The University of Newcastle
Faculty of Engineering and the built environment

In Home Appliance Scheduler Using Home Area Network

Jack McKew
c3232675

supervised by
Prof. Jamil Khan

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Abstract

This project aimed to develop and construct a home area network capable of monitoring and controlling appliances in accordance with an optimized schedule. This thesis includes theory on fundamental principles behind how each technology works and is continued by reviews of current technologies and strategies researched in the field of optimization and home area network design. The report continues with the progress made to date of the data collection device designed to monitor and control mains powered appliances; including descriptions of designs, justification for design choices and development of working components of the project.

The latter half of this report details investigations and implementation of a multi-objective optimization algorithm (MOEA). NSGA-II was chosen to be used to optimize the schedule for multiple objective functions including but not limited to: price, total power used and renewables utilized. An average general household model was developed for testing the limitations on the scheduling algorithm. The house also included solar energy generation capabilities along with on-site energy storage capabilities.

The scheduling algorithm after rigorous testing on scheduling multiple appliances showed a total reduction in daily energy prices of up to 50%. Further insights showed that the scheduling algorithm often scheduled the appliances to run within the middle of peak solar energy generation times as it was seen to be move favourable to use solar energy rather than export it to the grid for a tariff incentive of $11.9c/kWh$ [1].

Since the system was designed with no limitations on the size of generation/-consumption of the equipment it would be used, there is a future possibility of including this in commercial and industrial projects as large solar generation capabilities are further adopted and could be better utilized.

Acknowledgements

Throughout this project and through the course of my degree there are a number of people I would like to acknowledge and thank for their ongoing support. Firstly, I would like to thank both Hunter H2O and AECOM for giving me the industry experience and knowledge to tackle not only this project but many others during this degree. I would also like acknowledge my fellow peers for the advice and discussions I had with them throughout this degree and for helping improve my skills across the board. Finally, I would like to thank my family and friends for giving me the love and support I needed to make it through this degree.

Contributions

My key contributions to this project so far include:

- Literature review on current demand-side management techniques and optimization strategies,
- Reviewed existing technology on home area network development and construction,
- Develop a home area network for monitoring and controlling mains powered appliances,
- Develop a smart phone app for interfacing with the home area network,
- Implementation of demand-side management techniques for optimization of home appliance power usage,
- Analysis of effectiveness of demand-side management with home appliance power model.

My future contributions to be completed for this project include:

- Extra features for the smart phone application for increased usability.

Jack McKew	4/11/2018
Student: Jack McKew	Date
Jamil Y. Khan Digitally signed by Jamil Y. Khan Date: 2018.11.05 10:03:41 +11'00'	05/11/2018
Supervisor: Jamil Khan	Date

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Chapter 1

Introduction

This chapter establishes an overview of the project and the motivation behind it. It also provides a brief summary of the report structure

1.1 Project Motivation

Electricity consumption within the common residential home varies between different hours of the day, between days of the week, and between seasons of the year. In recent years, electrical distribution companies are under more pressure to consider more complex power balance scenarios due to the introduction of large scale renewable electricity generation, electric powered vehicles and distributed electricity generation in residential areas.

Generating electricity from renewable sources is often intermittent, such as wind, making them a dynamic generation source and will require additional balancing of power to maintain quality of supply to consumers. Additionally, as electric vehicles are further adopted, this will cause high electricity consumption that is not always predictable. With renewable generation sources dynamically contributing to the grid and electric vehicles seemingly *'random'* demand of power; these components require a balancing force in the distribution grid to remain stable.

Load balancing of residential electrical loads can be achieved by minimizing the usage of non-renewable generation and scheduling controllable loads to times when renewable energy generation is high. There are already existing ways to engage the consumer to participate in load balancing such as time-varying electricity tariffs. However, this requires the consumer to make conscious decisions and maintain their household loads (appliances) throughout the day/night. Additionally, with energy storage (batteries) becoming more commonplace for the residential consumer increases the complexity of load balancing.

1.2 Project Overview

This project investigates the design, construction and implementation of an automated system that can (as can be seen in Figures 2.1 & B.2):

- monitors appliance power usage,
- switches appliances on/off,
- optimizes schedule to minimize energy usage.

The project explores several disciplines such as smart phone application development, power monitoring, database management, network design and optimization algorithms. Prototype data collection devices are used for initial optimization investigations and configurations. Results are determined from cost of energy savings over a single day.

1.3 Report Outline

This report has been organised into 8 chapters and 3 appendices. The chapters begin with a brief summary of their contents followed by an outline of the aims of the chapter. This is done to improve the readability of the report and allow chapters to be read independently from one another.

- **Chapter 1 Introduction** - provides the motivation and an overview of the project as well as an outline for the Interim report.
- **Chapter 2 Background** - establishes fundamental information to obtain a sound understanding of the concepts outlined in this report.
- **Chapter 3 Previous Works** - an in depth look at previous work of a similar nature.
- **Chapter 4 Data Collection Node** - in depth look at the construction and testing of the data collection device.
- **Chapter 5 Optimization Algorithms** - in depth look at the development and testing of the optimization algorithms investigated.
- **Chapter 6 Economical Analysis** - an analysis on the economics of installing and maintaining of the system on the common household.
- **Chapter 7 Results and Outcomes** - an analysis on the results from the optimization algorithms and home network.
- **Chapter 8 Conclusions and Extensions** - an overview on the suitability of this project for real world use and further extensions to improve the project.

Chapter 2

Background

This chapter establishes relevant information to understand basic concepts of the project. It includes a summary of non-invasive power monitoring. This chapter also covers basic networking fundamentals and data transmission protocols.

As detailed in Section 1.2, the system will be required to utilise various technologies to meet the requirements. As can be seen in Figure 2.1, the system is comprised of:

- a SQL database (2.3) to store and process schedules for the system using an algorithm (2.4.2),
- data collection nodes utilising current monitoring via current transformers (C.T.) 4.4,
- data reporting via MQTT (2.2) over a Wi-Fi network (2.2),
- access to data reports and schedules via Android app.

These underlying technologies that have been utilised in this project are further detailed in this chapter.

Figure 2.1 shows a simplified block diagram of the system that is further detailed and implemented in this report. It is comprised of a network of data collection nodes configured in a star configuration with a Wi-Fi router at the center. All data collected is stored in a SQL database and is served to the end-user via web and app interfaces.

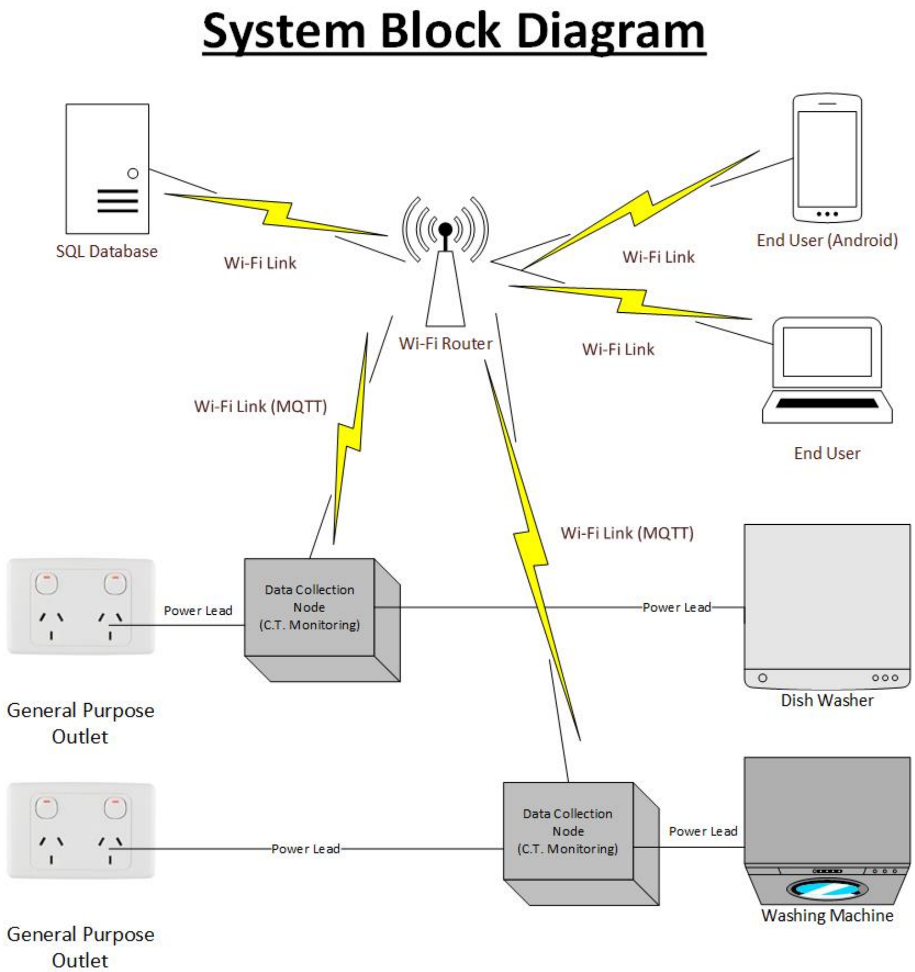

Figure 2.1: Basic Block Diagram of System

2.1 Non-invasive Current Monitoring

Non-invasive current monitoring is achieved through the use of a current transformer (C.T.), which is a type of *'instrument transformer'* that is designed to produce an alternating current in its secondary winding which is proportional to the current being measured in its primary. Current transformers reduce high voltage currents to a much lower value and provide a convenient way of safely monitoring the actual electrical current flowing in an AC line [2].

