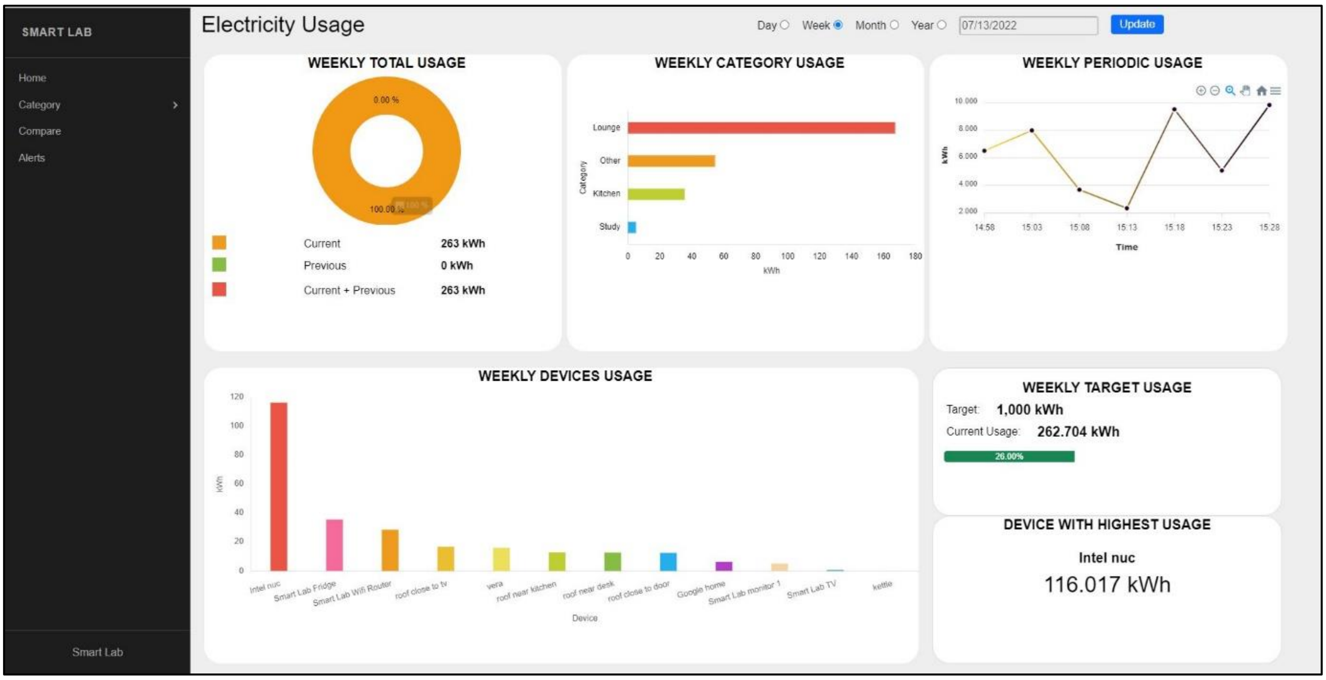


Figure 4.17: Home screen of weekly data on second prototype

ii. Category Screen

The category screen displayed the electricity usage information per category. Each category has its screen. It's important to note that the screen design for the kitchen category screen is the same as the other category screen pages. Figure 4.18 shows the information for the kitchen category for the week:

- **Top Right**: displayed the electricity usage for the current week and previous week for the devices in the kitchen category using a donut chart and showed the total usage for both weeks.
- **Top Centre**: the top section displayed the target usage set, the current total usage for devices in the category, and a progress bar indicating how much usage is still needed to reach the target. The bottom section displayed the device with the highest electricity usage in the kitchen category.

- **Top Right**: displayed the devices in the kitchen category in a vertical bar graph. Additionally, a user is taken to a device's screen when they click its "bar."
- **Bottom section**: displayed the periodic usage of the devices in the kitchen category using a line chart, where data was updated in five-minute intervals.

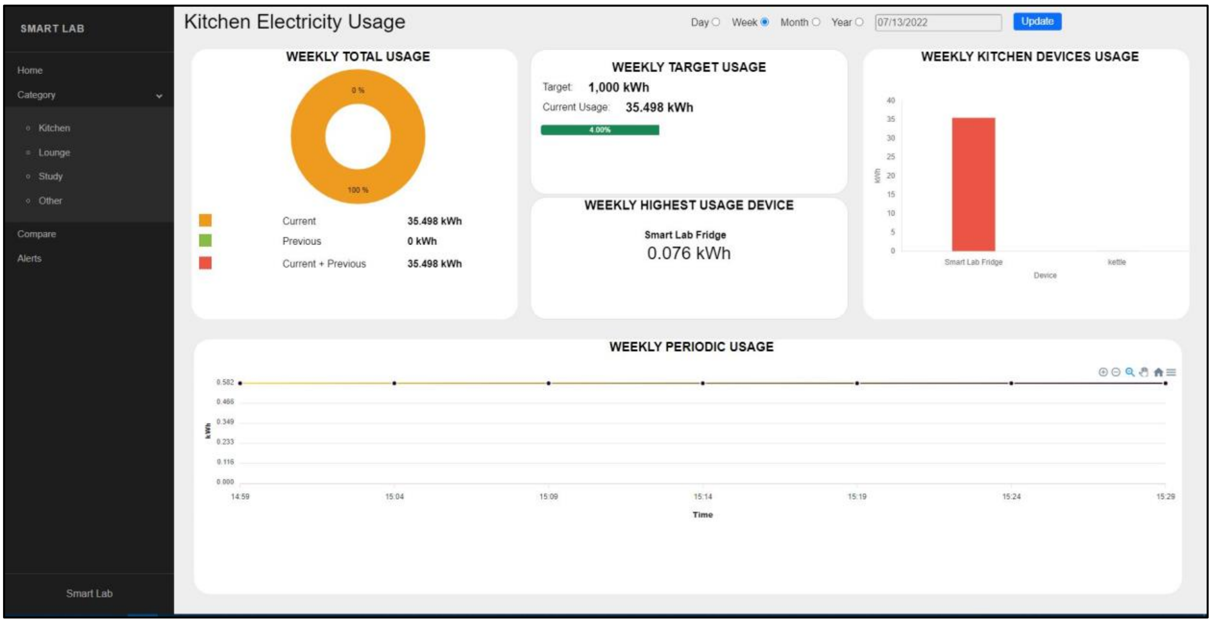


Figure 4.18: Kitchen category screen of second prototype

iii. Device Screen

The device screen shows the information of a selected device. Figure 4.19 shows an example of the Smart Lab Fridge electricity usage; the information displayed was as follows:

- **Top Right**: Using a donut chart the current and previous weeks' electricity usage is shown and also the total usage of both weeks is shown in the text below.
- **Top Centre:** the top section displayed the target usage set, the current total usage for the selected device, and a progress bar indicating how much usage is still needed to reach the target. The bottom section displayed the highest reading recorded for the week and the time of reading.
- **Top Right**: displayed the historical electricity usage of the device
- **Bottom**: displayed the periodic usage of the selected device using a line chart, where data was updated in five-minute intervals.

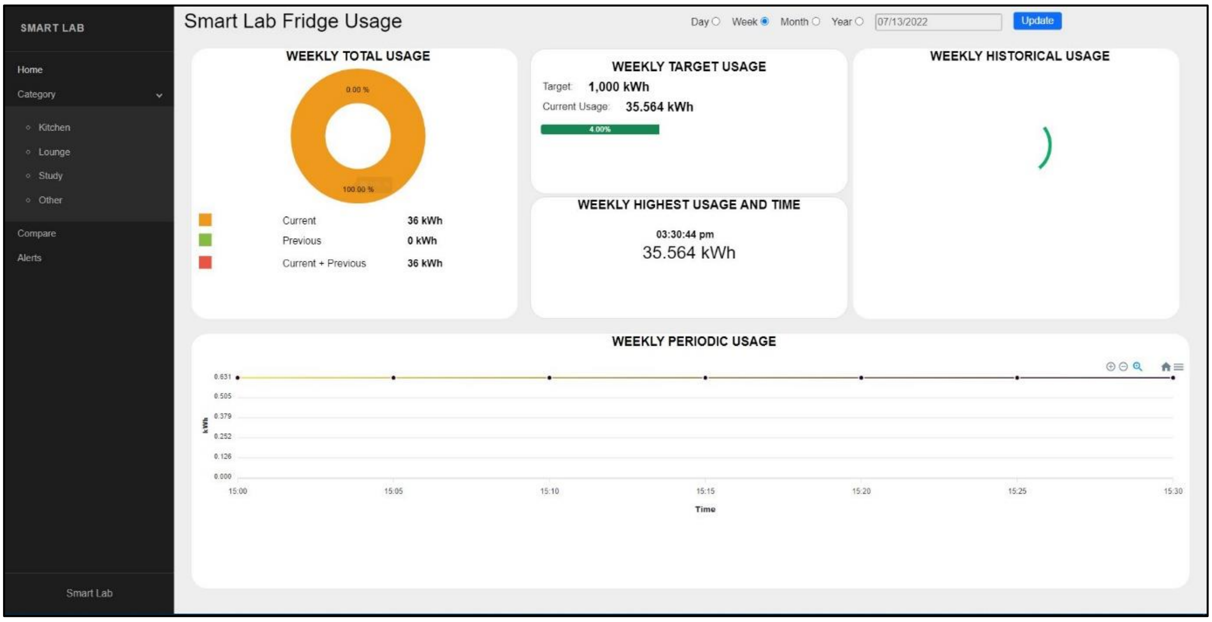


Figure 4.19: Device Screen of second prototype

iv. Compare Screen

Users can compare the electricity usage between two devices or two categories for the given time frame using the Compare screen; Figure 4.20 displays a comparison of two categories for the day. The user can choose a category or device to compare, and then they can choose two items to compare based on their choice. Clicking the Compare button after choosing what to compare displays the following details:

- **Top Left**: displays the total electricity usage for the selected devices in comparison using a donut chart. The total usage of both categories is also displayed.
- **Top Centre**: the top section displays the maximum electricity usage for both categories. The bottom section displays the average electricity usage for both categories.
- **Top Right**: displays the historical usage for each category selected.
- **Bottom**: displayed the periodic usage of both categories using a line chart, where data was updated in five-minute intervals.

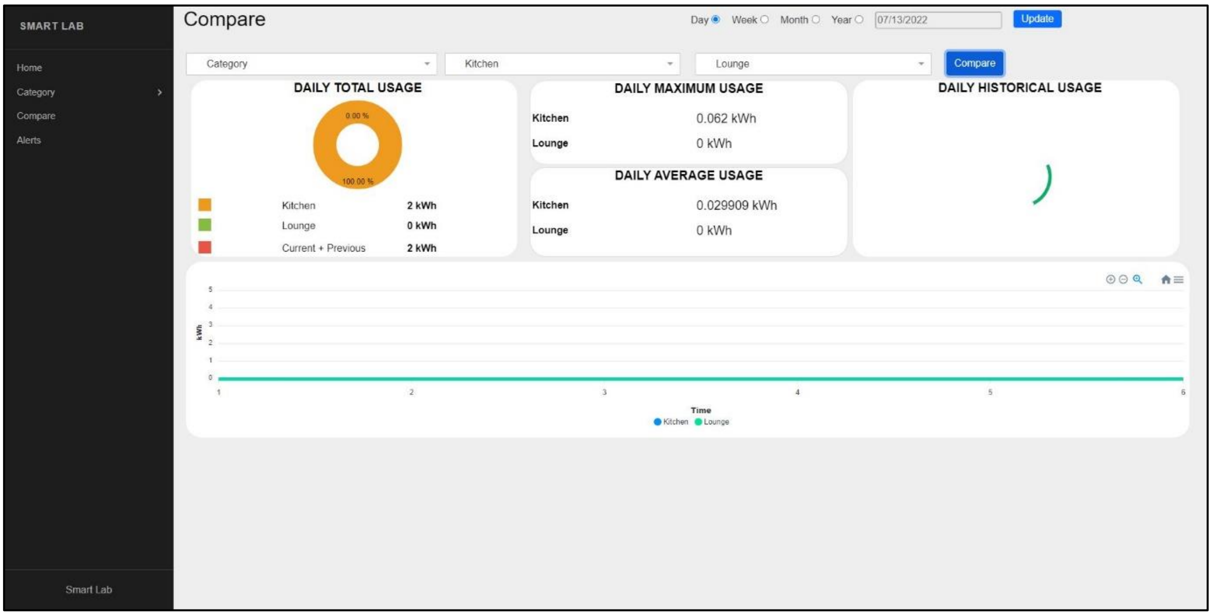


Figure 4.20: Compare Screen of second prototype

v. Alerts Screen

Users can select a target usage that they want to stay below on the Alerts page, Figure 4.2.1. The target usage can be defined for all devices or just one category. The opportunity to choose the devices or category to set targets for is visible on the screen in the top left corner. The user then has the option to select either all devices or a particular category for which to set targets. The user can then view the current and target usage set, if any, for each period, such as day, week, month, or year, after making their choice. Figure 4.2.1 shows the target usage set for all devices for the week to 5000kWh.

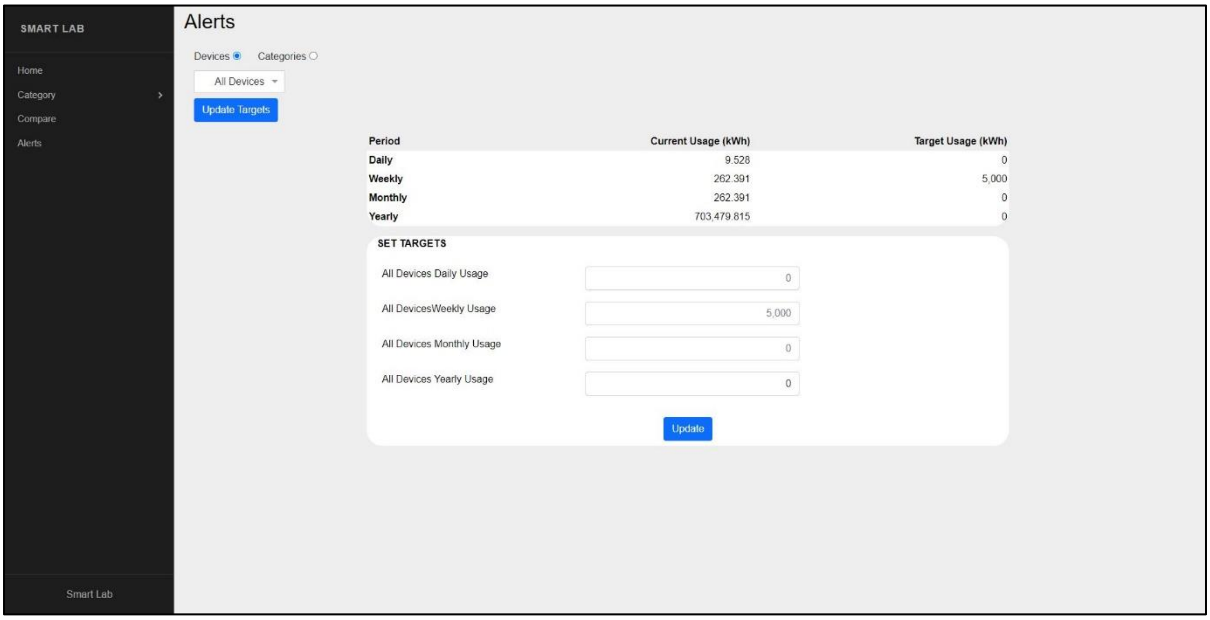


Figure 4.21: Alerts Screen of second prototype

Table 4.5 shows the list of requirements for the artefact and the corresponding screen where the requirement is met. As seen in Table 4.5 all the requirements that were listed were met on one or more screens on the developed artefact.

4.3. Conclusion

This chapter aimed to answer RQ_4, "*How should a system be designed to effectively support visualisation of electricity usage in a SE?*". To answer this question an artefact was designed and developed to support the feasibility of the design. In addition, a combination of design and development methodologies were followed. The design process followed Shneiderman's Mantra, Agile scrum methodology, and the nature of the design and development activity of the DSRM, focusing on the design aspect. In addition, the design process followed a set of suggestions and guidelines in Section 3.3.6 based on the literature review conducted in Chapter 3.

The development process followed the Agile scrum methodology and the design and development activity focused on the development part. The design and the development processes followed in this research contribute to the body of knowledge in showing the application of Shneiderman's Mantra, the Agile scrum methodology, and DSRM design and development activity. The chapter shows how the different methodologies were applied to this research and used in conjunction with each other to design and develop an energy visualisation tool effectively.

