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UNIVERSITY

School of Computer Science
College of Physical & Applied Sciences

Data Extraction and Display of Multi-Source Energy Metrics

Connor Hawes

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Supervisor Dr. D. E. Perkins

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> *Peel me off this velcro seat and get me moving,*
> *I sure as hell can't do it by myself*
>
> — **Longview, Green Day**

First of all, I would like to thank Dave for his supervision over this project. Second of all to my Family, Friends and Anita for their kicks of motivation and a constant reminder that 'I can do this'.

Statement of Originality

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Connor Hawes

Abstract

Energy monitoring is an emerging trend in present-day homes. With it becoming a trend in homes the industry is in need of an effective solution that provides the same effects. With larger companies, however, comes the possibility of large multi-building sites or of multi-site enterprises. This presents a problem in that providing this monitoring service to multiple buildings is challenging without additional hardware which can become expensive and difficult to set up. This dissertation explores the methods to solve this problem and details the development of a multiple input system that outputs data simulating visual cues.

Energy monitors have been implemented in buildings and commercially used since 1888. These monitors have recently started to be integrated with electrical monitoring systems and smart systems. The goal of this project is to create a simple to use energy monitoring system that positively effects the energy usage behaviour of a company based on the presentation of visual cues.

The resultant product is a system that takes two inputs (one SERIAL the other web-based XML) and processes them, later being displayed in a way that suggests positive and negative results in order to induce behavioural change.

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Chapter 1

Introduction

1.1 Aim

This projects aim is to create an application that takes data from multiple sources and to display these in multiple ways. The multiple sources are built with the intention to demonstrate the ability to access energy usage data from any possible source and display it within a single centralized system. The application will be interactive with the ability to see the data from each individual source and will also provide multiple graph types to allow the user to decide. On the implementation of this product into an organization, the end goal is for the energy usage behaviour of the multi-site establishment to change to a less wasteful usage level.

1.2 Objectives

- To achieve a system that takes multiple different inputs and processes them to work on a single formatted output.

- To use data display techniques in order to alter the energy usage behaviour of an establishment.

- To create a system that is easy to use and simple to set up.

1.3 Hypothesis

A multi-site establishment using this application will be able to see inputs from any of their sites by choosing different settings. An improvement in the energy usage behaviour should be observed at establishments that use this application over those that don't.

Chapter 2

Background

2.1 Energy Monitors

Energy monitors have been growing in popularity over the last 5 years. The reason for this is that the energy providers are actively encouraging users to see their usage and to change their usage. A reason for the energy providers to do this is that energy usage is "invisible to homeowners ."[6]

Studies suggest that displaying energy use data "can induce changes in customer behaviour."[9] This implies that by having a way to show consumers their energy usage will prove effective in altering their usage hence the need for energy monitors.

An energy monitor is defined by the US patent for a portable electrical energy monitor as "A portable electrical energy monitor for measuring the electrical energy usage of an appliance or the like,"[26] they follow on by adding "A visual display device is connected to the electrical measuring device and is mounted to the enclosure for visual display of electrical energy usage,"[26] The display of this data is currently centralized to one meter however the output of the data to a screen allows for the possibility to output in different ways. There are multiple technologies involved in different currently

2.1.1 Technologies Involved

Loads in Alternating Current (AC) Power

There are two main kinds of loads in AC power when considering energy metering. These loads are calculated using two basic components (Voltage and Resistance), measured in current and are used in calculating the energy usage.

The first of these loads just uses the principle above (Ohm's law) to calculate current draw. This type of load generates a voltage and current waveform similar to the graph below.

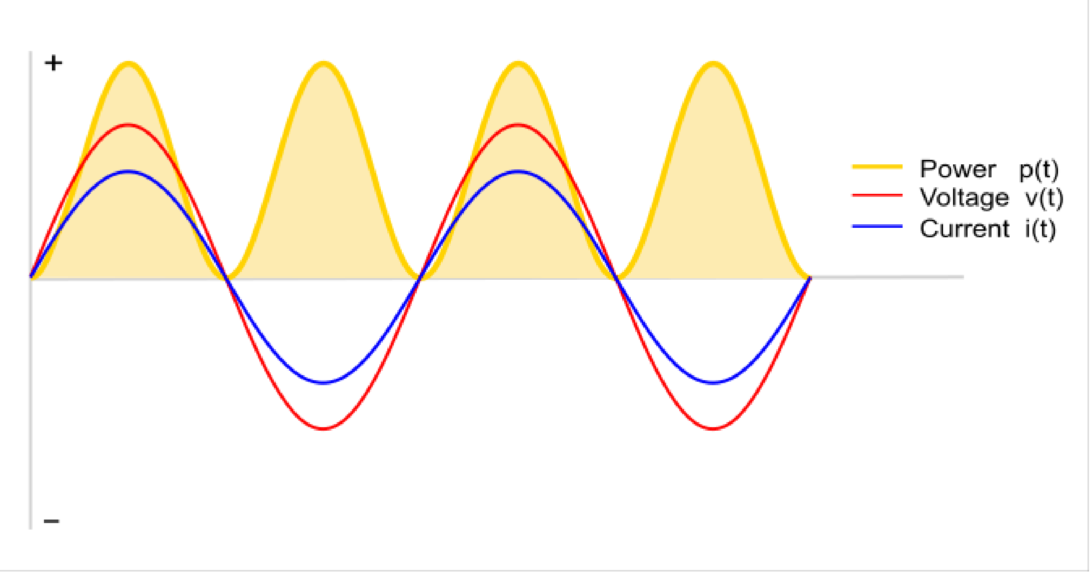

Figure 2.1: Resistive load showing the relationship between voltage and current phases.[13]

Partially reactive loads are the second type. As well as the voltage and resistance appliances using this type of load often release energy back. They have either an inductive or capacitive component. A Partially reactive load generates a voltage and current waveform similar to the graph below.