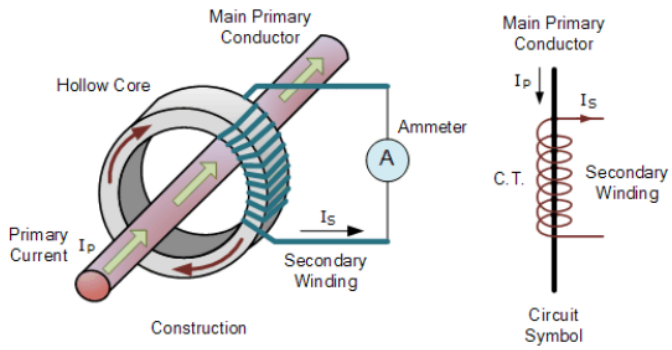

Figure 2.2: Diagram of Current Transformer Functionality [2]

2.2 Wi-Fi Networking

A network is defined as *"A network is a collection of computers, servers, mainframes, network devices, peripherals, or other devices connected to one another to allow the sharing of data"* [3]. There are various configurations of networks for specific design scenarios as represented in Figure 2.3:

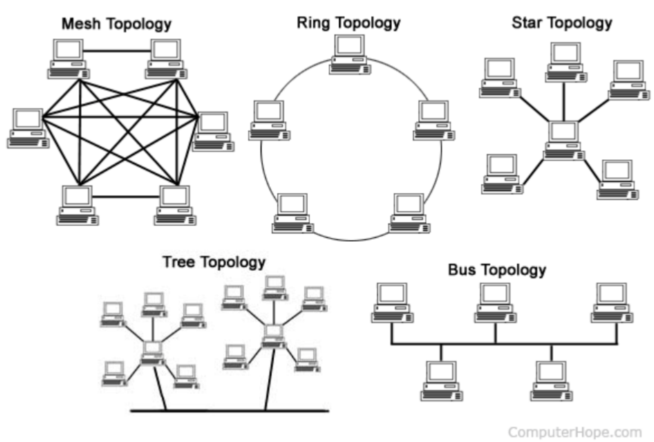

Figure 2.3: Diagram of Current Transformer Functionality [3]

Typical residential home networks are configured in a tree topology that is connected to the internet. This typically consists of a single router/modem that serves all the end-user devices on the network with internet connection. The router also acts as a gateway for the devices connected on the network to communicate with one another.

This project will utilise a star topology with the common home's Wi-Fi router at the center. Packets of data that are generated by the devices are encapsulated with destination routing information; which is passed to the router at the center which directs the data to it's destination in the network. For example, power usage data collected at the data collection devices is directed to the SQL database and is passed through the Wi-Fi router at the center of the star network.

MQTT Protocol

"MQTT is a machine-to-machine (M2M)/ "Internet of Things" connectivity protocol. It was designed as an extremely lightweight publish/subscribe messaging transport. It is useful for connections with remote locations where a small code footprint is required and/or network bandwidth is at a premium. For example, it has been used in sensors communicating to a broker via satellite link, over occasional dial-up connections with healthcare providers, and in a range of home automation and small device scenarios. It is also ideal for mobile applications because of its small size, low power usage, minimised data packets, and efficient distribution of information to one or many receivers" [4].

By using a publish/subscribe messaging model that facilitates one-to-many distribution, this means that the sending applications don't need to know anything about what is receiving the data. This type of messaging model is ideal for constrained networks (high latency, data limits, fragile connections, low bandwidth, etc.). Header information is kept as small as possible with the fixed header being 2 bytes. By using such a small header, the footprint on the devices is relatively small in comparison to that of other messaging models, eg HTTP.

Connection from the client to the server is as simple as a single TCP/IP port connection, allowing easier firewall and security integration into a network. Command messages for establishing client-server connections are as simple as CONNECT, PUBLISH, SUBSCRIBE and DISCONNECT.

Figure 2.4 shows how the MQTT protocol is based on TCP/IP, where both the client and the server need a TCP/IP stack. To initiate a connection the client sends a CONNECT message to the server, which is met with a reponse CONNACK message and status code. Once this connection is established, the server will keep it open until the client either sends a DISCONNECT command or the connection breaks.

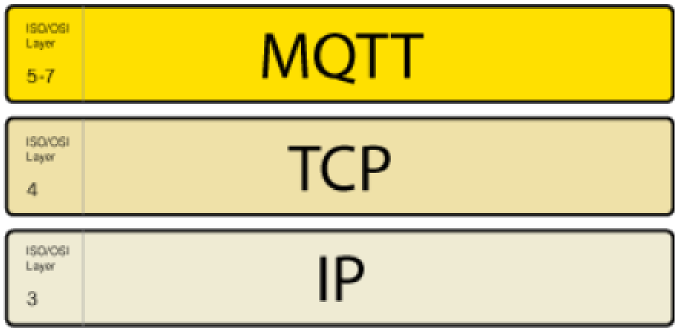

Figure 2.4: MQTT Protocol [5]

2.3 Database Management

When working with an ever growing database, being able to request specific data easily is a must. Utilizing a database structure, for storing sensor data, allows the system to fully benefit from the broad search functionality. For example, if the end-user needed to know the specific energy usage for the refrigerator at a certain date and time this could be easily accomplished with a SQL query.

SQL Database

"SQL (Structured Query Language) is a standardized programming language used for managing relational databases and performing various operations on the data in them" [6]. SQL can be used to update, remove or add rows of data and return requested data simply and effectively. For this project the database was established to detail when and how much power an appliance is consuming at any given time. An example of an SQL query is shown below:

```
SELECT APPLIANCE, POWER, TIME
FROM APPLIANCE_TBL
WHERE APPLIANCE = 'REFRIGERATOR'
ORDER BY TIME;
```

The query above results are shown in Table 2.1 below:

Table 2.1: SQL Example Results

Appliance	Power (W)	Time
Refrigerator	145.6	04/05/2018 15:15:37
Refrigerator	145.2	04/05/2018 15:16:40
Refrigerator	144.3	04/05/2018 15:17:43
Refrigerator	140.8	04/05/2018 15:18:46
Refrigerator	135.2	04/05/2018 15:19:49
Refrigerator	151.5	04/05/2018 15:20:53

2.4 Multi-objective Optimization

Multi-objective optimization problems deal with conflicting objectives (eg. while one objective increases the other decreases). There is commonly no unique global solution but a set of solutions that try to meet the objectives as closely as possible. A solution is determined that satisfies all constraints and variables bounds is known as a feasible solution, along with the set of all feasible solutions known as the feasible region. The objective space is constituted by the possible values of the objective functions for all solutions in the feasible region.

2.4.1 Definitions

Domination:

A solution $x^{(1)}$ is said to dominated the other solution $x^{(2)}$ if both condition 1 and 2 below are true:

- Condition 1: $x^{(1)}$ is no worse than $x^{(2)}$ for all objectives
- Condition 2: $x^{(1)}$ is strictly better than $x^{(2)}$ in at least one objective

The mathematical notation for $x^{(1)}$ dominates $x^{(2)}$ is:

$$x^{(1)} \preceq x^{(2)} \tag{2.1}$$

Non-Dominated Set:

Among a set of solutions P, the non-dominated set of solutions P' are those that are not dominated by any member of the set P.

Globally Pareto-optimal Front:

The non-dominated set of the entire feasible solution space is the globally pareto-optimal front.