Table 4-5: Where system requirements were met in the artefact

#	**Requirement**	**Screen with functionality**
1	Analyse the total electricity usage of all devices for a desired period.	Home screen
2	View the current electricity usage of all devices.	Home screen
3	View historical electricity usage for different devices for a specific hour, day, week, month, and year.	Home screen
4	View the current electricity usage of a specific device.	Home screen; Device screen
5	View historical electricity usage of selected devices.	Device Screen
6	Allow users to make comparisons of electricity usage among devices.	Compare screen
7	Allow users to compare electricity usage between categories of devices on selected dates.	Compare screen
8	Get alerts on high electricity usage.	Alerts screen
9	View the time with the most or least electricity usage for a specified period (hour, day, week, month, year).	Device screen; Category screen
10	View the category of devices with the most or least electricity usage for a specified period (hour, day, week, month, year).	Home screen; Category screen
11	View the time of day when the most electricity usage was consumed.	Category screen; Device Screen

The design process was conducted in two iterations, with each iteration aiming to improve the previous one. The design process started with paper prototypes to determine the layout and behaviour of the interface. After those design prototypes were completed, the designs were transferred to a prototyping tool, called JustinMind, to create higher quality and more interactive designs. Based on the more interactive designs, a heuristic evaluation was conducted to test the feasibility and usability of the designs. The feedback was used in conjunction with the design to produce a prototype in the first iteration.

The prototype was developed to test basic functionality and the ability to read device usage data from a database. In the second iteration, improvements were made to the artefact based on the designs, as well as to the process of transforming data into system visualisations. The development process was also carried out in iterations, with each iteration attempting to improve the artifact.

The development of the artefact tested and proved the feasibility of the designs made in the design activity. A review was conducted to check if the requirements set in Chapter 3 were met in the developed artefact, as shown in Table 4.5. It should be noted that due to time constraints, not all of the evaluators' feedback could be implemented in the tool's development process, but the suggestions were highlighted to be improved in future prototype improvements. The following chapter discusses how the evaluation of the developed artefact was conducted.

Chapter 5: Evaluation of Electricity Usage Information Visualisation Tool

5.1. Introduction

Chapter 5 aims to address RQ_5 which is "*How usable is the proposed tool?*" and reports on the evaluate activity of the DSRM. This chapter provides a discussion on the evaluation of the artefact designed in Chapter 4, to monitor the electricity usage of the Smart Lab at Nelson Mandela University. For this research, the focus was on evaluating the usability of the interface of the artefact, to assist in answering RQ_5. Usability (Barnum, 2021) refers to the degree to which a product, service, or system can be used by specific users to achieve specific goals with effectiveness, efficiency, and satisfaction in a specific context of use. The three critical measures of usability include satisfaction, effectiveness, and efficiency. Effectiveness and efficiency refer to how well a product supports a user's desire to complete a task with precision and speed. Satisfaction is based on the user's perception of the product.

Usability testing refers to the evaluation of a product through the testing of potential users. During a test, participants will often attempt to accomplish standard activities while observers observe, listen, and take notes. The purpose is to discover any usability issues, collect qualitative and quantitative data, and establish the level of satisfaction with the product among the participants.

Usability testing has several benefits, which include (Barnum, 2021):

- Determining whether participants can complete given tasks;
- Determine how long it takes to execute a set of given tasks;
- Determine the level of satisfaction with your website or other product among participants;
- Determine what modifications must be made to improve user performance and happiness, and
- Evaluate the results to see if they satisfy your usability goals.

The usability test made use of eye tracking software, which measured the effectiveness, efficiency, and user satisfaction such as time spent on a task, the ease of use, and consistency of the artefact. The artefact will be referred to as the Electricity Visualisation Dashboard for a Smart Lab (EVDSL) going forward.

Eye tracking is a type of psychological method of usability testing that was used in this research. Eye tracking is used in the field of human factors and usability. The eye-mind hypothesis (Wang et al., 2019) proposes that visual attention is a proxy for mental focus and that visual attention patterns mirror individuals' cognitive methods. Eye tracking has been used to investigate visual attention allocation in several visual tasks, ranging from visual search to reading, advertising viewing, and online video viewing (Wang et al., 2019).

The following section, Section 5.2 reports on the usability test process and how it was conducted.

5.2. Usability Testing

The purpose of evaluation is to determine if the EVDSL is considered useful and effective by its potential users, i.e., individuals who have an interest and or are knowledgeable in the related field of SEs and IV and are enthusiastic about saving electricity usage in their buildings. Eye tracking was the method of usability testing conducted for this research.

5.2.1. Eye Tracking

Eye tracking involves determining the location of the eye's focus or the eye's movement as a person examines a web page. There are two categories of eye trackers (Hedlund, 2018), namely remote/screen based and wearable, the main difference being in the placement of the eye tracker during a study. The equipment is often set up on a table in front of the participant with the eye tracker connected to a monitor.

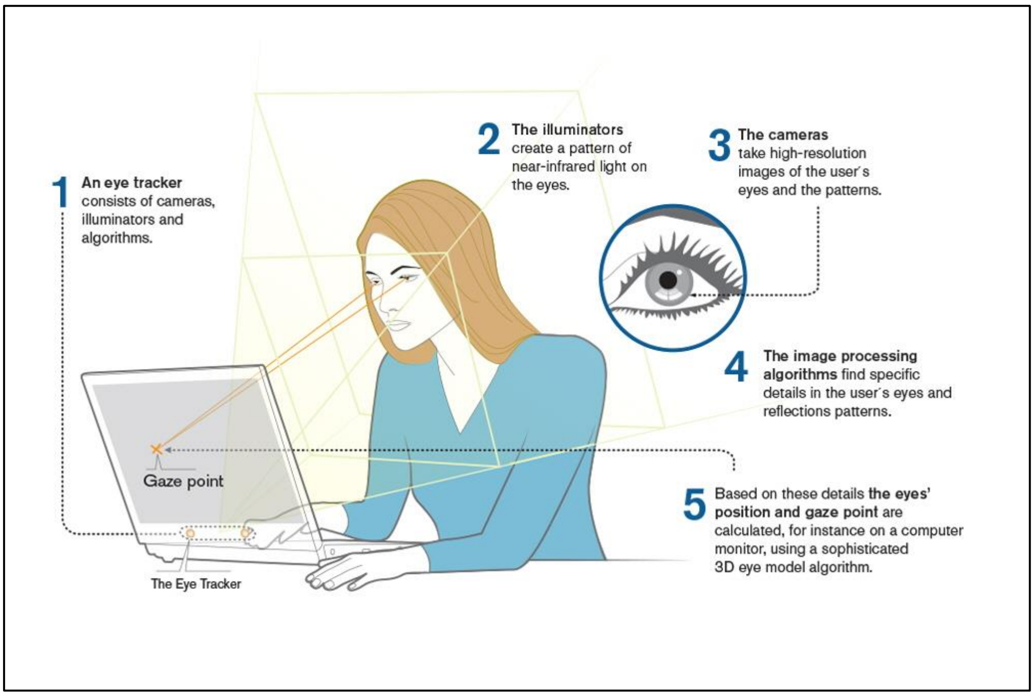


Figure 5.1: Screen based eye tracker (Tobii Pro, 2022)

The functionality of the screen-based eye tracker is shown in Figure 5.1. For the participant's eye movement to be detected by the eye tracker, the eye tracker is mounted on the laptop with the participant seated directly in front of it (Tobii Pro, 2022). The five components of eye tracking—the eye tracker, the illuminators, the cameras, the image processing algorithms, and the eye's position and gaze point—are also depicted in Figure 5.1.

Analysing eye-tracking data most frequently involves gauging visual attention to objects or areas. An illustration of how to designate page areas is shown in Figure 5.2. "Look zones" or "areas of interest" (AOIs) are common names for these areas. In essence, AOIs are the things you want to measure and are identified by a set of x, and y coordinates. The data gathered from defining AOIs include the ability to see the amount of time spent looking at the identified AOIs. This is helpful as the researcher can see the visual attention across a page and if it's consistent or not (Tullis & Albert, 2013b).

Gazeplots and heatmaps are just a couple of the visualisations that eye tracking software may create. Gazeplots display how much time a person spent on a certain page of a website. The size of the bubbles corresponds to the length of the fixations, which are represented by the bubbles as locations where the eyes have paused and focused (Moran, 2019).

The heatmap shows the participants' average performance on the same task. The areas where participants looked the longest are indicated by red, followed by yellow and green, respectively. Where the participants gazed is reflected in the coloured areas (Moran, 2019). A heat map is shown in Figure 5.3 to illustrate this.

The eye tracker can translate eye movements into useful insights by decoding them (Tobii Pro, 2022). Thus, the eye tracking program can be used to gather the following information:

- Where they are looking
- How long they are looking
- How their focus moves from item to item on your web page
- What parts of the interface do they miss?
- How they are navigating the length of the page, and
- How size and placement of items on your website or proposed designs affects attention?

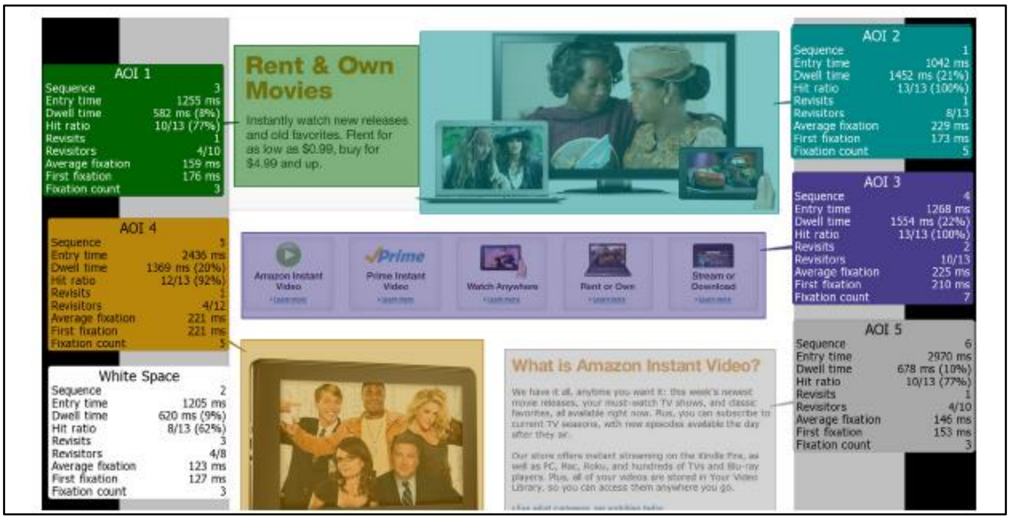


Figure 5.2: Example of the Amazon Movies website with AOIs showing summary statistics for each AOI (Tullis & Albert, 2013a).

Figure 5.3: Eye tracking gaze plot (Moran, 2019)

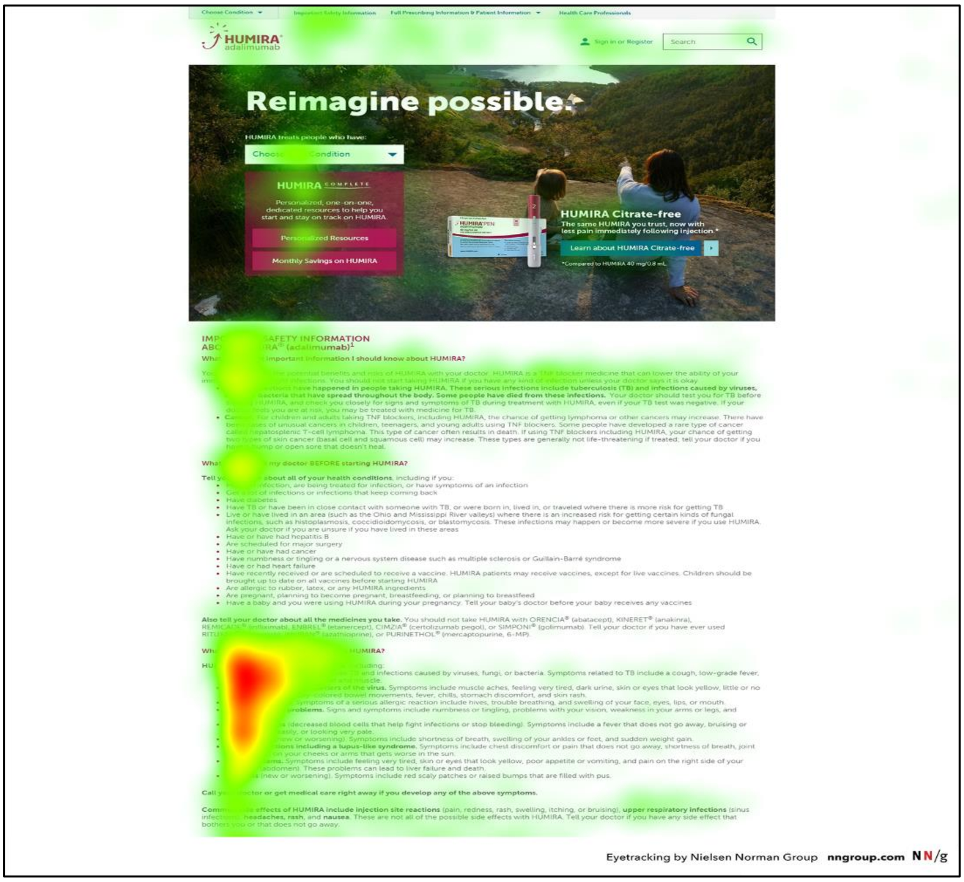


Figure 5.4: Eye tracking heat map (Moran, 2019)

The eye tracking metrics that were collected for this usability test are further discussed in Section 5.2.7. The following section discusses in detail the participants that were selected for the eye tracking usability testing.

5.2.2. Participants

A minimum of 15 individuals matching the target criteria served as participants in the usability test of the EVDSL. The target criteria for the participants included:

- Computing Science Staff, and/or
- Postgraduate Computing Science Student.
- It was considered beneficial if participants were enthusiastic about electricity conservation and had knowledge of Smart Environments.

Participants were recruited through email using the distribution email list of the Department of Computing Sciences targeting Postgraduate students and Computing Science Staff. Participant names were replaced with Participant IDs to safeguard the identities of participants. The demographics of the participants that were collected included gender, age, home language, and whether they were a student or staff members. Figure 5.5 shows the age distribution of the participants; most of the students were in the age range of 18-24 and the least number was in the 30-34 age range.

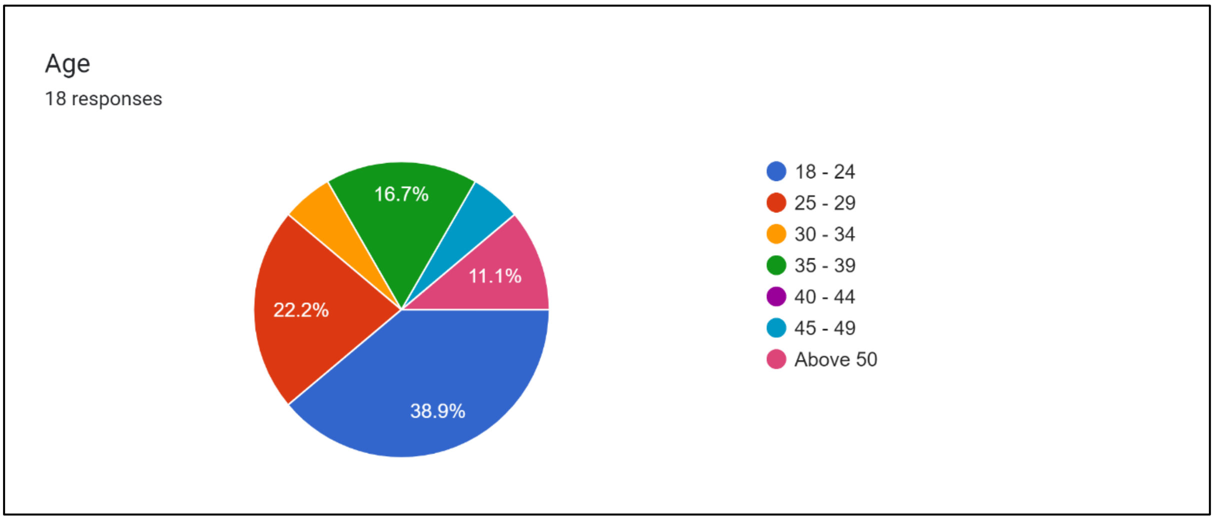


Figure 5.5: Usability test age distribution (n=18)

Table 5.1 and 5.2 show the participants' occupation and gender distribution respectively, the participants were mostly students, (n=10) and there were only 5 staff and 3 participants who fitted into both categories.

Table 5-1 Participants' occupation distribution

Occupation	**Number**	**Percentage**
Student	10	55.6%
Staff	5	27.8%
Both	3	16.7%

Table 5-2 Participants' Gender distribution

Gender	**Number**	**Percentage**
Male	9	50%
Female	9	50%
Rather not say	0	0

Figure 5.6 shows the language distribution of the participant's home language; this could help in understanding the reasons why participants may have had difficulty understanding the tests or the system itself, as the test and the system made use of English. Eight of the participants had English as a home language, while four of the participant's home language was isiXhosa.

