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GLOW

The Smart Thermostat – Group 13

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Abstract

The aim of this report is to describe the motivations and work behind the product GLOW, the latest generation of smart thermostat. Sections 1 and 2 present an analysis of the social need for such a product and a market analysis comprehensive of comparison with the competition. The final design is then explained in section 3, through a detailed breakdown going from the social implications of the product and its user interface, to more technical aspects such as the software and hardware specifications. Organisation and challenges of producing a fully working prototype are described in section 4, examining strategies adopted and further testing to carry out. More details on the long term vision are covered in section 5, in which the possibility of creating a larger community of users that will contribute together to more sustainable solutions is explored.

1. Introduction

1.1. Situation

Last November over the course of the COP21, also known as the 2015 United Nations Climate Change Conference, the UN negotiations aimed to achieve a legally binding and universal agreement for the first time in over 20 years. The main objective is for all countries to reduce consequently their consumption of greenhouse gas (mainly Carbon Dioxide) by 2020 (United Nations Framework Connection on Climate Change, 2015). Since the boom of domestic appliances in the 70s, domestic energy consumption in UK has kept growing over the years.

Energy used for space heating alone has increased by a third in the past 40 years (Palmer & Copper, 2013) mainly due to rise in population and accounts for 45%, of UK's domestic energy demand, (see Figure 1.1.1.). This consumption represents an important part of the households' budget.

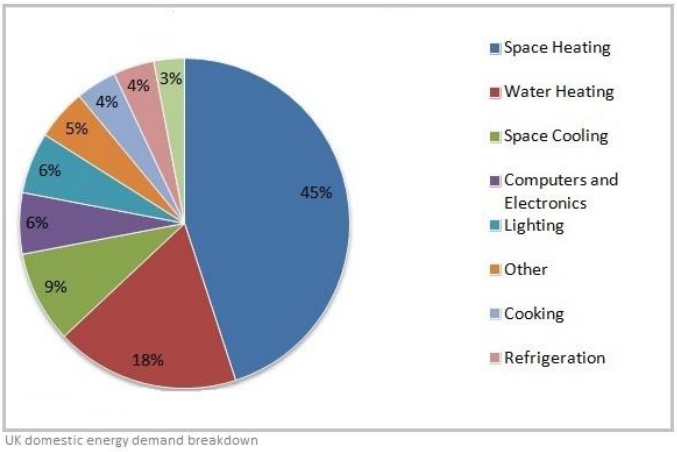

Figure 1: UK Domestic Energy Demand Distribution

Therefore, reducing UK's domestic space heating energy consumption plays an essential role in both improving environmental sustainability and reducing household spending. The UK has increased its renewable energy generation capacity in the past decade (Hemingway & Waters, 2015). Currently, "renewables produce 7% of the UK's electricity, and EU targets mean that this is likely to increase up to 30% by 2020" (Energy UK, 2015). This effort has successfully reduced greenhouse gas emissions in the UK due to the reduced usage of coal for energy generation (Eaton, n.d.). However, reducing energy demand and usage will be a more effective and direct approach to further reduce these emissions and benefit the environment.

A Smart Grid Forum's Vision and Routemap has been proposed to revolutionise the UK's energy sector (Department of Energy & Climate Change, 2014). This document "sets out how smart technologies will deliver cost-saving efficiencies, give consumers greater control over their energy use, support jobs and growth, increase energy security and enable integration of low carbon technologies" (Department of Energy & Climate Change and Ofgem, 2014). This project will support the UK's Smart Grid Vision. The new generation of thermostat plays an essential role in this energy revolution. GLOW, will "deliver cost-saving efficiencies" and "give consumers greater control over their energy use".

The aim of this project is to design an electronic device that provides users with live feedback on heating power usage and expenses, as well as other data to encourage users to reduce their energy consumption. GLOW provides different feedback to the various user groups in order to enhance user experience while benefitting the environment. Similar smart devices currently on the market will be analysed and compared with GLOW in section 2.2 of this report.

1.2. Project Definition

Lately, the Internet of Things (IoT) has played an increasing role in the electronics world and has expanded to many different applications, from automobile sensors to heart monitor implants. An object belonging to the IoT, can be any “natural or man-made object that can be assigned an IP address and provided with the ability to transfer data over a network.” (Rouse, 2014). This project has not entirely resulted in a device that can be described as part of the IoT yet, as it does not necessarily interact with other household devices, however it is a first venture into connected appliances. It effectively serves as a middle ground between traditional devices and IoT devices.
The project aims at introducing a new way for households to visualise their energy consumption for heating. Before saving comes understanding daily consumption and the goal is to design a device capable of displaying various information that can push any user of the general public to save energy. Social aspects need to be taken into account to encourage users to behave in an environmentally conscious way and by consequence cut down on their energy usage. Hence, GLOW differs from current smart thermostats available on the market as it focuses on both factual and social factors that affect domestic heating usage. GLOW offers additional user personalisation so that the device can be both automatically and manually adapted to better suit the needs and preferences of each individual. The feedback that will be provided is based on user profiling and analysis of factors (such as financial, social, and psychological) as well as user personalisation details are covered in section 3.4.1 of this report.

The following segments of this report will first cover an in depth market analysis resulting in the creation of design criteria. The product design, including user profiling and device interface designing using dedicated software and hardware will then be explained. The report will also go through the steps of product prototyping before describing the long term vision of this project.

2. Market Analysis

2.1. Targeted Market

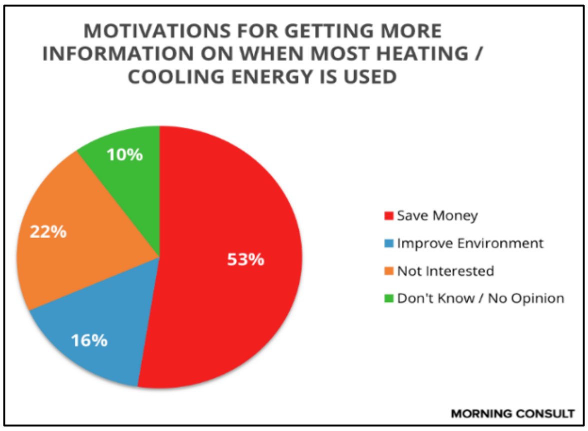

Figure 2: Morning Consult poll conducted from Oct. 3-5, 2014 among a sample of 1,587 registered voters. (Morning Consult, n.d.)

GLOW’s target market is potentially global and encompasses millions. In the United Kingdom alone, there are an estimated 23,171,000 households (GOV.uk, 2012); a vast majority of them are connected to the power grid and are equipped with individual heating systems. The aim is to make the product accessible to everyone, and adaptable to as many household profiles as possible within the domestic sector. The initial target market, one with the greatest potential, consists of the middle classes with limited income: this category limited financial resources and tight constraints over the management of their spending. On one hand, half of the UK’s households have an income of less than 23.556 pounds per year, and on the other the average energy bill for a medium sized household adds up to 1087 pounds yearly (Data from the Households Below Average Income (HBAI) report from the Department of Work and Pensions 2013/14: (Wikipedia.org, 2016)). These specific populations are very sensitive to spending in domestic energy, especially heating. Other household profiles (higher wages) are also targeted, however the objective will pivot from money saving to community involvement and carbon footprint reduction.

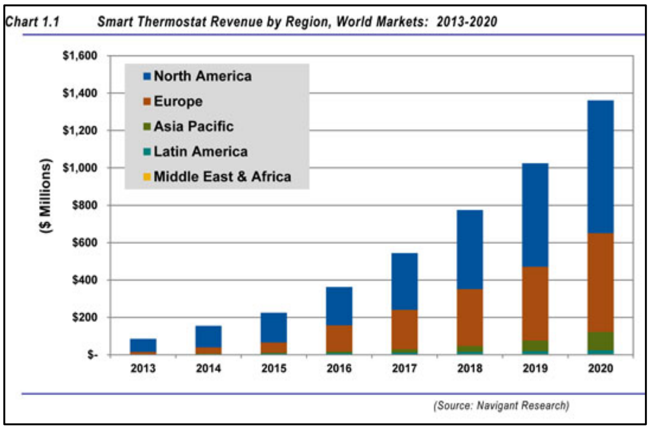

Figure 3: The market of the smart thermostat is facing significant growth in in the recent years. (Cloudfront.net, n.d.)

Smart thermostats have only been introduced recently to the general public with pioneer start-ups like Nest having commercialized their thermostat only in the late 2011. However, the recent innovations and investments made in connected devices and the so called "Internet of things" have quickly drawn other companies to create their own smart thermostat. The global revenue of smart thermostat sales has been increasing in the past few years and it is predicted that it will continue on this upward trend.

2.2. Competition Analysis

The smart thermostat market is still in a developing phase and only a limited number of corporations have introduced these products to the general public. In this section GLOW will be compared to the products of the most profitable companies in the industry: Nest's and Tado's Thermostats as well as British Gas's 'Hive'.

Figure 4: (Nest.com, n.d.)

Figure 5: (Tado.com, n.d.)

Figure 6: (Hivehome.com, n.d.)

2.2.1. Functionality Comparison

All the competition's products have as main objective the automation of climate control management: the aim is to make the device take independent decisions on setting climate control, according to household population and the user's daily schedule. This creates a certain illusion of comfort for the user that does not have to worry about manually changing heating settings. The thermostats of the competition take up the responsibility of climate control setup, leaving very limited control to the user. This leaves a gap in the market where GLOW can step in and offer full transparency over spending and energy usage to the user. The customer is made aware of their consumption and is supported by a community in making more responsible decisions. An objective shared by both GLOW and the other thermostats is saving energy.

Nest and Tado's thermostats fall into the same category, as they both try to save energy by automatically lowering the heater's programmed temperature when the user is away or asleep.

However GLOW's thermostat takes a completely different approach to tackle this issue. To save energy, GLOW brings the user's access to consumption statistics further than the competition: it returns statistics tailored to the user's profile type and pushes the user to act as a responsible member of a community and towards the environment. The synergy between functionality and tailoring of the user profile really makes GLOW's thermostat smarter than any other competing product.