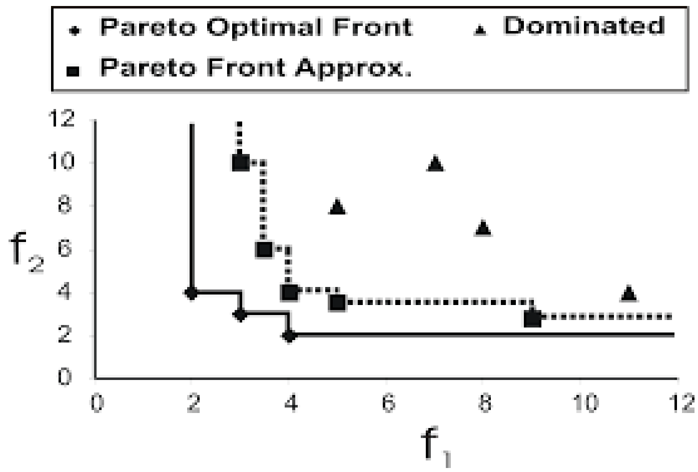

Figure 2.5: Pareto Optimal Front [7]

Objective Function:

An equation to be optimized given certain constraints and variables to be minimized or maximized dependant on the scenario.

Fitness Function:

A fitness function is a particular type of objective function that is used to evaluate how close a solution is to achieving the aims of the algorithm.

2.4.2 NSGA II

Non-dominated sorting genetic algorithm II (NSGA-II) is a multiobjective evolutionary algorithm (MOEA) that can be used for single purpose and multi-objective optimisation problems. For a population of size N, a group of N offspring are created using desired crossover and mutation operators. To ensure more suited solutions is maintained, the offspring and their parent solutions are combined into a group of size $2N$, and the fittest N solutions from this group are used as parents for the next generation.

To determine the top N solutions from the set, this is achieved by assigning each solution to non-dominated fronts. The first front is determined by comparing solutions in the objective space, and assigning the solutions which are not dominated by any other to the first front. This front is set aside and removed from the current population, this process is then repeated to determine the second non-dominated front and so on.

The fronts are then organized in order to create the parents for the next generation of solutions. To preserve diversity in the final group of solutions, NSGA-II removes the *most crowded* solutions from the final front, in order to fit into a group of N parents. To determine which solutions are the *most crowded*, each solution is assigned a crowding-distance. A solution's crowding distance is defined as the sum (over all objectives) of the distance between it's two closest neighbour solutions. If a solution is a maximum or minimum for the objective function, then it is assigned a crowding distance of infinity. The first solutions to be removed are ones with the smallest crowding distance.

After the offspring set and parent set have been combined, sorted and recombined into new parent populations, a new set of offspring is created and the algorithm is repeated for a set number of generation. The initial parent set is generated randomly from the solution space.

Figure 2.6 provides an illustration of a single generation of NSGA-II where the parent and offspring set are combined, sorted into non-dominated fronts, truncated if neccessary and the top N solutions are the parent set for the next generation.

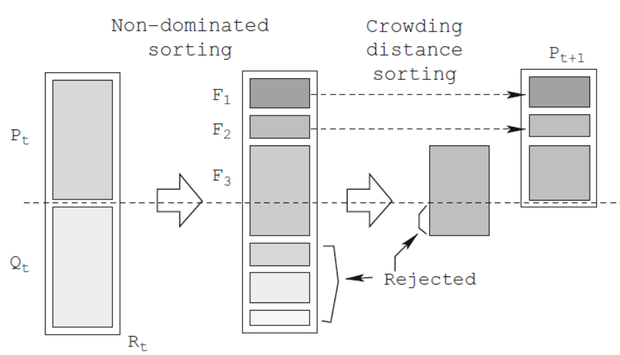

Figure 2.6: NSGA-II Procedure [8]

Chapter 3

Previous Works

This chapter is an overview of previously published works in the area of dynamic demand-side management and data collection devices and infrastructure within the residential home. The advantages and disadvantages of each technology are outlined, with a hope to justify why some design considerations throughout the project were made.

3.1 Data Collection Devices and Infrastructure

Many techniques have been investigated into scheduling household appliances to meet varying targets such as: lowered energy costs, lowered emissions and/or satisfying consumers dedicated time frame for appliances to run.

Varying implementations of home area network setups have been researched previously including:

- Wi-Fi,
- Zigbee,
- Z-Wave.

All having their own pros and cons depending on how the rest of the research was conducted.

The specifics of how a possible home area network could be setup are also proposed in [9]. The proposed solution of using a Zigbee network was chosen due to low power consumption, support for up to 64,000 nodes and short range, however, mention of the use of Wi-Fi was also highlighted. The authors thoroughly detailed delivery ratio, delay and jitter of using Zigbee as the chosen protocol. Future considerations for further research mentioned the use of artificial intelligence (AI) techniques in the optimization process.

The details of a proposed data aggregator named the *Energy Box (eBox)* were outlined in [10]. The aggregator's main objective is *to value* the *flexibility* of the consumption load profile of individual consumers [10]. The proposed optimization process in this paper was a mixed-integer linear programming model and a heuristic algorithm. However, details on the interfaces between the data collection sensors was not detailed in this paper.

Battery life for the network sensors and aggregators is another crucial component to a smart home solution. A dynamic routing protocol using Zigbee was the medium proposed in [11]. Drawing inspiration from how an ant colony determines the shortest path from their nest to a food source, the authors proposed for a dynamically shifting data path for the sensor nodes to the data aggregators. In the end, they found by dynamically changing the route in accordance to the remaining charge their networks lasted for up to 1000 more rounds in comparison to static network routes.

The end-user expects sensors to integrate seamlessly into the smart home network. In [12] a Zigbee-based Self Adjusting Sensor (ZiSAS) was proposed to meet five key requirements: energy efficient operation, easy deployment of a sensor, self configuration, quality of service and application specific operation. The authors proposed a three layered management architecture to achieve these requirements; a management layer for managing control decisions and coordinating sensor nodes, a network layer for managing routing and synchronization and an interface layer to provide the interaction between the device and the user. After implementing the system in real-world scenarios resulted in approximately 3-12% and 8-34% reduction in energy consumption.

3.2 Optimization of Demand-side Management

To alleviate the pressure on the electrical distribution network by scheduling controllable loads at the consumer side is known as dynamic demand-side energy management. This process aims to reduce usage of non-renewable generation and to utilize renewable energy generation.

In the study of dynamic demand-side management, many techniques and algorithms have been proposed. Such as mixed-integer linear programming, applied game theory and applied multi-agent systems to name a few. The underlying idea has been to reduce energy costs corresponding to the time-of-use (TOU) pricing determined by the utility [13]. TOU prices are determined throughout the day according to the supply and demand of the grid.

Consumers can also generate renewable energy locally, and then either consume it themselves or sell the excess energy to the utility. For example, the NSW Solar Bonus Scheme details solar feed-in tariffs for customers with small solar generators or wind generators connected to the utility Ausgrid [14].

3.2.1 Mixed-integer Linear Programming Optimization

In [15], an optimization algorithm is proposed based on mixed-integer programming techniques. The targets that the authors were attempting to achieve were: minimizing electricity cost fulfilling duration, energy requirements and user preference constraints. The authors also included the consideration of periods when the local utility offers monetary incentives to the consumer to export their excess energy to the grid into the optimization algorithm.

Types of loads were classified into three different categories:

1. Shiftable load (flexible delay with specified energy consumption profile), e.g. washing machine, dish washer, etc.
2. Interruptible load (e.g. water heater and refrigerator they are either ON with fixed energy consumption or OFF),
3. Weather based load (e.g. air conditioner and heater which depend upon the weather for their power consumption).

Non-manageable loads include television, lights, computers, etc. Their loads in comparison to the major loads identified above are consider insignificant power consumers. Additionally, these appliances are interactive and have little to no scheduling flexibilities. Figure 3.1 summarizes the system model used for optimization.

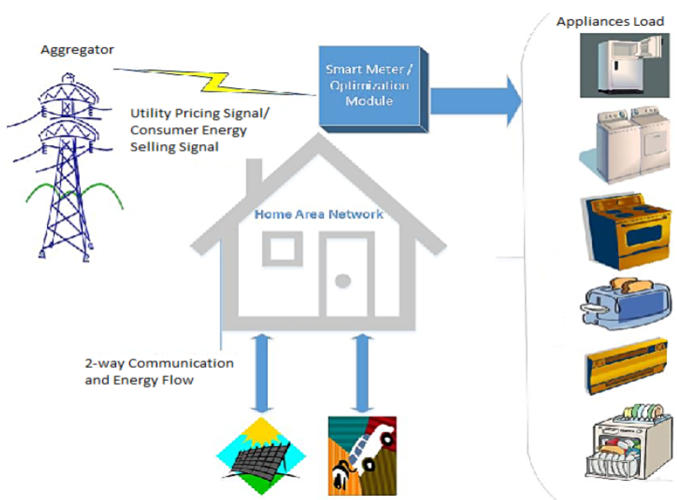

Figure 3.1: Model for Appliance Scheduling [15]

The authors of [15] found that the optimization method proved most successful when applied on the appliances with mixed time range and with solar included. Peak demand of the system remained the same when compared to the base example; however cost of energy decreased from \$4.46 to \$2.84 per kWh based on time of use tariffs without inclusion of the solar system. When the solar system was accounted for, the net cost of energy became $-\$1.20$ per kWh, showing energy cost reduction of 126.9% meaning the consumer was being compensated for the energy generated for the network. The amount of energy drawn from the national grid also decreased from $48.45kWh$ to $35.54kWh$.

