1 Microgeneration data logger device with an integrated viability reporting system

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2 Abstract

The renewable energy market and its microgeneration sector is growing rapidly, however it is found that microgeneration products are not always being implemented in efficient locations. The project explores the potential to create a system that can indicate the efficiency of a proposed microgeneration implementation by creating a low cost, system based solution that integrates data from real world meteorological sensors and particular microgeneration products. This enables the user to compare in real time power generation data and then to aid the economic viability reporting process used to justify the siting of microgeneration renewables.

The system is developed by researching the areas that make up the viability report and designing a method to automate the processes, using a mixture of hardware and software. The system is designed and documented as a potential system and implemented as a prototype of the system. All the key aspects of the system are documented and tested as well as full system tests, resulting in a system which is able to take in real world data from meteorological instruments and display is on a central web based application.

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3 Introduction

The rising cost of electricity, the increased concerns over climate change and the finite nature of fossil fuels means that the generation of electricity from fossil fuels is widely accepted as *not to be the way forward* in meeting the increasing demand for electricity. Instead new, more efficient less polluting technologies are being employed to generate our electricity.

One form this takes is the production of electricity through renewable energy generation, this is so called renewable because the source of the energy is freely available without having to consume finite resources. These sources include, wind, solar radiation, gravitational (tides, hydro-electric) and thermal. Converting these sources efficiently into enough useful energy in the form of electricity is probably one of the largest challenges facing developed and developing nations.

For each of the different sources there are a very large number of factors which need to be considered to make sure that the electricity can be generated efficiently and economically. Initial investigations must look into the potential that any particular site has for generation and then match it to a relevant technology.

One of these technologies is microgeneration. Microgeneration appeals to the domestic to small business market due to its low cost, potential to reduce the businesses' carbon footprint and to generate income from sale of excess electrical power. The problem for this kind of generation is that a very wide range products exist on the market, with an equally wide variance in claims for their potential to generate electricity by those who are selling these products. The only method to properly asses whether a particular product is viable, is to actually gather data on the proposed site and map it to the product's specifications.

This isn't a problem for large scale generation as site surveys make for a small fraction of the cost of implementation. However for domestic or small business this can raise the cost of implementation by a significant enough amount to make the cost prohibitive or uneconomical in the short to medium term.

This project aim to help with the match making process between technologies and site gathered data by creating a low cost integrated system in which real world data from a particular site can be gathered and evaluated against real world microgeneration technologies.

3.1 Objectives

1. Research the data needed to make accurate economic viability reports, for the siting microgeneration products.
2. Research the suitability system designs that meet the defined requirements
3. Develop a low cost flexible system design
   Identify..
   1. Common use scenarios
   2. Communication requirements
   3. Computation requirements
   4. Target hardware platform
   5. Target software platform
4. Build prototype system hardware and software
5. Critically test prototype system

4 Literature review

4.1 Introduction

To meet the project aims and objectives, good quality information on the following topics is essential to build a system that can give accurate and useful results. It is also useful to find out the context for the system and how similar existing systems have been developed.

4.2 Methodology

Relevant material has been taken from:

- Various resources located by using Brunel University's library search engines, which are able to search e-journals, available books, e-books and other academic publications.
- Directly taken from professional bodies such as the IET and IEEE.
- Brunel University's academic staff
- Industry publications – feasibility studies, data sheets and product specifications
- UK Government organisations

Where possible the information has been taken from sources which are peer reviewed, well known, recognised and where the age of the resource does not affect the accuracy of its conclusion. Some sources, such as data sheets and feasibility studies were not publicly available and therefore can not be considered as having a high accuracy, they were received upon request from the retailer or service provider. These are marked as "*received by request...*" in the references section of this report. With particular reference to data sheets for microgeneration products the accuracy has been known to be variable[16], where possible product data has been taken from products which are in the Microgeneration Certification Scheme[17] which aims to certify the accuracy of product data.

4.3 Metrics

The metrics that are used to make measurements are taken from the standards use in academic texts and industry, from all the publications read, the following are the standards used:

Name	Short reference	Description
Velocity	V	Measured in Meters per Second (m/s)[1]
Volts	v	Volts
Irradiance	W/m^2	Energy from short wave solar radiation
Power	kW	Kilowatts (1000 watts); measurement of energy. In electrical terms a product of current and voltage
Power in an hour	kWh	One Kilowatt of power delivered/produced in an hour

Table 1: Standard metrics used

1. In this report and in industry the metric of speed and velocity are synonymous, although one is a vector and one a scalar, wind speed **as measured** is a product of both direction and magnitude.

Occasionally in the case of the Met office wind speed is published in imperial units: miles per hour, the conversion factor of $m/s = mph \times 0.447$ is therefore used.

4.3.1 Conclusion

Standard metrics currently used are sufficient for meeting the aims of the project.

4.4 Microgeneration

The rising cost of electricity[1], the need to fill an energy gap, concerns over climate change and the subsequent need to de-carbonise the UK National Grid has prompted the government to bring into law various acts which commit the government to tackling these issues, Microgeneration is one way in which the government sees part of the solution.

The UK government in its Energy act of 2004[4] defines "microgeneration" as the generation of electricity "*which relies wholly or mainly on a source of energy or a technology" on "biomass, biofuels, fuel cells, photovoltaics, water (including waves and tides), wind, solar power, geothermal sources, combined heat and power systems and other sources of energy* [and] *technologies for the generation of electricity or the production of heat, the use of which would, in the opinion of the Secretary of State, cut emissions of greenhouse gases in Great Britain.* " and that the capacity does not exceed: "*in relation to the generation of electricity, 50 kilowatts*" and "*in relation to the production of heat, 45 kilowatts thermal.*"[4]

Microgeneration has many advantages over centralised energy production: It provides energy security as it does not rely on the national grid or finite resources, the inefficiencies of transmission (estimated to be 5-10% losses)[5] are removed and the initial cost and risk are in the private sector.

4.4.1 Conclusion

As the system is based around the microgeneration of electricity, it should include renewable technology products which have a capacity of no more than 50 kW as defined by UK government act.

Microgeneration is an emerging market expected to contribute a significant amount of power to the UK national grid in the near future.

4.5 Microgeneration demand

A survey[5] by the Energy Saving Trust showed that out of 6000 individuals 2/3 of those are in favour of renewable energy as a means of generation and 24% of them would opt for microgeneration using either solar or wind as the microgeneration technology of choice.

"*with the appropriate support small wind could supply 4% of the UK electricity requirement*"[6]

"*For microgeneration to have an impact on the UK electricity system, units must be installed by consumers in their millions* "[6] a prediction of 40,000 Giga Watt Hours[6] of energy generated due to wind and solar microgeneration in year 2050.

So far these statistics have come from UK government (related) sources which have all been pro microgeneration.

More recent reports[2] being published describe microgeneration to much less effective; professor Doug King states in his paper; "*The use of on-site renewable energy has become highly fashionable, but its contribution to the energy demands of conventionally designed buildings is negligible*"[3]. He is criticising microgeneration, or "on-site renewables", this is because he is of the opinion that existing and new building stock efficiency standards need addressing as a higher priority than promoting microgeneration. This is a fair point, but given that even the most efficient buildings use energy the role microgeneration can play to supply this energy is no different.

David JC MacKay, takes on a different point which relates to the low yield from wind microgeneration saying "*A 5.5-m diameter Iskra 5 kW turbine... ...mounted at a height of 12 m, has an average output of 11 kWh per day*"[7] , even though this is a physically large and expensive turbine it would be would not meet a typical home's electrical demands based on the British Wind

Energy Association's average of a typical home at 13kWh. David MacKay also poitns out that "*In a typical urban location in England, micro-turbines deliver 0.2 kWh per day* "[7] this would be a very small, (1.5%) proportion of energy use in a typical home in the UK.

David MacKay and others are suggesting that a large number of these micro renewables are being implemented regardless of the evidence to say that they are suited (efficient) for a particular location.

"*[microgeneration] Wind turbines do work, but only when installed properly in an appropriate location*"[15]

This criticism can be concluded to be caused by three main factors:

i) Misplaced over enthusiasm for microgeneration technologies

ii) Over exaggerated marketing claims based on higher yield values than are likely

iii) A general lack of good data to justify the technology on sites.

4.5.1 Conclusion

Solar and wind generation are the most useful technologies to include in the system as there is demonstrated significant demand.

Getting good historical data is crucial to getting accurate predictions on how a technology will perform on a particular site.

4.6 Economics

To gain the economic viability of a microgeneration technology the predicted electrical power output of the microgeneration product is taken by evaluating the gathered data against a product's energy conversion efficiency. For example if the data indicates that there is an average wind speed of 5 m/s and a selected wind turbine generates 0.5 kWh at 5 m/s then to work out the income from this, the current feed in tariff price needs to be multiplied by the expected kWh being generated.

$$Income = kWh\ generated \times price\ per\ kWh$$

Once the income is known it is then possible to multiply the income by time, to work out the amount of income generated in an amount of time; day, month, year etc. One important economic is the break even point, this is when the cost have been paid off from the income generated:

$$Break\ even_{Days} = \frac{Costs_{total}}{Income_{per\ day}}$$

Any income after the break even point is considered profit.

4.6.1 Conclusion

Working out the break even and other economic factors helps to show the efficiency of the technologies and if/when an investor would start to generate profit. Knowing this information as soon as possible helps to avoid costly mistakes.

4.7 Renewable microgeneration technologies

There are a wide variety of technologies that are considered for microgeneration. It is important to understand these to be able to create a system which can adapt to the different comparison requirements of each technology. As previously identified this will focus on Wind and Solar as the main microgeneration technologies:

4.7.1 Wind

Wind power comes from converting the kinetic energy in the wind into electrical energy by using a generator via a turbine[9]. Wind electrical power can be calculated by using the properties of a wind turbine as follows:

Generalised power equation (watts) $P = \frac{1}{2} \rho \times A V^3$

$A = Rotor\,(Area\,\pi \times R^2)\; V = Wind\ Velocity\ m/s\; \rho = Air\ density$ [8]. However particular wind turbine models greatly vary in design and therefore in effectiveness of converting this into electrical power, which is why wind turbine manufactures produce data sheets with this information on. Wind speed also varies with hight which can be adjusted for by the formula:

$$V_1 = V_0 \times \left(\frac{H}{V_0}\right)^{\alpha}$$

Formula 1: Wind gradient adjustment

$V_0 =$ Original wind velocity taken at 10m in m/s

$H =$ Desired height

$V_1 =$ Wind velocity at H m/s

$\alpha =$ Air friction: know as wind shear or Hellman exponent

Formula derived from[9].

The wind shear is the factor in which the movement of air on the vertical axis due to changes in air pressure affects the velocity on the horizontal axis.

Wind turbines also have specific wind speeds that they start operating at[12], these need to be considered when mapping wind speed values to wind turbines.

4.7.2 Measurement of wind

"*Wind speeds are difficult to predict and highly variable. New prediction tools are improved, but the Energy Saving Trust recommends that, where practicable, potential customers install anemometry [i.e anemometers] to determine their average wind speed over at least three months.*"[15]

Many wind speed databases exist but they have been shown to be greatly inaccurate in all cases seen, in some instances 93.7% inaccurate[16] *(see also appendix A)*

Wind speed is measured using cupped anemometers by the Met office[10] and Wind speeds are usually measured as 10 minute averages [9]. From 1st hand experience of viewing an electronic cup anemometer a hall-effect transducer is used to convert the rotational movement of the cup on its vertical axis into a series of pulses from the transducer. Depending on the circuit the values can be taken by counting the pulses or the voltage generated by the pulse width modulation effect that is being generated by the anemometer.

The wind shear can be calculated using anemometers set at different heights, and derived by using *Formula 1: Wind gradient adjustment.* Alternatively it can be taken from known environmental conditions such as *"stable air above flat open coast: 0.40"*[36].

4.7.3 Solar (PV)

Photovoltaics make use of the irradiated energy from the sun to in the form of short wavelength solar radiation, particular wavelengths generate electron-hole pairs, these are then polarised towards a negative terminal and the hole terminal (hole being the conceptual term for the opposite of an electron) which creates a potential difference and therefore volts and power[10].

The irradiance to power ratio can be mapped back to the power produced by any solar cell, but as is the case with wind microgeneration it is highly dependant on the product used and its associated efficiency[13].

4.7.4 Measurement of solar (PV)

The UK Met office use Kipp and Zonen [CSD 3] automated sunshine recorders[10], these use the irradiation measured in W/m^2 (Watts per meter square) from the sun and cost £1565.00[24] . The data sheets provided by manufactures of photovoltaic panels usually give the irradiance and power graphs[13] in the same units, this enables the estimation of a power value from a measured irradiance.

The Kipp and Zonen solar sensors which are used by the Met office use 3 photodiodes[14] the value taken from these has been calibrated to give a value of irradiance in W/m^2.

4.7.5 Conclusion

Given the wide range of efficiency and the non linear nature of microgeneration technologies, to map real world data to performance, it is best to compare values to a set of data rather than to calculate it via the technology's properties.

In the case of wind turbines it is possible to adjust values for varying height accurately

Solar and Wind potential can be measured using standard transducers that are readily available.

4.8 Existing systems

Systems exist to log data from meteorological sensors such as irradiance measurement (solar) and wind speed, these systems allow the user to look at historical values taken from their sensors.

The market currently consists of a range from amateur weather station devices to fully professional devices.