As will be seen later on (Refer to 5.3.), our vision of the product for the future is to create an open source platform where 3rd parties are free to develop applications to run on GLOW's operating software. This will not only drastically diversify the device's capabilities, but it will also make the product incorporate a market of application design and commercialisation. This vision would lead to a win-win situation where 3rd party developers would have a new platform to commercialise their applications on, and where GLOW would benefit from the constant diversification of the functionalities it has to offer.

Features	GLOW	Nest	Tado	Hive
Automatic Setting	✗	✓	✓	✗
Use from handheld device	✗	✓	✓	✓
Touchscreen Interface	✓	✓	✓	✗
Statistical feedback	✓	✓	✓	✗
Connected to the web	✓	✓	✓	✓
Online member's area	✓	✗	✗	✓
Outside weather measurement	✓	✗	✓	✗
Habitat profiling	✓	✗	✓	✗
Community comparison	✓	✗	✗	✗
User profiling	✓	✗	✗	✗

Table 1: Feature comparison with competition

2.2.2. Financial Comparison

The competition's unit prices add up to £176 for the Nest, £199 for Tado and £250 for Hive. These prices correlate quite closely with each other and average at about £200. The production cost for GLOW's prototype thermostat is distributed as follows:

- RASPBERRY PI-2B £28.34
- 7" Touchscreen Monitor for Raspberry Pi £48.12
- USB charger £5
- Wi-Fi Dongle £5
- Micro SD card £4

- D printed case £2
- Temperature sensor £2.78

On a mass production scale, the production cost could go down to £60 - £70 per device (assuming 30% cheaper component costs).

It is difficult to estimate a selling price at this stage. Taking into account miniaturisation of the components, further software design improvements (security, design etc.), server maintenance and business initiatives, the starting price should not be less than £150 per unit if the product was to be introduced to the market.

Table 2: Price Comparison with competition

3. Product Design

3.1. Design Criteria

After analysing the market's need for the product, the design requirements that allow the product to distinguish itself from the competition can be established. The most crucial and relevant elements in the Product Design Specification (PDS) for this project have not changed since the interim report. (Refer to section 1.3 of the interim report for explanation of choice).

The elements that define the essential functionalities of GLOW's thermostat are:

- Performance (PDS 1): The device should be usable in a domestic environment. It has to be connected to the internet and offer computing capabilities. It should be customisable by the user and should render a user-friendly environment.
- Environment (PDS 2): One of the objectives of the product is to save energy and reduce greenhouse gas emissions in domestic heating. It should be a low power device.
- Maintenance (PDS 4): A fully digital electronic device would improve its reliability to limit the maintenance needed over the long term (more than a year ideally).
- Target Product Cost (PDS 5): Should be offered at a low price to be attractive for the target market. (Estimation of 100 - 150 pounds).
- Aesthetics, Appearance and Finish (PDS 16): Aesthetically appealing as the product will be considered part of a room's furniture.
- Ergonomics (PDS 17): Should be easy to interact with and to use on a daily basis. Overall size restricted to common thermostat dimensions.
- Testing (PDS 21): All functionalities advertised for should be thoroughly tested in different conditions and on different subjects.

GLOW is mainly designed around these elements. The full PDS can be found in Appendix 8.1 of this report.

3.2. Initial Designs

The project is made up of three main areas: the GLOW thermostat device, a supporting website and an online database. In view of the fact that the website and the online database are supporting features, most of the analysis in this report will focus on the thermostat, especially its interface design. The details of initial designs and how they are linked to the design criteria can be found in section 2 of the interim report and Appendix 8.2 of this report.

3.3. General Description of final product

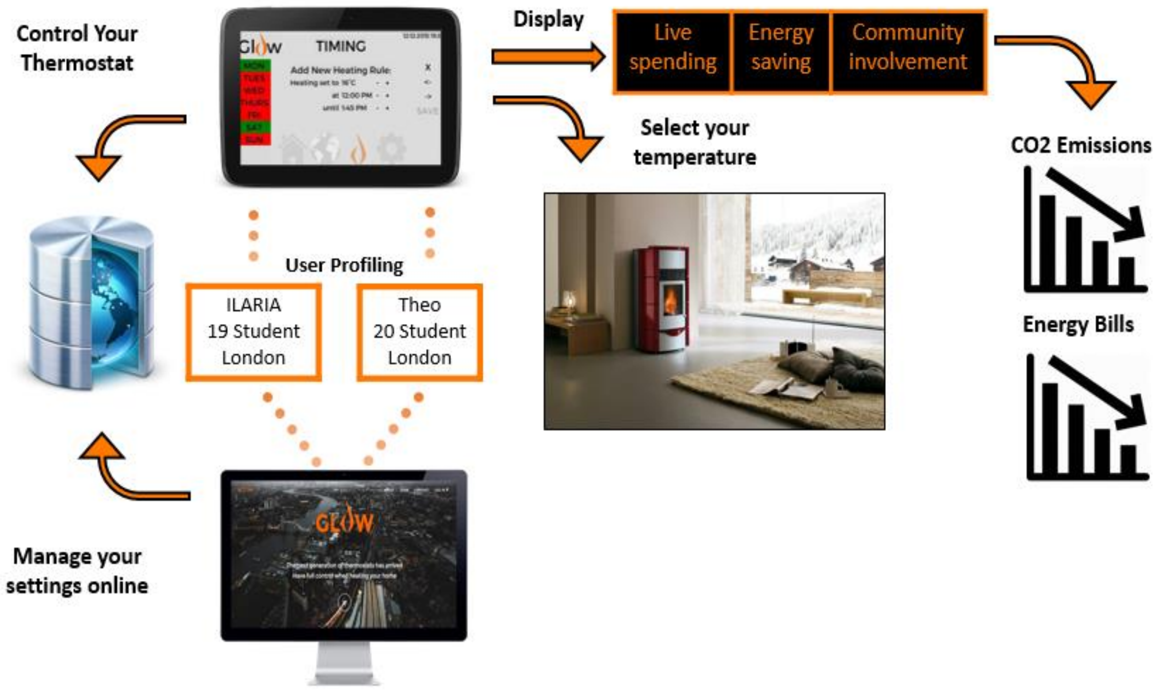

Figure 7: High level operation diagram

Connected and tailored to every user, the thermostat designed displays an accurate estimate of the consumption of your heating system, alongside energy saving progress in a user-friendly environment. Real-time cost of heating, live consumption statistics and energy saving progress are all evaluated by the thermostat and help every user control their heating power consumption on a daily-basis. User profiling is implemented through GLOW's website where every user can edit their personal settings, before they are submitted to an online database to be accessible by the thermostat. The next segment of the report will describe the operation of GLOW's product in more detail and at lower level.

3.4. Technical Breakdown

3.4.1. User Profiling and interface

The interactions between GLOW and users mostly take place on a touch screen where users can change setting of the thermostat and monitor their energy consumption. Hence, the design of the user interface is tailored to the needs of GLOW users. Research regarding user behaviours and social profiling were conducted to understand the needs of different social groups so that users can receive personalised feedback on their energy consumption. These personalised message also aims to motivate users to save energy.

3.4.1.1. Social Understanding

The majority of energy consuming behaviours are based on habits and routines. Giving personalised feedback can help making people more aware of their energy consumption and consequently influence their behaviour: feedback on energy consumption can encourage households to save on average 5-15% of their usual consumption (Martiskainen, 2007). GLOW's user interface is aimed at giving effective feedback to its users in the most intuitive and simple form. Given the variety of backgrounds of the target audience, the user interface is designed such that different social groups have a different default set of feedback measurements based on their energy usage. Social profiling will be explained in the next section.

3.4.1.2. Profile Types

Users are differentiated into 3 age groups and 3 economical categories, for a total of 9 default settings.

Socio-demographics have an influence on households' energy saving potential: low income households are likely to use low amounts of energy, implying little margin to save; higher income groups on the other hand are likely to be the largest consumers of energy and hence have the largest potential for saving (Martiskainen, 2007).

The economical background is differentiated by users' spending on their last bills. Energy saving tips will be provided to the lower income group to reduce heating expenses. Energy saving ranking is shown for the high income group to reinforce the idea that others in the same economic situation are making a public commitment. Other forms of incentives are represented by the percentages of cash and energy saved with respect to the last bill. The comparison with the last bill is particularly relevant to the higher income category, as absolute figures might not have enough impact because of the already high consumption and spending.

Monthly Bill/ £	Age		
	18-25	26-65	65+
0-40	Default information to display: ● Money saved ● Energy saving rank (compared with same user group) ● Energy saving tips	Default information to display: ● Money saved ● Energy saved ● Energy saving tips	Default information to display: ● Money saved ● Energy saved ● Energy saving tips Display format: ● Large font
41-70	Default information to display: ● Energy saved ● Percentage of money saved (w.r.t. previous bill) ● Energy saving rank (compared with same user group)	Default information to display: ● Energy saved ● Percentage of money saved (w.r.t. previous bill) ● Energy saving rank (compared with same user group)	Default information to display: ● Energy saved ● Percentage of money saved (w.r.t. previous bill) ● Energy saving rank (compared with same user group) Display format: ● Large font
70+	Default information to display: ● Energy saved ● Energy saving rank (compared with same user group)	Default information to display: ● Energy saved ● Energy saving rank (compared with same user group)	Default information to display: ● Energy saved ● Energy saving rank (compared with same user group) Display format: ● Large font

Table 3: User profiling information

The 18 to 25 age group is representative of young adults. They usually have limited source of income and live in rented properties: reducing expenses is likely to be a significant concern for them. However, some young adults have little financial burden. For them, raising awareness on energy consumption is essential since the monetary incentive alone is insufficient in stimulating energy saving behaviour.

The second age group (25-65) represents the active population. They usually are employed full-time with a steady source of income. The information presented will tend to be concise and simple, in order to avoid burdening them with complicated statistics on top of their daily working effort.

The last age group (65 and above) represents the elderly. To make a product appealing to the elderly who have rare experience interacting with an electronic device, it is important to adapt the interface environment by, for instance, displaying large text fonts and fewer on-screen buttons. Research by Honeywell Technology lab has found that a touch button sized around 16mm and spacing of 3.17mm to 6.35mm are more appropriate for older adults (Zhao & Kiff, 2007).