The main focus on the experimentation of the mixed-integer linear programming model in [10] was to determine the computational times in comparison to the heuristic algorithm. This was required due to the *eBox* possibly having severe limitations on memory size and computational power. While the algorithms proposed did not find the most optimal solution for the scheduling problem, they still determined suboptimal solutions within a limited computational time.

The authors considered four different scenarios for the algorithm to optimize for, as listed below:

- Balanced (BAL) - the user is equally interested in all the other scenarios,
- Climatic comfort (CC) - the user is mainly interested in keeping house temperature within a specified range,
- Scheduling preferences (SP) - the user is mainly interested in scheduling shiftable appliances to their preferences,
- Money saver (MS) - the user is mainly interested in reducing the electricity bill.

Table 3.1 is an extract of [10] that shows the computational times for the various scenarios listed above.

Table 3.1: Comparison of computation time between heuristic algorithm and mixed-integer approach

Profile	**Mixed Integer (s)**	**Heuristic (s)**
BAL	3.95	19.61
CC	9.28	26.1
SP	22.23	19.64
MS	1.94	19.73

Results showed that the heuristic algorithm determined a solution in 21.27 seconds on average, in comparison to that of the mixed-integer approach which determined the solution in 9.35 seconds.

3.2.2 Applied Game Theory Optimization

A game theory based solution was proposed in [16], utilizing two-way digital communication infrastructure. A model of a single utility company serving multiple consumers (as shown in Figure 3.2) was used for searching for the global optimal performance in terms of minimizing the energy costs. However, this model did not include constraints of end user preference in operating time for appliances.

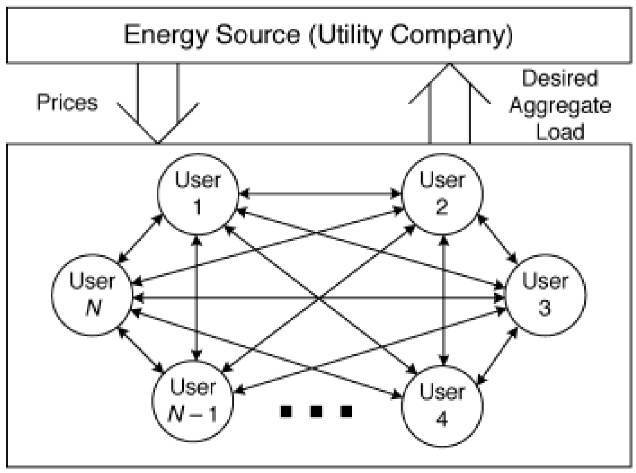

Figure 3.2: Demand-side Management Strategy Model [16]

By focusing on the interactions between the multiple users sharing a local resource rather than the interactions between the end-user and the utility, the model had considerations for 10 users sharing a local resource. When the optimization method was not applied, the cost of energy was determined to be $44.77 per kWh; moreover once the optimization method was applied the cost of energy was found to be $37.90 per kWh, an 18% reduction.

3.2.3 Multi-agent Optimization

An in-home energy management system (iHEM) and optimization based residential energy management application (OREM) were proposed in [9]. The goal of the OREM was to minimize the cost of energy for the end-user. By simulating a washer, dryer, dish washer and coffee maker with their respective appliance cycles and applying OREM showed an approximate 30% reduction in cost of energy over 210 days as shown in Figure 3.3. However due to drawbacks in calculation speed for determining the solution OREM did not reach the optimal solution (35%).

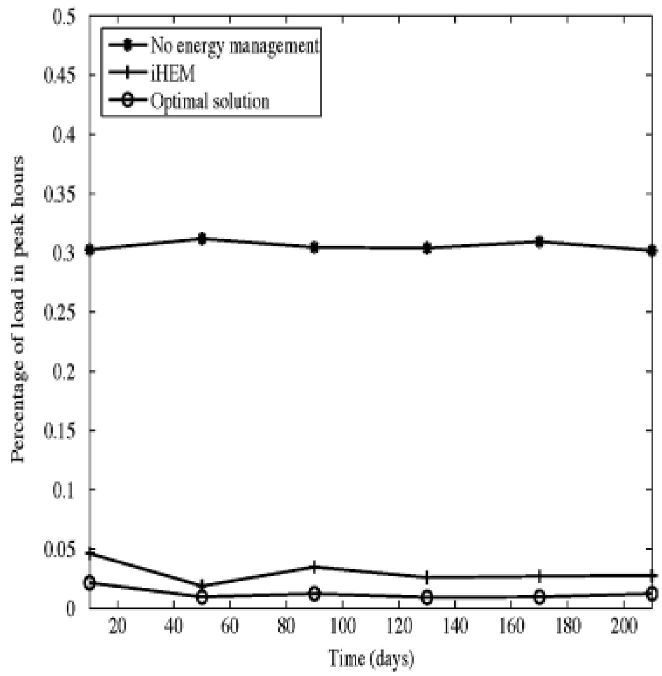

Figure 3.3: Percentage of contribution of the appliances to the total load on peak hours [9]

How a *Smart Home* interacts with the grid and how a home energy management system would affect this was the focus of [17]. Four scenarios were considered:

1. Individual consumer battery storage,
2. No energy storage whatsoever,
3. Communal storage between consumers,
4. Communal storage between consumers and a DC network for backup.

Scenario 4 was shown to be the more flexible and robust configuration in comparison to the other three scenarios; however required high capital costs in setting up, used developing technology and complex operation once installed.

Being able to accurately predict what the end-user is most likely to do next is a crucial part of the interactions between the end-user and the Smart Home. The authors of [18] investigated the use of two different types of predictive algorithms LZ78 and Active LeZi to attempt to predict the most likely next state or inhabitant action. The LZ78 algorithm was primarily used for trie[1] formation

[1] An ordered tree data structure that is used to store an associative array where the keys are usually strings [19].

while the Active LeZi algorithm is introduced to overcome the drawbacks of the LZ78 algorithm. As the Active LeZi prediction algorithm had the more simpler implementation in comparison to LZ78 it was determined to be the optimum choice for a Smart Home predictive analysis implementation. In regards to this project, this would be considered further/tentative objectives as it is not a necessity for this project.

Considering a smart *neighborhood* instead of optimizing a single home was investigated in [20]. Utilizing a multi-agent system (as shown in Figure 3.4) the authors were able to focus on optimizing around a single objective or a multitude such as:

- balancing energy supply and demand,
- reducing peak power demand,
- reducing utility energy costs,
- reducing consumer bills,
- improving grid efficiency,
- increasing the share of renewable energy sources,
- reducing carbon footprint of the power grid.

When focusing on optimizing fair usage between the consumers in the neighborhood, the authors were able to lower usage by 70%.

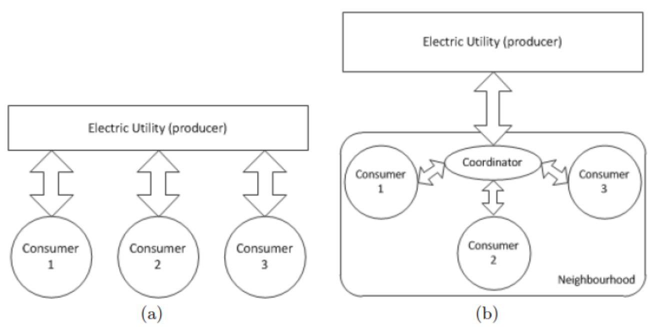

Figure 3.4: Interactions between utility and consumer(s) in demand-side energy management schemes [20]

Chapter 4

Data Collection Node

This chapter is an overview of development of the data collection device. It is further broken down into sections to breakdown the design and testing of the data collection device completed in this stage of the project.

As shown in Figures 2.1 & B.2, the data collection node must meet various requirements to become a suitable component of the system. The data collection node is comprised of multiple components including:

- A Wi-Fi enabled microcontroller,
- an analog to digital converter,
- current monitoring capabilities,
- a standard-compliant enclosure.

The design, development and testing of the components comprised in a single data collection node are further detailed in this chapter, note was made to include design choices that were made at this stage in the project.