A selection of off the shelf, £2000 and less devices, which have weather sensors and data logging features are reviewed in *appendix B.*

From this, generally the higher the accuracy calibration of the sensors the higher the cost.

With the exception of the Rainwise MKIII-LR which has an option to add a modem on, all of the devices in this section of the market rely on being connected to a data logger device which stores data in flash memory to be downloaded by the user, or they rely on being connected to a dedicated PC via USB or RS232 serial 24x7 for long data capture times. Where sets or intervals are specified this can be interpreted as *a recording* from the sensor. If you were to capture every 10 minutes for an entire day as is recommend for wind speed[9], you would need 144 sets, scaled up for a year this works out as 52,560 sets – far greater than the capacity of the products listed in *appendix B*, making a days worth of data from multiple sensors impossible to store on the device.

If connected to a PC however the data storage is much higher and is only limited to the disk space on the PC, having a dedicated PC increases the cost of implementation significantly and puts the total power consumption much higher.

The very high end automated data loggers that the Met office use are Campbell Scientific CR1000s[22] these units are typical industry data loggers, and can be found described in use, on site surveys[37], this particular one has 4MiB of data storage, 18 input ports, very fast sensor sampling (up to 400kHZ) as well as a multitude of communication methods; such as GSM, RF (radio frequency), Satellite, Ethernet and serial RS-232[23], and cost £1,115 each[40].

When connected to a communication method such as GSM, data is typically downloaded from the data logger after each month of data collection[37], this low frequency of data collection is due to the high cost of making satellite/GSM dial-up connections.

Propitiatory software is usually supplied with these devices which allows the user to download their data to a PC, this can be limiting, as only particular platforms and formats are supported.

4.8.1 Conclusion

For long data logging, having a PC connected to the sensors 24x7 is not practical without having a dedicated PC, which increases the cost and complexity for the user. It also reduces the accessibility of the data by restricting it to that particular PC.

The expense of systems which do not rely on a PC being connected all the time is prohibitive, they provide more features and complexity that will ever realistically be useful for the target market. The additional cost of sending the data over networks such as GSM is also unnecessary. None of the systems integrate a facility to map the data to microgeneration products on the market.

None of these existing systems are suitable to meet the aims of this project.

4.9 Microgeneration environment

There are estimated to be over 82,000 microgeneration installations active in the UK[6], in which microgeneration technologies are located include:

- Small and Large businesses
- Homes retrofitted and “Eco homes”
- Housing estates
- Estates
- Schools and Collages
- University campuses
- Tall buildings
- Farms

With regards to the data collection systems, microgeneration users have one large advantage over the professional products; their sensors and data logging equipment is not going to be in a highly remote location (e.g. not up the top of a mountain). This means that the system can be designed to tie into existing power supply and most importantly existing communication networks. In particular the uptake of Broadband internet in the UK means that over 70% of adults[25] have access to this network via wireless and wired router/modems which are usually permanently connected to the internet.

4.9.1 Conclusion

Having this connectivity available removes the need for storage and retrieval systems on the data logging device. The option to have data transmitted over the internet to a central location becomes possible. Where this isn't possible ethernet provides a good standard to encapsulate over other networks such as GSM or GPRS.

5 System requirements and specification

By taking the findings from the literature review and the aims and objectives of the project, the system requirements are defined in this chapter.

5.1 Data

No.	Requirement	Design Specification
1	Acquire data over a long period of time to enable calculations to be performed that can determine the economic viability of a microgeneration device in a location	Data can be stored on a central server, the economic viability is calculated by using the data gathered and mapping this to a microgeneration product's data
2	Provide precision data	Data is to 2 decimal places, Time between data submissions are user controlled variable. 3 years worth of data can be stored on the server.
3	Provide secure data management	Authentication used on all aspects where data is held
4	Be able to display the data in an useful and presentable manner	Graph generation, tables, and forms used

5.2 Communications

No.	Requirement	Design Specification
5	Be able to access the information from the user's location where ever this may be	A server with internet connectivity can be used to provide and display the data
6	Access the information generated at any time, in a timely manner	Server will have as near to 100% uptime as possible and enough bandwidth to be able to respond to requests within 4 seconds

7	Be able to use an ethernet network for its communications	The most common LAN network set ups are utilised, this usually consists of a modem/router/switch/wireless access point. Wired and if required non wired connectivity to be used
8	Have a notification system of any failures or errors	The server is to notify the client of any problems by email, for example; data submission error.
9	Not to require large amounts of bandwidth	A maximum of 8KiB per data submission

5.3 Other requirements

10	Not to be prohibitively costly	The device should cost in the region of £200 GBP
11	Be able to use and interface different sensors	A defined standard interface so that different sensors can be read onto the system, a way of selecting the sensor profile being used in the software system
12	Not to consume large amounts of power	The device will be on 24 hours, 7 days a week, 365 days of the year. It will not consume more than 10 watts
13	Be simple to set up	Configuration of the system can be done easily via a web based interface
14	Not to take up large amounts of physical space	The system should not exceed 300mm by 300mm
15	Be Platform independent	Web based applications will be tested to work on the 3 major operating systems; Apple's OSX, GNU/Linux and Microsoft Windows and the following web browsers; Apple Safari, Google Chrome, Mozilla Firefox and Microsoft Internet Explorer

Table 2: Requirements and specifications

5.4 Specifications to implement requirements

The specifications can now be divided into two categories of implementation type, software and hardware

5.4.1 Software

- Ethernet TCP/IP connectivity; local network and internet
- HTTP server; accessible from a web browser
- Responsive; responds within 4 seconds
- User configurable via user accounts
- Accessible; meets accessibility requirements
- Reliable; will have high availability (uptime)
- Keep costs low; within allocated budget
- Process data from hardware inputs
- Process data from submitted data
- Store a large number of data items - at least 26,280 (3 samples for 24 hours 365 days a year)
- Allow for querying a large number of data items

5.5 Data logger Hardware and sensors

- Input/output device; external device inputs
- Temporary storage; registers
- Permanent storage >= 1MiB
- Low power consumption =< 10watts
- Low cost <£200
- Ethernet connectivity (RJ-45 connection)
- Highly reliable

- Powerful/Fast enough to run system
- Does not exceed 300mm by 300mm

6 Design overview 1

From the specifications outlined the following design is abstracted:

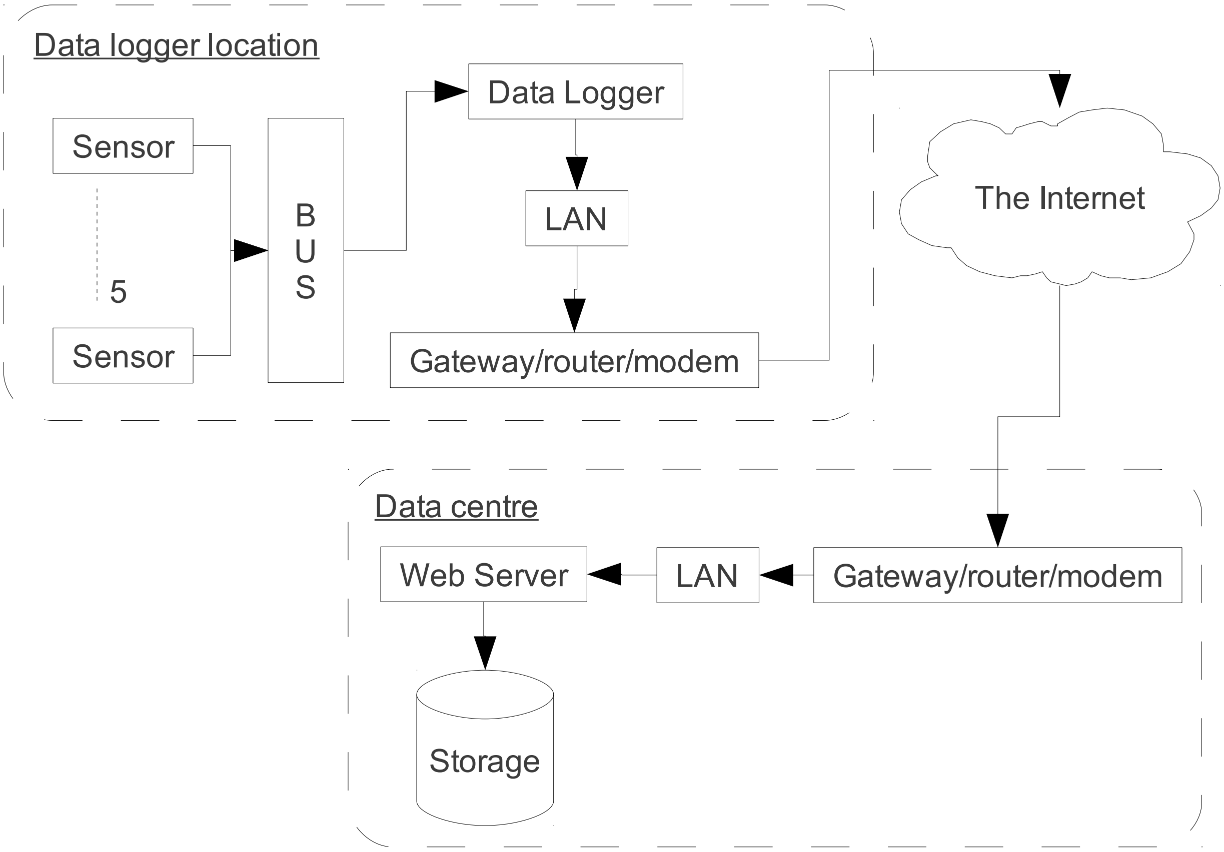

Figure 1: Design overview 1

7 Design implementation selections

In this chapter the design selections made are evaluated against their ability to meet the specifications.

7.1 Data logger and sensor hardware

Many computer devices meet the requirements, these requirements are common to most modern computers. However to gain a less than 10watt power consumption an embedded system is much more suitable. Embedded microcontroller based systems are especially suitable for input/output manipulation, are very cheap and do not require very much power.

For the prototype system Microchip PIC microcontrollers are used, these are cheap, readily available and familiar microcontrollers. Microchip also provides the source code for a basic TCP/IP software stack under an open source licence which allows it to be freely modified and used at no extra cost to the project. A Microchip PIC18F25J10 based ethernet board called "PIC MINI WEB" was acquired from Olimex Ltd for £28.42, *see appendix D for feature summary*

Existing E-Blocks HP488-00-3 development boards were used for their PIC16F877A microprocessors to extend the PIC-MINI-WEBs capabilities to support multiple sensors.

7.2 Web server

The software used for user operations is required to be web based and run on a typical web server, most web hosts on the internet use the LAMP stack – GNU/Linux, Apache HTTP server, mySQL and PHP[26] which are also all based on open source technologies, meaning no extra cost, no vendor tie in, high software portability and a very large number of platforms are supported.

PHP can also be written in an object orientated (OO) way which allows a transfer of software engineering methodology knowledge from the already familiar C++ language.

With this architecture, GNU/Linux runs as the operating system. The Apache HTTP server receives and processes the HTTP requests. The run time compiler, PHP, runs server side operations to perform calculations, interfaces with the data storage and generates dynamic web pages to display to the user. mySQL is a rational database management system. Given the nature of the data logging; creating logical sets of data and the dynamic configuration needed for the data logging of different sensors it is highly useful to store this information in a database, where lookup functionality makes for efficient data mining. From my own experimental data *(see appendix C)* one record in a table is estimated to take up 53.27 Bytes, for one sensor submitting every 10 minutes for a year it would take up 2.67MiB of disk space, this is well within the available space on a typical server and allows for multiple sensors submitting data. Although there are other data storage methods such as XML file databases, flat file databases and custom binary blobs, none of these have such good software bindings that can be found in PHP, SQL is also a very portable file format making the data easy to import and export from mySQL.

A local installation of the LAMP stack and an existing external server has been requisitioned.

8 Design implementation

This chapter documents the functional design stage of the components of the system, which are implemented on the hardware and software as specified by the design decisions in *7 Design implementation selections*.

8.1 Design Layout

The system facilitates the communication between; sensors, the data logger and the available local area network (LAN). The system is laid out in a similar way to that of professional systems, with the instruments and the sensor data logger physically located separately. This means that the instruments – the actual transducer hardware (e.g. the anemometer, photo diodes) are the only external components of the system. The signal processing from these instruments is done by the "sensor" element which turns the data into a usable data.