3.4.1.3. User Interaction and Implication

On top of the default display of information, users will be able to customise the information they wish to see on their home screen. Furthermore, options for setting personal goals for energy saving will be available. GLOW will compute the percentage achieved over the final target. Research has shown that those who had a self-set goal were the most successful in reducing their energy use with saving adding up to 21% of their usual consumption (Martiskainen, 2007).

3.4.2. Software

3.4.2.1. User Interface

Front End

The front end design of the program evolved from the initial interface designs due to a variety of factors, the primary one being what the team was capable of producing. This standard developed throughout the year as the part of the team in charge of software development became more familiar with the method of programming involved in making a Graphical User Interface (GUI). Testing with the touchscreen inspired changes to the interface; use of the actual product provided vital insight into how a user would interact with the GUI.

From the beginning the interface designed focused on the functional parts of the interface, such as the timing control settings, the basic features one might expect from a thermostat. This revealed to be a useful approach at first: being the essential features simple to implement, they allowed the team to become accustomed to interface programming and the Python language. Nonetheless, the wider scope of the project had to be integrated into the software and this led to the more advanced features of the product.

The overall objective of the project is to create a “smart” thermostat: when applying this to the software, the team decided that customisability and the capacity for expansion were two key components of the task. This led to the front page design, which is fully customisable, implemented using a basic plugin-like system: modules that can appear on the front page are in standalone files and many algorithms/routines for interfacing with these were created. Thanks to this system, modules can be arranged as the user wants them, displaying all types of data in a variety of ways to help reduce energy usage.

The advantage of this implementation is that, provided the file is written according to certain specifications so it can communicate with the master software, any module written by a user, enthusiast, or organisation, could be run and displayed on the front page. This third party module could be some form of entertainment (e.g. a game) or a tool (for example a calendar), but in the bigger picture it could lead onto the proposed future work (Refer to 5.3); with more functionality added to the device, modules could be made to help users share energy or find new ways to save, a goal of this project.

Back End

One of the objectives throughout the project is, as said previously, to present the user with live power and cost calculations. Whether these will be shown depends entirely on the social group selected and on the personalised settings of the interface, but will be present nonetheless. This functionality was made possible by many different technologies coming together into one fully coherent package.

The back end's main role is to seamlessly connect the website and the GUI of the program running on the device. This was done using a MySQL database running on a separate server to the website. The first step to using the product is for the user to enter his details on his dedicated page on the website (more details in 3.4.2.2), this will update the database and the information will then become accessible to the thermostat.

The database is divided into tables containing different data and all having separate purposes. For instance, there is a table containing user credentials, used in the sign-in process on the website, or another table that stores all current power plans and tariffs (both for electricity and gas), used by the thermostat in order to calculate prices. A third party library, MySQLdb, was used. This library simply passes MySQL commands onto the server, essentially acting like a bot entering commands (in entering data for example, see "database.py/dbfetch function" in Appendix 8.4). The device is then able to fetch data from the tables and store it in lists (python equivalent of vectors), to be subsequently used.

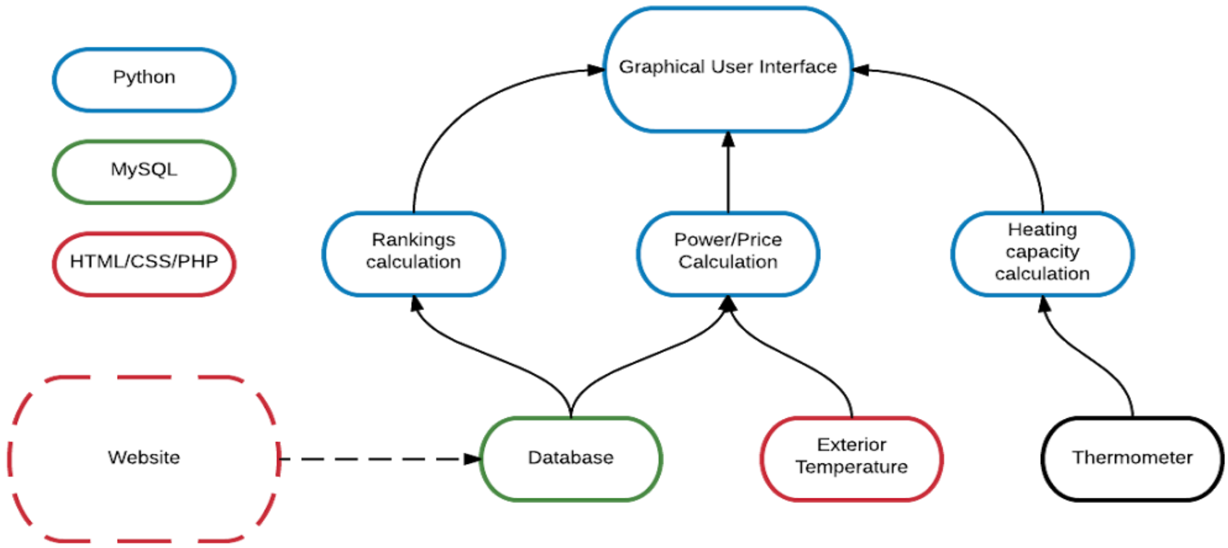

Figure 8: Flow chart representing the steps taken to achieve the desired device functionalities.

The data read from the database is used to feed multiple functions, such as the energy calculation function, which will calculate the energy required to heat a house to a certain temperature as a function of the information entered by the user on the website. In order to make this function possible, it was necessary to fetch some additional data along with the information provided through the website: the temperature inside the house and the temperature in the city the user lives in. The temperature inside the house is measured by a thermometer built into the casing while the outside temperature results from a combined use of two technologies. First of all, the code queries freegeoip.net in order to get the device's general location. It is possible to go as accurate as the user's postal code, but the program is restricted to only fetch the user's city and country for the sake of privacy. This information is then fed through the python weather API (pywapi), which queries weather.com to get the current exterior temperature.

The energy usage calculation function exists to support the power calculation and price calculation functions. When the user enters a certain temperature, the code is designed to calculate approximately how much time is necessary in order to heat the house up to and to maintain that temperature. This requires the device to have accurate knowledge of the user's heating system setup and capacity. The main issue with asking this information is that it is unlikely that the average user will be able to provide accurate values, which is exactly what this function relies upon. This problem was solved by developing an algorithm that performs the specific operations automatically. The algorithm makes an approximation of the temperature as a function of time (which is assumed to be linear) in order to extract the gradient (in centigrade per hour). This gradient can then be used in conjunction with the heating pattern set by the user on the thermostat as well as energy calculations, to compute kilowatt hour usage (and cost). This function will only be run once on first system start-up.

Fundamental Thermodynamics Notions

In order to understand the heat transfer (exchange of thermal energy) that occurs in a given room, some fundamental thermodynamics theory was needed. From the Law of Conservation of Energy, which states that energy cannot be created or destroyed in an isolated system, it can be derived that a certain amount of energy is needed in order to produce heat. Indeed, it is straightforward to calculate the amount of energy needed to heat a volume of a fluid using the formula:

$$Q = \rho V C (T_2 - T_1)$$

With Q the energy in Joule (J), C the specific heat capacity of air (at constant pressure) = 1005 J/ (kg*K), T1 the initial temperature of the room measured by the thermometer in kelvin and T2 the expected temperature of the room in kelvin, ρ the density of the air, V the volume of the air (m^3).

However, the room is not an isolated system: for this reason not all the energy delivered by the heating system will be used to heat the air, there will be losses. Leaks through the walls, windows, ceiling and roof will require extra amount of energy from the system. Windows are one of the primary areas from which rooms leak heat in the winter, in conjunction with the ceiling, since hot air moves upwards. To simplify calculations, leaks through the door and the ceiling surface will not be taken into account. Indeed in order to simplify the prototype, the software only takes into account apartments in which the ceiling and doors are not connected to the outside.

Figure 9: Heat losses in a common household (Mister Central Heating, 2015)

The thermal conductivity (k) is the property of a material to conduct heat. It has unit ($W \cdot m^{-1} \cdot K^{-1}$). A smaller k ensures a better material's insulation. The thermal resistance of a material: $R = \frac{e}{k}$ can be calculated from k, with e is the width of the material. The reciprocal of thermal resistance is the thermal conductance, given by: $U = R^{-1}$. The bigger R is, the better the material's insulation is. It can be noticed that insulation can be improved by either increasing the width of the material or by changing material. Calculating the heat leak through a material is equivalent to calculating the thermal flux through it. The thermal flux formula is:

$$\Phi = U \times S \times (T_{in} + T_{ext}).$$

With T_{ext} and T_{in} the external and internal temperature and S the material surface (m^2). Resistance is additive thus:

$$R_{house} = R_{walls} + R_{windows} + R_{ceiling} + R_{floor}$$

Therefore in order to calculate the energy leaks:

$$Q_{loss} = \Phi \times \mathrm{t} = U_{house} \times S \times (T_{in} + T_{ext}) \times t$$

To conclude an estimate of the total energy to heat a room up to a T_2 temperature can be obtained as:

$$Q_{total} = Q_{heat} + Q_{loss}$$

Although this result will not describe perfectly the real energy used, it provides a good approximation of the amount of energy needed.

3.4.2.2. Website

The website is at the heart of GLOW's functionalities. It includes a member's only area, restricted to thermostat owners only. By accessing their profile page, users can edit their account details needed for the thermostat to return accurate real-time statistical information. These include user profile information (such as age, last bill price), the energy tariff the user is subscribed to, as well as physical characteristics of the house (area, windows, walls connected to the outside) required for heat transfer calculations. This information is entered via a web form and uploaded to a database, managed through the "phpmyadmin" service.

The database contains data tables of account information, user's profile settings, energy prices and a user ranking within GLOW's community on energy saving. To read (e.g. login) or write (e.g. settings form) to the database, the website calls several php scripts embedded in the website's files to connect and interact with the servers using MySQL command lines. These back-end files include some security elements to avoid accessing the member's area page without a registered account.

The rest of the website, open to any connected visitor, offers a thorough description of the project as a whole, while keeping a user-friendly approach through simple concept explanations, keywords, animations and images as well as a sleek overall design. The website has been designed using an online bootstrap "home page" template. The addition of web pages and restructuring most of the homepage, using html, css and javascript programming languages, lead to implement the ideal website for the project. Inspired by the works of companies such as Dropbox, Soundcloud and Snapchat, the whole website is contained within a minimum amount of pages (here 3) to ease navigation and simplify the overall site architecture.