4.1 Microcontroller

The microcontroller has to meet various requirements to become a suitable component of the system. Filter of the input signal from the current transformer to eliminate noise in the signal is necessary due to the nature of enclosing all this hardware together in a single enclosure. Must be relatively small in comparison to a power outlet so that it can be reduced to a small outlet enclosure in future versions. Must have Wi-Fi capabilities and have compatibility with the MQTT protocol. Low power consumption so that this does not affect the total power of the appliance that is being connected; capability to be powered by a battery is also seen as beneficial but not necessary.

For prototyping purposes the NodeMCU was chosen as a suitable microcontroller. The NodeMCU board hosts a variety of features as listed below:

- Programmable Wi-Fi module,
- USB-TTL included,
- 10 GPIOs D0-D10, PWM functionality, IIC and SPI communication,
- Wi-Fi networking (can be used as access point and/or station, host a web server), connect to internet to fetch or upload data,
- Event-driven API for network applications,
- Deep sleep functionality.

However, if this project was to go into production smaller/cheaper microcontrollers could be used in conjunction with a Wi-Fi antenna to provide a more purpose built solution. This could be achieved by any simple 8 bit microcontroller although processing capabilities would have to be evaluated to determine if pre-processing the signal can be completed at the node side or move the processing stage to the network co-ordinator.

4.2 Data Networking

A previous project using the NodeMCU as a data logger communicating with a PHP hosted server via HTML requests highlighted drawbacks in constructing a network in that fashion. By communicating over HTML proved to be very difficult at maintaining the integrity of the database. If multiple nodes communicated data simultaneously this was often either misinterpreted or lost altogether. This also showed a drawback in PHP hosted data server by users not able to sync their data across multiple devices or multiple users viewing different *'caches'* of data.

MQTT (Message Queuing Telemetry Transport) is an ISO/IEC 20922:2016 standard publish-subscribe based messaging protocol [21]. By devices being able to publish data to topics and subscribe to topics this meets the criteria of the network requirements. By a node being able to publish the data acquired to a specific topic (e.g. FridgeData) and subscribe to a specific topic for control signals (e.g. FridgeControl). The network co-ordinator can then *'listen'* in on the data topics and push the data into a SQL database for further manipulation; the network co-ordinator can also then publish control signals to the control topics to switch appliances either from the schedule or user input.

Furthermore, MQTT can be interfaced with the user in that the smartphone application can publish its own data so the user can switch their appliances on/off at their own leisure, this can also be used to be able to determine the status of the appliance. If the user is worried that they left the heater on at home while they are out, instead of rushing home or calling a neighbour they can simply log into the smartphone application, check whether the appliance is on or off and switch it correspondingly.

The publish and subscribe channels between the broker and the device(s) in the simplified MQTT network shown in Figure 4.1 communicate over Wi-Fi in the context of this project. Data is published from the data collection nodes in this system every 7 seconds with header information following Table 4.1.

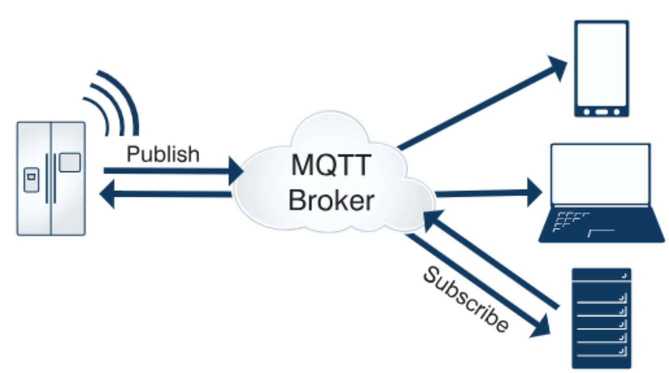

Figure 4.1: Simplified MQTT model [22]

Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
Byte 1	Message Type				DUP Flag	QoS Level		Retain
Byte 2	Remaining Length							

Table 4.1: MQTT Message Fixed Header [23]

4.3 Analog to Digital Converter

To improve resolution and measurement accuracy from the on-board analog-to-digital converter (ADC) from the NodeMCU, an external 16 bit ADS1115 analog to digital converter was chosen. By using the ADS1115's differential mode removes some processing that would be required of the microcontroller.

The ADS1115 communicates with the NodeMCU via an I2C bus, meaning there is no strict baud rate requirements like for example with RS232, where the master must generate a bus clock [24]. This also adds the opportunity to include a voltage transformer for calculating real power as well, due to the ADS1115 having 4 channels (2 differentials).

4.4 Current Transformer

Domestic installation of a general purpose outlet (GPO) is to be rated for up to 250VAC at either 10, 15 or 20 amps as stated in AS/NZS3000 & AS/NZS3122 [25] [26]. The current transformer must be suitable to interface with the microcontroller detailed in 4.1 and the analog to digital converter detailed in 4.3.A suitable current transformer had to meet (at a minimum) the following criteria:

- Capable of 20A input,
- Output in mA range,
- Relatively small in comparison to a GPO.

An SCT-013-000 current transformer was used in a previous project, and had the following characteristics (as can be seen in B.1):

- 0-100A primary range,
- 0-50mA output,
- 32 x 54 mm overall size.

While there are more suitable products that could be used in the production model of this project, the SCT-013-00 was used for prototype and testing purposes. Since this current transformer does not contain a burden resistor to convert the output to voltage a burden resistor had to calculated. The burden resistor calculations are shown below:

$$\text{Primary peak current} = \text{RMS Current} * \sqrt{2} = 141.1A \tag{4.1}$$

Since the SCT-013-000 has 2000 turns, the secondary peak current will be:

$$\text{Primary peak current / number of turns} = 0.0707A \tag{4.2}$$

To maximize measurement resolution, the voltage across the burden resistor should be equal to one-half of the microcontroller reference voltage (3.3V):

$$\frac{\frac{3.3}{2}}{0.0707} = 23.3\Omega \tag{4.3}$$

Since 23.3Ω is not a common resistor value a 24Ω resistor was used instead. A circuit diagram of the configuration detailed above is shown in Figure B.3.

4.5 Enclosure

The electrical enclosure to house the microcontroller 4.1, ADC 4.3 and current transformer 4.4 and connect to both the GPO and the appliance must meet the requirements of the following standards:

- AS/NZS 3112 - Approval and test specification - Plugs and socket-outlets [26],
- Nema 250 - Enclosures for Electrical Equipment [27],
- AS/NZS 3008 - Electrical installations [28].

For prototyping purposes a jiffy box has been used together with a mains panel socket and a IEC C13 male socket. This allows for the unit to be enclosed for testing purposes while meeting Work, Health & Safety (WH&S) requirements for safe work with mains power. However, for production purposes future development would need to be made, an example of another product for monitoring purposes is pictured below in Figure 4.2:

Figure 4.2: Existing smart plug product [29]

A comparison between the data collection device and the existing product can be seen below:

Data Collection Device	Existing Product
Connects to Wi-Fi	Connects to Wi-Fi
Manual switching via user input	Manual switching via user input
Automatic switching via power saving optimized schedule	

Table 4.2: Data Collection Device vs Existing Product [29]

4.6 Smartphone Application Interface

The Mobile Consumer Survey 2017 report shows that *"88% of Australians now own a smartphone, up 84% since 2016"* [30]. Furthermore, the report also shows that Australian households are becoming more *'connected'* with 5% of homes having *'smart'* home appliances that are readily accessible as shown in Figure 4.3.

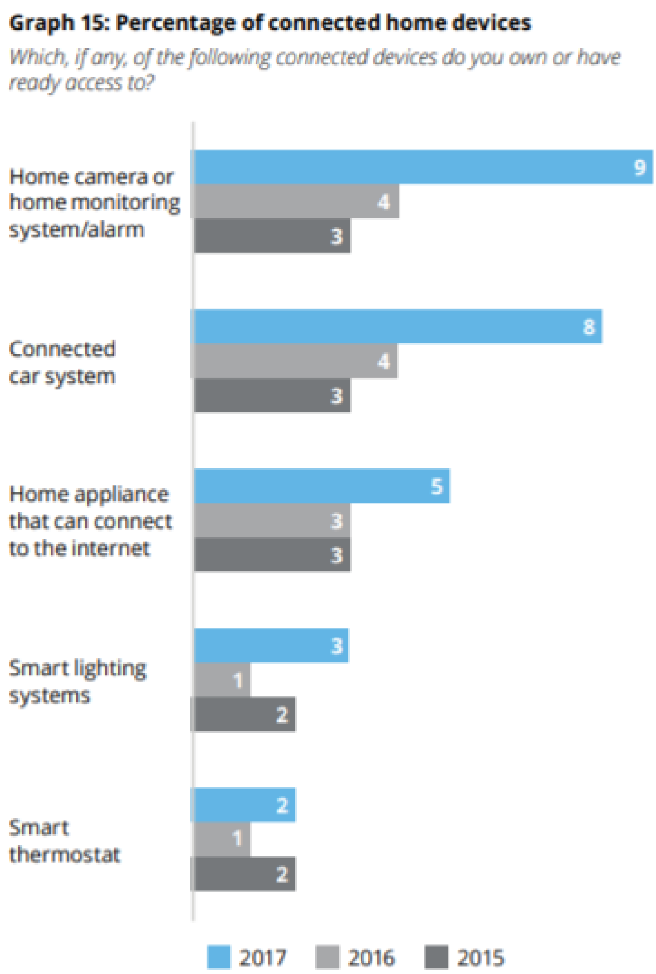

Figure 4.3: % of connected home devices [30]

With 75% of Australian smartphone owners either using an Apple or Samsung device, more specifically iOS or Android respectively. Since the aim of this project is to be user-friendly developing for both platforms would be the most beneficial for usability. However Figure 4.4 shows that there is a significant disparity between Android and iOS ownership globally [31].