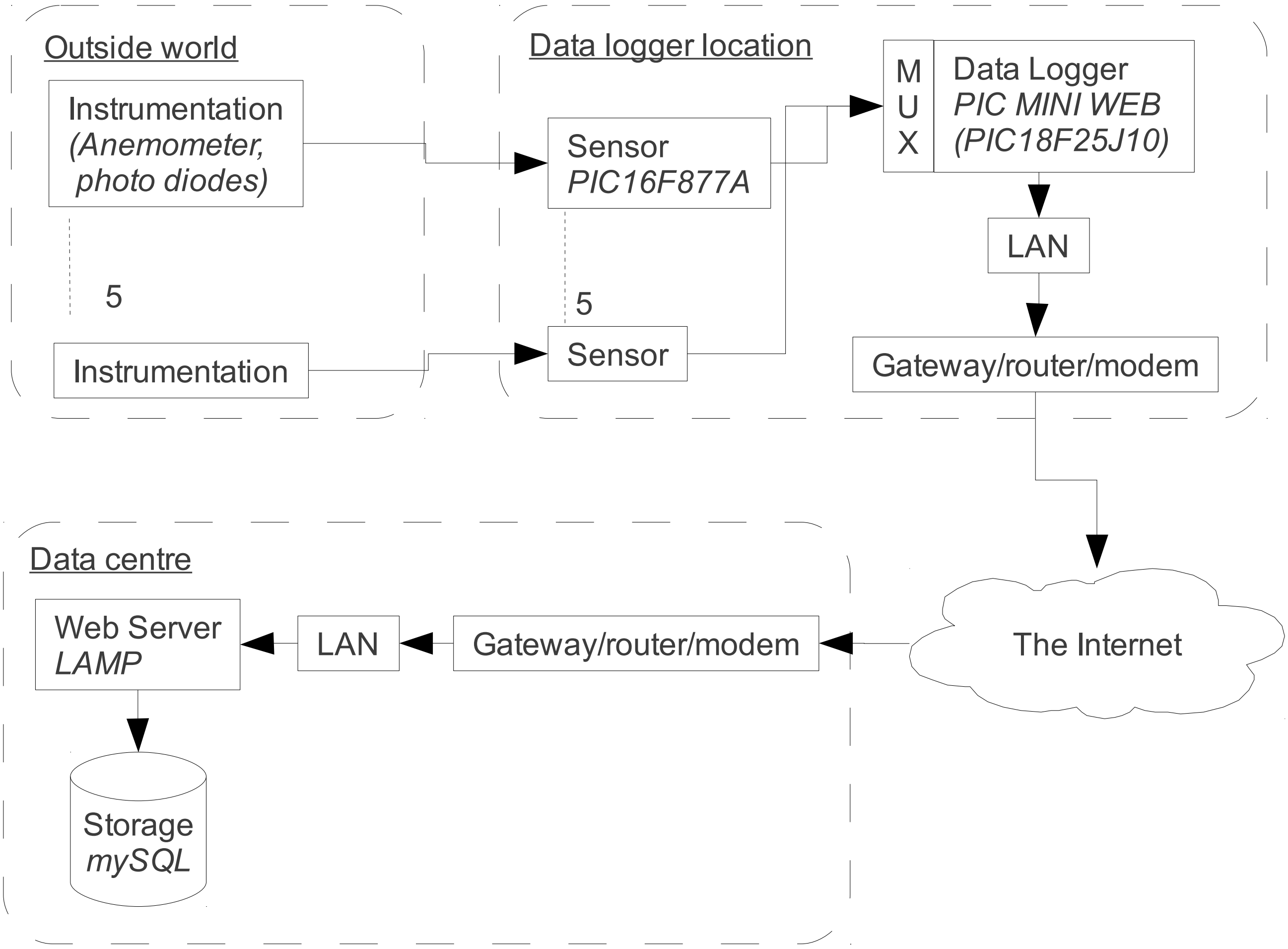

Figure 2: Design overview 2 – with design implementation decisions added

8.2 Sensors

There are multiple sensors and multiple types of instruments which are connected to a data logger, which are able to support 5 sensors attached at any one time. Each of these sensors are identified by an unique address assigned to them. The PIC MINI WEB has a total of 10 input(s) OR output(s), which fall into two categories, analogue and digital. The PICs use a system of sharing physical pins, which means that each of the 10 pins are configurable as **one** of the following;

10 Digital input or digital output and 6 of which can be, analogue input & digital output.

Sensors are connected by using a specially designed serial data transmission suitable for the sensors, this is the most efficient method of data communication as a decent (accurate) bit length parallel interface for each one of the sensors would quickly use up all the available pins on the device and would be physically large. Serial also allows for simple time division multiplexing between the sensors. One data line can be shared for all of the sensors, each taking turns to send on this data line.

8.2.1 Digital

As the design uses serial transmission it only needs one data line, a sensor selection line and a start stop line.

The connections are standardised as the follows:

I/O to/from data logger	Pin/Line	Short name	Purpose	Values
Output	Serial Data	S0	Data sent in timed pulses	High 1ms = digital 1 Low 1ms = digital 0
Input	Sensor Address bit 0	ADR0	Selection of the target sensor	Matched against stored address bit0
Input	Sensor Address bit 1	ADR1	Selection of the target sensor	Matched against stored address bit0
Output	Sending active	SND	Notification of sending	High = Sending Low = Not Sending

Table 3: Pins on each of the sensors

To format the input from the instrument and send the data in the above standard, the “Sensor”

PIC16F877A is used. This process is described by the following flowchart.

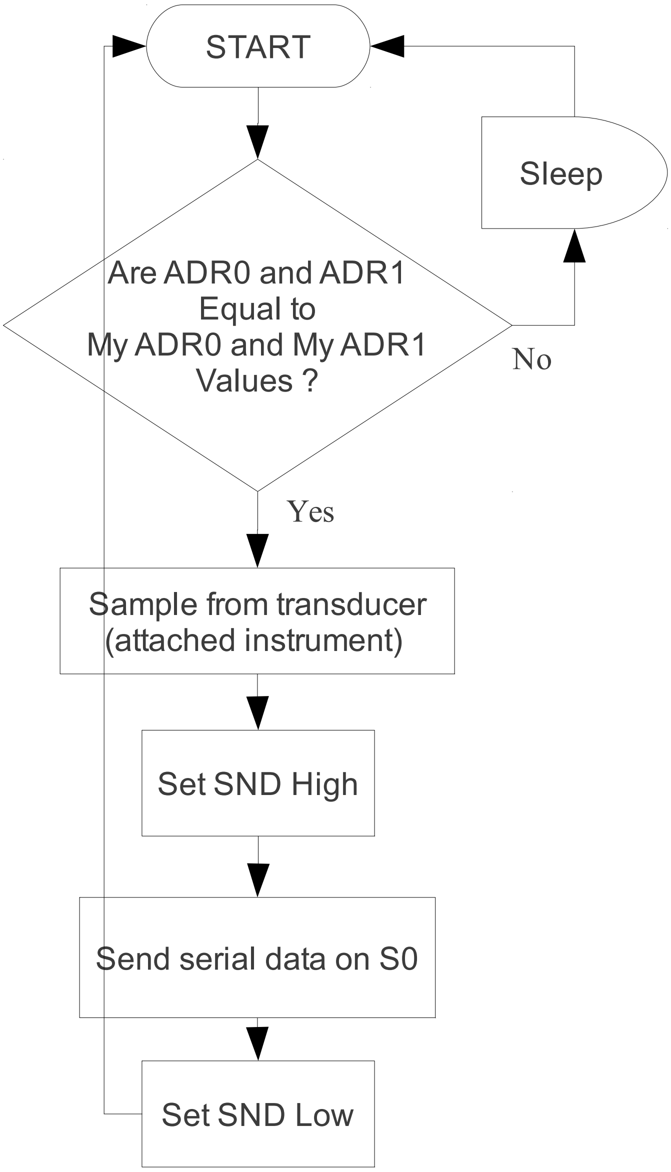

Figure 3: Flowchart describing the process each digital sensor goes through to communicate with the data logger.

8.2.2 Analogue

The PIC MINI WEB has a maximum of 6 analogue inputs available to it. Each one can be selected and sampled by the PIC MINI WEB, in the same way as the digital sensors it also requires an identifier. Without these identifiers there is no way to relate the result generated back to which sensor it came from.

For the analogue input there is no need to use a separate "Sensor" as the analogue sampling is happening on the PIC MINI WEB – "Data Logger", and does not need to be multiplexed.

8.3 Data logger software

The data logger software is the controller of the sensors and the TCP/IP output. The data logger (PIC MINI WEB) selects the sensor to be used and reads the data from it, it also formats the data so that it can be sent over a TCP/IP connection. This connection takes the form of an HTTP 1.0 POST, it is important that the communication is a POST request as this means that the data logger is *pushing* the information out to a specified web server, versus a pull method where the web server has to connect to the data logger and *pull* the data off it. The pull method requires that the data logger is connectable which would open up a security risk, requiring a hole in any firewall and/or port forwarding, also, in many cases awkward NAT (network address translation) issues. Using HTTP simplifies the operation at the sending end as HTTP request traffic is usually (relatively compared to other protocols) unrestricted. At the receiving end Apache HTTP server is already running to receive the connection and it is relatively trivial to interpreted HTTP POST requests using PHP.

The following flow chart shows the required steps of the program on the data logger to receive data from the sensors and send it to the web server.

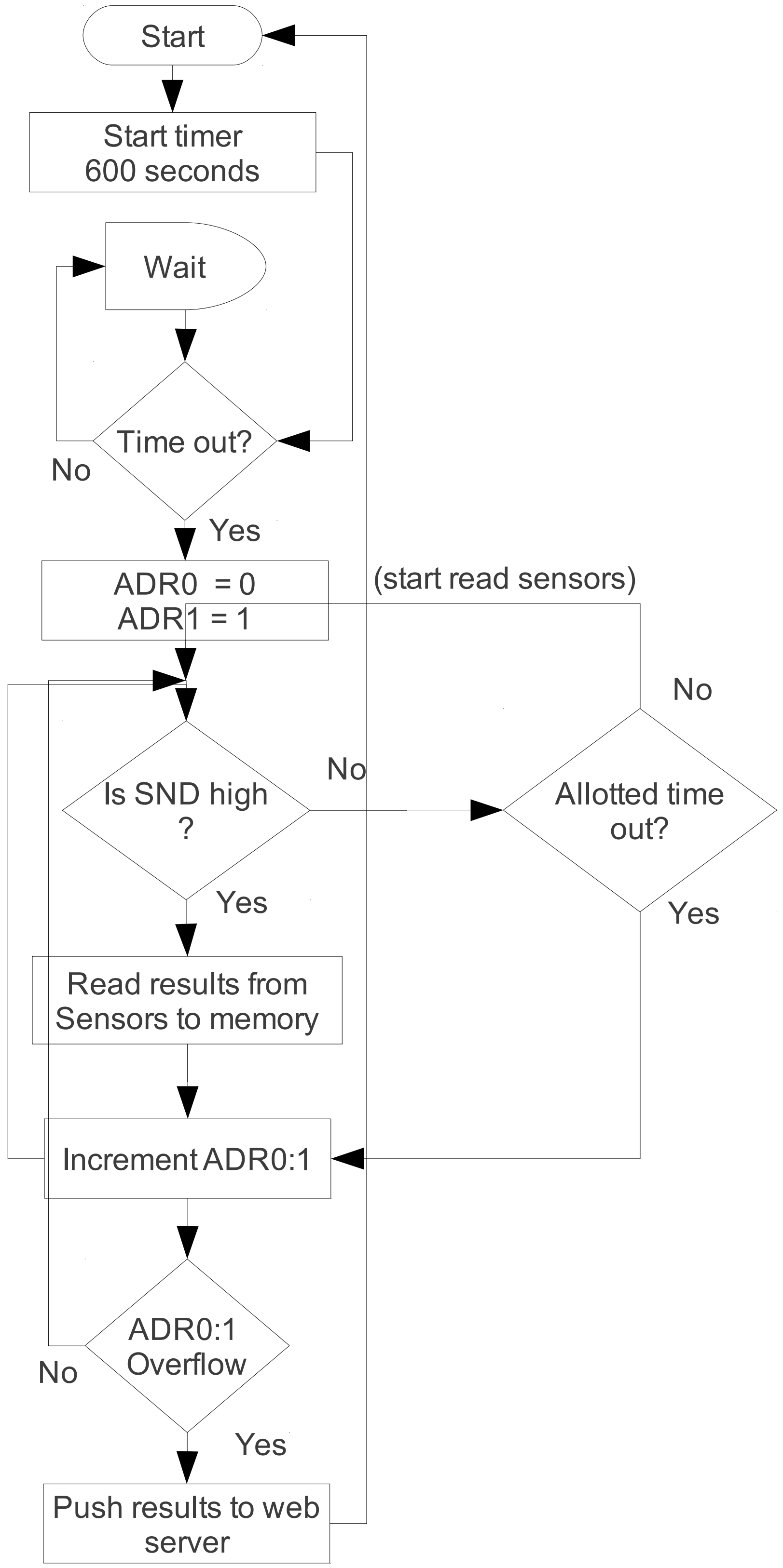

Figure 4: Flow chart describing the data logger main program to read data from sensors and then send it to the web server

8.4 User Software

This section describes the software which a user will interact with and the associated functionality.

The user software has two parts to it, the data logger configuration interface and the web based interface on the web server.

8.4.1 Data logger configuration

The data logger PIC MINI WEB is capable of running a very small web server, this is able to display a form that allows them to set up the IP settings; IP address, Internet Gateway address (default route), DNS (domain name server) address and the subnet mask. No sensor configuration is required here as the interfaces to which the sensors connect to are standardised and numbered, the user only needs to note which instrument sensor is plugged into which port number.