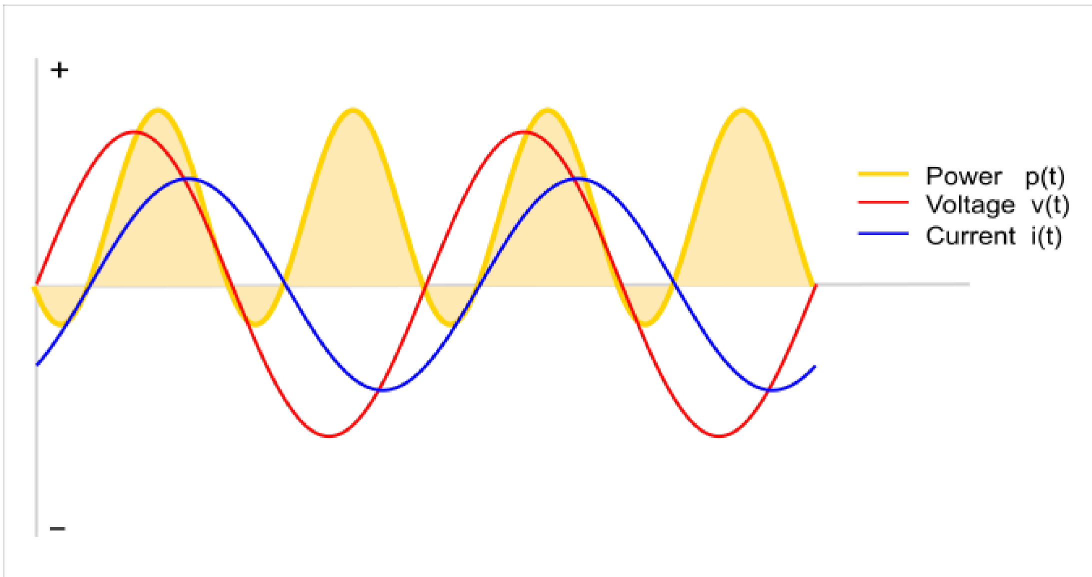

Figure 2.2: Partially reactive load showing the relationship between voltage and current phases.[13]

Three-Phase Power

Three-phase power is a common method of power generation and distribution. It is more efficient and economical than a comparable single-phase solution. [11][10]

Metering

Energy meters are commonplace in buildings due to the benefits they provide to the building owners.

There are multiple laws that regulate the use of metering in a building. The first of these is the Electricity act of 1989, this act governs the use and performance of meters.[7]

Meters accumulate digitally calculated values and produce visual displays. These modules effectively process, calculate and allow for the display of energy data using the technologies mentioned in this section. [17]

Current Transformers (CT)

A CT sensor measures the above-mentioned AC power. Usually, these sensors will be clipped to either the live or neutral wire that comes into the building. [13]

Pulse Counting

"Pulse reading is an easy method for monitoring meters based on the reading of very short duration electrical or optical pulses,"[21] this method is the main method in gaining the data for use in the metering calculations. "In the case of an electricity meter, a pulse output corresponds to a defined amount of energy passing through the meter."[13]

2.1.2 Existing Solutions

Home

Sense Home Energy Monitor

The Sense Home Energy Monitor works by clipping two CT Sensors around the mains in the consumer's house. The monitor emits the data over WiFi to the consumer's smartphone via their IOS or Android App. Over time the device learns the electrical devices in the users home and monitors the energy use smartly. "The Sense home energy monitor listens to devices through current sensors in the [users] electric panel. It records them millions of times per second. Then advanced machine learning detection algorithms work to distinguish one appliance form another."[23]

Curb

Curb connects to the homes breaker box, its sensors monitor energy usage. The consumer can view this information on Curbs app, the app shows usage spending and other information that it calculates from the usage data. "CURB is the home energy monitoring system that helps you take control of your house, condo or apartment and all the energy it uses."[20]

Smappee

Much like the Sense home energy monitor, Smappee identifies the users most used home appliances. Also, like the past two meters the data that Smappee collects is accessible by the consumer’s smartphone. This monitor connects to a smart home using "Smart Home platforms such as MQTT, IFTT, and Stringify."[25] These smart home protocols allow the meter to connect to Amazons Alexa, Google Home, and Siri. The meter works using sensors that clip to the consumer’s fuse box. after the installation the meter allows the user to control appliances remotely. Smappees claim is that this meter grants "more comfort, a better insight and sustainable energy savings up to 30%."[25]

Open Energy Monitor (OEM)

OEM is a more modular system. As with the other systems, the data from the platform is able to be read via smartphone. The OEM system calculates the cost of the power for any timescale. The system also works by attaching CT sensors to the mains power in the consumer’s house. One thing that is unique about OEM is that it is modular, the system allows for multiple sensors to be added. The sensors that this system allows are CT sensors, temperature and humidity sensors. This makes their platform more useful as a whole home monitoring system. "The Open Energy Monitor system can be used as a simple home energy monitoring system for understanding energy consumption."[13]

British Gas Smart Meter

The British Gas smart meter replaces the current in-home meter if the consumer is a British Gas customer. The customer also gets a monitor that displays all of the meter readings via a communication hub. This system is unlike any other in that it is stand-alone and does not work with any Internet of Things (IoT) device such as Alexa or any other metering or monitoring peripherals. "What they [Smart Meters] will give you is near real-time understanding of how much energy they are using allowing you to take control and reduce waste."[24]

Enterprise

Episensor Industrial Internet of Things (IIoT) for Energy Management

The system provided by Episensor is described as an IIoT system. This system, however, does have features aimed at Industrial energy management. They offer a wide range of energy monitoring sensors providing a solution for any enterprises situation. Their system allows for both small and large-scale systems with the offer to "start small and expand easily." As for their solution of displaying data, they have their own online gateway to manage and view the data that the sensors collect. The gateway also supports mobile devices allowing the company to change settings and view data remotely.[14]

SSE Energy Optimisation

SSE's system is a precision energy management system that provides 'Business Energy Intelligence' to an enterprise allowing visualization of energy data and the ability to determine where the company can save energy. As with the above system, SSE provides a system that is primarily web-based meaning that it can be accessed from anywhere at any time. The system uses alerts and notifications to improve its effectiveness in changing the overall behaviour of the company. They claim to be able to "help you to achieve significant reductions in costs." This showing their effectiveness in the current environment.[8]

Schneider Electric Power Monitoring and Control

As with Episensor, this system is an Internet of Things enabled platform. It allows for a modular system to be implemented over small and large businesses. Their system connects to new Schneider energy meters. This is aimed at "Improving the electrical quality and energy use," of a company. [22]