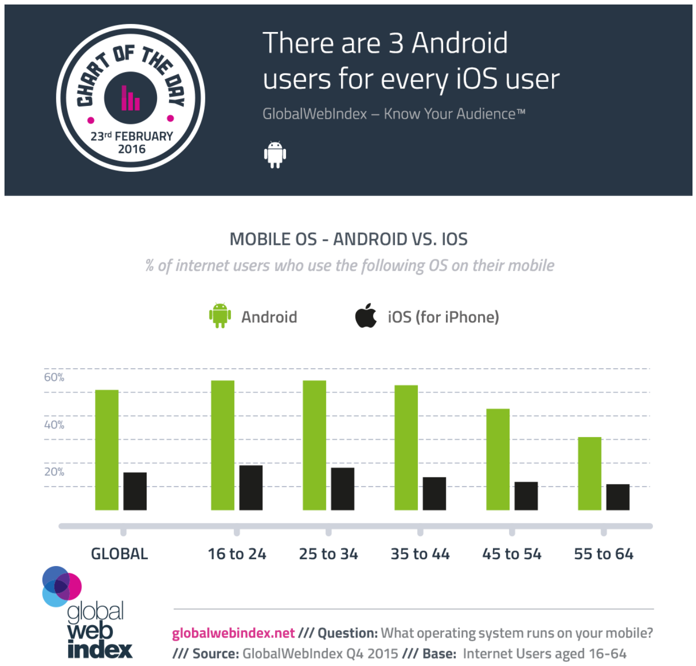

Figure 4.4: Android vs iOS of % of internet users [31]

4.6.1 Flutter

Flutter is a native framework for developing smart phone applications that both builds an application that can be used in Android and iOS from the same code base. By simultaneously developing for both platforms this drastically reduces the time taken developing, while increasing the amount of reachable users. Flutter also has been designed such that, when you develop an application, this meets Google's visual design standards meaning the production of the application has similarities with other apps so the user is not confused with the actions. Development images of the application are shown in Figures A.1 & A.2. However due to lack of support of third party interfaces Flutter was not chosen to be further developed past this stage.

4.6.2 Android

As detailed in 4.6, Android has a larger user base in comparison to that of iOS so further development of the app was chosen on the Android platform. Android also has high compatibility with third party interfaces as well, which will be required later in the project for real time updates on the data representations. An example of the progress thus far is shown in Figures A.3 & A.4.

The line graph shown in Figure A.4 is dynamic that the user is able to zoom in or out and select values to gain a further insight into the data. By implementing these features gives the user further flexibility to investigate and breakdown their consumption data. This information can then be used to make decisions on their every day living to possibly make lifestyle changes to further reduce power consumption. Also this information can be used to determine faults or errors in their current home appliances; e.g. the water heater might suddenly start heating in the middle of the night due to water leaking out.

Future features to be implemented include, but are not limited to:

- Real time updates of data as it is acquired (provided the user is connected),
- Visibility and interaction with the optimized schedule as it is created,
- Show optimization statistics (e.g. power saved, money saved),
- Allow user to monitor appliance status (e.g. ON/OFF).

4.6.3 Chapter Summary

In summary; a NodeMCU microcontroller, external analog to digital converter and current transformer were installed in a standard-compliant enclosure with a female and male socket for connection between an outlet and the appliance to be monitored. This system was installed in a real world scenario for collection of data on devices as shown in the load profiles in Appendix C. The nodes reported via MQTT back to a server hosting a SQL database. This data could then be queried by an Android application or web interface to serve the data back to the end-user.

Chapter 5

Optimization Model

This chapter is an overview of development of optimization model and schedule creation. It is further broken down into sections to breakdown how the data was arranged, how the appliances were modelled and the optimization algorithm utilized throughout this stage of the project.

5.1 Appliance Modelling

To model the appliances using data gathered with the data collection nodes (Chapter 4), python was chosen as the language to connect the SQL database together with multiple resources of data (e.g. Time of use pricing (5.5.1)). The optimization model as a whole is comprised of multiple sections which are further detailed later in this document. The entire structure is modelled from random generation of solar energy, solar battery modelling and quantization of appliances.

5.1.1 SQL Data Processing

The first step in the link between the data collection nodes results stored in a SQL database, is to produce the total energy use of an appliance over a time period. By utilizing a SQL query to select a single day period and iterate through appliance type to generate the data set to determine when the appliance was running. Once the load curve data set was identified from the SQL query it then undergoes a quantization process detailed in section 5.1.2

5.1.2 Quantization of Results

To effectively utilize NSGAII (2.4.2), energy use of an appliance was calculated by calculating the area under the load-time curve to effectively determine the kWh consumed by the appliance. Due to the nature of the curves being thousands to tens of thousands of discrete points, fitting a curve could prove detrimental to results by clipping some results from the curve. The decision was made to effectively convert the curve into a polygon with a number of sides equal to the number of discrete points used. This can be seen in Figure 5.1.

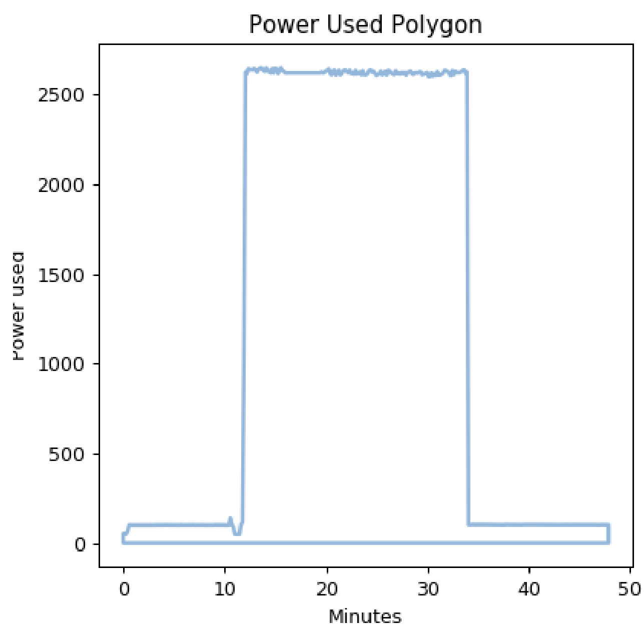

Figure 5.1: Dish washer Load Curve from SQL Database

5.2 Solar Generation Modelling

Given solar energy generation normally peaks at noon when the sun is highest, a theoretical model was designed ensuring to utilize the common similarities between a normal Gaussian distribution and solar energy curves. The theoretical also was developed with randomness (e.g. cloud cover) included to give a more realistic solar system model. The system has included functionality to be able to extract data from online meteorological data sources on the amount of cloud cover that the area where the system is installed may undergo on any given day.

An example solar PV curve is shown in Figure 5.2.