URL: http://intranet.ee.ic.ac.uk/theo.franquet14/yr2proj/default.htm#

3.4.3. Hardware

In order to effectively run the software and make the user experience as smooth as possible, it was necessary to develop a solid piece of hardware that would fulfil all requirements for a moderate price. The raspberry pi platform is perfect for this usage and offers a wide range of hardware and software support, as well as extensive troubleshooting guides on forums (Refer to 4.3.1).

The base of our product is a raspberry pi 2B. It features a modern ARM processor and 1GB of RAM and supports various versions of Linux operating system (OS). Because the pi is a computer, it can also run programs written in typical languages, such as python. This made the software development immensely easier. The choice of the touchscreen was motivated by the fact that raspberry released an official 7' touchscreen specifically designed to be used with the Raspberry Pi, guarantying compatibility, reliability and performance. It proved to be a suitable solution for the user input due to the fact that touchscreen smartphones are popular nowadays, making even a neophyte (technology wise) user feel comfortable using the product.

The core functionality of the device requires a constant internet connection in order to function, imposing the implementation of an internet access method. At first, using the pi's Ethernet port was considered, however the idea was promptly dismissed: the user will not necessarily have an Ethernet connection available in the location chosen to install the device, if not at all. It is common in households to only rely on a Wi-Fi connection, without routing Ethernet cables. However, the Raspberry Pi did not feature a Wi-Fi chipset or antenna, so it was necessary to opt for a USB (universal serial bus) extension. The chosen USB adapter is compatible with recent Wi-Fi standards (up to 802.11n, up to 150 Mbits/s), as well as all widely used encryption methods (wep and all WPA standards). This guarantees full functionality regardless of the user's internet access setup.

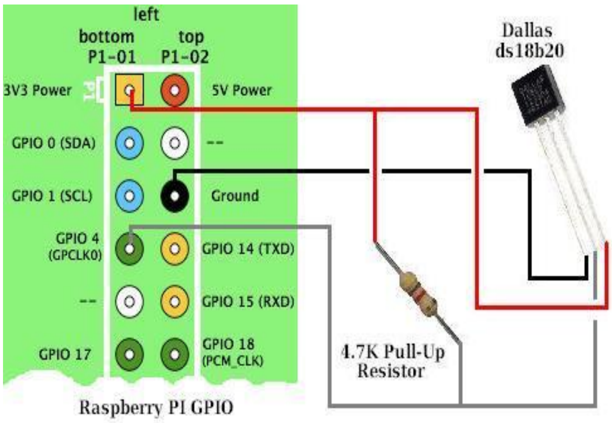

Figure 10: exact wiring used for the DS18B20 thermometer

As previously mentioned (Refer to Back end subsection of 3.4.2.1), the thermostat measures the temperature of the house via a temperature sensor located inside the case. Implementing this was marginally more complicated than the other hardware components due to the fact that nearly all affordable solutions require to use the GPIO pins situated on the Raspberry Pi itself. In fact, while USB thermometers exist, they were either too costly or of inadequate dimensions. The thermometer needed to be as accurate as possible, with a minimum of half a degree accuracy, while being competitively priced and reliable. In addition to these requirements, the sensor also needed to be digital, as the Raspberry Pi lacks analogue to digital conversion hardware. In the end it was opted to use the Dallas DS18B20. This sensor is fully digital, accurate to a half-degree from -10°C to 85°C. It also benefits from only requiring a limited amount of cabling: a ground, a supply rail, and a data pin. As for the implementation, the circuit only needed a single 4k7 pull up resistor. In essence, temperature measurement was dealt with in a very efficient and reliable way.

The last element required for the device was a 5V, 2A maximum power-supply. The pi uses a very common micro-USB port for power. Hence any mains to USB phone charger with sufficient maximum current, in conjunction with a USB to micro-USB cable, is suitable for the device. The necessary power rating for the power supply was calculated by summing the touchscreen maximum current, 1A, and the PI maximum current, 0.5A, as the other components are only contributing marginally to the overall power consumption of the device. However it is important to note that during normal use, the device will consume far less power.

3.5. Product Ergonomics

The hardware of the product can be divided into internal and external hardware. The internal hardware, hidden to the user, is composed of the Raspberry Pi and the cable connections (Adafruit.com, n.d.). On the other hand, the external hardware requires good ergonomics, being the only surface of interaction between the user and the device. The most essential hardware part with respect to the user is the touch screen. A large screen size was chosen in order to implement a visible, complete and intuitive user interface. This allows the home screen to encompass as much information as possible such as temperature data, costs and environmental and energy saving data. The screen dimensions are 194mm x 110mm x 20mm but only 155mm x 86mm represent the visible part, with a resolution of 800x480 pixels (Tech, 2015).

Another crucial hardware component is the case. Made out of a resistant and light polymer, it consists of 5 individual parts and is assembled to perfectly fit the device. 3D printing was chosen over other methods thanks to the unique design flexibility it offers. In order to simplify the process, it was decided to make use of some open source design files made for our screen. Using a software called Cura (Refer to Appendix 8.3 for the 3D models of the case), the design files were formatted according to the Ultimaker2 printer's requirements (ICAH.org, n.d.). Printing took place in the Imperial College Advanced Hack-space facility located in the college's design engineering faculty.

The case has various benefits: it provides good protection for the hardware and makes the device visually appealing.

Figure 11: the prototype external hardware

4. Product Prototyping

4.1. Working Strategy and Team Management

The team is made up of seven students. The significant and diversified workload necessary to build a fully functional prototype made it necessary to give each student a significant responsibility in the project's development phase. The roles were distributed during the initial stages and were maintained throughout the year as follows:

Theo Franquet: *Project Coordinator, Website Design, Database Management*
Ilaria Albanese: *Thermometer Implementation, Project Treasurer*
Matthew Abdoul Rahim: *Software Development for User Interface*
Alexandre Abou Chahine: *Heat Transfer Research, Enclosure 3D Printing*
Guillaume Ramé: *Software Development for Back End of User Interface, Database Management*
Xingzi Zhu: *Societal and Individual Behavioural Research, Statistical Information Selection*
Yumeng Sun: *Website and User Interface Graphical Design, Project Secretary*

Each group member has been working closely with each other and every idea and rebuttal was taken into consideration and discussed during weekly meetings. Prototype and website designing started early on during the autumn term, anticipating any failure to be taken care of later on. Research and task progress was accounted for by every group member on a regular basis to make the team well aware of the technicalities of the product. To further improve in efficiency working as a team, internal deadlines and meeting minutes were agreed on (Refer to Gantt chart and Minutes in Appendix 8.5). The team's interaction with the supervisor had a significant impact on the evolution of the vision of the product. Over the meetings held once every two weeks, Dr. Pitt raised the importance of user profiling and personalised interaction with the different customers types, implemented using social behaviour research. Further discussion was held towards making a "future proof" device, designed to handle changes in power production and consumption in society. Overall, being able to include every group member in the design and development of GLOW and getting some expert feedback on the progress made, was key in order to assemble a functional prototype.

4.2. Testing Processes

4.2.1. Functionality Testing

Following the development of the software, it was necessary to carry out testing in order to find any bugs that could impair the performance of the device. This required using the product in all possible configurations, as well as checking if individual functions behaved as intended (e.g. returned what they should). Testing every new function written at the end of the development phase is an integral part of coding, however it was necessary to test that the functions cohabited properly. While the bugs uncovered by this extensive testing process were usually of minor importance, the sheer number of them made it a time consuming procedure. Another possibly problematic element was that the Raspberry Pi's operating system is not identical to those run on the development computers. System commands, whose role resides in allowing communication between the code and the operating system, were not necessarily identical to those on the development computers, increasing the relative complexity of troubleshooting. This essentially forced the developers to test any changes directly on the device, to make sure that they did not bring out further issues.

4.2.2. Market Testing

After bringing the project to completion, it would be necessary to test the general public's perception and interest in the product. This would mean performing a test run with a small amount of households where their usage patterns are recorded and analysed over a certain period of time. The results of this study would not only return whether or not the implementation of the software is successful in the device's mission, but also return feedback on how to make the device more appealing to the market. Only through this kind of semi-widespread study would it be possible to confirm that the project has met the design criteria. Of course this study has not been performed due to time and money constraints, but if the project had been fully brought to completion, user testing would had taken place in the near future and would have been a major step in turning the prototype into a product.

4.3. Challenges met and Failure Analysis

4.3.1. Hardware

4.3.1.1. Wi-Fi adapter configuration

The Wi-Fi adapter included in the product was advertised as functional out of the box with the raspberry pi. This proved to be inaccurate, as additional configuration was needed to make it function, especially with the college's WPA2 Enterprise Wi-Fi connection. Ultimately, an application called "Wpagui" was used. This application serves as a user interface for the Wi-Fi driver (wpa_supplicant) included in the Linux distribution. Instead of having to manually modify configuration files through the command line, wpagui presents the necessary data fields and makes the Wi-Fi setup process seamless.

4.3.1.2. Thermometer configuration

Due to a bug in the Linux kernel, the Raspberry Pi originally was unable to read from the GPIO pin the thermometer was connected to. This was fixed by adding an argument ('dtoverlay = w1-gpio') in /boot/config.txt. The latter is a text file that tells the Raspberry Pi what to do when it boots up, while the command above notifies the Raspberry Pi to load the GPIO driver on boot instead of waiting for the user to actually use it (with the 'sudo modprobe w1-gpio' and 'sudo modprobe w1-therm' commands).

4.3.2. Software

There were several challenges involved in creating the software for the thermostat - the initial problem was that GUI programming was an entirely new concept to the group. To abate this, programming was started while the design was still in progress, to practice and become more familiar with the methods involved in such a task.

Another issue to consider was the timing of software production, because not only did describing the front end layout in code take time, but it depended on a variety of other tasks being completed. Having an interface fully designed, which involved deciding upon aesthetics, functionality and how the user would interact with the software, was of pivotal importance. To address this issue, deadlines and timescales were planned out ahead of time to ensure that the time available was used effectively.