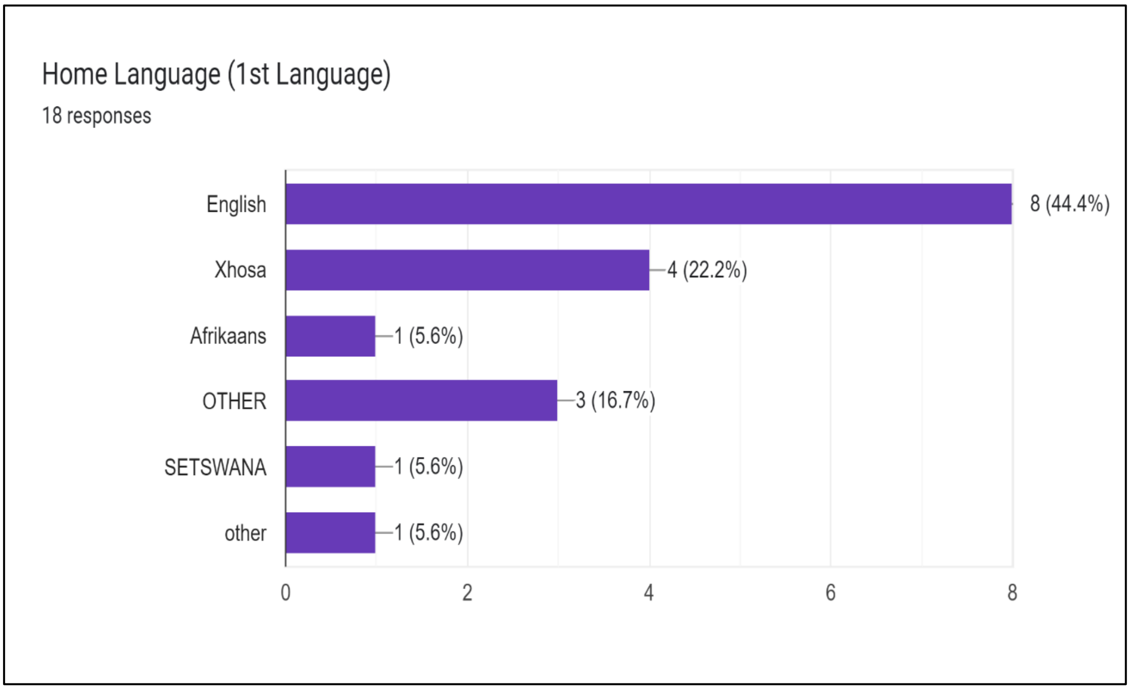


Figure 5.6: Participant home language distribution (n=18)

5.2.3. Test Design

The test's goal was to find areas where the EVDSL needed to be improved, such as where it failed to fulfil the tasks of the participants and where it worked well. The results of this test were utilized as a baseline for future testing using an upgraded version of the same EVDSL and/or comparisons with similar systems if the same tasks were employed. This testing was used to both document and measure usability, as well as to highlight areas where changes were needed.

During the usability test, participants interacted with the EVDSL. Each participant used the same database and were provided with the same instructions. The EVDSL was evaluated for effectiveness, efficiency, and satisfaction as defined by the measures collected and analysed for each participant:

- Number of tasks successfully completed,
- Time to complete the tasks,
- Number and types of errors, and
- Participants' satisfaction ratings of the system.

Additional information about the various measures can be found in Section 5.2.7 on Usability Metrics.

5.2.4. Test Tasks

Several tasks were created to be realistic and typical of the types of activities that a user might engage in while using the EVDSL. The following were the tasks that each participant was required to complete; a more detailed task information sheet is provided in Appendix 7:

1. Record the current electricity usage of all devices for the current month.
2. Record the current electricity usage of all devices for the current day.
3. Record the current electricity usage for the Intel NUC for the current week.
4. Record the current total electricity usage for the fridge for the current month.
5. Using the vertical menu click on the Category option then click on the other option and record the device with the highest electricity usage.
6. Compare the electricity usage between the Intel NUC and the Wi-Fi router for the current week and record which total current usage is higher.
7. Using the vertical menu click on the Compare menu option and then click on the Compare option and compare the electricity usage between the kitchen and the lounge for the current month and record which total current usage is lower.
8. Which device has the highest electricity usage for the current day?
9. Which category has the lowest electricity usage for the current year?
10. Set Target weekly usage for the Kitchen category to 5000kWh.
11. Record the current electricity usage of all devices for the current day.
12. Using the vertical menu, click on the Category option then click on the Kitchen category option, select week view, and record the progress (in percentage) of the current usage to reaching the target usage previously set.
13. Set Target daily usage for all devices to 10000kWh, and
14. Using the vertical menu, click on the home option then record the daily progress (in percentage) of the current usage to reach the target usage previously set for all devices.

The tasks were selected based on the criticality of the function, frequency of use of the function, and those that may be problematic for the user, and making sure that the requirements for the EVDSL were met. The following section discusses in further detail how the usability test was conducted.

5.2.5. Procedure

Upon arrival, each participant was assigned a participant ID. The administrator read out the participant instructions (see Appendix 1) and was given written instructions (see Appendix 2), which they were to read before they read and signed the consent form (Appendix 3). The consent form indicated that they understand the purpose and use of the study, what to expect from the study, and that they were willing volunteers.

The first step in the test was to calibrate the Tobii Pro Nano eye tracker; this was done by asking the participant to look at specific points on the screen, also known as calibration points. During this procedure, the eye tracker measures the characteristics of the user's eyes and uses them together with an internal, anatomical 3d eye model to calculate the gaze data.

The participants were then given a list of written tasks to carry out on the EVDSL (Section 5.2.3). Various eye tracking metrics were collected during the study and these metrics are further discussed in Section 5.2.7:

- Dwell time at a specific area of interest (AOI);
- Number of fixations;
- Fixation duration;
- Time on the first fixation, and
- Hit Ratio.

Other usability metrics that were considered include:

- Performance metrics: task success, time on task, errors, efficiency, and learnability.
- Issue based metrics: task success, time on task, and dwell time.

Following the session, the test administrator then gave the participant the Post Study Usability Questionnaire (PSSUQ, see Appendix 5), and thanked them for their participation in the study. The participant demographic information, time on task, errors, task success rate, deviations, and post study questionnaires were recorded.

5.2.6. Test Location

The usability tests were conducted at Nelson Mandela University's Usability Lab, which is part of the Department of Computing Sciences. A participant room was available in the Usability Lab, where participants could complete the tasks outlined in Section 5.2.3. All observers were in a separate room called the observer room, where they could watch the participant complete the tasks during the session. Both rooms have air conditioning, so they were well conditioned. All COVID-19 standards were followed, the social distance was maintained, and each participant's equipment was cleaned. In addition, Appendix 4 contains all the COVID-19 precautions.

5.2.7. Test Environment

The EVDSL would be typically used in a Smart Environment, which could be a Smart Home, Smart Building, or Smart Workplace. In this instance, the testing was conducted in a Usability Lab. The computer used was running Windows 10 Enterprise LTSC version 1809, on a Dell computer with Intel(R) Core (TM) i5-9500 CPU @ 3.00GHz processor with 16 GB of installed RAM. The monitor used was a Dell SE2419H with a display resolution of 1920 x 1080 and a colour format of RGB. The keyboard used was a Dell KB216 Wired keyboard. The eye tracker used was the Tobii Pro Nano, which easily attaches to a screen up to 24 inches using the supplied adhesive mounting brackets for monitors, laptops, and tablets. To make use of the eye tracker, the Tobii Pro Lab was used, which is eye tracking software designed to conduct research with Tobii Pro hardware, in this case, the Tobii Pro Nano. For this research, we used the Tobii Pro Lab Full Edition version 1.181. An image of the Tobii Pro Nano mounted onto a laptop is shown in Figure 5.7.

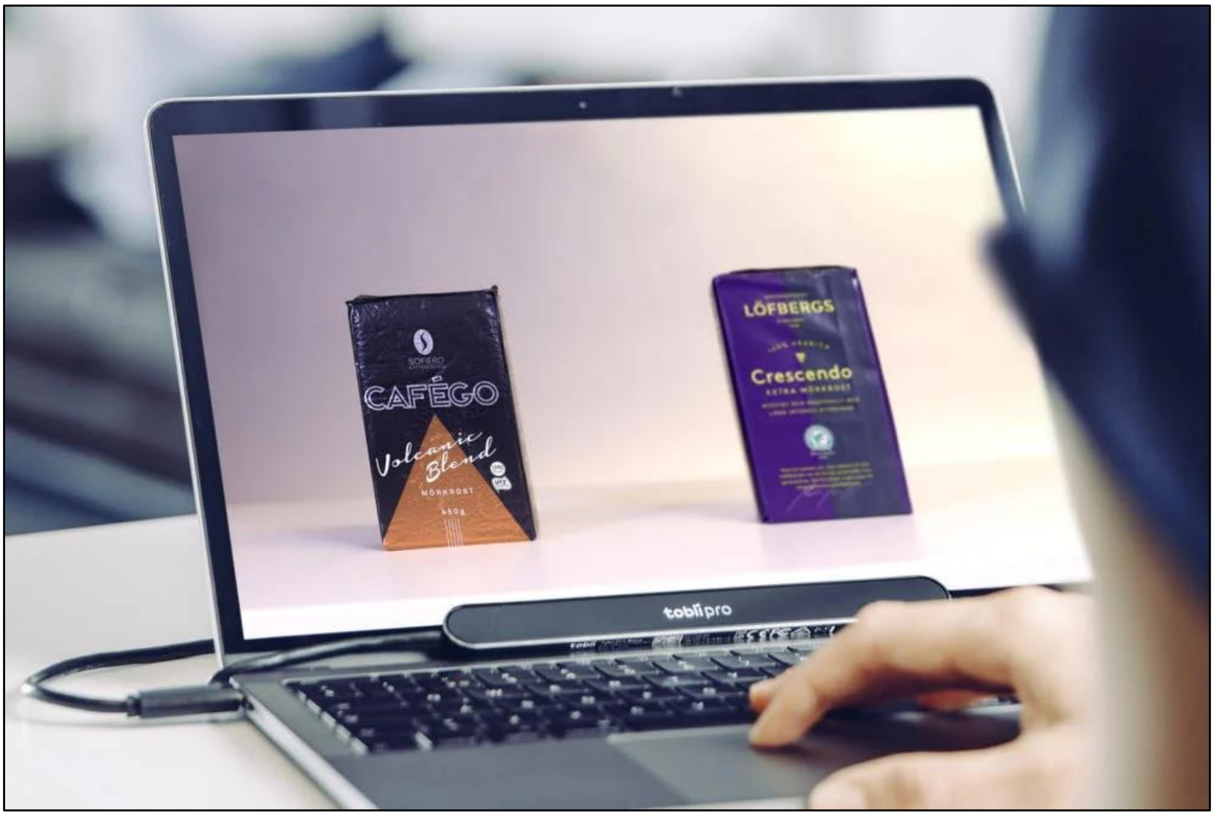


Figure 5.7: Tobii Pro Nano mounted onto the laptop

The metrics, which were collected to measure the usability of the EVDSL, are further discussed in the following Section 5.2.7.

5.2.8. Usability Metrics

The ISO 9126 standard defines usability as a software system's capacity to be comprehended, learnt, operated, attractive, and consistent with usability rules (Paz et al., 2019). Using user experience metrics, which show how users interact with a product, one can assess the usability of a software product. These metrics cover aspects like task success or failure, time taken to complete a task, mistakes made, amount of effort needed, and learnability. This means that some elements of a user's individual experience using a product may be reflected in the user experience metrics (Yee et al., 2018).

- Effectiveness: When a user can use the product to finish a task, that situation indicates effectiveness (Yee et al., 2018).
- Efficiency: the efficiency of a tool can be determined by the amount of effort spent, The amount of work required—the number of clicks or time—to complete a job can be used to gauge how effective a tool is (Yee et al., 2018).
- Satisfaction: This is based on how happy a user is with their experience when performing a task with the product (Yee et al., 2018).

The eye tracking metrics collected during the usability test assist in assessing the EVDSL's efficiency, effectiveness, and level of user satisfaction. The data collected during the eye tracking test included dwell time, number of fixations, revisits, sequence, time to first fixation, and hit ratio (Tullis & Albert, 2013b). There are metrics that are associated with eye tracking data. It is important that the metrics are associated with specific AOI's:

i. Dwell Time

The overall length of time spent staring inside an AOI is known as dwell time. This comprises all fixations, saccades, and revisits that occur during the AOI. An effective indicator for expressing the level of interest in a particular AOI is dwell time. Naturally, the longer the dwell duration, the more interest there is in the AOI.

ii. Number of fixations

The number of fixations is the total number of fixes made with an AOI. As might be expected, there is a significant correlation between the number of fixes and dwell time. As a result, we usually only report dwell time.

iii. Fixation Duration

The length of fixation is how long they typically last. The usual fixation time spans 150 to 300 msec. Fixation duration, along with the number of fixations and stay time, illustrate the degree of engagement with the subject. The amount of engagement increases as the average fixation duration increases.

iv. Sequence

The order or sequence in which each AOI is initially fixed is represented by the sequence. The sequence provides information to the researcher about the relative importance of each AOI in the context of a particular job. Usually, the sequence is determined by averaging the visits to each AOI. Remember that not all participants might have encountered that exact order. The sequence is merely a best guess.

v. Time to the first fixation

Knowing when consumers first notice a certain aspect is useful in some circumstances. Calculating an average of all the instances at which a specific piece was initially fixed is one method of analysing this data. Data must be interpreted as elapsed time beginning with the first exposure. The average shows how long it took for everyone who did notice the element to initially notice it.

vi. Revisits

The number of times the eye fixes within an AOI, exits the AOI, and then comes back to fixate within the AOI is known as the number of visits. Revisits show how "sticky" the AOI is. Do users fixate there and then exit the AOI, never to return? Or do users fixate there and then repeatedly return with their eyes?

vii. Hit ratio

The percentage of participants who had at least one fixation inside the AOI is known as the hit ratio. Therefore, this is the proportion of participants who viewed the AOI.

The goal of the usability test was to test the efficiency, effectiveness, and level of user satisfaction of the EVDSL. The metrics to measure effectiveness, efficiency, and user satisfaction were captured during the usability test. The goals of the test were to assess:

- How effective the EVDSL is in measuring participant’s task success and errors;
- How efficient the EVDSL is by measuring the participant’s number of fixations, dwell time on a specific area of interest, time on task, learnability, revisits, task rating, and sequence;
- The satisfaction of the EVDSL by measuring how easy it was to use the system based on the responses to the post study usability questions.

5.2.9. Data Scoring

Table 5.3 details how the tasks were scored, errors evaluated, and the time data analysed.

Table 5-3: Data scoring for usability test conducted

Measures		**Rationale and Scoring**
Effectiveness:	Task Success; Task Failure	The task success was measured by assigning a binary value of 0 or 1 to the participants; where 1 is a success and 0 is a failed task.
	Errors	The number of times an error occurs when performing a task, which can illustrate where issues are in the system and where improvements need to be made. The severity of the errors can show how simple and intuitive the system is. The error data was organised by task by recording the number of errors for each task for each participant. 0 = No error 1 = Error
Efficiency:	Task Time	Each task was timed from start to finish.
	Task deviations/ sequence	It was documented how each participant moved through the application. Deviations happen when a participant, for instance, navigates to the wrong screen, clicks on the wrong menu item, follows the wrong link, or uses the wrong on-screen control. The ideal route was contrasted with this one. To calculate the ratio of path deviation, divide the number of steps in the observed path by the number of ideal steps.
User satisfaction	Post-Study System Usability Questionnaire (PSSUQ)	The participant's subjective perception of the EVDSL was measured by administering a post study usability questionnaire. The calculation for scoring the PSSUQ is discussed in Section 5.3.6.

5.3. Usability Test Results

The following section discusses the results from the usability tests conducted on 18 participants.

5.3.1. Areas of Interest (AOI) results

Areas of interests were defined, which are the areas we wanted to measure on the EVDSL. The areas selected to be AOIs were important in that the participants needed to look at them to complete a task, and some areas were less important or did not need to be looked at as certain areas were not included in the test.