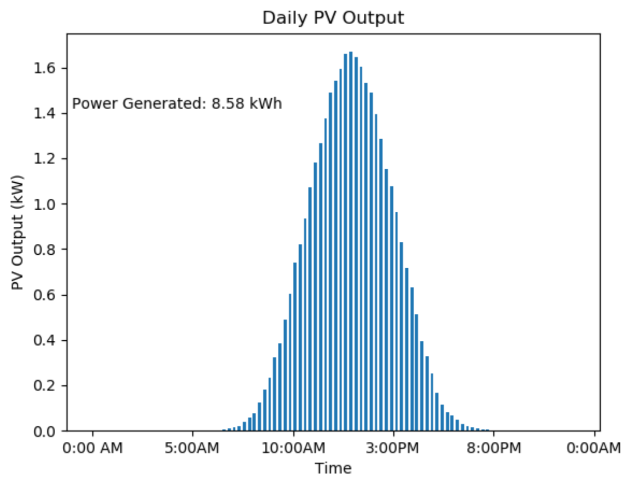

Figure 5.2: Solar PV Generation Model for Optimization Model

5.3 Energy Storage Modelling

For this optimization model, the solar battery storage size was chosen to be 12kW, as this was the average amount of energy an Australian home needs to offset the nightly energy usage [32] .To emulate a realistic solar energy storage system, this was designed with a system in mind that only charges energy storage modules when the total consumption of the home is compensated for and the home is exporting energy to the grid. Rather than exporting energy to the grid, it is stored in batteries for future usage. The system was also developed with functionality to retain a certain percentage of energy for use throughout the night with a selectable time to discharge. The state of battery charge throughout the day in the model is shown in Figure 5.3.

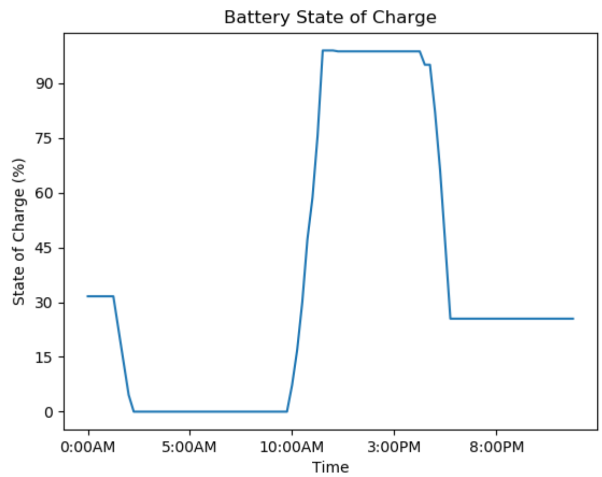

Figure 5.3: Solar Energy Storage Model for Optimization Model

5.4 General Household Model

For the load profile of the household model to be tested with the optimization model, common household appliances were broken into two categories: non-shiftable loads and shiftable loads. This is further detailed in Table 5.1.

Electric Appliance	Power Consumption (kW)	Time of Use
TV	0.08	non-shiftable load P_{NSt}
Refrigerator	0.25∼0.3	
Air Conditioner	0.2∼0.4	
Lighting	0.1∼0.5	
Dishwasher	1.2	shiftable load P_{SLt}
Washing Machine	1.4	
Cleaner	1.0	

Table 5.1: Load Classification of Common Household Appliances

From the classifications in Table 5.1, a general household load profile was developed as shown in Figure 5.5.

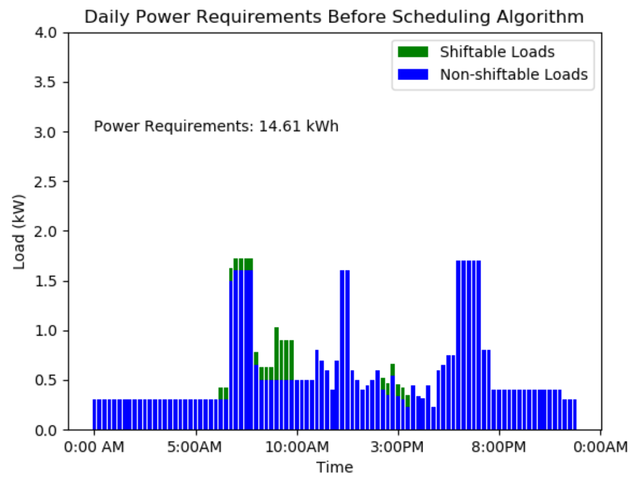

Figure 5.4: General Household Load Profile for Optimization Model

5.5 Objectives

As defined in 2.4.1, an objective function is *"An equation to be optimized given certain constraints and variables to be minimized or maximized dependant on the scenario."*. In this scenario there are multiple objective functions that are used in determining the most desirable time for the shiftable appliances. These objective functions are further detailed below.

5.5.1 Cost

Time of Use Pricing

Since a main objective of this system is minimize energy cost to the end-user, the total daily price of all energy consumed/exported is calculated via a time-of-use pricing system. The following time of use pricing model is in current use by Ausgrid in NSW homes [13].

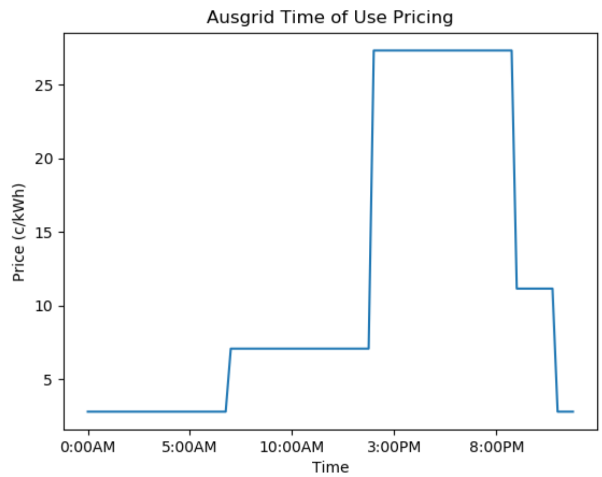

Figure 5.5: Ausgrid Time of Use Pricing Model

Furthermore, exported energy to the grid is not at an equivalent rate to the consumed time of use pricing. Also this tariff imposed by the energy authority also differs depending on the state that end-user resides in. Since this model utilizes the Ausgrid NSW time of use model, NSW solar feed-in tariffs were used in the optimization. To also allow for future changes in pricing, the lower of the bracket for NSW tariffs was used: $11.9c/kWh$ [1].

5.5.2 Net Power Use

Since the time of use model breaks down time slots on the pricing for energy, the optimization model breaks the load profile for the day into 96 slots of 15 minute intervals. Firstly the shiftable loads (P_{St}) data sets generated from the quantized SQL query are added to the non-shiftable loads (P_{NSt}).

$$P_T = P_{NSt} + P_{St}$$

This is followed by subtracting the total solar generation (P_{PV}) for each time slot from the total consumed power data set (P_T).

$$P_{Net} = P_T - P_{PV}$$

The battery model function is now applied to this data set as medium of trying to maximize renewables energy on the model.

$$P_{Net} = \begin{cases} discharge & t \geq \text{selectable time \& charge} \geq 0 \\ charge & P_{Net} \leq 0 \\ stay & t \neq \text{selectable time \& charge} \geq \text{selectable \%} \end{cases}$$

This result is then processed via a cost function detailed in 5.5.1 to determine daily price of power, the result also undergoes quantization of discrete points on the curve to determine total consumption/exported for the day detailed in 5.1.2. The result of these functions is shown Figure 5.6.

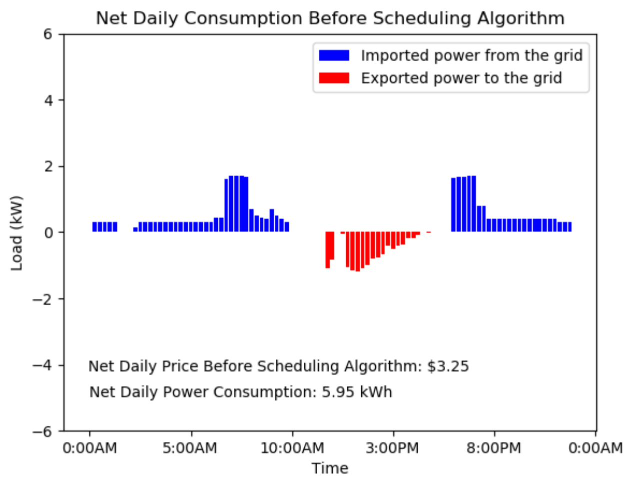

Figure 5.6: Daily Net Use of Power

5.5.3 Chapter Summary

After aggregating data generated from the data collection nodes (Chapter 4), this was then quantized before input into a multiobjective optimisation algorithm. Theoretical models of solar generation, storage and general household power consumption were also developed to generate a more realistic simulation system. A time of use pricing model was extracted from the local energy supplier (Ausgrid) and all these parameters were then detailed on how the optimisation algorithm will determine the most suitable solution.

Chapter 6

Economical Analysis

This chapter analyzes the economics behind installing and maintaining the system detailed in the previous chapters.

6.1 Scheduling System

A real world installation of the scheduling system detailed in previous chapters is comprised of a number of data collection nodes (Chapter 4) and a single server for the home. A data collection node would be required to be installed on all appliances within the home for automatic operation and data recording activity. The data collection nodes' also have a requirement of being able to have Wi-Fi access, as this is a common networking infrastructure found in homes, this would depend on the end-user.