4.3.3. 3D Printing

The 3D printing part of the project took a lot more time than initially expected due to multiple problems with the printers. Printing with this technology is a very tedious process, usually taking hours per print. Moreover, the printers are very sensitive machines: it is not uncommon for a small error in the printer to lead to the whole print being unusable.

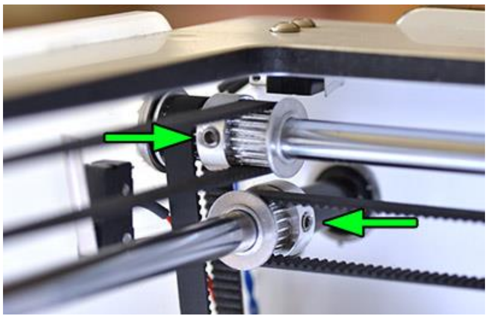

Figure 12: Loose pulley resulting in faulty layer shifting

The main part of the design is the shell: its print was 13 hours long and it took five trials to achieve the desired result. Due to a problem in the motors of the printer, some layers kept shifting to

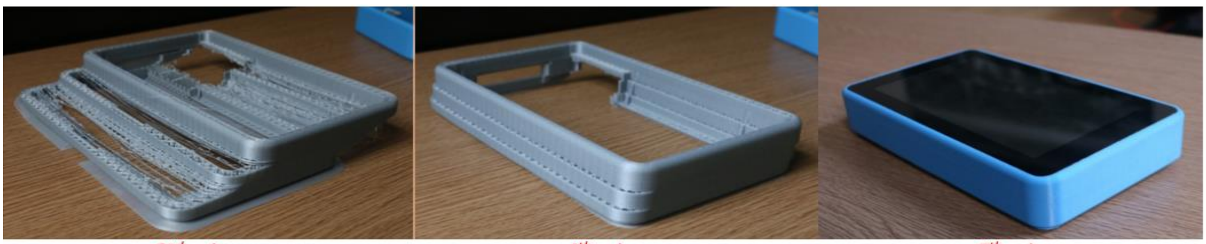

Figure 13: Failed attempts at printing shell of the case against successful print

the left, as can be seen in the pictures below. After researching the problem, it was found that one or more pulleys of the printer could have become loose with respect to their axles and needed to be realigned and tightened (Theor, 2014).

Another issue was that of obtaining accurate prints, as they resulted several times in being skewed and twisted. These errors, leading to unsuccessful prints and new trials, were due to purely random machine failures. After all the required components had been printed out, some of the pieces were skewed to the point that assembly proved to be severely difficult. In the end, it was decided to assemble the product differently than anticipated, requiring to make a few modifications and extra printing in order to achieve the same result. For example, it was necessary to drill a hole in the side of the case in order to let the power cable through, as well as permanently sticking the screen in place instead of screwing it. Finally, other problems involving the 3D printers, such as changing the filament, setting the correct parameters for the print or the colour of the filament itself, slowed the progression of this process.

5. Long Term Vision

5.1. Unaddressed Issues

In the long term, GLOW visions to solve more complex energy issues such as fuel poverty, and to help households with micro generation to utilise energy surplus in more meaningful ways. Potential cooperation with energy suppliers would be advantageous so that GLOW could bridge the connection between the suppliers and the consumers.

5.1.1. Fuel Poverty

Fuel poverty is a serious issue in the UK. According to the 2015 Annual Fuel Poverty Statistics Report, in 2013, the number of households in fuel poverty in England was estimated to be 2.35 million, representing approximately 10.4% of all English households (Department of Energy & Climate Change, 2015). A fuel poor household is defined as one which needs to spend more than 10% of its income on fuel use and to heat its home to an adequate standard of warmth. In England, this is defined as 21°C in the living room and 18°C in other occupied rooms (Energy UK, n.d.). Fuel poor households may move out of fuel poverty by reducing energy consumption, increasing incomes, or a combination of both. The emergence of micro generation lately might provide another method to alleviate households from fuel poverty.

5.1.2. The Emergence of Micro generation

Micro generation is defined in Section 82 of the UK's Energy Act (2004) as the production of electricity or heat from a low-carbon source at capacities of no more than 50 kWe (Kilowatt-electric) or 45 kWth (Kilowatt-thermal). It embraces a variety of technologies, including micro-wind turbines, solar photovoltaic arrays, solar hot-water systems, combined heat-and-power units and heat pumps (Allen, 2009). As part of its commitment to tackling climate change, the government is putting in place a range of financial incentives such as Feed-in Tariff, to encourage household micro generation (Department of Energy & Climate Change, 2011). Energy saving decisions for those households are more complicated, as they generate and consume energy at the same time. The current target users of GLOW does not include those establishments. In future developments, features handling surplus and deficit from micro generation will be added. Furthermore, the surplus of generated energy could be reused in other ways, such as fighting against fuel poverty. The possible redistribution of energy from excess generation to the needy will be discussed in the section 5.2.

5.1.3. Role of Energy Companies

Energy providers are inevitably part of any country's biggest corporations. In the UK, the big six - EDF, E.ON, SSE, British Gas, Npower, Scottish Power - provide gas and electricity to 50 million homes and businesses. Virtually every household is dependent on their service, yet there does not seem to be any other way for these companies to interact with or offer personalised services to their customers aside from through emails, saturated phone lines and paper mail. Some companies have been trying to design hardware and more specifically thermostats, British Gas's "hive" and Npower's "nest" etc., to be able to be closer to their customers. There is a need for a platform on which companies can develop their relationship with customers.

5.2. Energy Redistribution

5.2.1. From Potential to Necessity

As the number of private solar energy producers increases, excess energy will very likely develop into a problem: approximately 20-40% of the average household's total solar production is returned to the electric grid (commonly called "excess generation"). (SEIA, n.d.). It is not hard to imagine that people will be willing to donate this surplus to those in need.

This objective could be achieved in two main ways:

1. Obtain an agreement with the Grid
2. Auto sufficient energy communities

The first option clearly presents major obstacles as it would entail a comprehensive plan in conjunction with big-scale management. While net-metering is largely diffused, managing a system to redistribute energy to the less well-off for no extra profit would be much more complex.

This is why the energy communities' option might be more feasible. Community-scale projects enable residents to feel valued and empowered individually while having the biggest possible impact. Transmission losses are in fact significantly reduced and the use of renewable resources guarantees more energy security in sight of future shortages in fossil fuels.

This concept has already been developed in the UK by the Meadows Ozone Energy Services (MOZES) project. Solar panels were installed on 55 local houses: those hosting the panels make use of the electricity generated, while the revenue from the Feed-in Tariff is returned to the community. (MOZES, n.d.) One further step has been taken by the Community First! Village, the world's first community that runs on crowd sourced energy. This project is carried out by Gridmates, a cloud platform that enables peer-to-peer donation of energy. (Gridmates.com, n.d.) The idea to leverage on internet technology to ensure access to electricity for those in need clearly has a great potential.

The inevitable replacement of combustion engine cars with electric cars can also been seen as a unique opportunity to share energy in the near future. With considerable research effort being put into more efficient battery technologies, tomorrow's electric cars will form a whole new energy network, accounting to hundreds of kWh being stored. This "grid in movement" would be a perfect platform over which energy can be shared around individuals.

As the user base of GLOW will get larger and its diffusion will increase, it is possible to imagine that one of the customisations and applications on the device could provide a similar peer-to-peer sharing service. The connection of the device to the web and the open source nature of its code and OS make it particularly suitable for this proposal.

5.3. An Open-Source approach

5.3.1. Benefits of a Platform Opened to 3rd Parties

In light of the beliefs of the group, further stages of the project will include making the software open source. Making updates and application design open to 3rd party entities will extend the product's lifespan while always providing the user with the most reliable version of the software. It will also allow greater personalisation of the device, as it will provide more flexibility than the original version. The user will be able to adapt the device to personal needs, adding or modifying features. Creating new applications to achieve diverse objectives will make it possible to face different challenges to the ones already taken into consideration by the team. This may mean more customisability for every single user, but also the possibility to tailor the product to a particular company or industry. Coming back to the lack of a close relationship between energy companies and their customers, offering an open source OS would allow these corporations to create their own applications to run on the device. Expanding the potential aims of GLOW may even lead to including an entertainment side with games and leisure applications to encourage more interaction with the device. Finally, it will further strengthen the sense of community of the users, who will be able to help each other with the customisation of the product, share their implementation of new features and combine their knowledge for a more enjoyable user-experience.

5.3.2. Technical Challenges

In order to open the platform to third parties, it would be necessary to develop an API so as to distribute access to various hardware and software resources on the device to the developers of applications. This would require a considerable amount of time to develop an API that is as easy to use as possible. It would also necessitate setting a standard in terms of development language. This last point is not problematic itself due to the fact that the program is written in python, a widely used language. Nevertheless, some developers more familiar with C++ for example might take this as a drawback, even though the learning curve for python is relatively gradual. Since opening the device to third party development would inevitably extend the product's lifespan, it would be necessary to further proof the hardware so that it maintains relevancy in the future. This could possibly mean investing larger amounts of money in the hardware itself, to achieve better resilience now and acceptable performance in the future, which developers will leverage to achieve advanced features. By consequence, the shelf price of the product could increase past the desired amount, potentially reducing the attractiveness to the consumer. Another important consequence of the product's extended lifetime is component failure. Even though integrated circuitry such as the device's processor have a very large mean time before failure (MTBF, essentially infinite), they are not protected from random current or voltage surges due to inadequate, low quality, or even failing power supplies. Another example is the SD card, which can undergo a limited amount of writes, degrading performance over time and inevitably leading to failure.

6. Conclusion

The notion of the internet of things has opened numerous doors for new ideas in connecting everyday devices to operate wirelessly and with greater flexibility. Revolutionary functionalities became possible and a whole new and very promising market has introduced itself to the general public. GLOW's thermostat belongs to this line of products and goes far beyond offering comfort to the customer by exploiting its connectivity capabilities and give users an in depth understanding of their heater's power consumption. Climate control accounts to more than half of a household's bill expenses, yet residents are not able to visualise their spending and energy consumption in real-time, something that already is a norm in mobile/broadband subscription, personal vehicle fuel pumps, public transports subscriptions etc. This is precisely where GLOW's thermostat steps in to complete the loop for transparency in any household's major expenses.