8.4.2 Web based interface

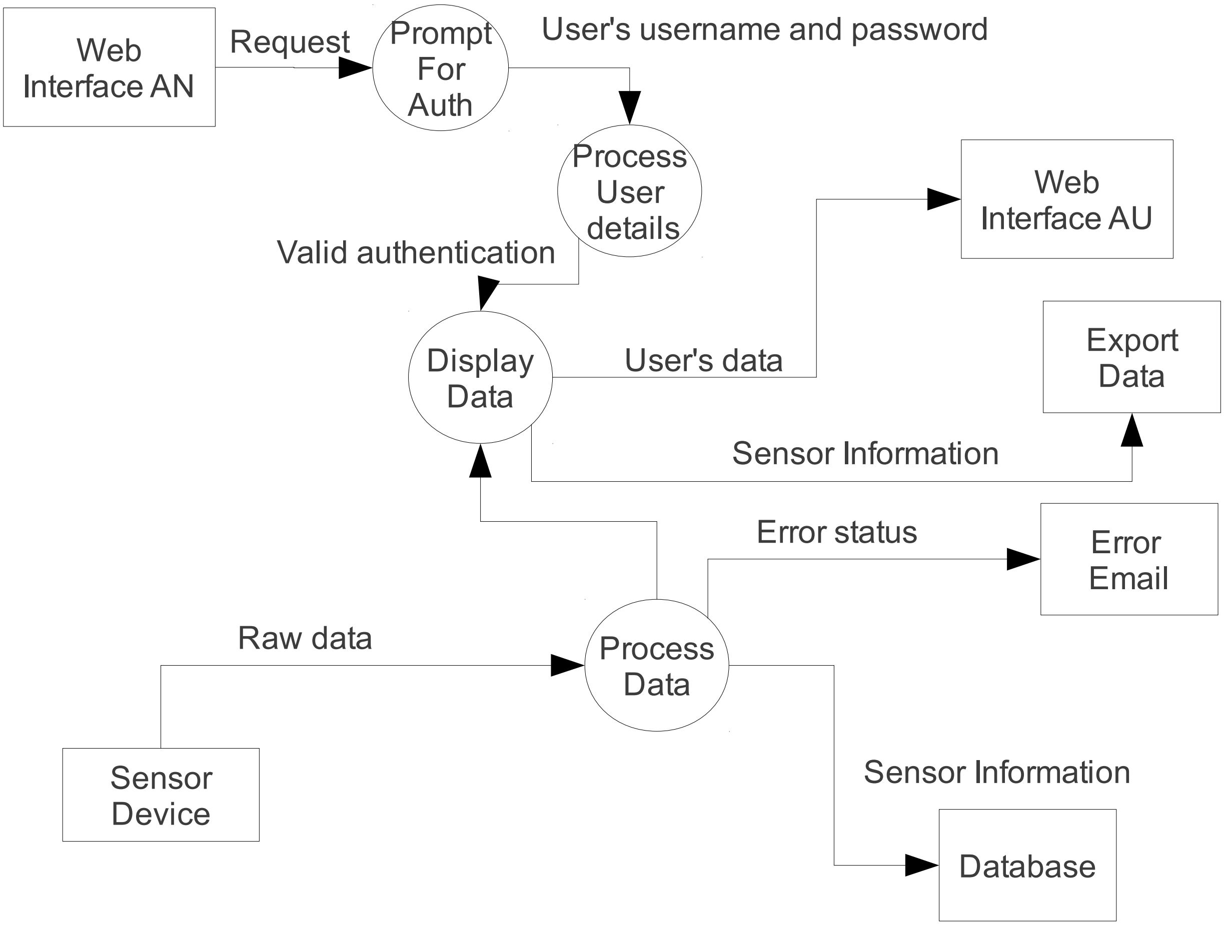

Figure 5: Data flow diagram for the web interface

Figure 5: Data flow diagram for the web interface Abbreviations: “AU” = Authenticated “AN” = Anonymous.

Given that the central web server has a large (comparatively) CPU the majority of the data processing happens on this part of the system. The web interface provides authentication to secure the user's data by associating incoming data with their user account via a device unique key/identifier.

It provides the user with a method of applying a profile to their data e.g. “wind speed”. Once this is defined the user can then view their incoming data, see it presented in graph form, perform calculations on the data, evaluate the data against a particular microgeneration technology product, export their data and receive notifications from the system. The web interface is written in OOPHP for the modularity and ease of future expansion.

The objects created facilitate the running of the dynamic pages and the interface to the database.

8.4.3 Data relationships

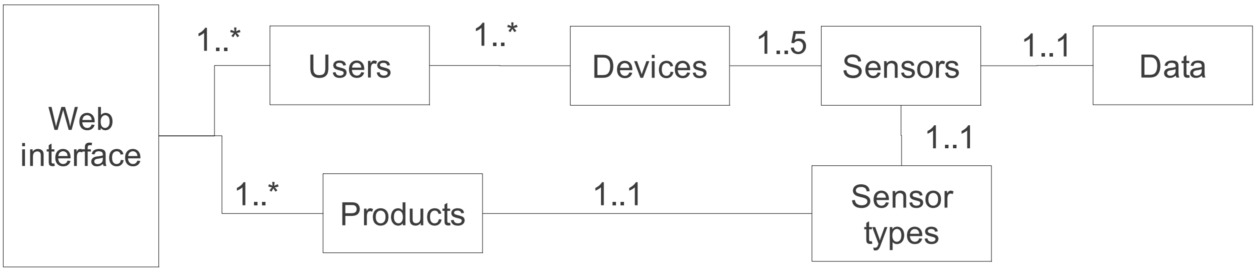

Figure 6: Data relationship diagram..

The Web interface allows any one user to have multiple devices with up to 5 sensors attached, each sensor is related to one data sample and one sensor type. Products are mapped to sensor types, e.g. a anemometer is mapped to the “wind sensor” type.

9 Prototype Implementation

In this chapter the implementation specifics of the prototype design are documented, with an emphasis on the key complex elements.

9.1 Data logger hardware

See appendix E,F,G for circuit schematics

Below is the flow chart for the main program as implemented on the PIC MIN WEB (Data logger)

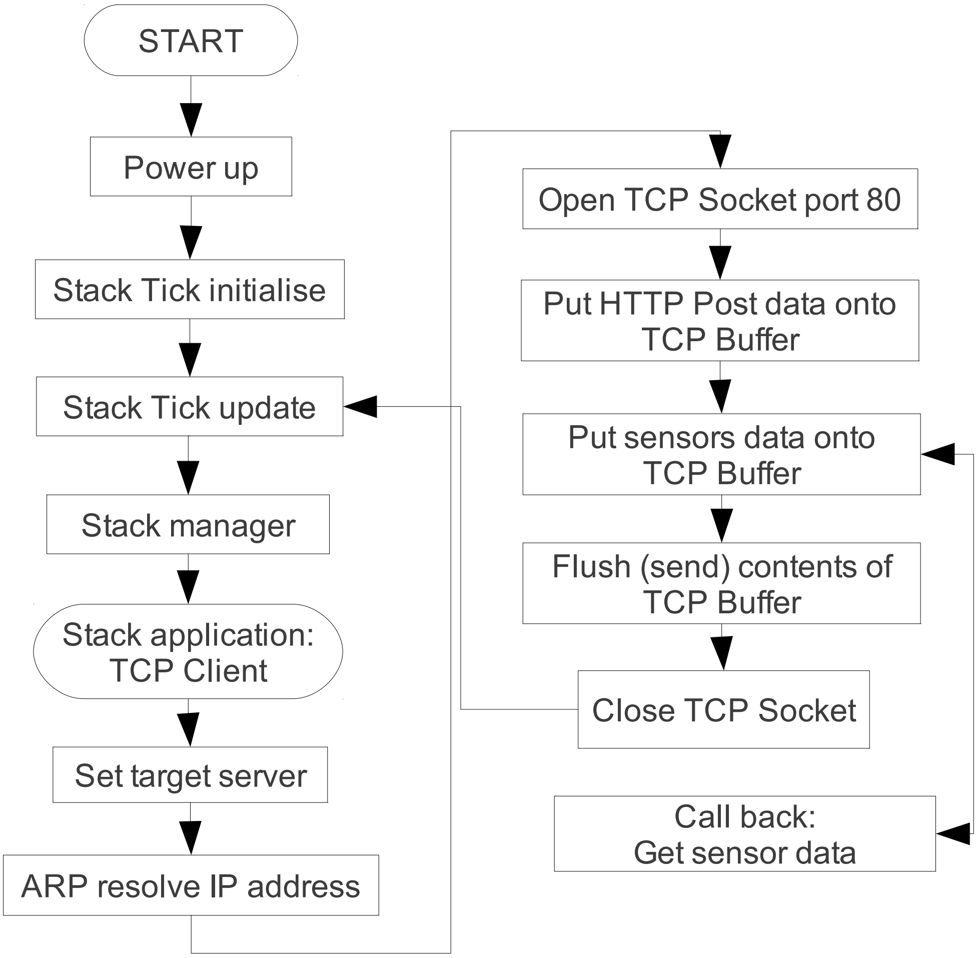

Figure 7: Flow diagram of the data logger (PIC MINI WEB)'s TCP/IP stack process

The data logger (PIC MINI WEB) is programmed using Microchip Technology's C18 language, which is a custom version of the C language. To program the hardware Microchip Technology's ICD2 programmer and debugger was used in conjunction with Microchip's MPLAB IDE, this provides an environment to compile, link and debug the code on the hardware. Only limited simulation features are available due to the connection orientated TCP/IP software stack.

The TCP/IP software stack has to be initialised, then the application which uses the stack has to be registered with the stack manager, it is then run within the main program loop, using a method of cooperative multitasking for all the modules which are built on the basic stack to run. The main stack has many applications that are packaged with it, including DHCP, DNS, ICMP, SNMP, Telnet and others, However the PIC MINI WEB has a very small amount of program memory, it is therefore necessary to disable all of the non-essential modules, where non essential is the minimum dependencies of the design, these extra modules take up more space than is available. The main challenge here is the loss of DNS (domain name resolver routines), which means that the TCP client needs to have a static target host defined as the IP address, this target is the web server to which the TCP socket will be opened on.

Once this socket is opened the TCP buffer is loaded with the HTTP POST request. This HTTP POST is formatted in accordance with the HTTP/1.1 RFC 2616 specification[27].

Using the *TCPPutROMString* and *TCPPutString* function provided by the TCP/IP stack API the POST data can be put onto the TCP buffer. For example:

```
POST /microgen/modules/receivedata.php HTTP/1.0
Host:green.michaelwood.me.uk
Accept: */*
Content-type: application/x-www-form-urlencoded
Content-length: 50

deviceid=5413562&sensorid=2&data=3204
```

The **POST URI** *"/microgen/modules/receivedata.php"* is the location to which the data will be posted on the server, Host *"green.michaelwood.me.uk"* is the HTTP host name identifier, this is important because it disambiguates the URI location, as HTTP supports having multiple "hosts" associated with a canonical host.

The ***Accept: */**** allows any kind of media type response to be sent back, as for this example we are not interested in the response, it doesn't matter what the server sends back.

Content-type: *application/x-www-form-urlencoded* tells the server that the data being posted to it is going to formatted in the *x-www-form-urlencoded* HTML 2.0 standard[28] in short in the form; "field=data&field2=data2".

Content-length: *50* is the maximum length of the data in bytes being posted in this request.

The data from the sensor *"deviceid=5413562&sensorid=2&data=3204"* contains three fields;

“deviceid”, “sensorid” and *“data”,* The device field is the totally unique identifier given to each data logger device, this allows it to be identified in the web interface system on the web server with a particular user, and allows the non-unique; “data” and “sensors” to be associated with it to become unique and therefore identifiable. The *sensorid* field identifies which sensor on the data logger device the data is coming from, this relates back to the device and the profile associated with it *see Figure 6: Data relationship diagram.*.

In the example the *data* field has the value “3204”, this data comes from a call back function written called *SensorDataCall (as seen in the flowchart Figure 7: Flow diagram of the data logger (PIC MINI WEB)'s TCP/IP stack process)* . This callback has to be defined as:

```
extern BYTE* SensorDataCall(void);
```

Which tells the program module that the function is outside of the current running routine, this is necessary because once the application is running on the TCP/IP stack its variables cannot be modified once it has been registered with the stack manager, therefore to pass data into this module it is required to have a call back function, It can be considered as pulling the sensor data into the TCP client module from the main program.

9.1.1 Data acquisition

As described in *Figure 3: Flowchart describing the process each digital sensor goes through to communicate with the data logger.* the data for **digital sensors** is acquired via a custom serial link, for example 83 from the sensor would be read:

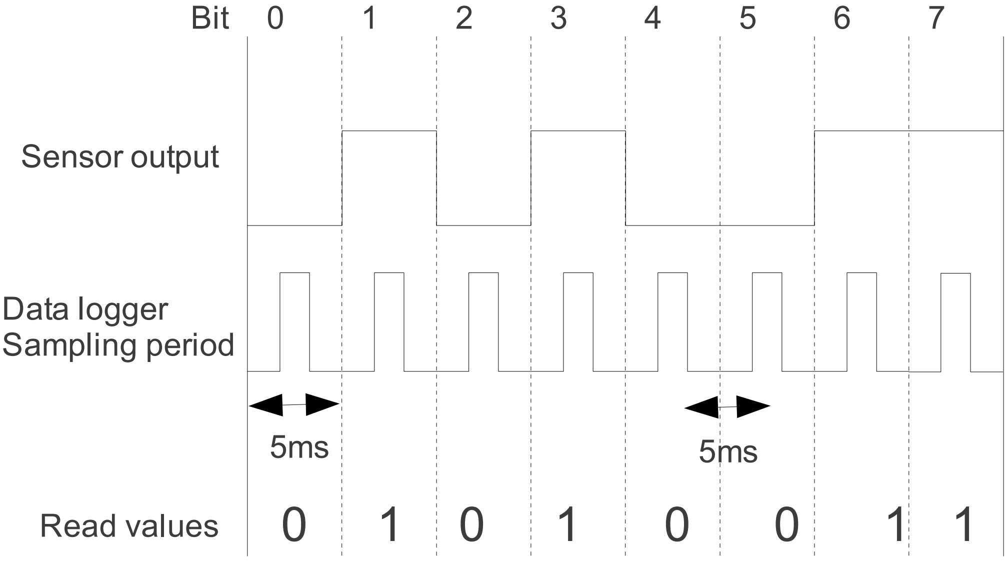

Figure 8: Serial data design

See Appendix G for the function *GetSerialData* that was created to handle this.