2.1.3 Effects of Existing Solutions

Using energy monitors as a way to induce better behaviour in energy usage is not a new concept. A study from 1989 addresses the fact that "Goal-setting in conjunction with feedback on the degree of goal attainment can assist consumers in monitoring and, thus, reducing or stabilizing their in-home energy use."[28] This principle is continued into present solutions even further than before by introducing these smart energy monitors. A study was conducted in 2010 that addressed whether or not these ’smart meters’ made any difference in the household use of energy. The results gathered from the study showed that the smart meters are effective in changing the behaviour of consumers, the findings state that "When asked whether or not the monitors had influenced their behaviour, all interviewees reported some changes,"[12] This study shows evidence in favour of energy monitors providing positive results in changing the energy usage behaviour of consumers. A second study also provides conclusive evidence of these benefits, this study focuses on the impact of smart metering on energy efficiency. The paper concludes, "This paper gives a comprehensive review on the benefit of smart metering in power network such as energy efficiency improvement,"[29]

2.2 Processing

The language of choice for this project is Processing. The reason for this choice is the use of java in a more prototyping based environment. The intention of using such an environment whilst developing such a prototype product was in order for the prototyping based essence of this project. The libraries provided by the Processing team and community provide useful resources to this project as the development can be focused on the project-specific elements of development rather than parts such as internet connectivity which could prove an issue without a library. The small scale of this project is suited to the less structured language. A language such as Java or C# would provide too much complexity for the scale of the project.

2.3 Database Storage Versus Cloud Storage

This discussion will review the technologies of database storage and Cloud storage and assess which is more suited to this project. The reason for this assessment of the two technologies is to determine between a standard storage throughout time (Databases) and a newer emerging technology (Cloud) to see which bests suits this project and which is most promising for the future of this project. Databases are a standard of application data storage and have been since the mid to late 1990's due to the advent of the internet and the increased investment in online services and businesses.[1] Whereas cloud storage is a comparatively new concept. With 2006 being the earliest most commonly known storage being available with Amazons 'Elastic Compute Cloud'. The cloud as we know it today with publicly accessible storage methods was first seen in 2009 with the release of Google's application system (Google Docs, Drive, etc.) the at least 10-year gap between the first uses of these technologies is one factor to be discussed in the following discussion.[2]

One of the advantages of using a database system over cloud-based storage system is the greater security. The overall benefit of having your data stored remotely on a server is that the security can be as tight as the companies administrators allow. With firewalls and the creation of Demilitarized zones within systems, servers can be incredibly well protected and made unreachable externally. As well as this having their own server to store data ensures the data safety in that the security of the physical server is also up to the company. This comes as a benefit as some data may be confidential and therefore safety is of the utmost importance. The second benefit of database storage is that the uploaded data is always consistent and to a set standard as it must meet the databases requirements in order to be uploaded. The number of incorrect data entries and outlying data is reduced as a result of this. Consistency is critical in the industry as often the data must be precise. This is also true for energy usage metrics, the numbers involved can be very precise and therefore it is crucial that the data is uploaded and processed correctly. The third advantage of database storage is that the data is stored locally along with the servers and therefore in order to access the data on-site the upload and downloads of the data can be incredibly fast dependant on what the company's network speed is like. The system may not need an internet connection in order to be accessed and therefore the system will be fast and reliable regardless of the state of the internet connection. A final advantage of a database system in relation to this project is that if the company already has an existing server on their network or in a better case already has database infrastructure then the setup and maintenance for a new system such as the one proposed in this project will be very simple and relatively cheap. Cost is quite the factor in this project as the solution should be relatively cheap compared to existing solutions, this is in order to provide benefits to consumers over the competitors should this product ever hit the market. The possibility of a cheap set up for most modern companies due to the existing infrastructure is a promising likelihood in the future life-cycle of this project.[3]

On the other hand, there are the advantages of the cloud-based data storage system. The first of which is the usability of these systems. Many of these cloud solutions (such as One Drive) provide Windows and Mac folders. In simple terms this allows users to use the storage between their local storage and the cloud solution. This would allow for any necessity to store the uploads locally for an audit, or for a local backup of the most recent uploads. The reason for this being a benefit to this particular project is that the necessity for audits, backups etc. are all possible due to regulation and inspections therefore having the added ease of the ability to perform these actions is a great advantage. The second advantage of cloud-based storage systems is the state of the accessibility of these systems. With the online availability of this platform, the accessibility is naturally very high. This meaning that in general a system that uses this platform can usually be accessed from anywhere. A very positive point to this advantage is that the system can more easily be displayed on mobile devices and also across sites and also at home. This access anywhere availability is very positive as some enterprises may require off-site accessibility. The third and final benefit of cloud-based storage in this solution is the overall cost of the system is very low. The system requires no expensive hardware and at most only requires a monthly subscription which in the long run is far cheaper than the database solution. The benefit to this is somewhat obvious in that the financial gain from using this energy saving system would be comparatively high compared to the cost of the system.

However, there are negatives to both sides which must also be considered when choosing a storage system for the data of this application. Firstly, the disadvantages of the database system. The first of these is that if the company does not already have an existing server and database system then the hardware and software start-up costs. For a smaller company, these costs could be a necessity due to the lack of existing infrastructure. However, these smaller enterprises also may not wish to set up such an expensive system. A second disadvantage of the database system is that the systems are difficult, and time-consuming to design and set-up. Another negative aimed at the enterprises that do not already have a system in place. The difficulty on the enterprise end of this project is a factor that should be avoided in the long run as if they are purchasing a system they will expect setup which will be costly on the service provider. This negative is significant however it is also rather circumstantial, the majority of larger companies (The kind of companies more likely to run multi-site operations) host their own server and database systems such as ASDA, who create and maintain their own databases.[5] This kind of large-scale enterprise would usually have multiple sites and be a customer for the proposed application. [3]

Cloud-based systems also have their downsides. One such downside is that with the lack of an internet connection the system becomes completely inaccessible as there are no wired solutions for the cloud as it is an internet-based service. For companies that wish for their data to be accessed off-site via mobile or a similar device then lack of signal is a real possibility. A downside to this is that overall the performance versus an in-house database driven system would be lower with much to blame on connection strengths. Another downside to this is that due to signal and connection the overall accessibility is low, the ability to connect where and when the system needs to be connected would be lower than a database system by default. The way that this is decided is that with a database system the assumption is made that the system will only need to be accessed over the company services whether that be online or in-house. The in-house connections will usually always be online unless there is a full infrastructure crash whereas the cloud-based system will only be available anywhere when there is an available internet connection which is not always feasible. A second disadvantage of cloud systems is the security concerns that they can create. With the data being stored in the cloud there are a certain number of security concerns. The first is that if the system is compromised then the companies data will be completely inaccessible and that will be out of their hands. Any security, either the physical security of the drives or the network security of the servers, the companies data would be almost completely out of the companies jurisdiction. This can make the companies feel that their data is not secure and cause worry, this is not ideal for a product aimed at an industrial setting as security is very crucial. The third and final disadvantage of the cloud-based storage system is the fact that in order to access them the company must download the cloud systems software. The overall time-consuming nature of setting up every device and training staff to use the cloud services application is not an optimal situation for the target audience.