The word "smart" is used to describe a vast majority of today's personal devices, specifically by competition on the market. However, being "smart" does not limit itself to making decision and calculations independently, but revolves around the capability of a device to adapt its functionalities to each user and to give customers the possibility to rethink their interaction with the device.

As a team of seven students, the concept was brought as far as possible and great emphasis was placed in building a fully working prototype to illustrate the potential of such a device that has not yet been introduced on the market. Scaling a prototype that could be accomplished in less than a year involved significant investment in both software development and hardware implementation, but also focused on the general public's various behavioural processes and the user's interaction possibilities with the device. The GLOW thermostat's unique versatility is implemented through a personalised website space, customisable thermostat interface and tailored statistical information.

Taking an initial concept to a fully functional prototype has led to rethink the limitations and further capabilities of the product. With increased development efforts and resources, GLOW's design has the potential to tackle many more issues involving power management in the domestic sector. This potential has been analysed by the team and would be applied to the fields of democratisation of self-powered households, fuel poverty and "supplier to customer" relationship (Refer to 5.1). Instead of independently implementing these functionalities, GLOW is envisioned as an open source operating platform where third party creators would be free to develop their version of a smart thermostat to bring its "smartness" as close to the one of the smartphone.

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8. Appendix

8.1. PDS

8.2. Initial Designs

The project is made up of three main areas: the GLOW thermostat device, a supporting website and an online database. In view of the fact that the website and the online database are supporting features, most of the analysis in this report will focus on the thermostat, especially its interface design. As the details of initial designs and how they are linked to the design criteria can be found in section 2 of the interim report, this section will only be a *brief overview* of the initial designs.

8.2.1. Device Functionality and Interface Designs

The initial brainstorming process started with the device interface and functionalities. This process was done on paper. Rough sketches of the device interface were drawn.

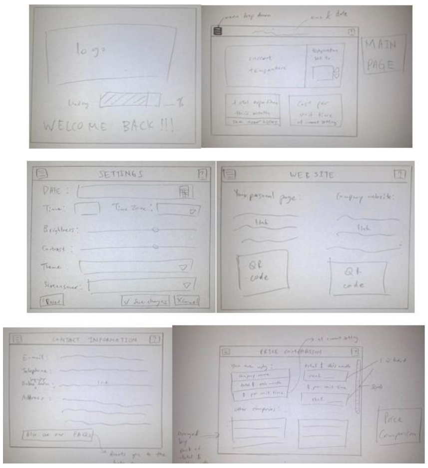


Figure 14: Interface Design 1

The first interface design, see Figure 14, contains a lot of details. It was later decided that some of these features are not necessary and such a packed interface design was impractical. Thus the design was modified and simplified to suit a touchscreen device. As a result, a new set of sketches was drawn for the second interface design, see Figure 15.

Figure 15: Interface Design 2

After further improvements and confirming the basic functionalities the device should have, the design of interface was carried on with software. Due to the choice of using a Raspberry Pi, the coding was done in Python and tested in a Linux environment. The first software interface design is as shown in Figure 16. As the project developed, some functionalities have been added or changed. However, the colour scheme and layout of the interface remained largely unchanged. The final design can be found in section 3.4.2 of this report.

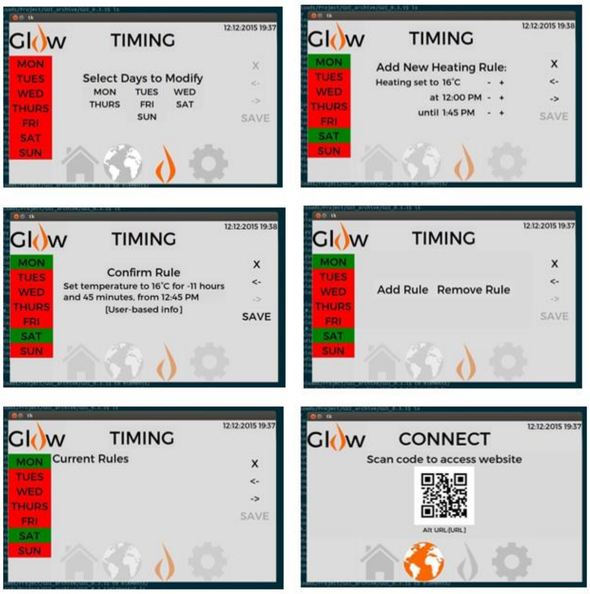


Figure 16: Initial Software Interface Design

Table 4 shows how the development of the interface design has improved to better meet the design criteria mentioned in section 3.1 of this report. While the first sketches have more features and functionalities, some of these have been removed due to being unnecessary or moved to the website to reduce the interface complexity. Thus, interface performance has reduced slightly. Reduced interface design complexity makes interface better meet the environment and customer requirements of a smart meter. The ergonomics improve as interface design is simplified and modified. Software design adds colour to the design, making it more attractive. Actual software implementation also allowed the interface to be tested.

PDS Points	**Ratings (0-5)**		
	Sketched Design 1	**Sketched Design 2**	**Initial Software Design**
Performance (PDS 1)	5	4	4
Environment (PDS 2)	3	4	4
*Maintenance (PDS 4)**	-	-	-
*Target Product Cost (PDS 5)**	-	-	-
Customer (PDS 11)	2	4	4
Aesthetics, Appearance and Finish (PDS 16)	3	3	5
Ergonomics (PDS 17)	2	3	4
Testing (PDS 21)	0	0	4
Total	**15**	**18**	**25**
**Note: As maintenance and target product cost are largely related to hardware, they are not relevant as design criteria for interface design.*			

Table 4: Unweighted Matrix for Development of Interface Designs

8.2.2. Hardware

Meanwhile, the team also made several choices for the hardware of our GLOW device, see Table 5.

Part Considered	Options	Choice Made	Reason
Display	1. Complete Touchscreen 2. Display with Buttons	Option 1	● Improve ergonomics. (PDS 17) ● Ease of interface design. ● Ease of maintenance via software. (PDS 4)
Screen Size	-	Larger than mobile phone but smaller than tablets.	● Reasonable size to improve ergonomics. (PDS 17) ● Suitable size to meet customer requirements of a smart meter. (PDS 11)
Temperature Sensor	1. Analogue 2. Digital	Option 2	● Does not require separate analogue to digital converter - reduce costs (PDS 5) ● Better performance (PDS 1) ● Ease of software design
Case	1. Buy 2. Manufacture	Option 2	● Flexibility of design and ease of testing (PDS 16 and PDS 21) ● Reduce costs (PDS 5)

Table 5: Initial Design for Hardware

Any other hardware parts were not considered in the initial design for hardware. More details on eventual hardware parts' choices and final hardware design can be found in section 3.4.3 of this report.

8.2.3. Website and Database

At the same time, the initial design of the website was also confirmed. It was decided for the website to have both public and private areas. The public page(s) will introduce the GLOW project and device, while the private page is for users to input their profile information. This includes age range, energy provider, housing parameters for thermodynamics calculations etc. The initial design for these two pages is as shown in Figure 17.

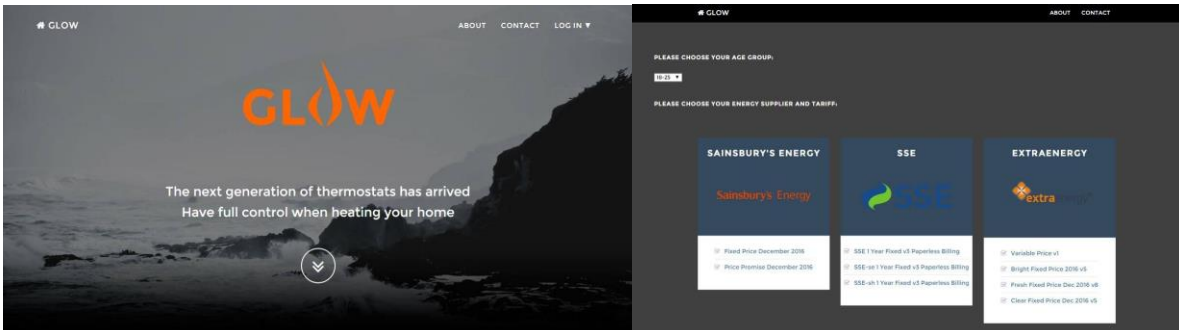


Figure 17: Initial Website Design

The website utilises HTML, CSS and JavaScript. There are many templates available online. However, it was decided against the use of a full template since the website had to be linked to a database and templates usually do not allow easily for this functionality. While the overall idea of having both public and private areas for our website remains unchanged, the contents of the public page(s) have changed greatly. There have also been some minor changes to the layout of the website. The online database that contains user details and interacts directly with the GLOW device is now fully functional. Please refer to section 3.4.2.2. of this report for more details on the website and database designs.

8.2.4. Thermodynamics

Last but not least, the mathematical calculations behind the device were also designed. Extensive research was done in thermodynamics and domestic heating calculations to minimize and simplify the factors needed to give an accurate estimate of energy consumed based on the device's settings.