Figure 5.8 shows the defined AOIs for the home page screen; the AOIs defined included:

- Home daily total usage of all devices
- Home total usage by category
- Home periodic usage
- Home devices usage
- Home target usage
- Home update period
- Home device with highest usage

Figure 5.9 shows the defined AOIs for the kitchen category screen; the AOIs defined included:

- Kitchen total usage
- Kitchen target usage
- Kitchen highest usage device
- Kitchen device usage
- Kitchen periodic usage

Figure 5.8: Home page AOIs

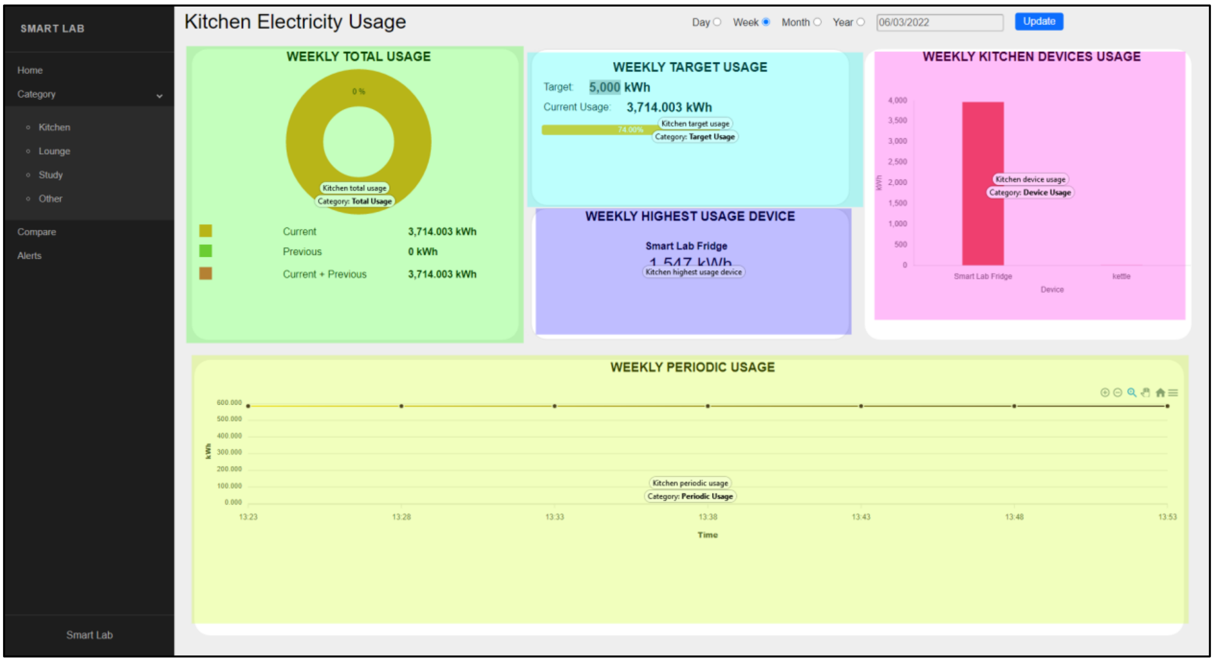


Figure 5.9: Category screen AOI

Figure 5.10 shows the defined AOIs for the device page, which included:

- Total usage
- Target usage
- Highest usage value and time
- Device usage
- Periodic usage

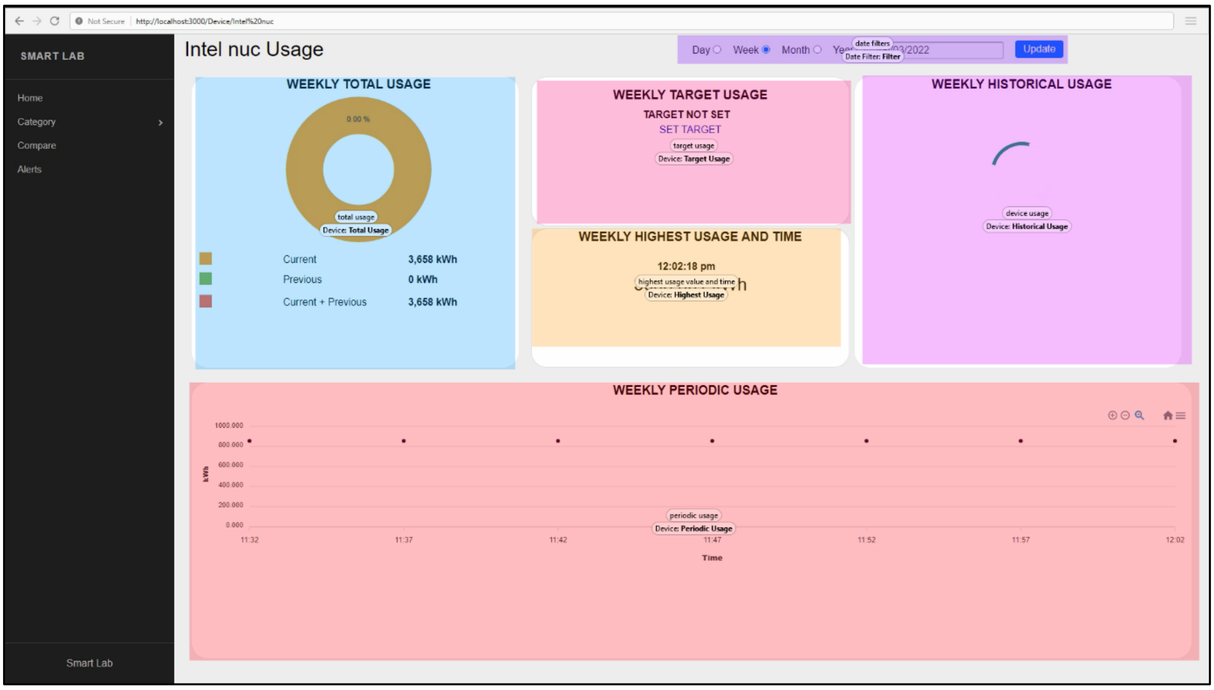


Figure 5.10: Device page AOIs

The Alerts page had the following defined AOIs:

- Alerts select category/device
- Alerts current usage
- Set targets

The Compare page had the following defined AOIs:

- Compare selection

The established AOIs are crucial for assessing which sections were examined throughout the usability test, which aids in detecting problems with users being able to find what they are looking for. For example, one can check whether it was challenging to find a particular functionality. If so, this serves as crucial feedback for the researcher to better position the functionality.

Figure 5.11 displays the heat map obtained from the usability test after all 18 participants had finished aiding in further evaluating the AOIs. The heatmap displays the individuals' typical performance on the same task, as mentioned in Section 5.21. The colour of the area that participants spent the most time looking at is shown in red, followed by yellow and green, respectively. Figure 5.11 shows that all AOIs were examined during the usability test and that the "home periodic usage" AOI received the least amount of attention—as would be expected given that none of the tasks were related to this section. This information can be obtained by looking at the AOIs defined for the home screen in Figure 5.11. Additionally, because they were crucial to finishing the task, all other areas were also given attention.

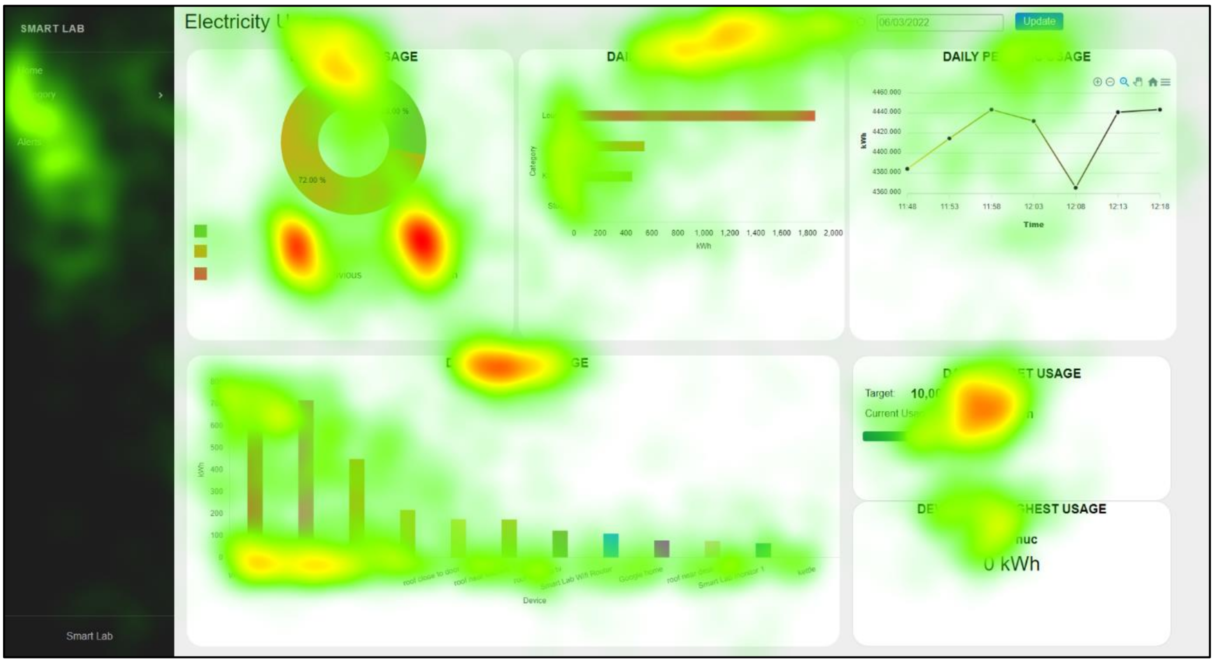


Figure 5.11: Home page heat map from all participants during usability study (n=18)

The same can be said for the other AOIs defined on the other pages, as shown in Figures 5.12 and 5.13 for the Kitchen category page and Alerts page, respectively. The areas with the most visual attention were expected to have the most attention because they were required to complete the tasks

Figure 5.12: Kitchen page heat map from all participants during usability study (n=18)

Figure 5.13: Alerts page heat map from all participants during usability study (n=18)

5.3.2. Task Completion Success Rate

The 18 participants were asked to complete 14 tasks during the test, and Figure 5.14 depicts task success by participant. In Appendix 9, Table 9.1, a detailed recording of the task success/failure results of the test is shown, with 1 indicating success and 0 indicating failure. The success rate, which measures the effectiveness of the system, was calculated by multiplying the number of tasks completed successfully by the total number of tasks taken by 100 for each participant. The success rate can be summarised as the percentage of participants who could successfully complete their tasks.

Figure 5.14 shows that nine of the 18 participants completed their tasks successfully. Four of the 18 participants made a single error, lowering their task success rate to 92.85 per cent. Four other participants also had two errors, but only one struggled, p13, who had seven errors during his usability test. Nothing stands out after reviewing the characteristics of the participants in Figures 5.5 and 5.6 and Tables 5.1 and 5.2, except that they were the only participants who spoke Afrikaans as their first language. The overall success rate per participant was 92.45 percent, reflecting the high effectiveness of the tool.

The average task success rate of all 18 participants is depicted in Figure 5.15. Figure 5.15 depicts which tasks the participants struggled the most with, with task 7 appearing to have the lowest success rate of 77 percent. Task 7 focused on navigation and the use of the Compare page; however, participants reported that the Compare page would crash, resulting in participants failing to complete the task. In addition to task 7, users had difficulty with tasks 10 through 14.

Participants reported difficulty navigating to the Alerts page, navigating how to set the required target, and locating the progress of electricity usage in relation to the target set for these tasks. Section 5.3.4 discusses the errors in more depth. The first six tasks, which covered the home page, category page, device page, and the navigation associated with those pages, were completed successfully by all participants. The overall task success rate per task was 72.2 percent, demonstrating the system's effectiveness by allowing participants to successfully complete all tasks using the tool. Section 5.3.6 reviews the errors that lowered the success rate.

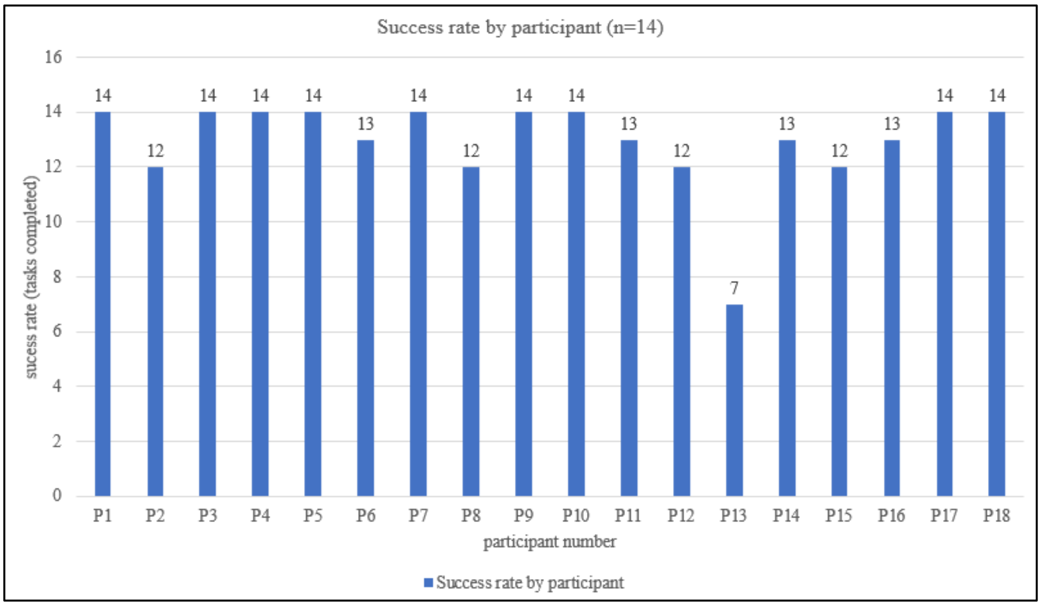


Figure 5.14: Success rate per participant (n=18)

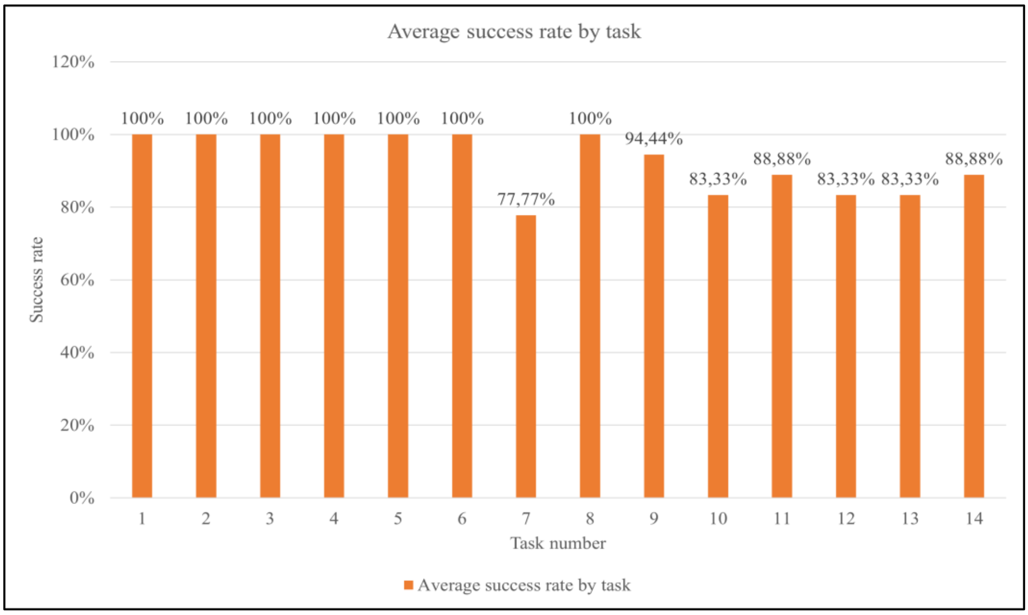


Figure 5.15: Success rate per task (n=18)

5.3.3. Efficiency

Typically, efficiency is measured by the amount of time it takes the user to complete a usability task or the number of errors the user makes while completing the task. According to ISO-9241, (Moumane et al., 2016), product efficiency is defined as "resources spent by the user to ensure accurate and complete achievement of the goals". In the case of software and information systems, the key measured resource is typically the time spent by the user to achieve the goals. Figure 5.16 depicts the time it took all participants to complete all the tasks during the usability test. Figure 5.16 also shows the average time as a straight line in comparison to the time participants spent on the study, and the average time is calculated as the geometric mean. The geometric mean was chosen over the mean because it contains less bias. Measuring the amount of time needed to complete a task is useful because it reveals the amount of effort required by the users (Tullis & Albert, 2013a).

Because of the nature of the tool created, the faster the completion time, the better. Users should be able to quickly obtain the information they require. Participants 3, 4, 5, 6, 7, 10, 11, 12, 13, 15, and 17 finished the test in the same or less time than the average time, whereas the remaining 6 took longer.

The group was made up of a diverse range of characteristics, according to Figures 5.5 and 5.6 and Tables 5.1 and 5.2, which show the different characteristics of the participants who took less time to complete the tasks. Participant 8 took the longest and had the lowest success rate, by looking at how many tasks were completed successfully, according to Figure 5.14, indicating that the participant struggled with the test and thus took longer to try to complete or continue until fail.