To conclude this discussion, the type of data-storage that meets the needs of this project is database storage. The first reason for this is that in the development environment there is a currently existent database infrastructure that provides all the needs of the project. Secondly, the security of this system over the cloud storage is massively superior and more reassuring to any customers. A major benefit of the database system, that ensured that a database system would be used for this project, is that in order for this to be developed for this test purpose the database can be easily designed and constructed due to a knowledge of MySQL and of the system as a whole.

2.4 Other Technologies Considered

2.4.1 Open Energy Monitor (OEM)

OEM was initially proposed as a platform for this entire project. The plan was to write a plugin for the existing system to deal with multiple wireless inputs. It was to be used as a platform to retrieve, process and display the data using its inbuilt functions as well as writing new plugins to process the multiple inputs.

The benefits of using this system are: the already built data process and display modules and easy compatibility with existing meters as these were what the system was already built for. If used, the OEM platform would provide functionality to process and display the data from the start. All that is needed to be written is a plugin that retrieves and aids in the processing of multiple data inputs.

However, the documentation for this system is lacking and in the first few bouts of research the OEM documentation brought up nothing to aid in writing a plugin for the system. The website and archived documentation was a spiders web of information that was all useful for different parts of the project.

Although, it was unusable for the development of the project as the part explaining and aiding with the plugin aspect of the product was buried deep. This documentation was later found however at the start of development it was proven difficult to find and so another solution was thought up and Open Energy Monitor was put to the back bench.

If the documentation was found faster in the life cycle of this project then it would have been assured to be the platform on which this product was developed as the system is very efficient and useful and there are many libraries and plugins that would have made the final product of this project much more enterprise-worthy. However, due to the poor layout of the documentation and lack of ease in navigation, the OEM platform is left unused in this project.

2.4.2 CPU Temperature monitoring

One proposed input for this project was to have the input from a remote or local CPU. Most computers have the functionality to measure the CPU temperature so to have this used or transmitted to the product seems that it would be an appropriate input to the system. CPU temperatures are easy to take and transmit from a system so this input addition would have been appropriate to the final product.

The benefits of this input are that it is easy to implement and that the data that would be transmitted is similar to that of energy data which means that as a transmittable input it is very appropriate to the scope of this project. The aforementioned ease of taking the CPU temperature from a system is certainly an attribute of the ease of implementing this feature the second being that to transmit this data only a non-complex system must be written.

However, the ever-shortening timescale of the project and problems with the product early on meant that a couple of features were to be let go in order to benefit the overall functionality of the system on the completion of this project. The timescale meant that in order to have a completed product this feature must be forgotten, the reasoning behind this is that the time that it would take to implement this feature can be used to iron out any existing problems or bugs and then complete the system rather than to potentially add more bugs and problems. With the tightening schedule, the feature became less feasible and had to be let go.

Overall this feature would have been a valuable asset to the project, with the above-mentioned ease of implementation and appropriate nature it proved to be worth adding to the project. However, due to time constraints caused by existing issues and bug, this feature simply became unfeasible.

2.4.3 Raspberry Pi

Following on from proposed inputs, the raspberry pi was initially brought into this project as a method of transmitting multiple inputs to the system in order to simulate the multiple input sources that the product would actually work on if it were to be implemented into a multi-site organization. It would have transmitted simulated power usage data for the main system to intercept and then process and display. Another use for the Pi in this project would be to run Open Energy Monitor (OEM) as the platform of the entire system. However, as stated above OEM became unfeasible so this usage also became obsolete in relation to this project.

The benefits of using this platform as a transmitter for inputs to the system are that as a remote transmitter it could be easily left on to simulate real-time data sources. An addition to this is that the platform could also be used to transmit multiple different sources. This functionality, as well as ease of implementation, makes this platform invaluable to the project as it can be left on to simulate day to day data transmission for use in the project.

The one major downside that ensured this platform left out of the project was that there were far simpler more useful solutions to the problem that required fewer steps and fewer resources but that provided the same outcome. The problem was that although it was very simple as a solution it was still far too complex to fit within the scope and timescale of the project. The use of another hardware resource and with it, more software resources that would need to be written it proved unnecessary effort to use this.

Instead of this a new solution was devised: keep the software but simplify it and have it work behind the scenes in the application. This removed the additional hardware and simplified the software overall, confining the project to one language. The reason that this is preferred over the more complex solution is so that the project would fit into the timescale and so that the complexity didn’t outweigh its worth in terms of its weight in the project. This part of the project was devised as a background part and would never be shown as part of the product so, therefore it was not worth the immense complexity and effort of this solution and instead a better solution was created.

Chapter 3

Design

From the beginning, it became clear that the visual design of this application was incredibly important to the success of the product. The product is to be implemented with the expectation and aim of changing an establishments energy usage behaviour. To achieve this effect the design needs to be heavily considered. The reason for the heavy consideration of this portion of the product is that in order to achieve this change in behaviour the human psychology needs to be studied. This examination will go through multiple areas to determine and finalize the design of this project.

Firstly the type of graph was to be decided, in order to assess this the type of data that the graph was to display needed to be established. In this choice, there were two questions to answer: is the data discrete or continuous? and is the data numerical or categorical? The data used in this project is both continuous and numerical. This meaning that the data produced is raw numbers over time rather than categorical data such as would be seen in a pie chart. A lesson on 'graphs for discrete and continuous data' by Brenda Meery showed that the best graph suited to this kind of data was a bar graph.[19] Other graphs that can be considered in this project are the broken-line graph and the histogram due to their use in the display of numerical data. These graphs will also be taken into mind during the production of the system. To place these into the system as well as the optimal bar chart there will need to be multiple toggled views within the application.