8.3. 3D case Models

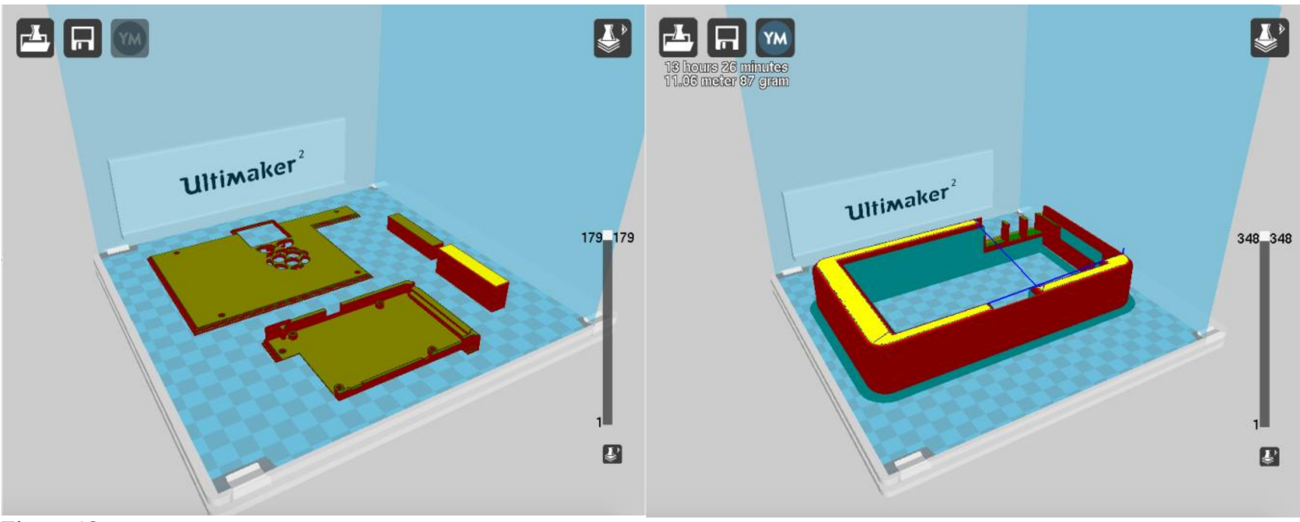
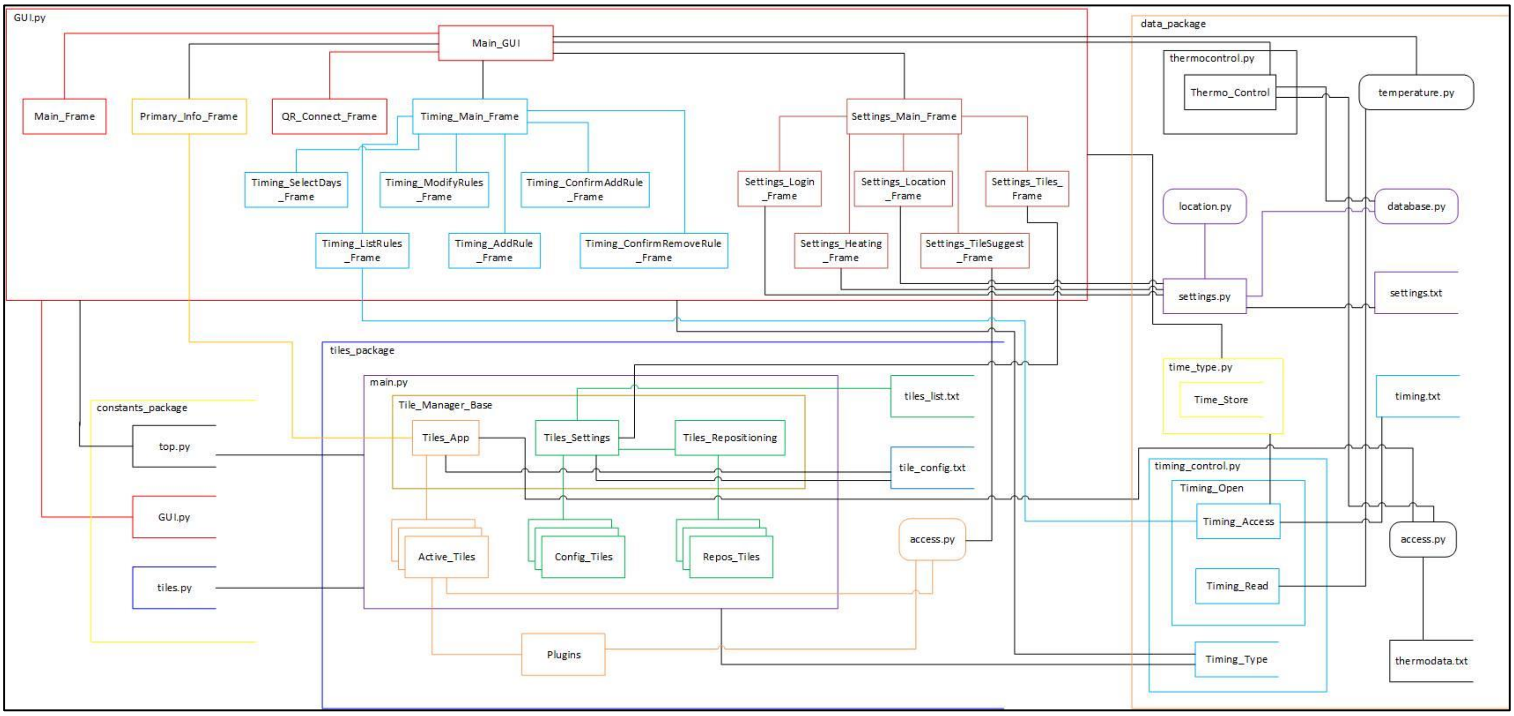


Figure 18

8.4. GUI code

The code segments for the front and back end software is not present in the appendix, due to its excessive length and to simplify formatting of the report. However, it is available on request if needed. The following diagram presents the software's architecture.



*. User Implication and Sense of Community - GLOW's Philosophy

The possibility to donate energy to those in needs would be just one more aspect of the philosophy behind GLOW. The product was born from a simple solution to a simple problem, but evolved to become much more. The user group created with GLOW is more than a source of data and statistics: it is a real community of people working towards a bigger global intent. The culture on which GLOW has its roots is one that believes in the potential of the individuals to contribute together to more sustainable solutions. The humankind depends on the environment for its welfare; at the same time, human activities can seriously impact on it even through very little actions. GLOW aims at creating a sense of community between users, with the aim of letting them help and assist each other as well as the whole planet.

8.5. Meeting Minutes and Gant Chart

Theo Franquet: Leader, Lead web developer
Alexandre Abou Chahine: Assistant Leader, thermophysics research, 3D case

Yumeng Sun: Secretary, Web developer
Guillaume Rame: Raspberry Pi
Matthew Abdul-Rahim: Raspberry Pi
Ilaria Albanese: Treasurer, Researching databases and help with software programming, thermometer
Xingzi Zhu: Countersignatory, Stock Keeping, Researching energy websites

Supervisor: Dr Jeremy Pitt (http://www.iis.ee.ic.ac.uk/~j.pitt/Home.html)

***Meetings every Monday, 2-3pm, at EEE Computer Lab

Deliverables:

- ~~By Wednesday 14 October, 22:59 - Outline proposal~~
- ~~By Monday 19 October, 22:59 - Voting~~
- ~~By Wednesday 2 October, 22:59 - Join a group~~
- ~~From Friday 22 October - Arrange meeting with supervisor~~
- ~~By 17 January, 22:59 - Interim Report~~
- By 13 March, 22:59 - Final Report and Website
- On 22 March - Presentation and demo

Meeting 1 22/10/2015

- assignment of roles and tasks
- discussion about stock keeping (rent EEE locker)
- decided on weekly meeting day and time
- created Facebook group and meeting minutes

Things to do:

- Individual research
- Rent a EEE locker
- Need someone in-charge of hardware, someone to do research on which sites have heating price databases, and someone to assist in web developing (distribute roles among Ilaria, Xingzi and Yumeng)
- Something about joining robotics club???

Meeting 2 26/10/2015

- Locker rented (Level 3, 374) by Xingzi. £5 per year.
    - Combination lock (6993)
- Researching databases and help with software programming
    - Xingzi and Ilaria
- Website developing
    - Yumeng
- Interface design (working with software)
    - Everyone can contribute, best design used
    - Layout, buttons, options
- Make an algorithm to suggest which company is the most price efficient for the user
- Main functions on device, additional functions on website

Things to do:

- Need to confirm hardware to order (raspberry pi*, screen (7" - size of iPad mini)*, thermometer etc.)
- Ilaria look up on how to claim from budget (which stores can we order from?)
- Arrange meeting with supervisor (think of choosing a supervisor?)
- Everyone try to design a suitable interface!!!
- Everyone come up with a few product names.
    - ETNA (logo on FB grp)
        - Europe Volcano
    - AESTAS

        - Roman Goddess of Summer, http://www.thaliatook.com/OGOD/aestas.html
        - meaning: our smart thermostat allows you to feel as though it is summer
    - GLOW
    - AURORA

Meeting 3 2/11/2015

- Ilaria Absent
- Email supervisor & arrange meeting
    - Next week Monday (12-1pm or 2-3pm)
- Confirm interface
    - Temperature setting: use up and down buttons
    - Settings page (brightness, screen off time)
    - QR code page (with short links)
    - Swipe or tabs to change page
    - Draw local time from Internet
    - Price Comparison
    - Programme

Things to do:

- Choose name & logo???

Meeting 4 9/11/2015

- Confirmed component ordering platform (online stores)
- Confirm hardware to buy
    - Latest raspberry pi module [Onecall 2461029]
    - 7" Raspberry Screen [Onecall 2473872]
    - MicroSD 4GB [Rapid 493633]
- Get a USB module thermometer/ thermal sensor for the raspberry pi or build one?
    - Found on Amazon but not on stores. Try to negotiate for budget?
    - OR: consider alternative digital thermal sensors available on stores?
    - OR: Build an analogue sensor and use with an analogue digital converter

Things to do:

- Further suggestions on product name
    - ITER (Intelligent Thermostat for Expense Reduction)
- Rearrange meeting with supervisor: 12 Nov 1pm EEE Level 10 Supervisor's Room
- Order confirmed components

Supervisor Meeting 1 11/11/2015

- Price transparency (is this the actual objective?)
    - Think of the actual problem you want to solve!
- Energy saving (so that ppl don't use more energy because they find it cheap, negative behaviour change) - don't focus only on prices (your target audience is not only students, be more abstract?)
    - Give statistics to give incentive to save energy
    - Consider social aspects too
    - Game/ competition to save energy??? (Refer to PHD students' work?)
    - Instead of one house, do a few (a system) - to encourage energy saving - cooperation - collective attention
    - User modeling (rich ppl, poor ppl, antisocial ppl etc…)
- Consider houses that have their own energy supply (PV panels etc.)