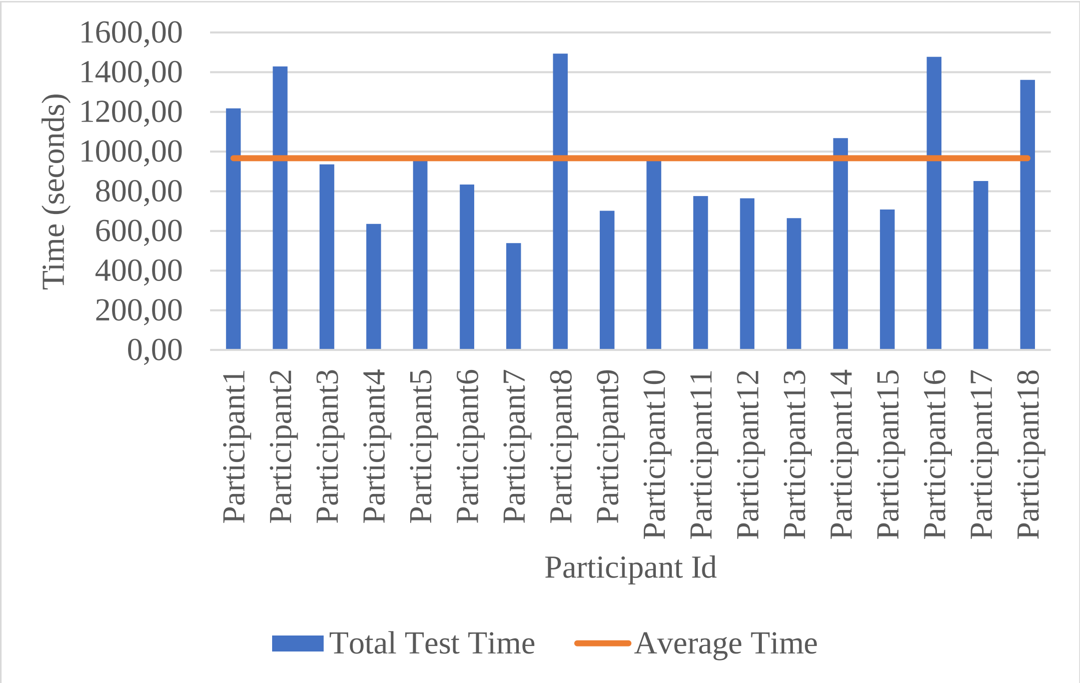


Figure 5.16: Total task time (seconds) for all participants during the usability study (n=18)

The shorter the time it takes users to complete the test, the more efficient the tool. The results showed that 61 per cent of the participants were able to achieve the goal of completing the same tasks in the same or less time than the average time of all participants, indicating the tool's relative efficiency.

However, because they were participants who took longer to complete their tasks, it indicates that improvements could be made. The issues identified that could have contributed to participants taking longer than others are described in Section 5.3.4. If these issues are resolved, the average time it takes for users to find the information they are looking for will be reduced.

5.3.4. Eye tracking qualitative results

Data from eye tracking can be analysed both quantitatively and qualitatively. Video replay of visual scan paths and eye movements can provide valuable insights into the patterns of attending to various interface features, allowing usability researchers to identify where and how long people focus their attention (Wang et al., 2018). For this study, each participant's fixation behaviour was subjected to a quantitative analysis. The quantitative analysis revealed where and how long participants concentrated their attention, assisting in the identification of potential usability issues within the system (Wang et al., 2018).

Table 5.4 summarizes the issues discovered from watching the recordings of the participants test showing the visual scan paths, eye movement, and mouse location while performing the test, based on qualitative eye tracking data. Table 5.4 also includes the suggested solution for each of the issues raised.

Table 5-4: Eye tracking qualitative results

#	Issue viewed	Recommendation
1	Participants took time to find the filters for day, week, month, and year and this led to incorrect figures for electricity usage being recorded	Improve the location of the filters on the screen.
2	Difficulty understanding the target percentage values	Recalculate percentages to ensure valid percentages are presented.

5.3.4. Questionnaire Results

After the test, participants had to submit a post-study usability questionnaire. Participants were given the Post-Study System Usability Questionnaire (PSSUQ), version 2 which has a 19-item assessment aimed at determining user satisfaction with system usability. It is a well-liked and trustworthy psychometric tool (Rosa et al., 2015). The questionnaire has 19 items, and the users were asked to rate how much each item they agree with. It consists of the 19 items listed in

Appendix 5 Section B, where users score their agreement using a "strongly disagree" or "strongly agree" Likert scale of 1 to 7, with a remark box following each rating. The PSSUQ allows for the evaluation of the system's usefulness, information quality, and interface quality (Pinem et al., 2020).

System Usefulness (SysUse), Information Quality (InfoQual), Interface Quality (IntQual), and Overall Satisfaction are four categories in which the survey responses can be analysed (Tullis & Albert, 2013b). The calculation for scoring the PSSUQ is as follows (Lewis, 2011):

- Overall: Average the responses to items 1 through 19;
- SysUse: Average the responses to items 1 through 8;
- InfoQual: Average the responses to items 9 through 15;
- IntQual: Average the responses to items 16 through 18.

The questionnaire used a score that starts with 1 (strongly disagree) and ends with 7 (strongly agree). The higher the score, the better the performance and satisfaction. However, a 4 is regarded as neutral but it cannot be the average, and a score below 4 does not indicate that your product has performed above average. It is important to note that the higher the mean score the more usable the tool is. Table 5.5 summarizes the PSSUQ results, showing the mean score for each question and the mean score for each category for all 18 participants. The higher the score, the higher the level of satisfaction. Figure 5.17 deconstructs and highlights the PSSUQ's different categories' scores namely Overall, SysUse, InfoQual, and IntQual.

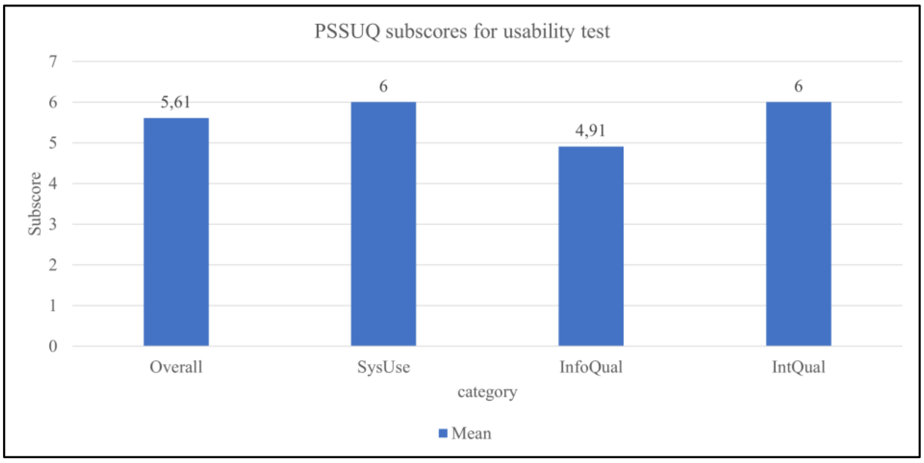


Figure 5.17: PSSUQ subscores for usability test (n= 18)

Figure 5.17 shows that all categories had a score of above 4, proving that the participants found the tool to be satisfactory. Only the InfoQual category had a lower score of 4.91 and SysUse and IntQual had a score of 6. The overall satisfaction was 5.61 indicating user satisfaction.

Table 5-5: PSSUQ results summary for 18 participants

Category	**No**	**Item/Question**	**Total**	**Mean**
SysUse	1	Overall, I am satisfied with how easy it is to use this system.	107	5.94
	2	It was simple to use this system.	109	6.06
	3	I could effectively complete the tasks and scenarios using this system	102	5.67
	4	I was able to complete the tasks and scenarios quickly using this system.	101	5.61
	5	I was able to efficiently complete the tasks and scenarios quickly using this system	104	5.78
	6	I felt comfortable using this system	111	6.17
	7	It was easy to learn to use this system.	115	6.39
	8	I believe I could become productive quickly using this system	115	6.39
Mean				6
InfoQual	9	The IV tool gave error messages that clearly told me how to fix problems.	34	1.89
	10	Whenever I made a mistake using this system, i could recover easily and quickly.	87	4.83
	11	The information (such as on-line help, on screen messages, and other documentation) provided by IV tool was clear.	56	3.11
	12	It was easy to find the information i needed.	106	5.89
	13	The information provided by the IV tool was easy to understand.	112	6.22
	14	The information was effective in helping me complete the tasks and scenarios.	110	6.11
	15	The organisation of the IV tool screens were clear.	114	6.33
Mean				4.91
IntQual	16	The interface of the IV tool was pleasant.	112	6.22
	17	I liked using the interface of this system	112	6.22
	18	IV tool has all the functions and capabilities i expect it to have.	100	5.56
Mean				6
Overall	19	Overall, I am satisfied with this IV tool	110	6.11
Mean				5.61

5.3.5. Errors and Recommendations

There were errors that were experienced while participants were attempting to complete the tasks. The errors that were encountered were rated according to their severity. The severity of a problem is based on a combination of three factors (Nielsen, 1994):

- The frequency with which the problem occurs: Is it common or rare?
- The impact of the problem if it occurs: Will it be easy or difficult for the users to overcome?
- The persistence of the problem: Is it a one-time problem that users can overcome once they know about it, or will users repeatedly be bothered by the problem?

The following 0 to 4 rating scale can be used to rate the severity of usability problems, and was used in this usability test to show the errors encountered (Nielsen, 1994):

0 = I don't agree that this is a usability problem at all

1 = Cosmetic problem only: need not be fixed unless extra time is available on the project

2 = Minor usability problem: fixing this should be given low priority

3 = Major usability problem: important to fix, so should be given high priority

4 = Usability catastrophe: imperative to fix this before the product can be released

Table 5.6 shows the list of usability problems/ errors identified during the usability test and the severity rating that was allocated to the problems using Nielsen's rating scale.

During the usability testing, participants noted functional issues with the system. These types of issues could be reduced in future testing by conducting pilot testing on a small sample size of participants to reduce these types of issues and potentially increase system usability.

5.4. Conclusion

The goal of this chapter was to answer RQ_5 which is "*How usable is the proposed tool?*". Following the evaluation activity of DSRM, a usability study using eye tracking technology was conducted to test the usefulness of the tool. The usability test was conducted in the Usability Lab at the Department of Computing Sciences at Nelson Mandela University. The lab has a participant and an observer room where the researcher could watch as the participants conducted the usability test. The participant room was equipped with a computer and a monitor with the Tobii Pro Nano eye tracker attached to it for eye tracking.

Table 5-6: List of usability problems found and their severity ratings

Usability Problem	Recommended solution	Severity Rating
1. Compare page crashing	Fix compare page (functionality issue)	4
2. Target usage setting incorrectly (incorrectly sets for both devices and categories sometimes)	Make sure when setting a target it is set for the correct device or category (functionality issue)	3
3. Historical devices component not working, currently continuously loading	Make sure data is sent through correctly for historical devices component (functionality issue)	3
4. The target page layout is not clear and easy to follow	Update page layout	2
5. The input field for setting targets allows text to be entered	When setting the target limit input field to only take in numbers	2
6. Some electricity usage values show "NaN" as a usage value	Make sure to show actual usage value even when null	2
7. Compare page does not auto update data upon selecting what to compare	Make it dynamic to compare usage without clicking compare page (functionality issue)	1

Satisfaction, effectiveness, and efficiency are the three most important usability metrics. The effectiveness and efficiency of a tool referred to how well it supports the user's desire to complete a task with precision and speed. The user's perception of the tool determines satisfaction. A total of 18 participants were asked to complete to the best of their ability a list of tasks given to them. The overall task success rate was 72.2 percent, demonstrating the system's effectiveness by allowing participants to successfully complete all tasks using the tool. The time taken for each participant to complete the study was recorded. For this research the faster the completion time the better it is because of the nature of the tool developed, users need to be able to quickly find the information they need.

The tool's efficiency was relatively high; tracking the time taken and also observing the eye tracking recordings of the study revealed that participants may have struggled in the first few tasks as they became acquainted with the system but were faster in the later tasks. Users filled in a post study satisfaction questionnaire, which was the PSSUQ after completing the tasks. The PSSUQ was used to evaluate the system's usefulness, information quality, and interface quality. The PSSUQ results showed that all categories had a score of 4 or higher, indicating that the tool was satisfactory to the participants. Only the InfoQual category received a lower score of 4.91, while SysUse and IntQual received mean scores of 6. The overall satisfaction score was 5.61, indicating that users were satisfied.

Issues found within the system and highlighted by the users in Table 5.6 noted as functionality issues could be avoided in the future and could have been fixed before usability testing was conducted. The researcher acknowledges that these functionality errors could be reduced in the future by conducting a pilot test before the usability test.

The findings show that the tool was relatively usable, i.e., the participants were satisfied and could use the tool effectively with the given tasks. However, due to the nature of the study, the true effectiveness of the tool could not be fully measured. The tool was developed for a small smart lab on campus and then tested by participants for a limited amount of time, and it could not have been tested as thoroughly in a proper smart environment with participants interacting with the system for an extended period of time to obtain better results on the tool's effectiveness.

Despite the shortcomings, the usability of the tool was tested, and the results showed that the tool was indeed usable and useful.

Chapter 6: Conclusion and Future Work

6.1. Introduction

This chapter discusses the findings of this research and recommendations for future studies. The main research question for this study was: RQ_m: *How should electricity usage in a SE be effectively visualised?* The design and development activity discussed in Chapter 4 was an iterative and rigorous process to design a tool to visualise electricity in a SE. Chapter 5 reflects on the findings of the evaluation of the proposed tool and to what extent it met the requirements defined in Chapter 3. The extent to which the research questions were answered determines the success of this research.

6.2. Achievements and Contribution

The contributions made by this research study are categorised as theoretical and practical contributions. The theoretical contributions are discussed first and then the practical contributions.

6.3.1. Theoretical Contributions

The DSRM was successfully used in this study to answer the research questions, and a visualisation tool was designed and built using a combination of Shneiderman's Mantra and the Agile scrum methodology. The methodologies demonstrated their ability to work together to achieve a common goal.

The second chapter discussed a literature review conducted to answer RQ_1 "*How does a smart environment influence electricity consumption?"* According to the literature, various factors in a SE, such as misuse of services, inadequate maintenance, and user mismanagement of applications, can cause increases in energy usage in SE systems (Alaa et al., 2017). The SE architecture of a SE is interconnected with communication technologies, because a SE is automated, it must constantly work, resulting in significant energy consumption (Alaa et al., 2017). The requirement for continuous connection necessitates the inclusion of a standby function on devices. Vampire power is caused by standby power mode, in which devices consume electricity even when they are not in use. The literature review in Chapter 2 assisted in providing an understanding of SEs and how they are constructed.

Chapter 3 is centred on visualisation techniques by reviewing the various types of visualisation charts available, with a focus on electricity consumption. This was done in an effort of addressing RQ_2, *"How is electricity usage currently visualised in a smart environment?"* which was successfully addressed. According to the research, HEMS are currently used to visualise electricity usage in SEs, but their efficiency is determined by the user's interpretation of the data based on the interface. This study aimed to contribute to the advancement of the design and development of power usage displays, as further discussed in the practical contributions.

RQ_3 was also addressed in Chapter 3: "*What are the most effective methods for visualising electricity usage in a smart environment?"*. According to research conducted, designers are in a difficult position when deciding which visualisations to use (Sandouka, 2019). There are no clear standards for which chart types should be used, and chart type selection is based on the type of electricity usage statistics provided to the user, as well as an examination of current systems. The author was able to determine that pie charts, doughnut charts, line charts, bar charts, progress bars, scaled up data, and tables were the most utilised chart formats for visualising electricity usage in SEs after reviewing existing systems. Further analysis of the literature assisted in establishing design guidelines for dashboards that could be used in a similar use case.

6.3.2. Practical Contributions

Chapter 4 aimed to answer RQ_4, "*How should a system be designed to effectively support visualisation of electricity usage in a SE?"*. To answer this question an artefact was designed and additionally developed to support the feasibility of the design. In addition, a combination of design and development methodologies were used. The design and development process highlighted the iterative nature of the design and development process of the DSRM. In addition, Shneiderman's mantra of "Overview first, zoom and filter on demand" was demonstrated in the implementation. The tool provided users with layers of information on their electricity usage in a SE and allows them to set goals for their electricity usage, keeping them motivated to save electricity.

Data was required to develop the tool, which necessitated a method to capture data on electricity usage from devices in the SE and save it to a database, where it could then be manipulated and visualised. Smart plugs were used to collect data on electricity usage in the SE and save it to a database every minute. This demonstrated the successful use of the tplink-smartplug-api API to save electricity usage data from devices in a SE. The tool was also able to provide users with this data which could be used and could potentially encourage users to reduce their energy consumption.

The proposed tool demonstrated the effective use of visualisation by identifying effective visualisation techniques and information to display for a user, to communicate their electricity usage understandably, and to allow users to make informed decisions to save electricity.

To answer RQ_5, *"How usable is the proposed tool?"*, a usability study using eye tracking technology was conducted to test the tool's usefulness. Overall, the results showed that the tool was relatively effective, efficient, and acceptable to the participants (despite a few functionality issues)

These findings also demonstrated that the tool was practical and useful. The proposed tool was able to consistently update the electricity usage data and met all of the requirements outlined in Chapter 3.

Participants in the usability test stated that they found this tool useful because it allows them to view their electricity usage and be motivated to reduce their usage by knowing the source. The dashboard's information breakdown proved to be a unique and useful component of the dashboard, as users could drill down on a device or a category to find out more about the device's electricity usage.

6.2. Issues Encountered

Measuring usability entails examining user satisfaction, user efficiency in completing tasks, and the tool's effectiveness in completing tasks. The system's satisfaction and efficiency were fairly tested on participants during the usability test, and the results demonstrated that the tool was usable. It should be noted, however, that testing the effectiveness of the tool has limitations due to the location and timeframe in which it was tested. To get a more accurate picture of the tool's effectiveness, it would need to be tested in a smart environment, such as a smart home instead of a lab, for an extended period of time to see if the tool assists users in successfully reducing their electricity consumption.

The COVID-19 pandemic was a major issue because of the lockdowns that were imposed, limiting access to campus. The delay in access to the computer laboratories slowed the data collection process, which was critical in determining the type of data that the author was able to collect and then design and develop.