Analogue data is simply taken directly into an analogue input port on the PIC18F25J10 microcontroller which is on the PIC MINI WEB, the PIC18F25J10 has special analogue digital (A/D) conversion routines, these are used to sample the analogue input to produce a digital value, *see appendix H* for the function *ADRun* created to do this.

9.2 Web interface

The dynamic web pages are generated by using OOPHP (Object orientated PHP) programming language, HTML and Javascript, The class diagram shows the implementation of the OOPHP .

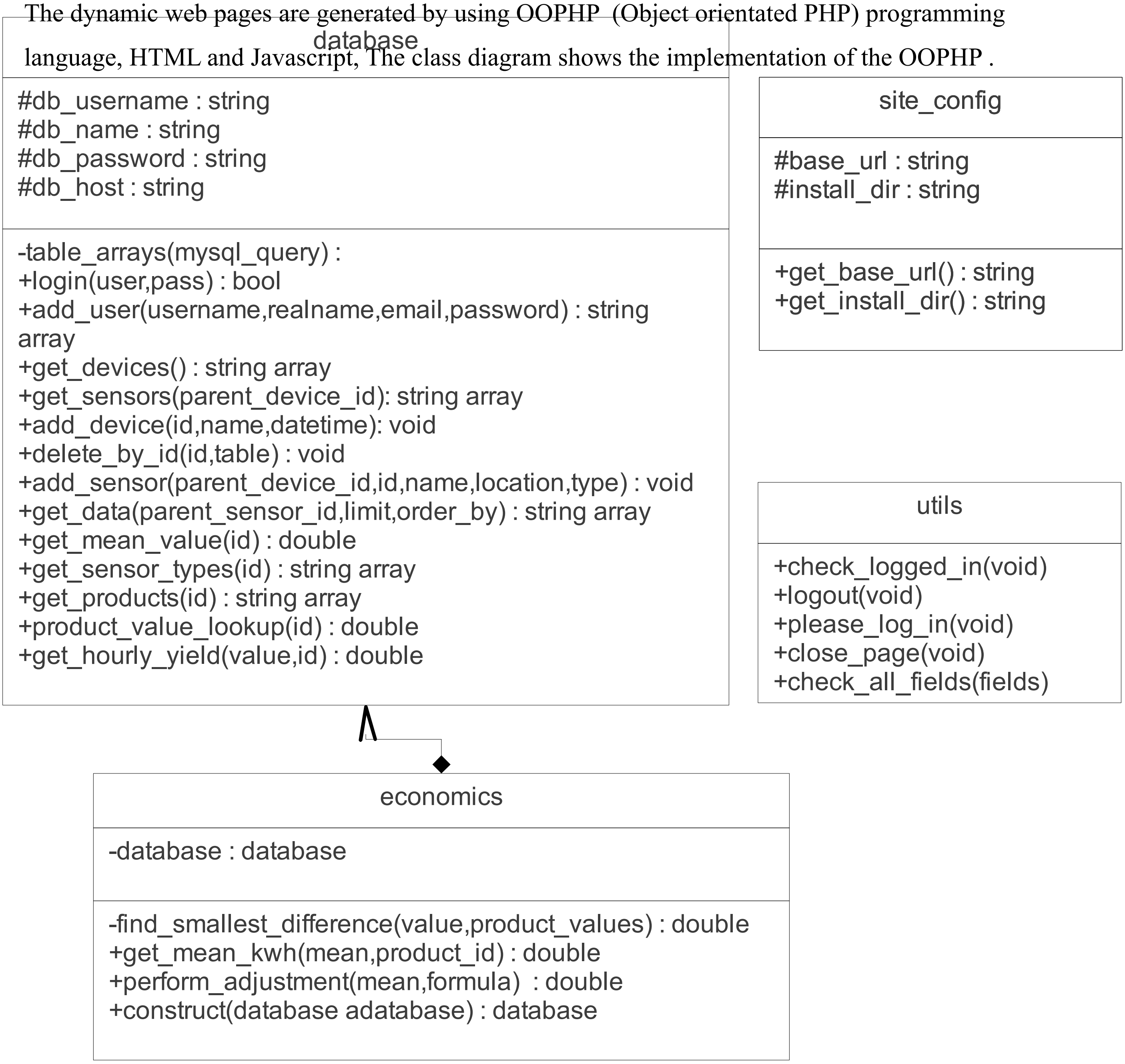

Figure 9: Web interface class diagram

As can been seen from the large number of methods/functions in the database class, the OOPHP main job is to create an interface to the database. Which is described with the following database relationship diagram, the large end of each line is the foreign key and the small end is the primary key:

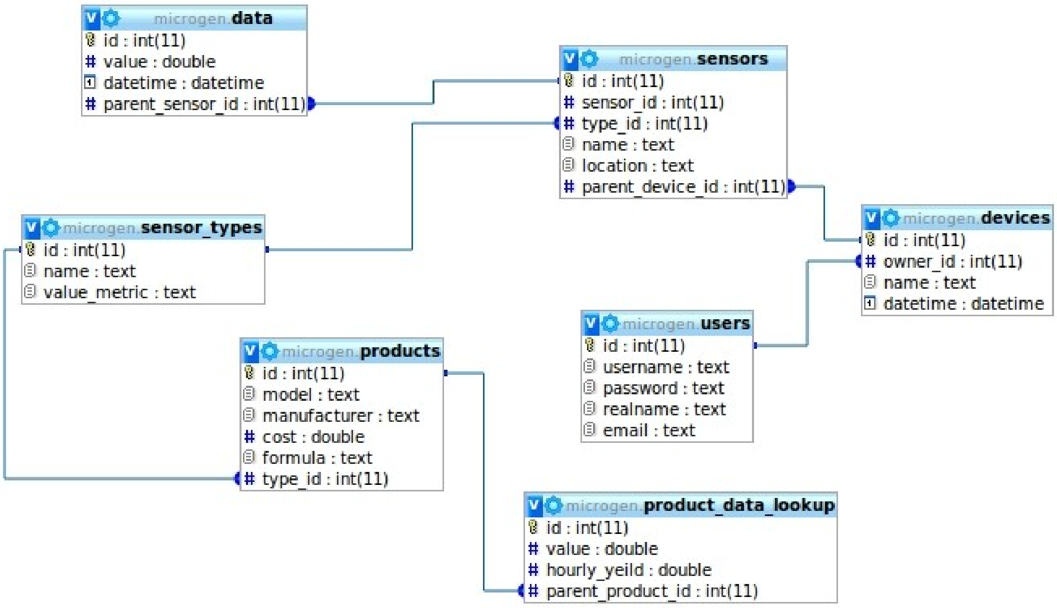

Figure 10: Database table relationship diagram

The database design is abstracted from the initial design described in *Figure 6: Data relationship diagram..*

9.2.1 Key Functionality

User accounts: PHP sessions have been used to create a personalised and secured session for a logged in user, this session data is taken from registration information that the user has provided via a HTML form and subsequently been stored in the users table. Once this data is collected a secure user account is available to then be associated with their data logger device(s) using their unique data logger device id.

User's Configuration: Each user of the system can configure the settings that they are using for their data logger devices. The user can then add sensors with *sensor type* profiles to these devices, additional data is collected about the sensor including, a "friendly name" and location. *See*

Data display: Given the need to return large chunks of dynamic data, from the various tables accessed by the database object, a private function was created called *"table_arrays"* in the database class *see appendix I.* This function creates a multi dimensional array of the requested data query allowing entire database results to be returned in one go to the main application. This is used in the *get_sensors*, *get_data*, *get_sensor_types* and *get_products* functions *(see Figure 9: Web interface class diagram),* the array can easily be traversed using a loop, or specific elements of the array can be picked out as needed.

Sensor Data display: By default the number of data records returned is limited to the last 100 ordered by date descending, this is to reduce unnecessary server load as returning the large amount of sensor data (10,000s) that could be collected is a costly process in terms of CPU time. This however can be overridden by the user in the data display page. The data can also be displayed in graph form, this is done using an embedded Open Source JavaScript program called "Flot" developed by IOLA and Ole Laursen. The PHP in the data display page whilst drawing a table of the data also creates a CSV, (comma separated values) variable which is then passed into the Flot's JavaScript configuration. *See appendix O for results in graph form.*

Sensor data vs microgeneration product: The sensor data is used to create a mean average value, this mean is then used to either calculate a (electrical) power yield from the microgeneration product using a known value for a power coefficient or it lookups a value and match it against the closest known value to power value. Product data exists in the system in two forms; a coefficient or a lookup table (*see Figure 10: Database table relationship diagram)*. These two approaches are taken due to the non-linear power generation of certain microgeneration technologies.

To run the matching algorithm a function in the *economics* class called *find_smallest_difference, (see appendix J)* was created to find the smallest difference between, the mean value and a value in a product's lookup table. The function returns the power value that causes the smallest difference. For example a microgeneration wind turbine data might look like this:

Product (m/s)	Product power generated (kWh)	Wind Sensor mean (m/s)	Difference
5.5	1	4.8	3.7
5	0.8	4.8	0.2
4.5	0.3	4.8	0.3
4	0	4.8	0.8
3	0	4.8	1.8

Table 4: Example product vs sensor data lookup table

The function would output the value “0.8” kWh (hi-lighted) which is later used in the calculations for economic viability as it has the smallest difference between the product data and the sensor data.

Manual adjustments: A method has been created which allows the user to adjust the calculated economic viability, this can be done by adjusting the sensor data mean.

For example, for wind speed data it would be possible to investigate the change in wind speed that is caused by change in the height of the sensor by inputting an adjustment formula, in the form: “[old_mean]*(15/[old_mean])^0.2”

This would adjust the mean wind speed to a value as if it were taken at 15m with a wind shear factor of 0.2 (*see Formula 1: Wind gradient adjustment)*, the token [old_mean] is automatically substituted with the current value for the mean when the user submits the change using the *perform_adjustment* function in the *economics* class, this new value is then used for the economic calculations. Other adjustable items include, Price per kWh and Product cost. *See appendix L.*

Economic viability: The economic viability is shown by displaying the calculated annual income and the year(s) until break even values. These are based on the outcome of the *Sensor data vs microgeneration product* routine. The selected product is chosen from a menu within the data viewing screen.

Sensor data export: The user is able to export the data that they have collected from their sensor in to a CSV format, this is done by a PHP program written which modifies the HTTP header being sent to change the file format that is being given to the browser:

```
header('Content-Type:text/csv');
header('Content-Disposition: attachment; filename="Data_'.$_GET[name].
$_GET[id].'_'.date("d-m-y").'.csv"');
```

Which for example would output the file *"Data_HouseSensor4_03-02-10.csv"* to be downloaded by the user.

Receiving sensor data: The receiving sensor data routine is very simple, it takes the HTTP POST array which is automatically created by PHP in the form *$_POST[fieldname]* when the program is called, it checks the deviceid and formats it into a mySQL query with a time stamp.

Failing to receive sensor data: If the sensor data is not received within a time of the set time period the system sends an alert email to the users' specified email address. e.g. if a data logger is supposed to send a sample every 20 minutes and a sample is not received by 25 minutes an error email is generated.

10 Testing

In this chapter the testing of the prototype implementation described in the previous chapter; *Prototype Implementation* is defined in methodology and where significant as case by case tests.

10.1 Strategy

During the development process, testing of each major software code change or addition was carried out, this tested only that portion of the system which had been added or changed, which is why testing on completing the system is carried out using a mixture of white box and black box testing. White box testing will be used for generalised tests which involve many components of the system following use cases through the system with the emphasis on the process correctness. Black box testing will provide particular module and function testing of the system where the test emphasises a particular result as the outcome, regardless of the process. With these two approaches the system will be comprehensively tested.

10.2 Data used for testing

To test the system three sources of data have been used:

1. **Met office weather data via BBC feeds – White box test**
   A special GNU/Linux Bash script was written to parse the RSS (XML) weather feeds that the BBC provide on the BBC weather website[30] this Bash script is placed in the Crontab (time based job scheduler on GNU/Linux) on the server and run once an hour, it has been running for over a month with wind speed being logged from three different locations: Heathrow, Barrow-in-Furness and Tiree. The data its self is submitted to the web interface in exactly the same way in which the data from a data logger would do, and thereby also provides a simulation of multiple data sensors providing data. *See appendix M*

2. **Prototype sensor data – White box test**
   The data logger PIC MINI WEB was set up with an LDR (Light dependant resistor, similar to the photo diodes used to measure sunshine by professional systems) and a potentiometer the potentiometer allows calibration of the LDR values, the device was placed so that the only light available to it came from a 1st floor window (ideally with weather proofing this would have been placed outside) the PIC MINI WEB's timer was then set to send a sample

every 8 seconds for 24 hours the data was recorded using the system. *See appendix N*

3. **Data requested via the Encraft Warwick wind trials[29]**
   A large data gathering research project was under taken by Encraft for the Pilkington Energy Efficiency Trust and BRE Trust. The project monitored 23 rooftop microgeneration wind installations on a variety of urban and rural sites over 12 months, starting in 2007, one month of this data for a particular site has been made available to this project by Encraft.