- Prototype need not include all considered functionality
- Feasibility VS Ambition

Things to do:

- Do reading and research!!!?
- Arrange next meeting with supervisor

Meeting 5 16/11/2015

- Monday 2pm as usual
- Raspberry pi has arrived
- write problem definition & PDS bullets points
    - Define the problem and link to functionality (Solution)
        - Lack of control and understanding of heating (electric and gas) expenses - Price transparency (& Contractor Price Comparison [optional])
        - Energy overconsumption - Energy saving via behavioral change; Give statistics to give incentive (energy saved can be used to power…) to save energy (user profiling - different statistics for different age groups/ occupation type)
    - Audience
        - United Kingdom
        - Both houses and flats
        - All age groups/ occupation type etc.
        - Need special functionalities for direct debit payment users?
        - Only those using grid power
            - How about those with their own energy supply? (Solar power etc.) - might not be adapting our project to these group of users.
- Website content
    - User Profile and Settings
    - Website page (product information and functionalities)
    - Additional functionalities
- Prototype - should be ready before holidays
- Interim report
    - PDS, management deadline, idea details, prototype functions, future extensions, references, Appendices etc.
    - Do during holidays?
- Decided to use Digital Thermistor

Things to do:

- Write up a proper problem definition & PDS from above points (see separate Google docs)
    - Can do up a bullet point for supervisor
- Next week start separating report up and assign work
- Confirm details for feasibility study
- 3D printing for the case (next term) - can start thinking of design

Supervisor Meeting 2 20/11/2015

- Friday 1pm
- Understand our users - He gave us some reading about collective action. (The reading is with Xingzi)
- Think both from consumers and citizens' perspectives
- we currently focus on the present issues - might want to think about the future of a distributed energy system
- Consider what actions users take-switch down the heater/insulate windows
- Our project can solve energy poverty - we can help people without sufficient income to pay for the heating to visualize their spending

Things to do:

- building of the prototype
- Things to do before the next meeting

-present the idea of interface
-system architecture(hardware/software configuration)

- Consider
  -user behavior(Xingzi research on it)
  -what info we shall present to the users
- Arrange next meeting with supervisor

Meeting 6   23/11/2015

- Alex absent
- Brief all members about supervisor meeting content
- Discussed what to do next (see below)

Things to do:

- Write a proper PDS (in drive folder)
  - Can be slightly vague initially
  - Some points can be "not applicable at this point"
- Decide name and logo
- User behavior analysis - Xingzi & Yumeng (read article provided)
  - Brainstorm what information to provide to which group of users (affect interface design)
- Continue working on raspberry pi interface
- Start working on website soon
  - Wordpress
- Choose thermostat
- Alex to explain his research to group
- Report task assignment
  - Read up criteria on BB
  - Assign before Christmas
  - Mainly research?
- Arrange next supervisor meeting

Meeting 7   30/11/2015

- Discussing what statistics to display - aim to encourage improvement in power saving
  - Power saved compared to average in region (on device)
  - Optional non-anonymous selection
  - A button that directs to money saved
- What to put in website - bootstrap (Grayscale theme)
  - Public - product explanation
  - User - login & settings
- report work distribution
  - Requirements see PDF in drive
  - See drive for details

Things to do:

- See same section in previous minutes in blue.
- Arrange next supervisor meeting (for last week of term)

Meeting 8   7/12/2015

- Settle hardware delay problem
- Discuss project tutorial content
- Discuss stuff to show/ discuss with supervisor on Friday
- Product name decided: GLOW, logo done
- Discuss device design roughly
  - Position of thermistor probe
  - Case design

Things to do:

- Everyone continue working in their parts of the report (refer to tutorial slides)
- Interface design

Meeting 9 & Supervisor Meeting 3 14/12/2015

- Thermometer sensor decision remade (better option discovered)
- Supervisor meeting today
    - Mainly show him interface design
    - Visualization of important data!!! Instead of Joules of energy used, show energy used can power (electrical appliance) for (time) etc.
        - Predictions?
        - Professor Spence? Human-computer interaction books
    - Different data shown to different types of user
    - Document what you are trying to get the user to do, how you would like them to react, what you would like them to understand, how you are going to achieve it
    - Encourage ppl to check statistics (incentives, point accumulation etc.)
        - Show data every time some heating settings are changed
        - Users can set notification frequency (how often data notifications will be sent)
        - Or notification after data has not been checked after a while
        - Attention capturing (red if too much energy used? Green if very good?Yellow if normal?) - link to phone app?
    - How to sustain users' interest in the product?
    - Find out how users use this device
    - Device is opt in (but if it is not configurable/ customizable, ppl might be discouraged from using it)
    - Future extensions - api

Things to do (for Winter Break):

- Individual report sections (by end of December)
- Compile & submit interim report (everyone must read through the report at least once before this)
    - Can consider emailing report to supervisor before submission
    - If report can be submitted multiple times can submit drafts
- Website & device interface design

Meeting 10 11/1/2016

- Hardware available
    - Screen 16:9 ratio
    - Raspberry Pi
    - SD card
- Report matters
    - Confirm suggestions & changes
    - Tone & Language
    - Delete overlapped content
    - Format report
    - References and Appendices
- Submit report for formative marking by 6pm

Things to do:

- Report
    - Further Editing
    - Submit by 17 Jan

Meeting 11 18/1/2016

- Report submitted yesterday
- Thermometer (digital) arrived
- Arrange next supervisor meeting
- Updated member roles and tasks (see top)
- Discuss further progress needed
    - Program
        - Calculations

        - User interaction
    - Case - logo
    - Due on March: Report, Website, Presentation & Demo
    - Power supply, wifi chip?

Next:

- Supervisor meeting (Thursday)
- Management discussion after supervisor meeting
    - Timeline/ chart etc.
    - More roles & tasks discussion

<u>Supervisor Meeting 4</u>   <u>26/01/2016</u>

- show supervisor project progress so far
    - website
    - device interface
    - report
    - partially printed 3D casing
- supervisor comments and suggestions
    - user profiling has to include more than age group
    - personal page of users on website should be tabbed
        - some sections are mandatory upon first log in and others can filled in gradually as time passes
        - should show which sections are completed

Next:

- device
    - database fetching
    - thermometer
- user profiling (device and website)
- organisational Gantt Chart (see Excel file in drive folder)
- final presentation & report

<u>Meeting 12</u>   <u>16/2/2016</u>

- Discuss interim report comments
    - Gantt Chart - will be available for final report
    - Links between sections needed
    - Brief description of diagrams & figures
    - More technical details
    - Less referring to Appendices - Appendices only additional information!!!
    - Discuss competition - more analysis!!!
        - Make a chart
- Discuss progress so far
    - Website
        - Learn more page added
        - Some more photos & code to add
    - Hardware
        - wifi stuff haven't arrived
        - some problems with 3D printing of case
    - User profiling almost done
- Deliverables
    - Slides, PPT
        - Everyone do their own part???
    - Final report
        - See marking scheme on FB group
        - Improve based on interim report - especially research & structure (these are easier to improve on) - refer to interim report marking scheme

Next:

- Finish user profiling (done, see document in drive)
- Discuss deliverables
    - Plan the content page first (can be based on interim report)

- Finish programming device & website

Supervisor Meeting 5 23/02/2016

- A more detailed architecture diagram
- how different components connect

He wants to see the hardware next week, meet in the Robotics lab and the following week the whole thing
WIFI adaptor having problem

Be clear of what needs to be done and who is doing it(check the task to be done doc)

Website
want to have pictures of the product rolling

He is interested in the broad applicability

- how the product maximise different values
- appealing to different roles ppl have (good citizen/ saving money/ investment decision)
- how this can solve energy poverty

He suggested an example for future work

- BT MyDonate
- Add a donation feature

praise their generosity

Next:

- email pitt to meet
- same time next week
- assign tasks

Meeting 13 & Supervisor Meeting 6 01/03/2016

- update supervisor about project progress and team management details
    - everything is on track as planned in Gantt Chart
- modified report structure template
- finalised final report work distribution

Next:

- finish first draft
    - individual report sections by 6 March
- next supervisor meeting on 8 March 4pm
    - show supervisor report draft
- finish interface design
- finish website design (note the extra requirements from the marking scheme!!!)
- finish prototype & prepare for presentation

Meeting 14 07/03/2016

- Each member has complete first draft of their parts of the report
- Putting the report together
    - Resolve repeated content (especially hardware part)
    - Tenses and Tone
    - More options and choices in the initial designs, less details

        - Website template vs no template
        - Digital vs analogue
        - Touchscreen vs Physical Buttons
    - More figures (diagrams & charts etc.), avoid too much continuous text
    - Testing - confirm content (software & hardware?)
        - Software - debugging etc.
    - Production cost (prototype, production model, overall price…)
    - By this evening (6pm for those without Horizons, those with Horizons ASAP)
- Prepare for next supervisor meeting
    - Everyone improve on their parts of the report
    - Finish 1st draft of report
- Check website and interface progress

Next:

- Supervisor meeting tomorrow
- Finalise case printing and interface design
- Finalise report and website for submission
- Prepare for presentation

Supervisor Meeting 7 08/03/2016

- Basic content of report finalized.
- 1st draft printed for supervisor
    - 27 pages now. Need to cut down
        - cut down on repetition
        - reduce spacing to 1.2?
        - Determine which diagrams/ figures are useful/ effective and which are not
    - Still some sections to be completed
    - Note the numbering in the contents page!
    - Future work: plan for physical demonstration & user evaluation to determine device effectiveness
        - Definition of ergonomics (part of testing plan)
- Website
    - Add some default values to user profile information & include option of "brick" to wall material
    - Check if website works ok on other displays. (Tablets & other sized screens etc.) Remember to mention that website does not work on mobile phones!
- Explain report structure to supervisor
    - Can consider breaking down section 3

Next:

- Finalise case printing and interface design
- Finalise report and website for submission
- Prepare for presentation

Gant Chart:

Items	Weeks									
	11 - 17 Jan	18 - 24 Jan	25 - 31 Jan	1 - 7 Feb	8 - 14 Feb	15 - 21 Feb	22 - 28 Feb	29 Feb - 6 Mar	7 - 13 Mar	14 - 20 Mar	21 - 27 Mar
Term Duration											23 Mar
Detailed User Profiling											
User Interface Design											

Website Design											
Final Report Writing											
**Final Report and Website Deadline*									13 Mar (22.59)		
Presentation PPT											
Presentation and Demo Rehearsal											
**Presentation and Demo Date*											22 Mar
Current Progress	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**Week 9**		