The second consideration was the colour needed to aid the design in producing the correct energy usage behaviour in the customers. To achieve this change, more positive colours are to be used for positive usage on the graph, and more negative colours for the more negative results. The colours associated with more positive data, for example, a lower power usage would be green, a medium usage would be yellow or high would amount to a red output. The reasons for choosing these colours over either the opposite (red for low and green for high) or random colours (i.e. brown for low, blue for high and gold for the middle) is that the appropriate positive and negative colours can be seen to promote positive behaviour changes in people. If people are able to recognize the fact that red is bad and green is good then they will change their behaviour in order to try and make every output green.

One study to back up the previous point suggests this, using smiley or sad faces as the reinforcements rather than colours. The study worked with energy, much like this project. They gave users with above average energy consumption sad faces and people with below average energy consumption smiley faces. Their findings were as follows: "Unsurprisingly, but significantly, the big energy users showed an even larger decrease when they received the unhappy emoticon."[27] These findings match the above paragraph in saying that positive and negative reinforcements have the desired effect or reducing energy usage. In this case, the unhappy face, when shown to big energy users, would significantly reduce the user’s energy usage. Therefore using these positive and negative cues in this project should produce the positive energy behaviour change that this product aims at producing.

Another element of the design was the interaction design, putting together the way that the user would navigate through the system. The aim was to create a simple interface that required only very simple navigation and could easily be set up by someone with minimal training. This aim supervised research into minimalist interface design but also gave the inspiration to look into functional interface design. The first question in this exploration of the interaction design of this product was whether or not there would be any need for navigation through the product. To answer this firstly the function needs to be questioned; what functionality would possibly require navigation? In the above paragraph discussing the graph type it was determined that multiple graphs would be used to find the best for this type of application. These three graphs cannot be placed in the same window without the application looking cramped. Therefore the need for navigation is confirmed. Next, the method of navigation is to be discussed. The choices for this are between buttons that link and buttons that toggle between the different outputs. A discussion about this in modern web apps suggests that the main difference between a link and a button " is that a link navigates the user to a new resource, taking them away from the current context."[18] This suggestion seems to make it clear that the choice for this project should be to use a toggle-able button, such as the radio-button in order to toggle between the different views rather than using links that take open a new window or something similar.

To conclude the above discussions about design choice the final design (See figure 3.1) is to be decided. Firstly the graph. As decided before, the three graphs that best suit the data of this project will be used. These are all used with the intentions of finding the best graph suited to this project. Next, to toggle between these graphs as well as other inputs, there are to be radio-buttons. These are used with the intent of producing an easy to use toggle system to switch between each display and input. In the final iteration of the product these will not be used to switch between graphs but instead to switch between which sites energy data is displayed. Finally, one feature that is not displayed in the below prototype (See figure 3.1) is the coloured outputs that are to be used to alter the company, or individuals energy usage behaviour. As addressed in the above discussion this output will be red for high energy usage, orange or yellow for an around average usage and green for a low and better usage.

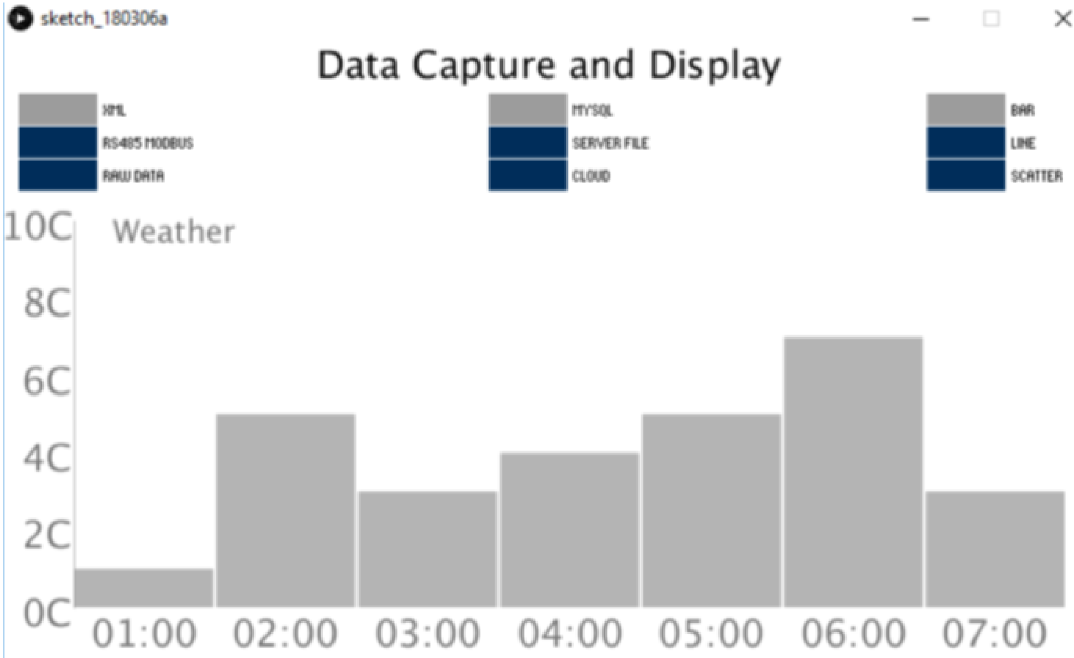

Figure 3.1: A screenshot of a final design concept partially proposed by the above discussion, and design research.

Chapter 4

Implementation

4.1 Early Prototyping Applications

4.1.1 MySQL Tests

This application will retrieve data from multiple sources and therefore requires a location to store this data. One of the options for this storage is MySQL. Therefore one of the requirements for this product would be to have a working MySQL input and output. Hence the reason for this test application. The aims of this test application are to both send and retrieve data from a MySQL database.

Before either of this functions can execute a connection between the application and the database needs to be established. To establish a connection the domain of the database as well as the schema, user-name and password are needed. Once these details are input into the MySQL instance a connect function can be run on the instance in order to establish a working connection.

The second function, and first main function, of this test app, is the ability to input the data into the database using the above-established connection. To do this an insert query must be written in the MySQL syntax. Secondly, this Query must be executed by calling the query function of the instance against the query. The data included in the query will then be placed into the database.

The third and final function, of this test application, is the retrieval of the data from the MySQL database. To do this, as above a query must be written in the MySQL syntax however in this instance the query must be a SELECT statement. This statement will be written to retrieve the table of values that have been input into the database. For now, this data will be stored in a text file to show that the data has been successfully read from the database. The query will be executed alongside the query function of the MySQL instance. This will then retrieve the data in table form which will need to be processed if it is needed to be displayed in any other way, however, in this case, the retrieved data will be pasted into the file in the format that it arrives in. In this case, a for loop will iterate over the data to paste each row into the file separately on a separate line.