10.3 1. Black box tests

1. Data logger successfully connects to the server

By using a program called "forward" developed by Firmstep Ltd the TCP packets can be intercepted and viewed, then forwarded to the server. A successfully made connection results in the following output:

```
################# New Connection #################
>>>>>>>>> 1221967 >>>>>>>>>>
POST /listen.php HTTP/1.0
Host:green.michaelwood.me.uk
Accept: */*
Content-type: application/x-www-form-urlencoded
Content-length: 20


>>>>>>>>> 1221977 >>>>>>>>>>
testdata
<<<<<<<<< 1221977 <<<<<<<<<<
HTTP/1.1 200 OK
Date: Wed, 20 Jan 2010 02:50:47 GMT
Server: Apache/2.2.14
Last-Modified: Wed, 20 Jan 2010 02:50:14 GMT
ETag: "1862c2580-1c-47d8fa54e2580"
Accept-Ranges: bytes
Content-Length: 28
Connection: close
Content-Type: text/plain

Thank you, all data received
```

2. Data is stored in the mySQL database

Any functions which store data in the mySQL database; data sent to the receive sensor data routine, *add_user, add_device* and *add_sensor*. On success, the data appears in the corresponding tables which can be viewed using the mySQL command line tool.

3. User account sessions are set-up correctly

The user account can login using the login form, once logged in *"Preferences, My data, My devices,* *[logout]"* appear and are accessible. On logging out these pages are not accessible in anyway.

4. Data is acquired from sensors into the data logger

The Microchip ICD2 can be connected to the PIC MINI WEB board and put into debug mode via MPLAB IDE, running the board until after the data logger has run the acquire sensor data routine, then inspecting the relevant memory contents. This is repeated twice once for the analogue sensor, where the result will be placed in ADRESL register and once for the digital sensor where the result will be held in ROM. In this test the digital sensor is being selected correctly but the serial clock synchronisation is found to be unreliable and therefore any data collected via this method has been disregarded.

5. Data is acquired from the data logger to the web interface

Data that has been sent from the data logger appears in the web interface, known data is sent from the data logger, this is done by using the potentiometer on its own *(see appendix N for circuit diagram with the modification of by passing the LDR).* Setting the potentiometer to 100%, 50% and 0% all give the corresponding values in the web interface: 0, 1.65 and 3.3 volts respectively.

6. Standards compliant and multiple web browser rendering

The web interface renders correctly in a minimum of Mozilla Firefox 3/3.5, Microsoft Internet Explorer 6,7,8 and Apple's Safari 4.0.5 web browsers, in addition a very large range of browsers also tested using the "browser shots" tool[31]. The web interface passes the XHTML 1.0 Transitional standard compliance test. This is verified by using the W3C's markup validator[32].

7. TCP/IP connection and reconnection

The data logger PIC MINI WEB is physically disconnected and reconnected from the ethernet network. The data logger reconnects as soon as physically reconnected to the network. With any results which were being sent at the time, resuming their send when disconnected for less than 60 seconds.

8. Data logger powers up and starts up

The data logger powers up and resumes operation 100% of the times tested, in a minimum sample of 20 times.

10.4 2. White box tests

1. Users can complete registration correctly

The user registration process is completed correctly by filling out the registration form and subsequently being able to login to the web interface.

2. Sensor data reaches the web server and is displayed correctly
Using the data collection method described in *"Data used for testing: 1. Met office weather..."* simulated sensor data was imported into the system, this is verified by comparing the source data (from the met office) to the data being displayed in the web interface.
A second test using the prototype was also carried out described in *"Data used for testing: 2. Prototype sensor data..."* this incoming data can be verified using Black box test 5.

3. Correct calculations are performed and displayed in the web interface
The mean, hourly kWh, daily kWh, annual kWh, annual income and years until break even, can all be calculated manually from the data that exists in the database. Verifying the calculations done by the web interface are correct.

4. Device, sensor and user account are associated correctly together
A user account is created and a device (data logger) and sensor(s) are configured for this account. The data then ends up being able to be viewed by this account and no others.

5. Large amounts of data is stored and manipulated correctly
During the *"Data used for testing: 1. Met office weather...."* and *Data used for testing: 2. Prototype sensor data..."* data acquisition, totalled 23,602 samples which were stored in the database. 10,170 of which came from the 8 second sample period in the 24 hours sun light experiment. A program was written to compare the time stamp differences and the existence of a submitted value in the 23,602 results.
5**.1 Stress test –** This test also acted as a stress test for the entire system as the number of samples per hour was very high – much higher than realistically would ever been needed, testing the ability of the system to maintain stability at this high rate for a long duration.

6. Data from multiple sensors and devices is stored simultaneously

During the *“Data used for testing: 1. Met office weather....”* data came in from three different “sensors”, each in different locations; Heathrow, Barrow-in-Furness and Tiree, chosen for their wide difference in location and the ability to view feasibility studies made for wind turbines in the same area.

7. Economic prediction accuracy

By comparing the predictions that were generated by the web interface to predictions stated in relevant professional site surveys.

11 Results

Having run the tests defined in the above section the results of tests which returned interesting results are analysed in the following sections. All other the tests returned positive results.

11.1 1.4 Data is acquired from sensors into the data logger

The data was successfully acquired from the sensor into the data logger PIC MINI WEB and useful data was produced in data acquisition 2; "*Data used for testing: 2. Prototype sensor data...*" However the digital sensors did not communicate reliably with the data logger, this was due to the custom serial stream not synchronising correctly with the read serial data routine *see Figure 8: Serial data design* this meant that although the serial data appeared to be being sent it wasn't being sampled at the same rate giving inconsistent values. This is due to various factors which made the design more complex than perhaps necessary; the code written for the digital sensor in PIC16F877A assembly and the PIC MINI WEB was written using the C18 language. One of the sensors was running at 4Mhz (the reliability of which is debatable) and the other at 10Mhz, the sample times and the period of the serial signal were deliberately kept large in comparison to the clock period to reduce the effect of clock skews and other unavoidable/incalculable delays, This indicated the problem was with the control of the data flow, this is confirmed after investigating the function that was used to create the delay in the C18 code was not operating as described because the function was intended for Hitech-C language based implementations. A rewrite of the function would be necessary to retest this.

11.2 1.6 Standards compliant and multiple web browser rendering

Due to Microsoft Internet Explorer interpreting CSS in non standard ways a fix was required to get the user login box to appear in the correct location, Microsoft developers seem to have pre-empted differences in their browser by creating a special tag system in HTML comments; *" <!--[if LTE IE 7]> "* which translates to "if less than or equal to internet explorer version 7" an overriding CSS style is then placed within this to fix this issue.

11.3 1.7 TCP/IP connection and reconnection

To encompass the possibility that the data logger is connected via ethernet to different platforms further testing was done; connected to a Microsoft Windows platform the default TCP settings are different for different versions, e.g. Server based versions tend to have larger retries and time outs. The way in which the platform deals with the network cable physically being disconnected also differs for example, in Microsoft Windows the action is to shut down the network interface causing a time lag while the interface is brought up and down, whereas the GNU/Linux kernel obeys the TCP timeout rules and the cable can be reconnected within (typically) 60 seconds without any adverse affects. The recommendation from this is, for more reliable results a GNU/Linux based operating system would be preferable for the data logger to be connected to if a PC based platform is used. Ideally the data logger is connected to a standalone router.

11.4 2.6 Sensor data reaches server and is displayed correctly

	BBC Wind Heathrow	BBC Wind Barrow-In-Furness	BBC Tiree	LDR Sensor
Number of samples	8338	2706	2370	10170
Sample period (seconds)	1800	1800	1800	8
Values missed	0	0	0	0
Sample submission not on time	5895	1872	1754	59
Average time delay (seconds)	6.04	18.62	21.26	0

Table 5: Results from data acquisition

The results indicated a good reliability for receiving the data, no values were submitted blank and no data values were lost, strongly indicated by none of the results being delayed by anything close to their sample time. From the LDR sensor experiment, for which the data acquisition method is described in "*Data used for testing: 2. Prototype sensor data...*" 59 of the samples were not on time or 0.5%, however these *not on time* samples mostly only differed by around +/- 1 second. As there were 10,170 samples this averaged out to a delay per sample of 0.0008 seconds. The reason for any delay in this experiment is likely to be caused by operating system tasks on the server that were happening at the same time, delaying the submission processing.

The number of *not on time* submissions for data collected using the method described in *"Data used for testing: 1. Met office weather..."* greatly increased to ~70% for each of the sources, however as a proportion of the sample period the average delay is only 0.33% to 1.2% of the total period time and therefore has less of an impact. The delays are caused by the additional complexity of retrieving the data from the BBC website in the first place, this retrieval process is across the internet which, due to the nature of the internet, the speed at which it can retrieve data is highly variable.

The average time of the delay in the Barrow-in-Furness and Tiree results was artificially increased due to human error in configuring the script that went unnoticed for a couple of days, removing these results brings the average time delay down to ~6.89 seconds, which is more in line with the result from the Heathrow source.

The human error went unnoticed due to the error handling system having not been fully implemented at the start of the data acquisition stage. It would have been able to pick up this error as the delay between results would have indicated no result had been sent.

11.5 2.7 Economic prediction accuracy

11.5.1 Met office Heathrow wind data

The nearest microgeneration wind turbine to the met office's Heathrow weather station is in the grounds of Uxbridge High school which is 6.1km due south, as part of the planning process they had a report written by BDP[33] – an architecture and engineering company. This recommend using a Proven 6 kW wind turbine at 15m height with a **predicted** wind speed of 5.0m/s. According to the BDP report this would generate 11,622 kWh annually for the school. Having input the wind speed to power data from the Proven 6 kW wind turbine data sheet[34], into the web interface which also contains Heathrow wind speed data for 3 months, the web interface is then able to display the annual yield based on the mean wind speed of 5.167 m/s this gives an annual yield of 8760 kWh. This figure is approximately ¾ of the amount BDP predicted. It is difficult to understand how they came by this figure as it is possible to verify the results via the data sheet which states that 5.0 m/s generates 1kWh, $Annual\,Yield = kWh \times Hours_{Day} \times Days_{Year}$ therefore 1*24*365 = 8760. If the wind speed is 5.5 m/s however 11,633.28 kWh would be generated, which is suspiciously close to the value quoted in BDP's report. It is possible that there is a mistake in the BDP report, or more cynically, it is greatly exaggerating the reality. BDP were contacted to comment on this discrepancy, but to date have not responded.

The issue of the accuracy of using data gathered 6.1km away in this test case is debatable. Met office data is taken at 10m height so it was necessary to adjust the values using the wind gradient formula *see Formula 1: Wind gradient adjustment* to a height of 15m, a value of 0.27 is used for the

Wind shear/Hellman exponent[36] which translates to *"Unstable air above human inhabited areas"* being an exponent this value has a great impact on the wind speed change.

Having consulted a geography climatologist Philippa Day (BSc, PgDip) there are a number of factors which would be different in "urban" Uxbridge high school vs "rural" Heathrow weather station, ranging from building's wind shadow to ground temperature and funnelling. She concluded that at Uxbridge high school there would be "*lower average wind speeds because of increased disturbance of the wind flow from obstacles, whilst the funnelling might cause short sharp bursts it doesn't provide a good consistent flow" - Philippa Day (BSc, PgDip).* This means that the calculated values from the wind speed are likely to be creating a best case scenario, this compounds doubt that a wind speed of 5.0 m/s predicted by BDP would be sustainable for the entire year especially given the seasonal variance towards lower wind speeds in summer months[35].

11.5.2 Met office Tiree wind speed data

In the second test case the Scottish island of Tiree as a location was used, it reportedly has one of the highest wind speeds in the UK[38]. Comprehensive reports are available for this site, and unlike the Heathrow test a full wind site survey was undertaken and published in 2007[37].

By looking at a aerial view map the weather station is not far from a number of buildings, which is why the Hellman exponent value of 0.27 is used again for the height adjustment formula (*Formula 1: Wind gradient adjustment)*. A value of 8.96 m/s is generated by the web interface compared to a 9.8 m/s measured at the site. The two results differ as would be expected from results taken 3 years apart, However by comparing the annual kWh between wind turbine products on the system using both values for wind speed against Proven 6,7,11,35 microgeneration wind turbines and a Vesta V52-850 - large 850 kW, which is what was eventually used on site, the web interface displays that the most economically viable solution based on the annual kWh yield is to use the large 850 kW Vesta wind turbine, rather than for example four Proven 35 microgeneration wind turbines to generate roughly the same output. *See appendix P.* This conclusion is backed up by the results of the Tiree survey: *"we could employ a number of smaller turbines across the island, but this would be less cost effective"*[41] this result is relevant because the economic viability of wind turbines are only partially determined by the number of installations. Smaller wind turbines can be more efficient in lower average wind speeds than their larger counterparts.

11.5.3 Other results

These results relate to quantifiable parts of the original system requirements *see Table 2: Requirements and specifications*, The results have been generated as a product of other tests.