Loadshedding was an issue that was encountered throughout the design process, development process, and evaluation activity. Power outages made it difficult to collect consistent data on electricity usage, resulting in data gaps.

Learning how to use Tobii Pro Lab and Tobii Pro Nano to set up and run the usability test was a difficult task because the documentation wasn't very helpful for this specific case study. The task times were not collected due to the steep learning curve, as the documentation on how to do so automatically was not very helpful.

6.3. Future Development

The design suggestions which could not be included in the development of the current tool developed could be completed to improve the overall usability and functionality of the tool. A more intuitive alert notification system could be added to the tool in the future to better alert users when they reach their target electricity usage. Even though participants in the usability study demonstrated that the tool was useful and that participants were satisfied with the functionality of the proposed tool, improvements to the information architecture could be made to reduce the time it would take for users to find information.

Showing electricity usage in monetary terms can be useful to the users. It proved difficult to implement electricity costs as they are ever changing, and it would have been time consuming to implement a solution.

More devices could be added to the dashboard to test the scalability of the proposed tool and determine whether the design would be as effective with more devices attached to it.

The usability test procedure could be improved; errors were made in not collecting task time for each task and instead collecting the total time for the entire study. The results were still useful, but more information on the tool's efficiency could be provided with recorded task times. The tool could be improved to be cross-platform, allowing users to track their electricity usage on the go using their mobile phones.

The tool could be tested in a smart environment, such as a smart home, with more activity and for a longer period of time to provide a clearer result on the tool's effectiveness. Furthermore, the tool can be used to conduct an impact study to measure the actual electricity usage that occurs in smart environments, which was not possible in this study due to the study's location and timeframe. The testing process could be improved to provide more accurate results. The fact that the questionnaire was written in English and that 10 of the 18 participants were not native English speakers could call into question the validity and reliability of the results because they may not have understood the terminology in the system usability scale used in the questionnaire (Finstad, 2006). To reduce the possibility of future misinterpretation of the questions, the participation of native English speakers could be required, or an attempt could be made to replace big words that participants may not understand with much simpler words.

The tendency to change one's actions or thought process subconsciously in response to someone else's comments or behaviour is known as cognitive bias (Natesan et al., 2016). The accuracy of the usability test results could be improved. This could include adding tasks that are "unhappy paths" in an attempt to understand how the system could be broken or determining how to guide a user when an error occurs. These enhancements may contribute to the tool's overall usability.

Appendices

Appendix 1: Verbal Information Provided to Participants Prior To Signing the Consent Form

Abbreviations will be used in this document, but all abbreviations will be read out in full when reading the information to the participant.

Good morning [Participant Name].

I am Moreblessing Ngwenya, and I am conducting research required for the completion of my Master's through Nelson Mandela University (NMU). I am researching on Information Visualisation (IV), which I will tell you more about in the following sections, and its usefulness in assisting users to better understand their energy usage and make better-informed decisions on saving energy in smart environments (SE).

I am going to give you information and invite you to be part of the research that I am conducting. You do not have to decide today whether you wish to be a participant in the research. Before you decide, you can talk to anyone you feel comfortable with about the research. There may be some words that you do not understand. Please ask me to stop as we go through the information, and I will take time to explain. If you have questions later, you can ask them of me.

Your participation in this research is entirely voluntary. It is your choice whether to participate or not. Whether you choose to participate or not, all the services you receive at NMU will continue and nothing will change. You may change your mind later and stop participating even if you agreed earlier. Should you wish to withdraw from the research, you are able to do so, and all your collected data will be deleted.

There may not be any personal benefit for you, but your participation is likely to help me find the answer to my main research question. There may not be any benefit to society at this stage of the research, but future users are likely to benefit.

The information that I collect from this research project will be kept confidential. Information about you that will be collected during the research will be stored and no-one, but the researchers will be able to see it. Any information about you will have a number on it instead of your name. Only the PI will know what your number is. It will not be shared with or given to anyone.

The knowledge that I get from doing this research will be shared with you upon completion of the study. Confidential information will not be shared. After the study has been completed, the results will be published for other interested people to learn from the research. Again, no personal information or information that could possibly lead to your identification will be shared in the published document.

You do not have to take part in this research if you do not wish to do so. You may also stop participating in the research at any time you choose. It is your choice, and all your rights will still be respected.

If you have any questions, you may ask them now or later, even after the study has started. If you wish to ask questions later, you will be provided with a list of individuals that you can contact.

Do you have any questions?

Appendix 2: Written Information Given to Participant Prior To Signing the Consent Form

Information Sheet

1.1. Introduction

I am Moreblessing Ngwenya, conducting my research through the tertiary institution, Nelson Mandela University. I am researching on Information Visualisation (IV) and its effectiveness in communicating energy usage information in smart environments to its occupants. I am going to give you, the potential participant, information and invite you to be part of this research.

1.2. Purpose of the research

Current systems visualising energy usage in smart environments do not enable users to interact with the system, thus enabling them to analyse their energy usage and increase the user engagement with the system for longer periods.

Visualisation plays a critical role in communicating information to the user, and this can be achieved through the use of pictures (Al-Kassab et al., 2014). The main benefit of visualisation is the sheer amount of information that can be quickly understood if presented well (Ware, 2019).
The purpose of this research is to investigate the effectiveness of the Information Visualisation (IV) tool to support smart environment occupants, in saving energy by visualising information on their environment's energy usage. The IV tool aims to make use of multiple visualisation techniques to communicate the energy usage, and allowing for analysing the information, which includes comparing energy usage between devices and dates. This will provide users with more information and subsequently make better-informed decisions on saving energy.

1.3. Type of Research Intervention
This research will include the use of the Tobii Pro Nano eye tracker. Participants are asked a series of questions of known points on the eye-tracking system; this is used to calibrate the eye tracker before the study begins. The next step is to give the participants a list of tasks to carry out and complete on the developed IV tool. After completion of tasks, the participants will be asked to complete a post-study questionnaire (Appendix 5).

1.4. Participant selection

For this research, we will be inviting individuals with either experience, interest, and those knowledgeable in visualisation and/or smart environments (Final year, Honours Computing Science students and staff).

1.5. Voluntary Participation

Participation in this research is entirely voluntary. It is the participant's choice whether to participate or not. If they choose not to participate in this research project, they will be offered the treatment that is routinely offered in the institute that they were selected from. Participants may change their mind later and stop participating, even if they agreed earlier.

1.6. Procedures and Protocol

Participants will be given a list of tasks to carry out. Once the participants are done with the tasks, they will be asked to complete a questionnaire. The questionnaire will have questions about how useful the system is, the quality of the information provided, the participant's overall satisfaction with the system, as well biographical details of the participants.

1.7 Device Loans

The usability test will be always conducted with the PI present, and the use of the Tobii Pro Nano eye tracker and or any damages that occur are the responsibility of the PI.

1.8. Duration

The research will take place over one month.

1.9. Risks

There will be no added risk introduced in using the Tobii Pro Nano eye tracker.

1.10. Benefits

There may not be any personal benefit for participants, but participation is likely to help the PI find the answer to her main research question. There may not be any benefit to society at this stage of the research, but future generations are likely to benefit.

1.11. Reimbursements

Participation is free. No monetary or other imbursements will be given for participation.

1.12. Confidentiality

The identity of those participating in the research will not be shared. The information that the PI collects from this research project will be kept confidential. Information about participants that will be collected during the research will be stored and no-one, only the researchers will be able to see it. Any information about participants will have a number on it instead of names. Only the PI will know what the participant numbers are. This information will not be shared with or given to anyone.

1.13. Sharing the Results

The knowledge that is obtained by doing this research will be shared with participants upon completion of the study. Confidential information will not be shared. After the study has been completed, the results will be published for other interested people to learn from the research. Again, no personal information or information that could plausibly lead to participant identification will be shared in the published document.

1.14. Refuse or Withdraw

Participants do not have to take part in this research if they do not wish to do so. They may also stop participating in the research at any time they choose, upon withdrawal all recorded participant data will be deleted.

1.15. Alternatives to Participating

If participants do not wish to take part in the research, they will be provided with the established standard treatment available at the centre/institute from which they were selected.

1.16. Who to Contact?

If participants have any questions, they may ask them at any point before or during the research study has taken place of the following individuals:
Miss Moreblessing Ngwenya e-mail: s215169611@mandela.ac.za
Prof. Janet Wesson e-mail: janet.wesson@mandela.ac.za

This proposal has been reviewed and approved by the Nelson Mandela University Research Ethics Committee - Human (REC-H), which is a committee whose task it is to make sure that research participants are protected from harm. If participants wish to find about more about the REC-H, they can freely view the information publicly available at:

http://rcd.mandela.ac.za/Research-Ethics/Research-Ethics-Committee-Human-(REC-H)

Appendix 3: Informed Consent Form

Appendix 1 will be read aloud to the participant, and they will be provided with a copy of Appendix 2.

The Informed Consent Form is for the men and women who will be taking part in the usability testing using the Tobii Pro Nano eye tracker. The usability testing will be carried out on the Information Visualisation (IV) tool that will be used to assist in communicating the energy usage in the smart environment.

The title of the research project is: *"Interactive Visualisation of Energy usage in Smart Environments".*

Name of Principal Investigator: Moreblessing Ngwenya
Name of Research Institute: Nelson Mandela University

This Informed Consent Form has two parts:
• Information Sheet (to share information about the research with you, the potential participant) (Appendix 1 and 2)
• Certificate of Consent (for signatures if you agree to take part in the study)

You will be given a copy of the full Informed Consent Form.

Statement by the participant:

I have read the foregoing information (Provided in Appendix 1 and 2), or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked, have been answered to my satisfaction. I consent voluntarily to participate as a participant in this research.

Print Name of Participant____

Signature of Participant
____

Date _____________________________ (day/month/year)

Statement by the PI:

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands that the following will be done:
1. They will be part of the study for a length of one month.
2. They will be required to make use of a desktop application of the IV tool.
3. They will be required to evaluate the usefulness of the developed IV tool.

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly, and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily. A copy of this consent form has been provided to the participant.

Print Name of Researcher/person taking the consent______________________________________

Signature of Researcher /person taking the consent_______________________________________

Date ____________________________ (day/month/year)

Appendix 4: Covid-19 Protocols for Access to Computing Sciences Labs

The following Computing Sciences department Covid-19 regulations for using the labs need to be adhered to for the health and safety of all our participants, principal investigators and any other individuals involved in the study:

1. To make use of the labs in the Computing Sciences labs, a booking needs to be made to *Hayley.irvine@mandela.ac.za* and approved at least one day before the intended use.
2. Mask up - Students who do not always wear their masks while in the lab will be removed from the labs and could be banned from using the lab in the future.
3. Hand sanitising - please sanitize your hands on your way in
4. Social distancing - social distancing protocols will be adhered to during the study i.e., 1.5m to 2m between individuals always or else one could be removed from the labs.
5. Feeling sick: If you are unwell stay at home, and if you have trouble breathing seek medical attention.
6. Please ensure that you follow good cough hygiene, sneeze, or cough into a bent elbow or into a tissue, which you should immediately dispose of and then wash or sanitize your hands.
7. Per COVID regulations, please notify the principal investigator if you test positive at any time for COVID, as we will need to do contact tracing if this is the case.
8. Equipment used by participants will be cleaned after each participant's test.
9. To limit the number of people in a room at a time, we will conduct study with one participant at a time.

Appendix 5: Post Study Usability Questionnaire

Section A – Biographical Information

Please answer the following biographical questions.

(Please tick appropriate responses)

Participant Number:	**(For official use only)**
Age:	O 18 - 24 O 25 - 29 O 30 – 34 O 35 – 39 O 40 – 44 O 45 – 49 O Above 50
Gender:	M: ☐ F: ☐ Other: ☐ ________ Rather not say: ☐
Home Language (1st Language):	English: ☐ Xhosa: ☐ Afrikaans: ☐ Other: ☐
Staff or Student?	Staff: ☐ Student: ☐ Both: ☐

d

Section B – Usability Questions

Please answer the following questions by **circling** the appropriate number as honestly as possible and add comments under the question if applicable.

1. Overall, I am satisfied with how easy it is to use this system.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

2. It was simple to use this system.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

3. I could effectively complete the tasks and scenarios using this system.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

4. I was able to complete the tasks and scenarios quickly using this system.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

5. I was able to efficiently complete the tasks and scenarios using this system.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

6. I felt comfortable using this system.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

7. It was easy to learn to use this system.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

8. I believe I could become productive quickly using this system.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

9. The IV tool gave error messages that clearly told me how to fix problems.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

10. Whenever I made a mistake using the system, I could recover easily and quickly.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

11. The information (such as on-line help, on-screen messages and other documentation) provided by IV tool was clear.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

12. It was easy to find the information I needed.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

13. The information provided by IV tool was easy to understand.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

14. The information was effective in helping me complete the tasks and scenarios.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

15. The organization of information on the IV tool screens were clear.

STRONGLY DISAGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

16. The interface of IV tool was pleasant.

STRONGLY AGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS

17. I liked using the interface of this system.

STRONGLY AGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

18. IV tool has all the functions and capabilities I expect it to have.

STRONGLY AGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

19. Overall, I am satisfied with this IV tool.

STRONGLY AGREE 1 2 3 4 5 6 7 **STRONGLY AGREE**

COMMENTS:

Section C – Open Ended Questions

1. **What did you think about the Electricity Visualisation Dashboard for the Smart Lab v1.0 (EVDSL)?**

2. **How would you describe your overall experience using the EVDSL?**

3. **Rate the layout of the EVDSL on a scale of 1-10 (With 1 being very poor and 10 being Excellent)**

4. **Rate the clarity of the navigation on the EVDSL on a scale of 1-10 (With 1 being very poor and 10 being Excellent)**

5. **What are the problems you have experienced using the EVDSL?**

6. If you could change one thing on the EVDSL, what would it be?

Thank you for your participation

Appendix 6: Research Ethics Committee-Human (REC-H) Approval Letter

NELSON MANDELA

UNIVERSITY

PO Box 77000, Nelson Mandela University, Port Elizabeth, 6031, South Africa mandela.ac.za

Chairperson: Research Ethics Committee (Human)
Tel: +27 (0)41 504 2347
sharlene.govender@mandela.ac.za

NHREC registration nr: REC-042508-025

Ref: [H21-SCI-CSS-003] / Approval]

14 September 2021

Prof J Wesson
Faculty: Science

Dear Prof Wesson

INTERACTIVE VISUALIZATION OF ENERGY USE IN A SMART ENVIRONMENT

PRP: Prof J Wesson
PI: Ms M Ngwenya

Your above-entitled application served at the Research Ethics Committee (Human) (*29 June 2021*) for approval. The study is classified as a medium risk study. The ethics clearance reference number is **H21-SCI-CSS-003** and approval is subject to the following conditions:

1. The immediate completion and return of the attached acknowledgement to Imtiaz.Khan@mandela.ac.za, the date of receipt of such returned acknowledgement determining the final date of approval for the study where after data collection may commence.
2. Approval for data collection is for 1 calendar year from date of receipt of above mentioned acknowledgement.
3. The submission of an annual progress report by the PRP on the data collection activities of the study (form RECH-004 available on Research Ethics Committee (Human) portal) by 15 November this year for studies approved/extended in the period October of the previous year up to and including September of this year, or 15 November next year for studies approved/extended after September this year.
4. In the event of a requirement to extend the period of data collection (i.e. for a period in excess of 1 calendar year from date of approval), completion of an extension request is required (form RECH-005 available on Research Ethics Committee (Human) portal).
5. In the event of any changes made to the study (excluding extension of the study), RECH will have to approve such amendments and completion of an amendments form is required PRIOR to implementation (form RECH-006 available on Research Ethics Committee (Human) portal).
6. Immediate submission (and possible discontinuation of the study in the case of serious events) of the relevant report to RECH (form RECH-007 available on Research Ethics Committee (Human) portal) in the event of any unanticipated problems, serious incidents or adverse events observed during the course of the study.
7. Immediate submission of a Study Termination Report to RECH (form RECH-008 available on Research Ethics Committee (Human) portal) upon expected or unexpected closure/termination of study.
8. Immediate submission of a Study Exception Report of RECH (form RECH-009 available on Research Ethics Committee (Human) portal) in the event of any study deviations, violations and/or exceptions.
9. Acknowledgement that the study could be subjected to passive and/or active monitoring without prior notice at the discretion of Research Ethics Committee (Human).

Please quote the ethics clearance reference number in all correspondence and enquiries related to the study. For speedy processing of email queries (to be directed to Imtiaz.Khan@mandela.ac.za), it is recommended that the ethics clearance reference number together with an indication of the query appear in the subject line of the email.

We wish you well with the study.