4.1.2 UI Test

This test application is an alteration of the above MySQL test in that when the data is received from the database, it is then processed and displayed as a bar-chart on the screen. The more difficult task of getting the data from the database is already implemented into this application however the data is not in a format to be displayed on a chart. Therefore the first task in developing this test is to process the data into a more malleable format in order for it to be able to be displayed in a chart.

To remove confusion from this test app the function that adds data to the database is to be removed and placed into a separate application. The first step once this function was removed is to process the unedited table of data that is retrieved from the database. The first step in doing this within Processing is to place the data into a ’.csv’ file so that later on the data can be easily referenced. After the data is placed in the ’.csv’ it is returned from this file and placed into an array which will later be used as the data used in the bar-chart.

The final and more simple part of this test is the displaying of the data onto the bar-chart. The reason for the more in-depth processing of the data than necessary was due to the use of a ’BarChart’ class in Processing. This class takes an array that is formatted in the same way that the above process formatted the database data. The data of the ’BarChart’ class is set to be the array of database data. After this, the bar-charts settings are set to make the chart the size and specifications that are necessary for this project. Once this is complete the chart will automatically render as filled with the data from the database.

4.1.3 Weather XML Test

The following test application will take the separated input part created at the beginning of the last test. This particular test will edit this application to input real-time data from an online XML source rather than randomly generated numbers.

To achieve this first the weather XML must first be accessed. To do this the link to either a local or online XML file must be placed into a string. This will then be used to load the XML file into the application. This file will not only contain the data that is needed by the application but will also contain a lot of unnecessary data. Therefore, the next step in creating this test application is to get the data that is needed out of the XML file and to store it locally for later use.

To select the data that is needed out of the XML file the structure of the file is needed. The reason for this is that with the way that XML forms are formatted there is a hierarchical structure in that the format resembles a tree structure. In essence, the information that is needed to be farmed out of this file is under a file path type of string. For example, the XML file that is being used in this case is from the Met office. It is a 3 hourly updated weather report and the only data that is needed from this is the most recent temperature. To gather this data the path is this, "DV/Location/Period/Rep", and the data is under the reference ’T’. This information is needed to be known in order to gather the data from the XML file. The data will be gathered by getting the child of the above ’tree’ structure and then by finding the data and getting the value under the ’T’ reference. Once this is achieved the application will have this data stored or displayed. In this test applications case, the temperature is displayed as a string onto a separate window (See figure 4.1)

Figure 4.1: Screenshot of the output produced by the weather XML test application.

4.2 First Iteration

After the early working prototypes, part of the functionality of the finalized application was completed. Following these prototypes, additional functionality is required. The application needs to be able to take another input in order to meet the aims of this project. Hence in this first iteration, there need to be more features.

4.2.1 Features

In this first iteration of the system there are a few new features from the addition of the prototype applications:

- Additional input: Serial input.

- Radio-buttons to switch between inputs.

The serial input is for implementation on both sides of the application. First, a signal must be developed and sent over serial from the data capture end of the application. Secondly, the serial signal must be retrieved and then the data that is received from the signal must be placed into the graph.

In the case of the radio buttons in this scenario, they are to allow for the toggling between inputs. This is to simulate the situation that would occur during the final implementation should the project be implemented in industry, showing that the multiple location inputs can be toggled and switched to.

4.2.2 Complications

With this first iteration of the project, the serial element caused the largest number of complications. The first element here is that in the initial stages of implementing this feature it was the aim to get the signal from an existing meter. The issue with this was that in order to find the output from this the type of output is needed to be known to see if the feature works. The reason this couldn't be solved initially is that the documentation of the meter does not include the type of output that was expected.

A second issue was the implementation of the design. With this design, the complication was that the spacing and layout of the design were difficult to layout. This could not be fixed in the initial iteration. The reason for this is that the design at that point worked however, this was not the intended design.

4.3 Second Iteration

For the most-part, the first iteration of this application was a success. However, with the design and the issues with the serial input, the application was not complete. The first iteration was not a failure however just an earlier prototype. This second iteration is the more finished application with further completed features and design.

4.3.1 Changes

In this iteration, the design was finished. All of the elements of the design were finalized using a UI library within processing. The library used for this was controlP5, according to the libraries website it contains "Controllers to build a graphical user interface on top of your processing sketch," It creates a simpler way to place and organize the graphical assets of this project.

4.4 Spike Solutions and Other Unused Applications

- C# MODBUS/SERIAL Test Application
  - This application was the first of the initial ideas. It was a test that involved blindly searching for the signal from the existing energy meter. In this application the connection was able to be established however due to the blind nature of the search for data, none was found. The reason for this is that the data-type and format of the

meter was unknown and therefore by trying to find data with no idea of its virtual appearance proved very unsuccessful.

- JAVA MODBUS/SERIAL Test Application
  - After the failure of the C# test app a similar approach was attempted in JAVA in an attempt to see if the existing monitor was truly a closed door until further notice. This solution also ended in failure as data was being put into variables however the type of this data was still unknown to processing it into a readable format was not at that moment possible. Following this discovery, the existing meter was discontinued as a primary aim of this project.

- Python to MySQL Connector Class
  - This application was initially intended to work server-side in sending data to the database for the actual application to then retrieve from the database. The reason that this application became unnecessary was that the use of too many languages would have overcomplicated the project. Also, the question came up of 'Can processing perform this too?' This was surely answered with a 'Yes'. Therefore instead of developing half a dozen applications, each with their own individual function, the project became to create the one application that demonstrates multiple inputs with the inputs being generated behind the scenes.

Chapter 5

Testing

5.1 Introduction

The application has been tested throughout the development process to provide assurance that each function is working as expected and to check for any unexpected bugs. During the development, the tests were primarily white box tests ensuring that the processing code syntax was all correct and that everything worked as it should internally. The next part of the testing is to black box test the application to ensure that the program seems to work on the outside from the user's point of view. Finally, the application will go through integration testing, this will establish whether the modules of the application work together. If it passes these tests then the application can be deemed functional. A test will also be carried out by a number of members of the public who will then fill in a questionnaire aimed at rating their experience and asking questions to see whether this product meets the projects aim.