Design specification No.	**Comment and value**
2	23,707 data records are held on the server, well over one years worth of data, currently only using 1.0 MiB, well within the disk space constraints
6	The web interface on a standard broadband connection returns a result in 0.3 seconds using `time curl <url>`, the web server uptime is high from a reputable company, although no uptime guarantees are stated.
9	195 bytes payload (HTTP POST) + 20 byte (TCP overhead) = 215 bytes, well within defined data submission size constrains.
10	The device costs £28.42 + Misc electronic components (LEDs, Resistors, LDR) est £1.50 + approx £5 for AC/DC transformer *see Cost* section for further details.
12	Device uses a maximum of 350mA, well within the specification of a maximum of 10watts verified via a Brennstuhl power meter.
14	The main device measures 55x36 mm, well within the specification of a maximum of 300x300mm

12 Conclusion

The information obtained through the research in the literature review formed the basis of the requirements that a microgeneration economic viability system should incorporate. The amount of information was sufficient to state the corresponding specifications and to identify the key components that are evaluated to generate an accurate economic viability report for microgeneration products.

The suitable design emerged from abstracting the specifications that were drawn from the requirements and the identification of the individual component requirements. Justification of the design choices was a mixture of the project's constraints and the best solution available to implement the specifications.

A prototype design was implemented in hardware and software which allowed for the testing of the system as a whole.

12.1 Results

The results indicate that the system overall is successful in meeting its objectives, the majority of the quantifiable constraints placed on the system by the requirements have been surpassed.

The exception of the digital sensor multiplexing routines, which failed to give reliable results meant that 5 sensors could not be added to the system at any one time, however multiple analogue sensors are able to be connected to the system and gave enough results to testing the system.

The testing process produced a good number of positive results and the data used was realistic to the system's intended use.

The challenge of accurately testing the economic predictions made by the system calls for a more conclusive test results, this could be obtained by using the prototype system in parallel to the system developed by industry as described in many site surveys. This test would require a large amount of meteorological hardware and a years worth of data, making it outside of this scope of this project. There are few alternatives to get the accuracy of this test due to the nature of meteorology – any values made in any date in any location can not be compared accurately to those made in, a different date or location.

In the same test, to gain economic viability factors the total cost of implementation would need to be taken from quotes given for all the works required to implement a certain scenario with microgeneration technology and then input into the system. Other factors such as income from the technology need to be taken from a power purchase agreement made with a supplier, these are often variable rates depending on the amount of power supplied to the purchasing company. An addition to the system would therefore have to be made to incorporate the different rates that would be applied based on differing power supplied quantities.

12.2 Reliability

The reliability of data logging part of the system was shown to be high from the testing and in comparison to that of industry: *"During the logging period the data recovery rate was 99.7%, with a period of 24h missing during 8-9th January 2007 for unspecified reasons."[37].* The results were 100% data recovery (when the system was correctly configured). To ensure extended long term reliability a dual active redundant system could be used without any additional configuration. Cost and physical space would be the limiting factor as the system is designed to be able to take data from multiple data loggers. The possibility of internet connection drop outs would have a great affect on the reliability, therefore being able to install a local web interface on the LAN that the data logger is connected to, should be considered.

12.3 Other further work

The following sections contain further work that could be done to extend the project but have not been addressed in the previous sections

12.3.1 Digital serial communications

The lack of input/output pins on the PIC MINI WEB prompted the design of the custom serial interface, which in the end was not successful, there are three viable solutions to this;

1) As stated rewrite the serial data routines with more control signals and better timing (possibly by sharing a clock signal over one of the connections).
2) Use dynamic reconfiguration of the pins - It is possible to use circuitry to allow the reconfiguring and re-use of each of the pins. e.g. a simple diode on an analogue input would allow it to be also used a digital input/output, however this level of complexity was beyond the scope of the prototype.
3) Reduce the number of pins, by extending the protocol to encompass start/stop and the address selection making the serial bidirectional.

4) Upgrade the board to the next model which encompasses an RS232 port and controller

Option 4 would be the most preferable as RS232 allows the support of the UART protocol which means that interoperability is increased and error handling from the sensors can be dealt with at the protocol level.

12.3.2 Configuration of data loggers

The design at the moment does not require configuration of the data logger hardware. e.g. All the attached sensors are scanned for incoming data and submitted to the web interface, whether or not the user has configured the matching sensors on the web interface decides on whether the data is logged or not. This is slightly in efficient as the data logger could be sampling a sensor which is not attached to any instrumentation, this wouldn't set off the error handling routine because it is assumed that the user has not configured a sensor which does not exist. Still, this delay could be removed by adding a configuration module to the data logger to allow the user to define how many sensors are currently attached.

The second issue which emerges from the result of no configuration on the data logger its self, is the lack of configuring the ethernet settings. The DHCP (Dynamic host control protocol) module was removed from the PIC MINI WEB's stack to save space, which means that the IP address information is statically configured in the programming. Therefore a user would have to adapt their LAN to accommodate the settings already configured. This could be rectified by either upgrading to the next model of board to gain enough space for DHCP module or pre-configuring the device before being handed over to the user.

12.3.3 Data security

The system has basic data security, to increase the security the following measures could be taken:

1. HTTP traffic could be encrypted to use HTTPS
2. Longer keys could be used to identify data logger devices
3. A system of htaccess instead of PHP sessions could be used to secure the user accounts
4. Data could be stored encrypted in the mySQL database
5. Access to both the data logger and the central server monitored/logged
6. Use a local server instead of an internet based server

12.4 Other applications of the system

The system design can be reinterpreted to be used for other applications where reporting systems are used. For example a security system could be adapted from the design; the sensors could become movement sensors and the web interface the monitoring of the sensor activity. Many more possibilities open up if the communication flow is extended to be bidirectional between the web interface and the data logger. For example it could become a control device for remote automation with the web interface becoming the control panel and the data logger relaying and feeding back the control signals.

12.5 Costs

The following sections are a break down of the estimated costs associated with the system

12.5.1 Project costs

This is the breakdown of the cost of the project if it were to be run again:

Description	**Cost (£) ex vat**
PIC MIN WEB development board	28.42
PIC ICSP connector	2.47
PIC16F877A sensors	3.00*
AC/DC transformer	4.30*
LEDs, LDRs, Resistors, circuit board, wire	3.00*
2 months server rental	24.90*
ICD 2 programmer/debugger	119.95*
Total	**186.04**

Table 6: Project costs break down

*These items were already available and were not bought specifically for the project, however they are included as the project could not have been completed without them. A PC is also a required item with internet connectivity, USB and ethernet.

12.5.2 Potential cost to consumer

The following table estimates the total material cost to a consumer if purchasing the system having been put into small production:

Description	Cost (£) ex vat
PIC MIN WEB development board	28.42
PIC16F877A sensors*5	15.00
Transducers (anemometers, LDR etc)	7.00
AC/DC transformer	4.30
LEDs, Resistors, circuit board, wire	2.00
Casing	3.00
Total	**59.72**

Table 7: Potential cost to consumer

13 Notes

The project's web interface is accessible via http://green.michaelwood.me.uk/ with the user credentials username: testaccount password: brunel

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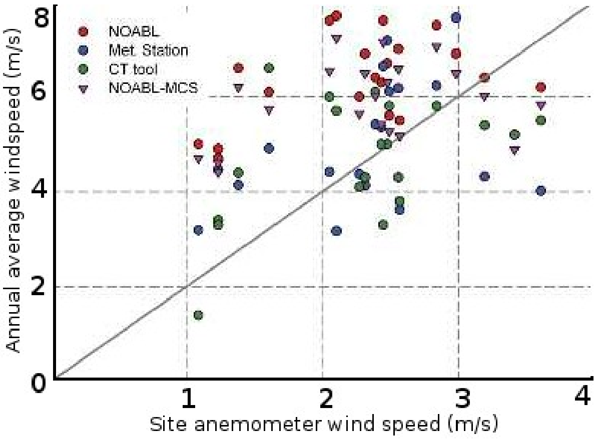
16 Appendix

16.1.1 Appendix A

Graph showing the vast array of wind speed predictions from various tools and the wide ranging accuracy, graph taken from[15]



16.1.2 Appendix B

Table of compared data loggers with meteorological instruments included

Manufacture	La Crosse Technology[21]	La Crosse Technology[21]	Rainwise Inc[20]	Oregon scientific[17]	Davis[19]
Product name	WS 2550	WS 2310	MKIII-LR	WMR200 plus	Vantage Pro2
Internal Data storage	8 days (3k sets)	175 sets	none	10 min intervals for 194 days	24 intervals
Power consumption	3.75w	0.7w	1.5w	6v?	0.5w
Target Market	Mid end	Low end	High end	Mid end	High end
Data retrieval communication	USB to PC	USB or Serial to PC	USB to PC/Serial to PC/Modem	USB to PC	USB to PC
Sample time	3 minutes	8 seconds	2 seconds		20sec – 1min
Cost	£357.56	£115.00	£1,052.50	£399.99	£1,243.15

16.1.3 Appendix C

Table with 742 records with 4 columns in it requires 38.6 KiB (39526.4 Bytes) therefore 1 record = 39526.4/742 = 53.27 Bytes per record

Year*No. Ten minutes in a day*Bytes per record

365*144*53.27/2048 = 2.67 MiB

16.1.4 Appendix D

PIC18F25J10 microcontroller ENC28J60 Ethernet controller 32KB Flash 1K RAM features:

- 1Mbit on board serial flash for web pages storage
- ICSP/ICD connector for programming and debugging

- Reset button
- User event button connected to RB0 interrupt
- Complete web server and TCP-IP stack support as per Microchip's open source TCP/IP stack
- Power plug-in jack for +5VDC power supply
- Voltage regulator +3.3V and filtering capacitors
- status LED
- Extension header to connect to other boards 10 GPIOs and power supply, reset signals
- Dimensions 55x36 mm (2.16x1.42")

16.1.5 Appendix E

PIC circuit connection diagram (see sheet)

16.1.6 Appendix F

Olimex's schematic for the PIC-MINI-WEB featuring the PIC18F25J10:

Copyright Olimex Ltd 2006, available from: http://olimex.com/dev/images/PIC/PIC-MINI-WEB-REV-C-SCH.gif

16.1.7 Appendix G

Function written to provide reading of custom serial data into the data logger “PIC MINI WEB”

```
static int GetSerialData(void)
{

BYTE temp[8];
BYTE i;
BYTE result;
BYTE pos;

//read the pulses on RA0 for 8x5ms into the temp array
//each array bit contains the result from each sample
i=0;
while (i < 8) {

            DelayMs(2.5);
            if (PORTAbits.RA0 == 1) {
                  temp[i] = 1;
            } else      {
                  temp[i] = 0;
            }
            DelayMs(2.5);
            i++;
}
```

```
//convert value in temp array to decimal number by adding up the weight of
each value in the position of the array, e.g. if position 3 in the array is
1 then 2^3 is accumulated onto “result”
i=8;
pos=0;
result=0;

while (pos > 8) {
   result += temp[i]*(pow(pos));
   i--;
   pos++;
}

return result;

} //end get serial data function
```

16.1.8 Appendix H

Function written to provide the reading of an analogue signal and converting it to a digital value stored in ADRESL on the PIC MINI WEB

```
static void ADRun(void)
{
//clear the ADRESL register
ADRESL = 0x00;
//setup port A0 (AN0) as an input
TRISAbits.TRISA0 = 1;
//options set by adcon0/1/2: references are VSS and VDD (3.3v), incoming
port is AN0
//Left Justified result, clock set at 16 TAD with sampling of FOSC/16
ADCON1 = 0x00;
ADCON2 = 0x3A; //00111010
ADCON0 = 0x00;
// Switch on A/D
ADCON0bits.ADON = 1;
//start A/D
ADCON0bits.GO = 1;

while (ADCON0bits.GO) { }  //wait for AD to be done

}
```

16.1.9 Appendix I

Function to provide a single returned variable of a large set of data in a 2D array

```
private function table_arrays($mysql_query){
//create a multi dimensional array of the results
      $query = mysql_query($mysql_query);

      while ($row = mysql_fetch_array($query, MYSQL_NUM)) {
                  $table_arrays[] = $row; //automatically creates a new array
instance with the array $row
      }
```

```
     return $table_arrays;
}
```