Yours sincerely

Dr S Govender
Chairperson: Research Ethics Committee (Human)

Cc: Department of Research Development
Faculty Administration: Science

/uspies

Appendix 1: Acknowledgement of conditions for ethical approval

Appendix 7: Usability Test Tasks

Please perform the following tasks:

1. **Start eye calibration and follow-on screen instructions**
2. **Wait for researcher to check calibration results, if calibration results are acceptable participant may proceed to next task, else recalibrate**
3. **Complete the tasks in the table on the following page and record the answer in the answer column**

	TASK	ANSWER
1	Record the current electricity usage of all devices for the **current month**	
2	Record the **current** electricity usage of all devices for the **current day**	
3	Record the **current** electricity usage for the **intel nuc** for **current week**	
4	Record the **current total** electricity usage for the fridge for **current month**	
5	Using the vertical menu **click on** the **Category** option then click on the **Other** option and record the device with the **highest** electricity usage	
6	Compare the electricity usage between the **intel nuc** and the **Wi-Fi router** for the **current week** and record which total current usage is **higher?**	
7	Using the vertical menu **click on** the Compare menu option and then click on compare option and compare the electricity usage between the **kitchen** and the **lounge** for the current **month** and record which total current usage is **lower?**	
8	Which device has the **highest** electricity usage for the current **day**?	
9	Which category has the **lowest** electricity usage for current **year**?	
10	Set Target **weekly** usage for the Kitchen category to **5000kWh**	
11	Record the **current** electricity usage of all devices for the **current day**	
12	Using the vertical menu, click on the Category option then click on the **Kitchen** category option, select **week** view, and record the progress (in percentage) of the current usage to reaching the target usage previously set	
13	Set Target **daily** usage for all devices to **10000kWh**	
14	Using the vertical menu, click on the Home option then record the **daily** progress (in percentage) of the current usage to reaching the target usage previously set for all devices	

4. **Press F10 when done with ALL the tasks**
5. **Complete the Post Study Usability Questionnaire provided**

THANK YOU FOR YOUR PARTICIPATION!

Moreblessing Ngwenya

Appendix 8: First Iteration of Development Activity

The outcomes from the first development iteration are shown in figures 7.1 to 7.5. Note that "period" here refers to a day, a week, a month, or a year.

Figure 7.1 depicts the initial iteration's home page screen, which had the following information:

- Top Left: displays the total electricity usage of all devices for the selected period.
- Top Centre: displays the changes in electricity usage of all devices for the selected period and0 previous period such as current day and previous day.
- Top Right: displays the electricity usage in real time, showing current reading for each minute.
- Bottom Left: displays the total electricity for each category namely kitchen, lounge, study and other, for the selected period
- Bottom Centre: displays a table of all devices connected, the category the device is in, the total usage in kWh, the highest reading for that device and the average usage in kWh, for the selected period.
- Bottom Right: at the top shows the target electricity usage set relative to the current total electricity usage recorded for the selected period in percentage. The bottom shows the device with the highest electricity usage.

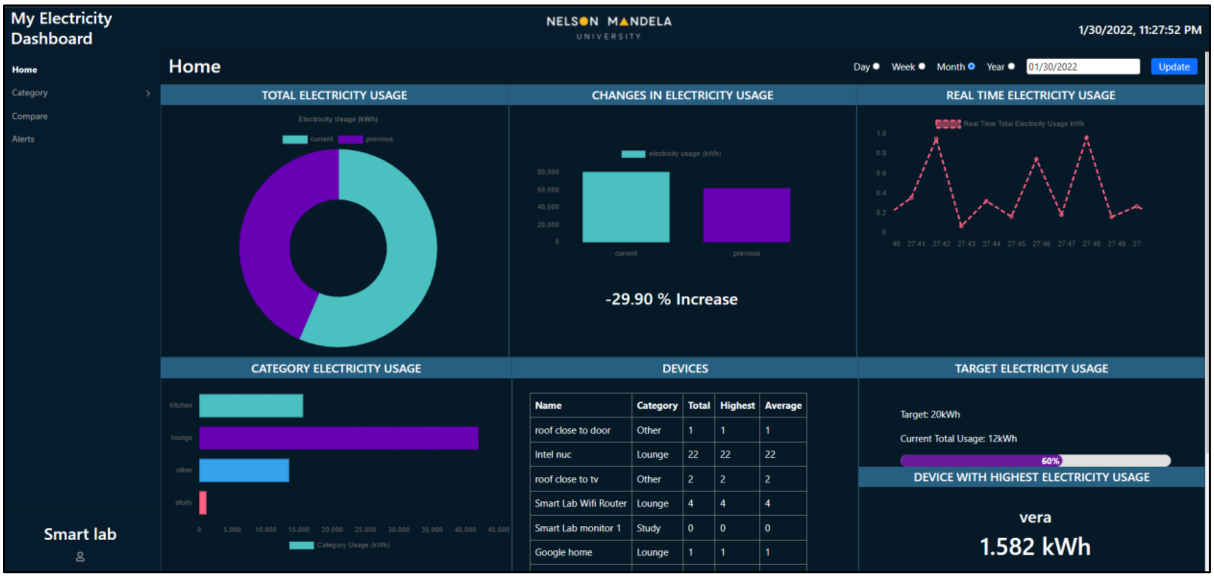


Figure 7.1: First iteration home page screen

It's vital to note that the screen design for the kitchen category screen is the same as the other category screen pages, as shown in Figure 7.2, which represents the screen designed in the first iteration:

- Top Left: displays the total electricity usage of all devices in the kitchen category for the selected period.
- Top Centre: displays the device with the highest electricity usage in the kitchen category
- Top Right: displays the target electricity usage set relative to the current total electricity usage recorded for the selected period in percentage
- Bottom Row: displays the real time electricity usage for the devices in the kitchen

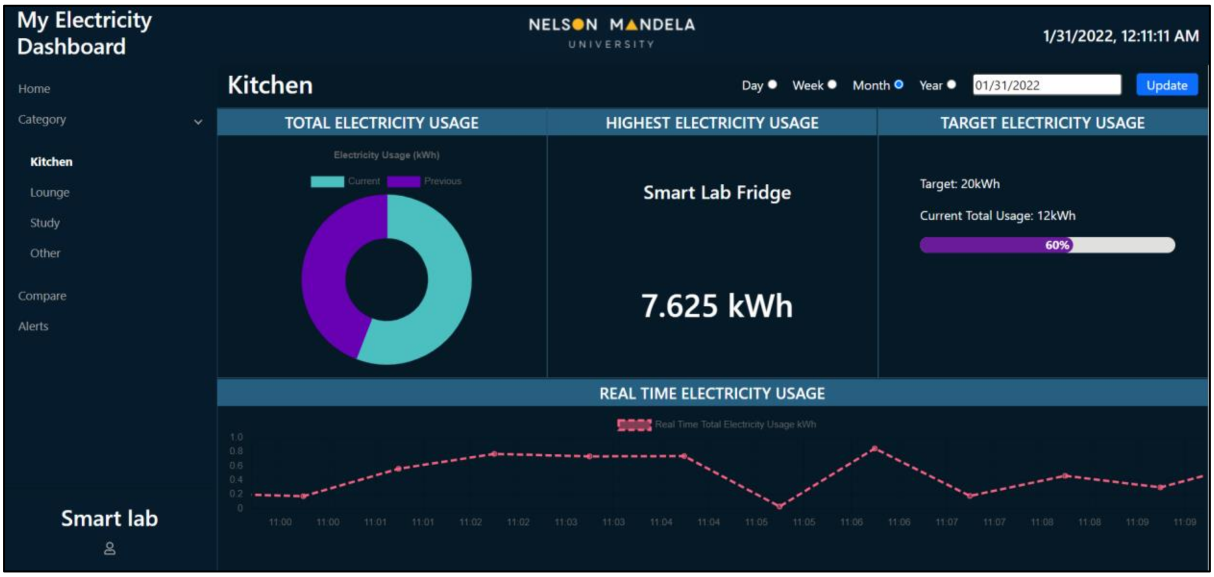


Figure 7.2: First iteration kitchen category page screen

Figure 7.3 shows the device screen developed in the first iteration:

- Top Left: displays the total electricity usage for the selected device for the selected period.
- Top Centre: displays the highest electricity usage reading and time of highest electricity usage reading for the device.
- Top Right: displays the target electricity usage set relative to the current total electricity usage recorded for the selected device and period in percentage
- Bottom Row: displays the real time electricity usage for selected device

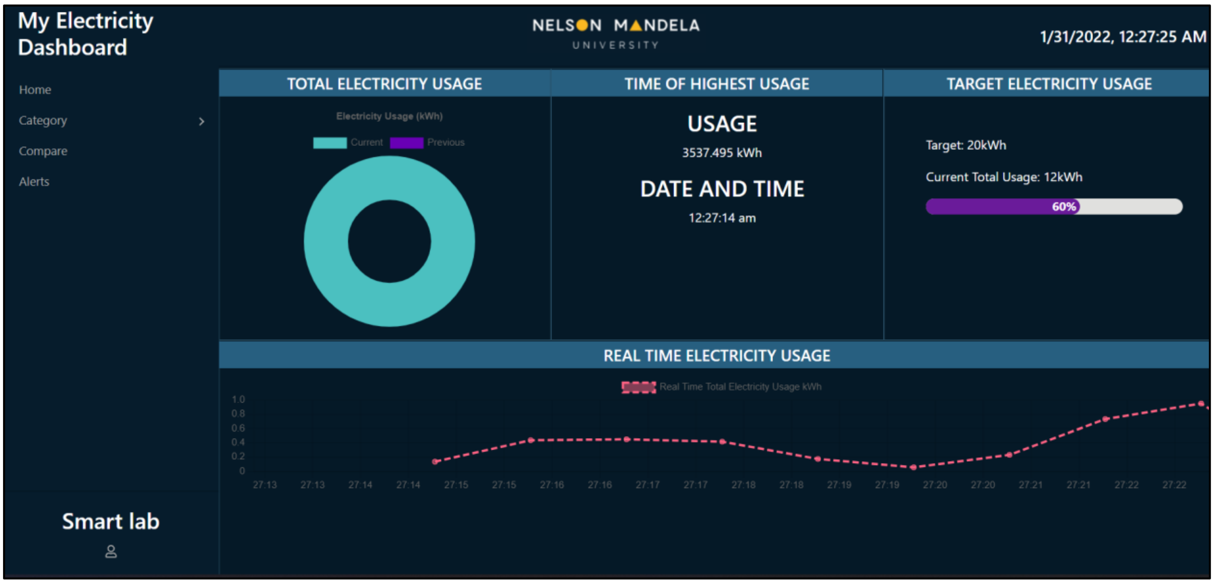


Figure 7.3: First iteration device page screen

Figure 7.4 shows the compare page screen of two devices developed in the first iteration: The option to choose the category or device to compare is on the top row. After choosing the option to compare two devices or two categories, the following is shown when you click the compare button:

- Top Left: displays the total electricity usage for the selected devices in comparison
    - Top Centre: displays the maximum electricity usage for both devices.
    - Top Right: displays the highest reading recorded for both devices
    - Bottom Row: displays the real time electricity usage for both devices

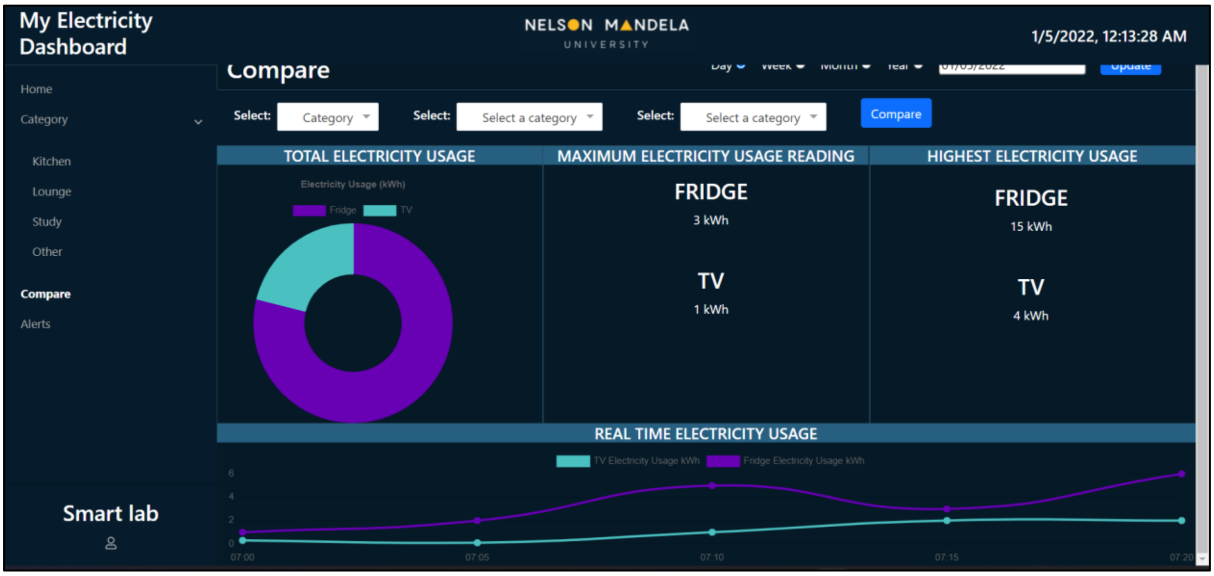


Figure 7.4: First iteration compare page screen

Figure 7.5 shows the alerts page screen developed in the first iteration. The alerts page displayed a table showing the current usage and the target usage set for a specific period. There is also a section which allowed users to set targets for the different periods.

Figure 7.5: First iteration alerts page screen

Appendix 9: Usability Test Results

Table 9-1: Task success/failure for all participants

Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Success rate**	**Errors**
P1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100 %	0
P2	1	1	1	1	1	1	0	1	1	1	1	1	0	1	85.71 %	2
P3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100 %	0
P4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100 %	0
P5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100 %	0
P6	1	1	1	1	1	1	0	1	1	1	1	1	1	1	92.85 %	1
P7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100 %	0
P8	1	1	1	1	1	1	1	1	1	0	1	0	1	1	85.71 %	2
P9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100 %	0

P10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100 %	0
P11	1	1	1	1	1	1	0	1	1	1	1	1	1	1	92.85 %	1
P12	1	1	1	1	1	1	1	1	1	1	1	1	0	0	85.71 %	2
P13	1	1	1	1	1	1	0	1	0	0	1	0	0	0	50 %	7
P14	1	1	1	1	1	1	1	1	1	1	0	1	1	1	92.85 %	1
P15	1	1	1	1	1	1	1	1	1	0	1	0	1	1	85.71 %	2
P16	1	1	1	1	1	1	1	1	1	1	0	1	1	1	92.85 %	1
P17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100 %	0
P18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	100 %	0
Average	100 %	100 %	100 %	100 %	100 %	100 %	77.77 %	100 %	94.44 %	83.33 %	88.88 %	83.33 %	83.33 %	88.88 %		

SMART LAB ELECTRICITY USAGE DASHBOARD DESIGNS

Abstract

Saving energy is a trending topic due to the energy challenges that are being faced globally. Smart environments (SE) are environments that are equipped with physical objects which include computers, sensors, actuators, smartphones, and wearable devices interconnected together through the Internet of Things (IoT). IoT provides a network to achieve communication and computation abilities to provide individuals with smart services in a ubiquitous manner. Rapid developments in information technology, which subsequently increases the number of gadgets and appliances being used leading to greater reliance on electrical resources. Furthermore, devices and appliances in SE can have a standby functionality, where if the device is not in use, they continue to use electricity, waiting for a command from the user such as remotely switching on a television. The issue is how to reduce consumption of energy to save electricity, through effective communication of their energy usage. In this research, we design a dashboard that aims to use visualisation several visualisation techniques to effectively communicate energy consumption to the user. Knowledge of their energy consumption can lead to actions that reduce energy usage and make better decisions on their consumption.

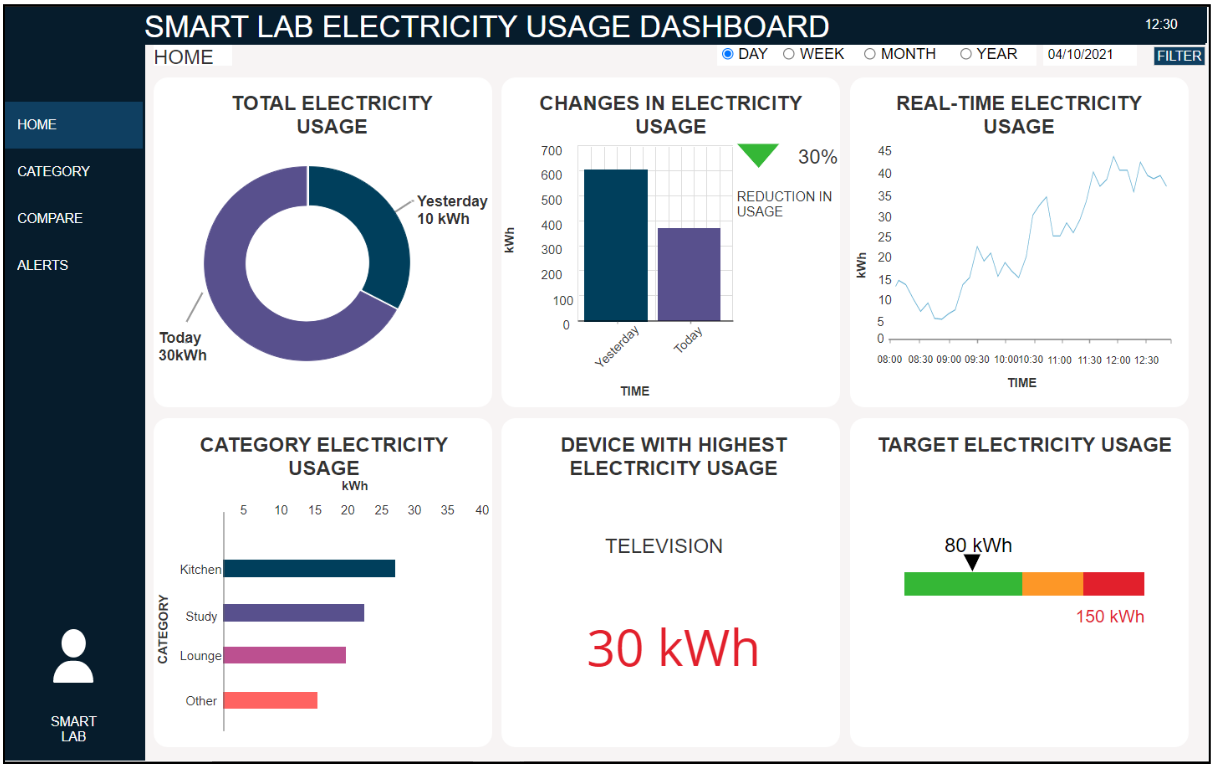
Instructions:

NB: Take note all values and dates used in the designs are fictitious.