5.2 Tests

5.2.1 White Box

These tests have taken place over the course of the development of this application. They consist of a few lines throughout the code that print values to console in order to check whether the functions in the code are performing as expected. They are peppered throughout the project to test specific values. One example of a white box test within this project is a line within the module that posts to the database that posts the date and time to console every time the data is posted. If the post is unsuccessful then nothing will post to console and the test will be unsuccessful.

5.2.2 Black Box

As above these tests take part throughout the development process. However rather than looking into the individual values at times in the running of the application these tests look at the full outputs of the individual modules. In this project, there are two such modules to be tested: the module that adds to the database, and the module that takes from the database and displays the graph of values in the designed UI.

The test for the module that sends data to the database involves running the program and then looking into the database to check that all of the correct values are being placed into the storage correctly. These black box tests also involve checking every possible input and output of the system to check for any unexpected results such as crashes or corruptions of the data.

As for the black box test of the display module, the results rely on the displayed values matching the values in the database and also the UI being displayed correctly. As above all inputs are tested to check for bugs and crashes.

5.2.3 Integration Testing

The final stage of the testing of this application is to place the two main modules together and test if they work in unison as intended. The idea is to see whether the application can work together as intended and as a single executable rather than the two sections. This test forms the final stage of both the testing and the implementation.

5.2.4 User Tests

This stage of the testing of the system involved introducing members of the public to the application. This test is to be conducted with the aim of assessing the application's effectiveness once the project is fully implemented. The six participants (who returned feedback) were subjected to the system for ten minutes for a quick glance at the functionality and design of the system. These participants were then asked a series of questions about the system to assess whether this product would be a success come a time where it would be released and implemented in a multi-site corporation.

5.3 Results and Analysis

5.3.1 White Box, Black Box, and Integration

Firstly any white box test was run every time the application was run, these tests provided an output on the console of the environment. At the start of the development, these tests mostly proved to be failures. However, as development progressed and an understanding of the application and the technologies involved developed the errors diminished and thus concluded in many working segments of the application.

Secondly, the black box tests of the fragmented system were run infrequently towards the end of the development when the system was more functional. These resulted in successes due to the successful white box tests that preceded and took place during these tests. The only faults found, at any iteration of this project, via the black box tests were graphical. These errors where usually misplaced or displaced graphical elements such as buttons.

Lastly, the integration tests. Two such tests took place during the development of this application. each of these tests took place at the end of an integration cycle (of which there were two) these were to determine if the program functioned as expected. The first of these displayed multiple graphical errors which were deemed undesirable. These errors were mostly asset displacement and for the second implementation were easily fixed. The second implementation was a success, both sides of the program integrated well and the application worked as intended.

5.3.2 User Tests

The user tests were partaken by ten members of the public and potential users of this system. The result provided positive reinforcement that the product is a success in completing the aims. The questionnaire that six of the participants took part in was devised in order to gather the public opinion on the system and to conclude whether or not the system works as intended. Six questions formed the questionnaire. There were two main focal points within the questions with the intention of finding out the effectiveness of all design elements. From the visual design aimed at changing behaviours to the interaction design intended at making the application simple to use. Two questions from the questionnaire gave interesting insights into the success of the application.

The first of these is a question pertaining to the effectiveness of the application in changing energy usage behaviour. The question read as follows: "*To what extent would you agree with the following statement? If placed in my home the application would help change my energy usage behaviour.*" The answers to this question averaged a result of *4.2* which rated as an overall agreement of the statement. This proves a partial success of the final implementation of the application as this question involved a leading objective of the project. These results can be seen below (see figure 5.1).

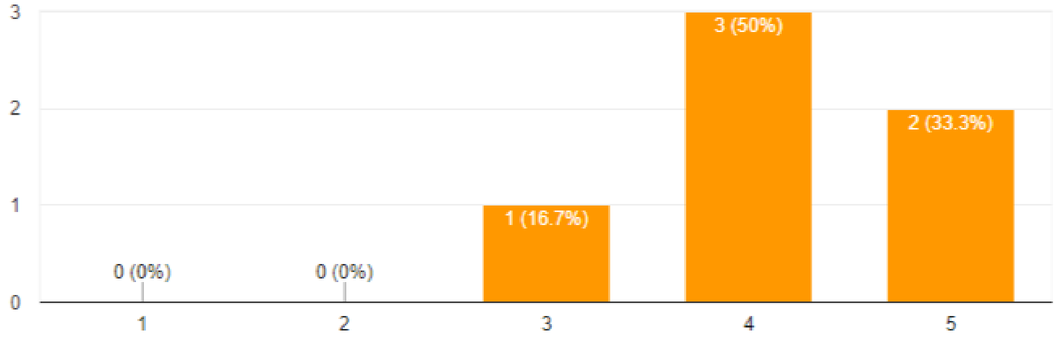

Figure 5.1: A graph showing the percentage of users that agreed that the application would change their energy usage behaviour (5 being agree - 1 being disagree)

Lastly, the second of these questions references the factor of this application being easy to use.The aim of this question was to assess the interaction design. Participants were asked: "To what extent would you agree with the following statement? The application was easy to use and understand." The response to the above question was very positive (an average of *4.5*). An average result rounded up to strongly agree with the statement showing that the application was easy enough to use so that it did not warrant an interaction design change.

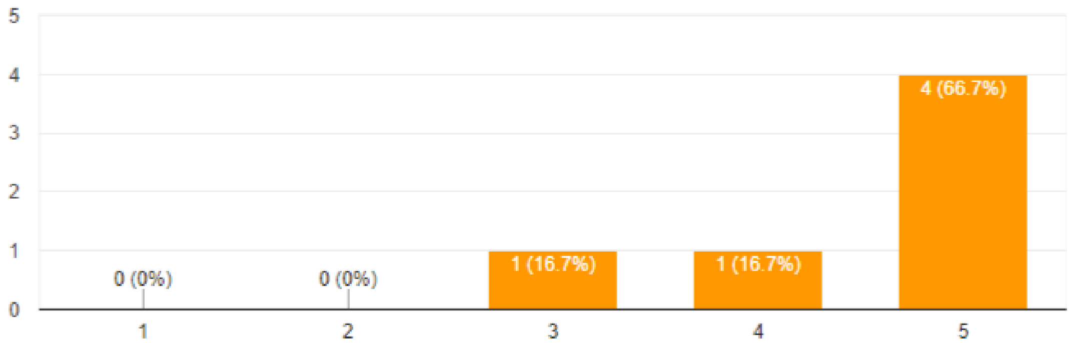

Figure 5.2: A graph showing the percentage of users that agreed that the application was easy to use (5 being agree - 1 being disagree)

Chapter 6

Evaluation

In this project, there are plenty of examples of which it can be compared to in order to successfully evaluate the success of this project in regards to the original aims, objectives, and hypothesis. Firstly, however, this project can be compared against the existing solutions with the aim of discovering unique and innovative features as well as unearthing the positives of this system over those that are already on the market.