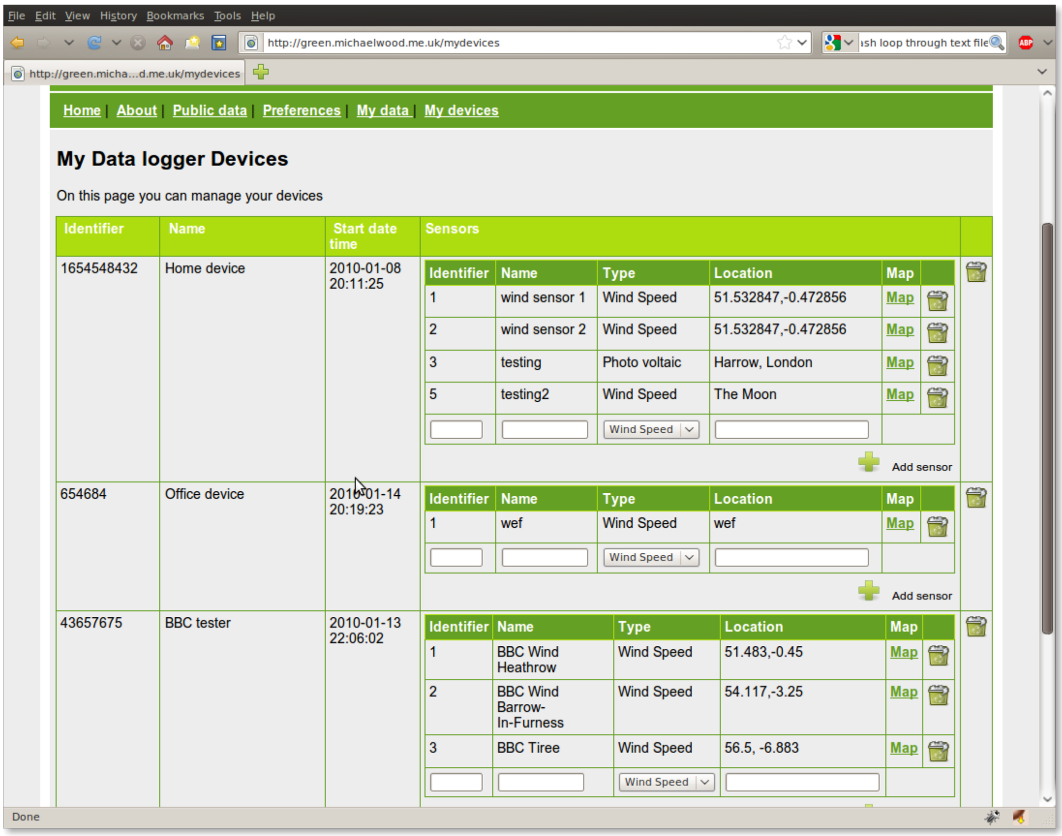
16.1.10 Appendix J

```
private function find_smallest_difference($value,$product_values) {
     //finds the value with the smallest difference and returns the kwh
which causes the smallest difference
          foreach ($product_values as $pvalue) {
          //php doesn't support unsigned int so we need to switch the
values around depending on which is largest to get the real difference
               if ($pvalue > $value) {
               $diff[$pvalue] = $pvalue - $value;
               } else { $diff[$pvalue] = $value - $pvalue; }
          }
          //sort the array in numerical order
          asort($diff,SORT_NUMERIC);
          foreach (array_keys($diff) as $first) {
                         $smallest_diff_caused_by = $first;
                         break;
          }
          return $smallest_diff_caused_by;

}
```

16.1.11 Appendix K

Configuration of the user's data logger on the web interface screenshot:



My Data logger Devices

On this page you can manage your devices

Identifier	Name	Start date time	Sensors
1654548432	Home device	2010-01-08 20:11:25	

Identifier	Name	Type	Location	Map
1	wind sensor 1	Wind Speed	51.532847,-0.472856	Map
2	wind sensor 2	Wind Speed	51.532847,-0.472856	Map
3	testing	Photo voltaic	Harrow, London	Map
5	testing2	Wind Speed	The Moon	Map
		Wind Speed		

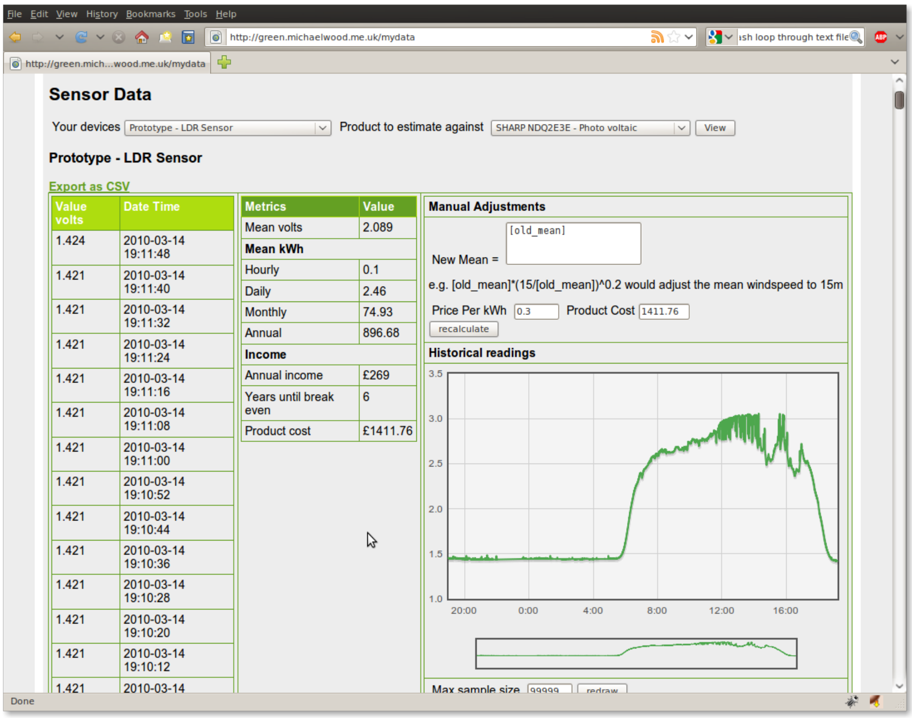
Identifier	Name	Start date time	Sensors
654684	Office device	2010-01-14 20:19:23	

Identifier	Name	Type	Location	Map
1	wef	Wind Speed	wef	Map
		Wind Speed		

Identifier	Name	Start date time	Sensors
43657675	BBC tester	2010-01-13 22:06:02	

Identifier	Name	Type	Location	Map
1	BBC Wind Heathrow	Wind Speed	51.483,-0.45	Map
2	BBC Wind Barrow-In-Furness	Wind Speed	54.117,-3.25	Map
3	BBC Tiree	Wind Speed	56.5, -6.883	Map
		Wind Speed		

Data viewing web interface screenshot:



Sensor Data

Your devices: Prototype - LDR Sensor
Product to estimate against: SHARP NDQ2E3E - Photo voltaic

Prototype - LDR Sensor

Export as CSV

Value volts	Date Time
1.424	2010-03-14 19:11:48
1.421	2010-03-14 19:11:40
1.421	2010-03-14 19:11:32
1.421	2010-03-14 19:11:24
1.421	2010-03-14 19:11:16
1.421	2010-03-14 19:11:08
1.421	2010-03-14 19:11:00
1.421	2010-03-14 19:10:52
1.421	2010-03-14 19:10:44
1.421	2010-03-14 19:10:36
1.421	2010-03-14 19:10:28
1.421	2010-03-14 19:10:20
1.421	2010-03-14 19:10:12
1.421	2010-03-14

Metrics	Value
Mean volts	2.089
Mean kWh	
Hourly	0.1
Daily	2.46
Monthly	74.93
Annual	896.68
Income	
Annual income	£269
Years until break even	6
Product cost	£1411.76

Manual Adjustments

New Mean = [old_mean]

e.g. [old_mean]*(15/[old_mean])^0.2 would adjust the mean windspeed to 15m

Price Per kWh 0.3 Product Cost 1411.76

Historical readings

Max sample size 99999

16.1.13 Appendix M

Script used to automate the processing of data from feeds supplied by the BBC weather web site. Simulating that of a sensor doing the HTTP post process.

Crontab (scheduler) entry:

```
30 * * * * bash '/var/www/green.michaelwood.me.uk/post_from_bbc.sh'
>>/dev/null 2>&1
…
```

(once an hour at 30 minutes past the hour)

Bash script:

```
#!/bin/bash
#this shell script pretends the the bbc weather feed is a device with a
sensor submitting data
current_weather=`curl -s
http://newsrss.bbc.co.uk/weather/forecast/333/ObservationsRSS.xml | grep
"mph" | awk '{print $9}'`
windspeed=${current_weather/"mph,"/}
windspeedms=`echo "$windspeed * 0.447" | bc`
deviceid="43657675"
sensorid="16"
webhost="green.michaelwood.me.uk"
length=`echo "data=$windspeedms&deviceid=$deviceid&sensorid=$sensorid" | wc
-c`
(
sleep 1
echo "POST /modules/receivedata.php HTTP/1.0"
sleep 1
echo "Host:$webhost"
```

```
sleep 1
echo "Accept: */*"
sleep 1
echo "Content-type: application/x-www-form-urlencoded"
sleep 1
echo "Content-length: $length"
sleep 1
echo ""
echo "data=$windspeedms&deviceid=$deviceid&sensorid=$sensorid"
echo ""
) | telnet $webhost 80
```

16.1.14 Appendix N

Circuit diagram for testing of an analogue sensor based on a LDR:

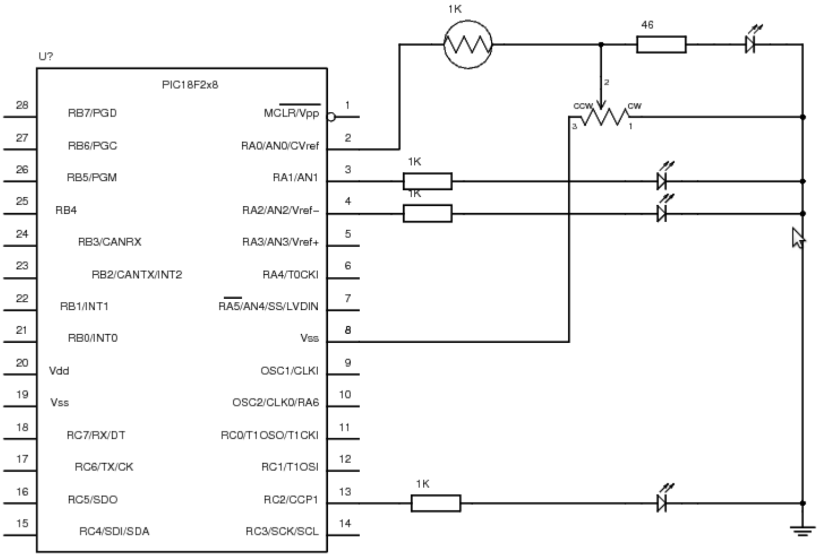
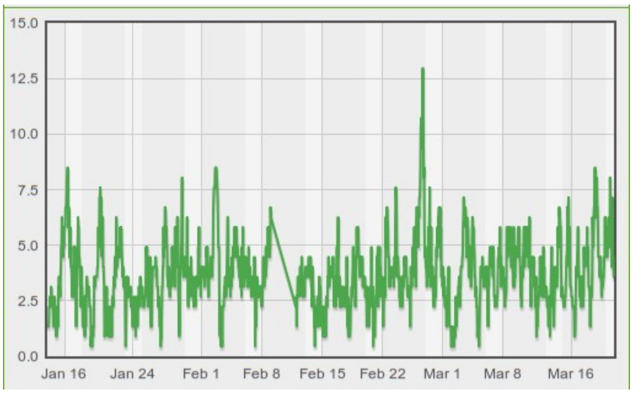


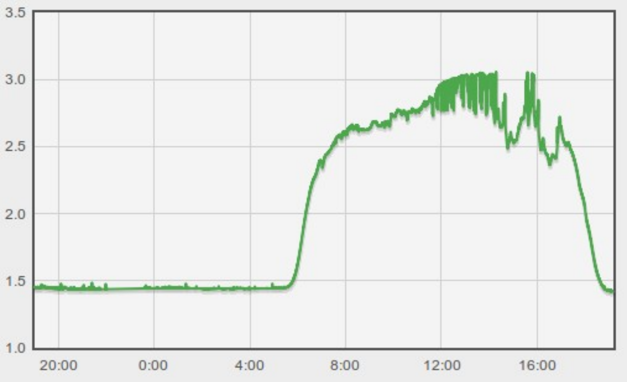
Figure 11: LDR circuit diagram used for data cature

16.1.15 Appendix O

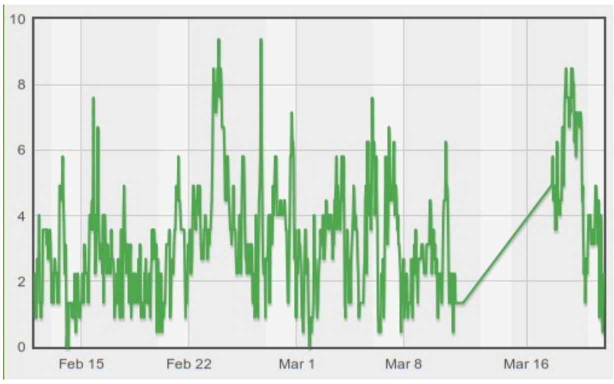
Results from data acquisition experiments, screenshots of graphs generated on the web interface.



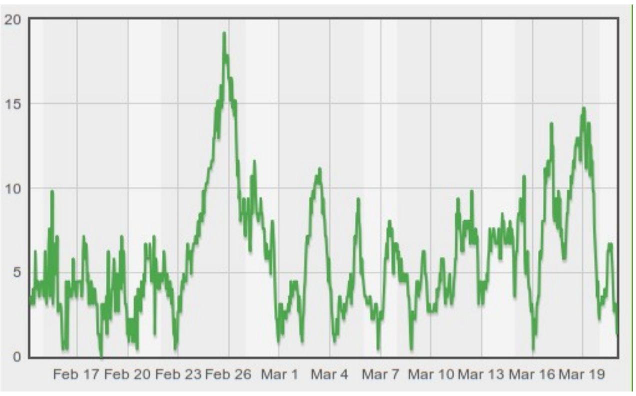
Graph 2: Heathrow wind speed acquired from Met office data feeds



Graph 1: LDR experiment, 24 hours of light intensity recordings



Graph 3: Barrow-In-Furness wind speed acquired from met office data feeds



Graph 4: Tiree wind speed acquired from met office data feeds

16.1.16 Appendix P

Yield generated by the wind speed at Tiree at 40m

Wind turbine model	**Annual Yield**
Proven 6	29083.2
Proven 7	12,772.08
Proven 11	22,627.08
Proven 35	59,497.92
Vesta V52-850	1,839,600.00

Figures Index

Index of Tables