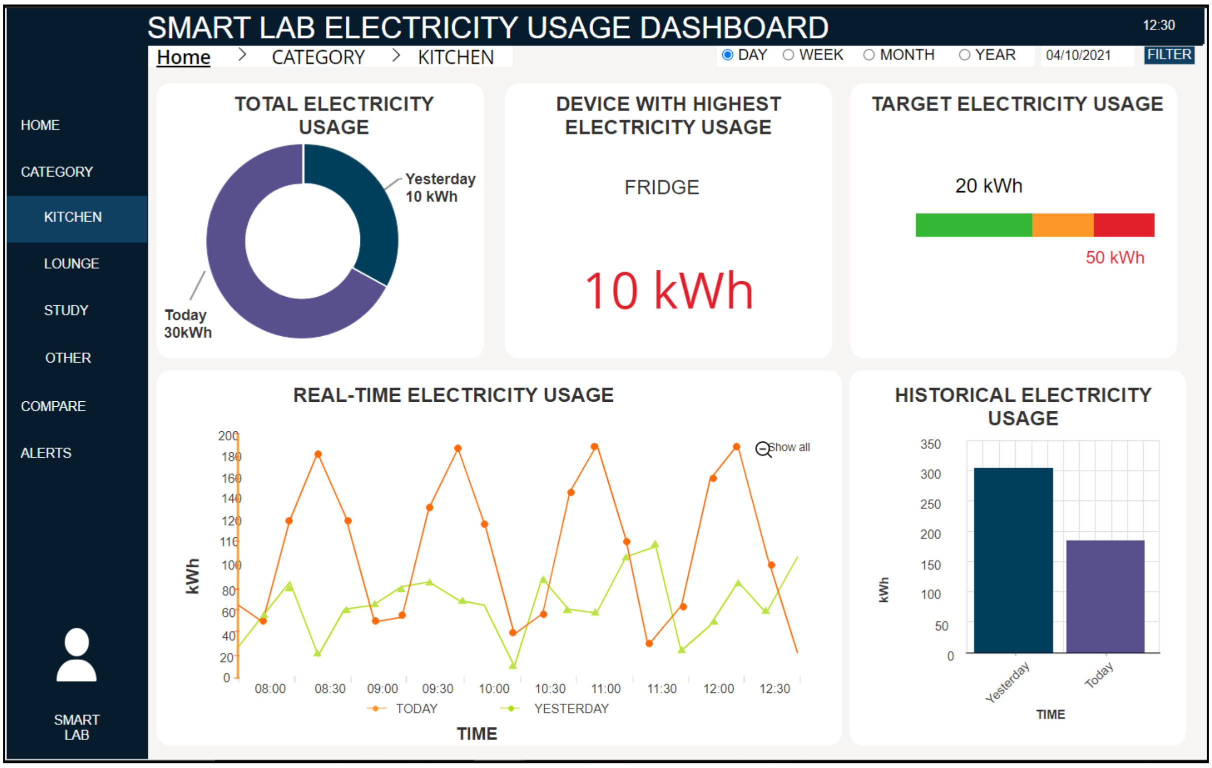
1. **Please go through the designs of the various screens available.**
2. **On completion of evaluation of the designs please complete the questionnaire found on the following link: https://forms.gle/g7n1cN1bwAvK4Zk27**

Thank you!

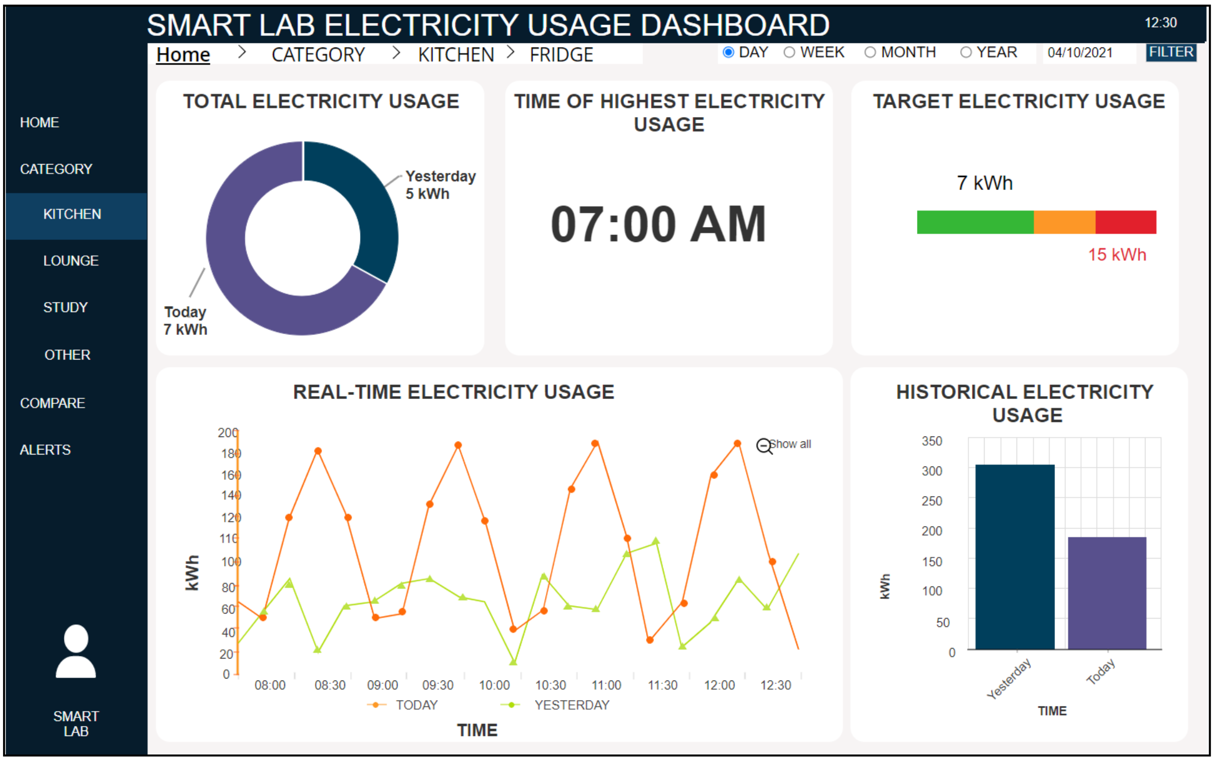
A: Home screen (daily usage view)



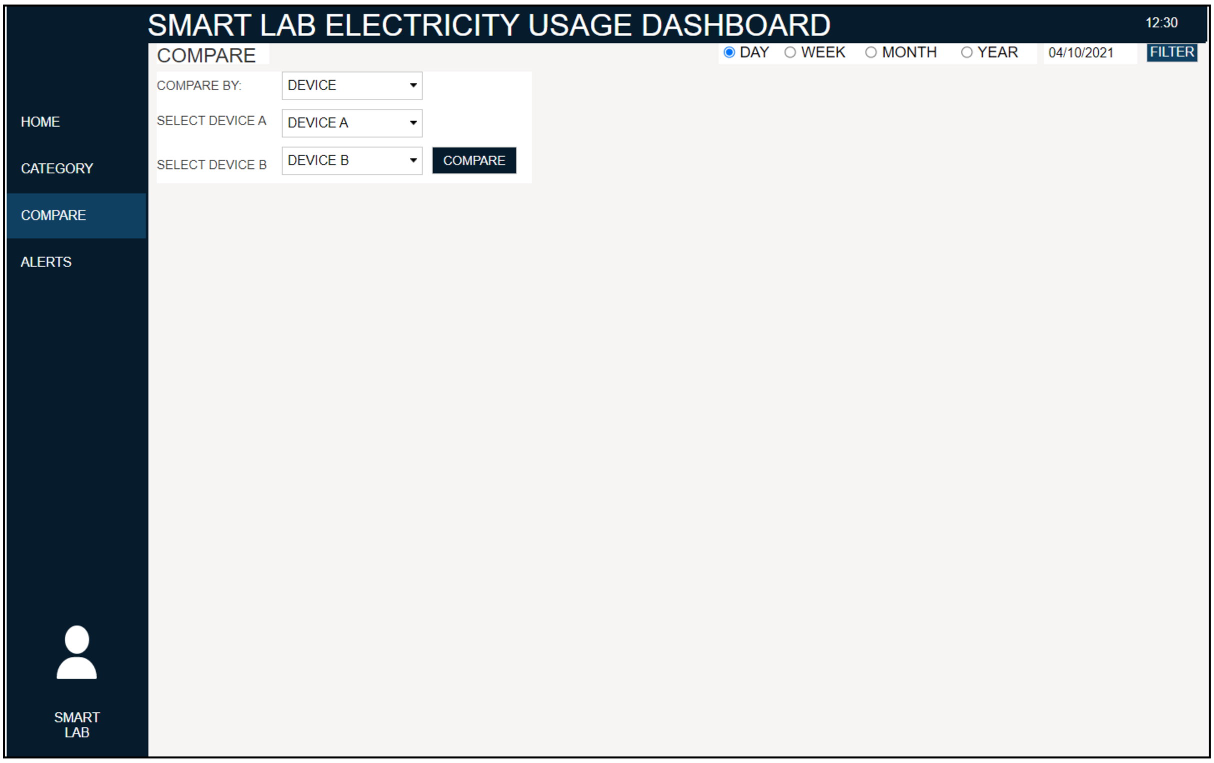
A: Category screen



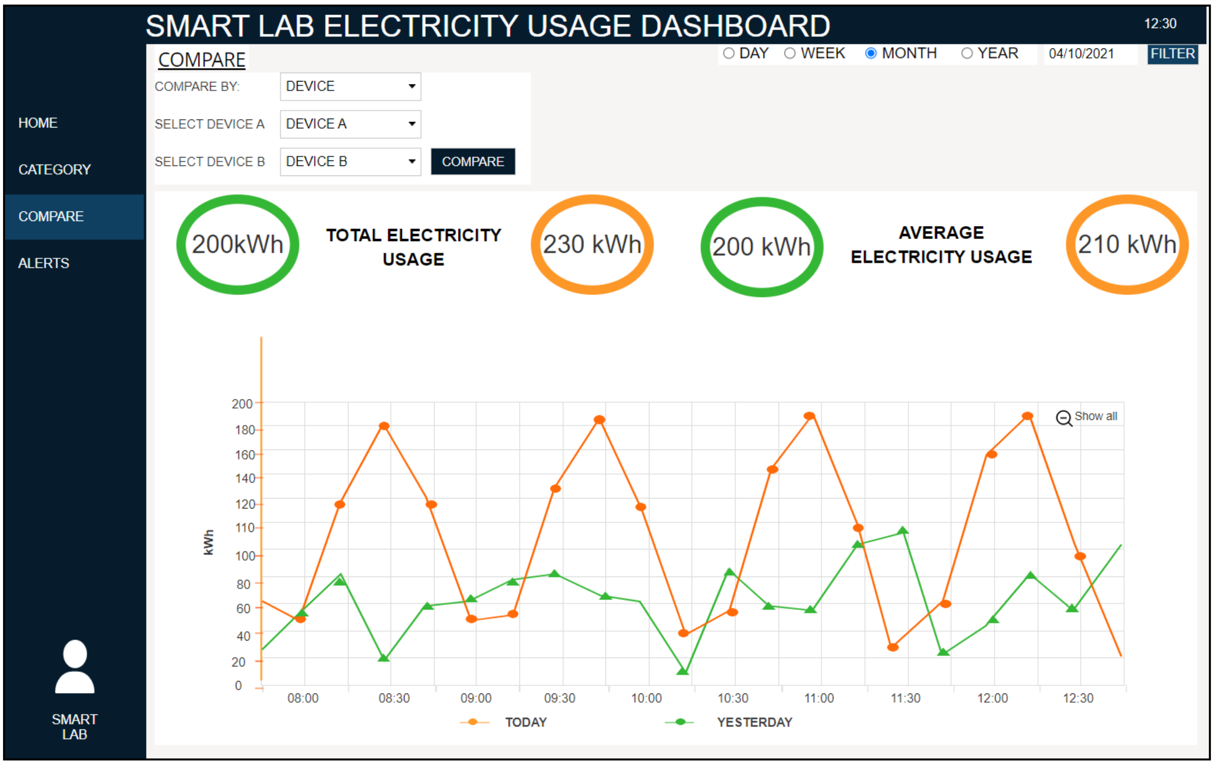
A: Device Screen



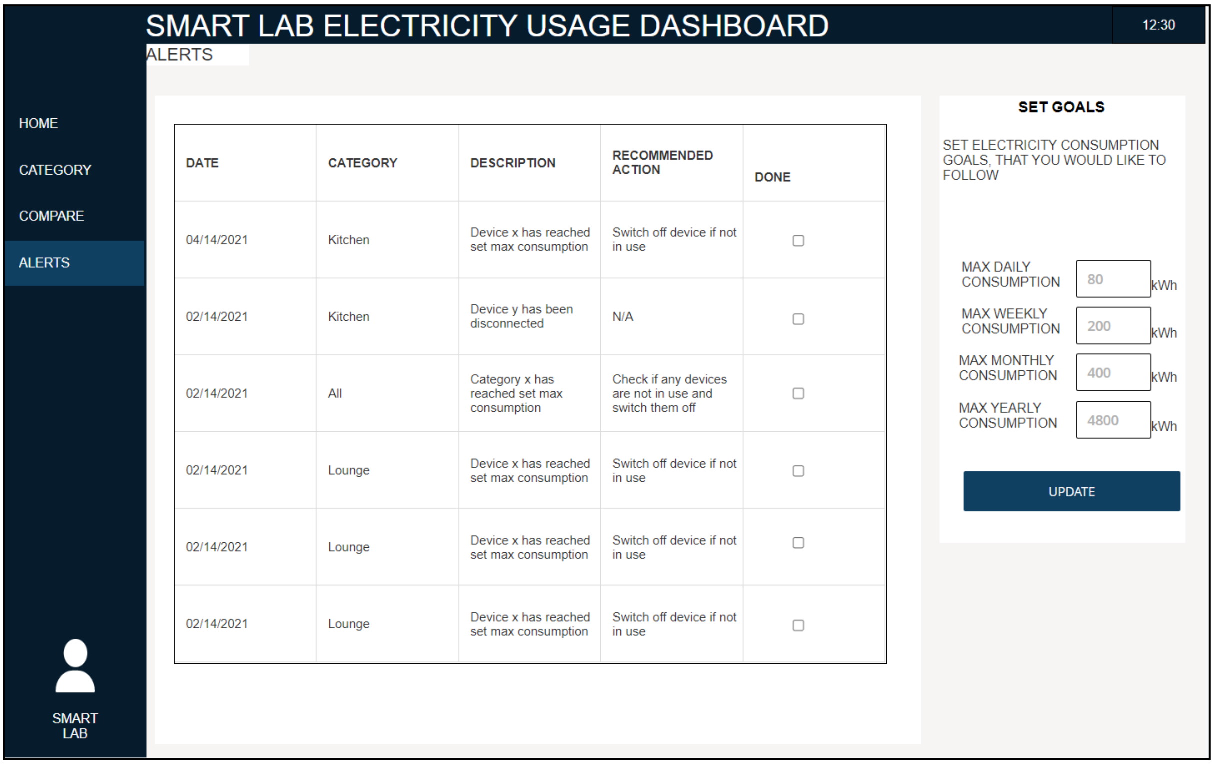
A: Compare Screen (home)



A: Compare screen (device)



A: Alerts Screen



Appendix 10: Similarity Report

Interactive Visualisation of Electricity Usage in Smart Environments

ORIGINALITY REPORT

11%	8%	7%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

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6	www.tandfonline.com Internet Source	<1%
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8	hdl.handle.net Internet Source	<1%
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