The first unique element of this project that is lacking from the existing solutions is the ability to use a buildings already existent meter to monitor the usage with no need to purchase new hardware. The primary benefit of this is the cost, however, there should also be a focus on the compatibility with older or pre-existent meters which reduces the need to update these systems or include current transformer (CT) sensors as part of the system. The second of the unique elements is the cut-back interface with fewer calculation features. this benefits the system by making it cheaper and more accessible to smaller companies. Not only this but the systems lesser features makes it simpler to use by the company but still produces results. The function of this product in the workplace is to display to the workforce their energy usage with the intention of changing their behaviour. This means that the system is not focusing on the cost of the energy or the specific ’per-appliance usage’. Following on from this, a third and final defining feature of this project is the simplistic interface allowing the ease of display and use by the company. With a minimal setup, this product allows for a simpler experience than the existing solutions.

In terms of the aim and objectives, the project was a success. The system successfully took in multiple outputs and processed them before producing a graphical output. It also used data display techniques and offered energy usage behaviour changes as a result. The final objective of creating a system that is easy to use was also a success as the user review questionnaire provides proof that the application was, in fact, easy to use. As for the set up element of this final objective, this was proved met as discussed above as the lesser number of features and its compatibility with existing meters proves useful. Each point mentioned in the aim has been met throughout the project. Research on behavioural changes due to visual cues and the development of a system that utilizes such research met most of these points with the others having been met throughout the development process.

The hypothesis, on the other hand, was confirmed as successfully met on the conclusion of the user tests. The reason for this is that before this point it was only theorized that the design would change the energy usage behaviour. However, by the end of the user's tests, it was confirmed that the application would, in fact, change their behaviour.

Chapter 7

Conclusions and Future Work

7.1 Future Work

At present, the application meets the aim of gathering multiple inputs and processing this information ready for a display with the aim of changing the user's energy use behaviour. To further this project there are multiple improvements that could be made as well as multiple further additions to the system.

The first improvement would be to further improve the design. The design was created by primarily using a library that aided in the placement of the assets. However, the assets were always going to look the same due to the use of the library. Due to this, the application can be seen to look bland and almost without design. Due to this, further design considerations could take place to make the application look more modern and have an aesthetic to aid the function.

The second improvement would be to change the storage of the data to solely cloud storage. As a more accessible storage method, this solution would be more feasible however for the scope of this project it was a more accessible solution to use an available MySQL database. The reason for using the cloud in this future work would be in order to make the solution cheaper and work on existing cloud platforms.

The third and final improvement is to add the input required to make this product into the market ready product that is alluded to throughout this project. This would involve removing the serial simulation and weather application of this product and instead add a module that retrieves the serial signal from the meter. Finally, the processing portion of the application would need to be edited to deal directly with the finalized data.

7.2 Conclusion

The project started out to prove that a system with multiple inputs can process and display that data with the resultant product being a reduction in energy usage. The application gave encouraging results, by creating a visual feedback to multiple inputs the above aim was met successfully. The created application was made lighter than existing solutions, deliberately less-featured to make the system more simple than the above mentioned existing monitoring products.

This final system runs on the processing language and environment and takes in two inputs whilst allowing for the process of these and displays this processed data with the intention of effecting the user's behaviours.

The goal of making a system that is simple to set up and easy to use was intended on making an improvement on the more complicated existing solutions. This application has met this goal, as seen in the user test results. All test results run on this application ended with successful results.

Chapter 8

Legal, Social, Ethical and Professional Issues

8.1 Legal

One consideration with this project was to keep within the standards set by law. In this case, there are two particular pieces of legislation and regulation to take into consideration. These are the Electricity Act of 1989 [7] and the National gas and electricity metering regulations [4] respectively.

8.2 Social

This application is aimed at changing peoples behaviour, it should be noted that this is not for the sake of changing behaviour it is to be a subtle change with the intentions of creating a positive environmental effect.

8.3 Ethical

Not a replacement for the mentioned existing solutions, it is, however, a new take on the solution with a somewhat more focused, niche outlook.

As above this project aims to change peoples behaviour, anyone who partook in the questionnaire and review of the application gave consent to the possibility of having their behaviour changed. In the final release of a product based off of this project would have this agreement in their terms and conditions.

8.4 Professional

To be considered a more professionally viable product the product should be made to meet the guidelines set by the ISO-50001 - energy management systems standard [15]. This project involves technologies related to energy management systems and could, in fact, be considered one. Therefore, alongside the above management system standard, this project should also conform to the ISO-50003 - energy management systems standard [16].

The difference between the two above standards is that the former deals with guidelines pertaining to the use of these systems and the latter provides guidance on the requirements for audits and certification of energy management systems.

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Appendix A

Appendix

A.1 Survey/Questionnaire

Effectiveness of multiple input monitor

Questionnaire to assess the effectiveness of the processing and display of data.

*Required

1. **To what extent would you agree with the following statement? The colours associated with good and bad usage were clearly distinguishable.** *
   Mark only one oval.

	1	2	3	4	5	
Definitely disagree	◯	◯	◯	◯	◯	Definitely agree

2. **How would you rate your overall experience?** *
   Mark only one oval.

	1	2	3	4	5	
Bad	◯	◯	◯	◯	◯	Great

3. **To what extent would you agree with the following statement? The application was easy to use and understand.** *
   Mark only one oval.

	1	2	3	4	5	
Definitely disagree	◯	◯	◯	◯	◯	Definitely agree

4. **To what extent would you agree with the following statement? I would like to see this application across the University or other Multi-site establishments.** *
   Mark only one oval.

	1	2	3	4	5	
Definitely disagree	◯	◯	◯	◯	◯	Definitely agree

5. **To what extent would you agree with the following statement? If placed in my home the application would help change my energy usage behaviour.** *
   Mark only one oval.

	1	2	3	4	5	
Definitely disagree	◯	◯	◯	◯	◯	Definitely agree

6. **Did the design catch your eye?** *
   Mark only one oval.

   ◯ Yes
   ◯ No