6.1.1 Data Collection Node Manufacturing

Manufacturing of the data collection node for mass production can be broken into several major sections:

- Electronics parts
- Mechanical parts
- Packaging
- Final Assembly
- Logistics

Electronics Parts

A single data collection node for a real world installation would require:

- A current transformer (SCT-013-000) RRP $20 [33]
- A microcontroller (ESP-8266) RRP $10 [34]
- Male and female outlet sockets $15 [35], [36]
- Three core twin and earth $1.60 per meter [37]

For the prototype development version of a single data collection price, the total price for electronics is around $\sim$ $45.

Mechanical Parts

A single plastic enclosure for each data collection node is required, as this is a scalable component that would commonly be a plastic injected mould would be of minimal cost in comparison to the electronic components. A price of $5 was given for the plastic enclosure with taking into consideration mass manufacturing prices [38].

Packaging

Presentation to potential clients is a major component of ensuring success of electronic products. An estimate for packaging prices for a product is 9% of the total product manufacturing cost [39].

Final Assembly

The final assembly stage to get the product to shelf-ready state includes assembly of electronic components, construction into mechanical enclosure and finally packaged in an appealing manner for the end-user. Pricing for assembly of electronic components on a large scale ($\geq$ 1000 units) is $\sim$ $1.5 per unit [40].

Logistics

Logistics of distributing the product is a major component of the final pricing of the product to the end-user. Since logistics is calculated by weight and volume of the product container. From an estimate prototype model's weight of 300g and volume of 158 x 95 x 53mm, this results in a total of $37.8kg/m^3$. With a rate of $\$1perkg/m^3$, this works out to be roughly $\sim 30c$ per unit [41].

Data Collection Node Pricing

Together with component pricing, component assembly and packaging prices, this brings the total production price of the product to $\sim$ \$60 per unit. With a profit margin of 11% this brings the price for the end-user to roughly \$70 per data collection node.

Server Requirements

A raspberry pi 3 was used as a temporary development server for this project, this retails for $\sim$ \$60 [42]. The opportunity for the end-user to save cost on the implementation would be to host the network on a personal computer, however this comes at the risk of losing connection if the computer is taken offline.

Opportunity

The opportunity from a business perspective, is that it would be beneficial to include this system within an existing appliance manufacturer's ecosystem of products. As this would push the end-user to implement a suite of appliances from a single manufacturer to ensure compatibility and inter-functionality within software and hardware.

Cost to End User

Since the total price of the system is dependant on the number of appliances the end-user wishes to install data collection nodes on, the initial outlay from the end-user will drastically vary. However, for a common household that requires a single server and 3 data collection nodes to schedule the main appliances of the household this would be an outlay from the end user of \$270. This price to the end-user would be of a \$30 profit to the manufacturing company.

6.2 Renewable Energy

One of the objectives for this project was for the average home owner with renewable energy generation to understand and better utilise this source of energy. The system was also modelled with energy storage generation in mind, that is the opportunity to consume energy generated at a better time rather than export it to the grid for an incentive tariff.

6.2.1 Solar Energy

As more Australians are installing solar panels on their homes, the amount of end users that this system could reach is growing rapidly. With 1 in 5 Australian homes now having the capacity to generate renewable energy with solar panel [43].

This system would also prove beneficial to energy suppliers as an upcoming issue is being able to compensate energy generation feed-ins from solar panels. By better utilising the energy within the home and minimizing the amount of energy exported to the grid would relieve stress on the energy suppliers.

Figure 6.1 shows the increasing number of solar panel installations across Australia, along with the growing energy generation capacity as solar panels are becoming more efficient due to technological advancements.

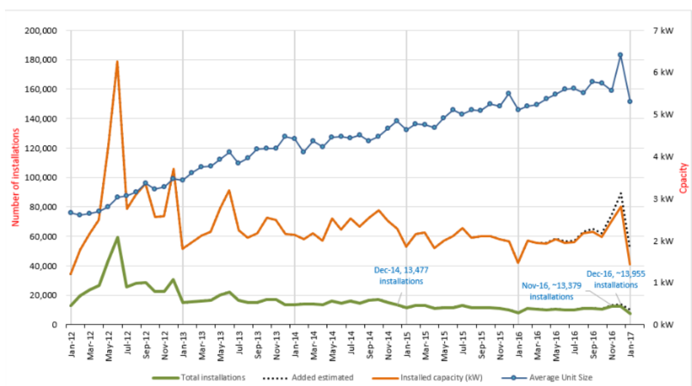

Figure 6.1: Australian Solar Panel Statistics 2017 [43]

6.2.2 Energy Storage

As illustrated in Figure 6.2, adoption of household renewable energy storage capabilities is rapidly increasing. Households which choose to adopt this technology in an attempt to better balance peak demand and generation, would also recognise the benefit in an automated system to balance their loads.

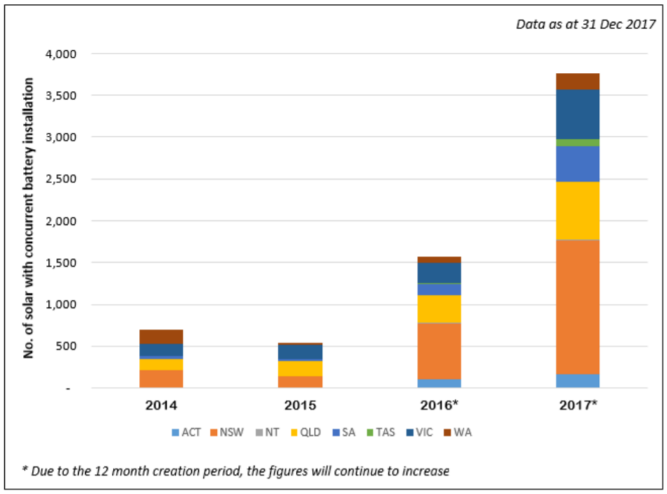

Figure 6.2: Australian Solar Energy Storage Statistics 2018 [44]

6.3 Payback Period

Please note the figures determined in this section are dependant on the model and appliance use times. These figures may vary dependant on the times that the appliances are already being used at. Use caution when using these values as a comparison.

Determining the payback period heavily depends on how many appliances that the system is automatically scheduling and how unfavourable they were being used before the system was installed. For this report, payback period will be determined using the same model as detailed in Chapter 5. With a daily net power price before the scheduling algorithm is applied of \$3.23, this figure extrapolated annually equates to \$1,178.95.

With the system installation cost for this model as outlined in Section 6.1.1 being \$270 and the daily net price after the scheduling algorithm is applied being \$1.78 or \$649.70 annually (see Figure 7.3). This is a total savings of \$529.25, meaning the system has a payback period of roughly 5 months. This is comparable to that of an average 5kW solar system with a payback period of 4 years [45].

Chapter 7

Results and Outcomes

This chapter is an overview of results obtained from the model discussed in the previous chapter. It is further broken down into sections to breakdown the different results from each stage and scenario of the optimization process.

7.1 Data Collection Node

The data collection nodes were installed on common household devices as per Figure 2.1, to obtain real world appliance load profiles, these devices were:

- Refrigerator (Kelvinator KSM6100WF 610L Side By Side Fridge)
- Dishwasher (Miele G 4203 SC Active Freestanding dishwasher)
- Washing Machine (6kg Top Load Simpson Washing Machine SWT604)

After the system was left running over multiple months, $11,000$ samples of current power used per day were collected, which amounts to one sample every 7 seconds. This allowed for a large data base for testing real world results on the optimization model.

The capability to switch the outlet from within the data collection device was not implemented at the time of this report as this feature would provide no value to the end-user without communications between the device and the appliance (e.g. *"Start deep cycle washing now"*). This was determined to be a future opportunity for an appliance manufacturer to include capability within their product or adopt the scheduling algorithm to provide a whole system solution for the home.

Example load profiles for these household devices over a single day are shown in Appendix C.

7.2 Schedule Optimization

NSGA-II (2.4.2) was chosen as the multi-objective optimisation algorithm, and this was applied on the model outlined in Chapter 5. Shiftable appliance's load profiles to be tested within the model were extracted from the database collated via the data collection nodes detailed in Chapter 4 with an added extra *'test'* appliance. These power load profiles are shown in Appendix C, with the summarized profiles shown in Table 7.1 and in Figure 7.1.

Electric Appliance	Power Consumption (kWh)	Time of Use
Dishwasher	1.2	"09:11:56" to "09:59:55"
Washing Machine	1.4	"06:27:53" to "08:32:44"
Test	0.6	"14:27:20" to "15:12:44"

Table 7.1: Input Load Profiles for Optimization Model

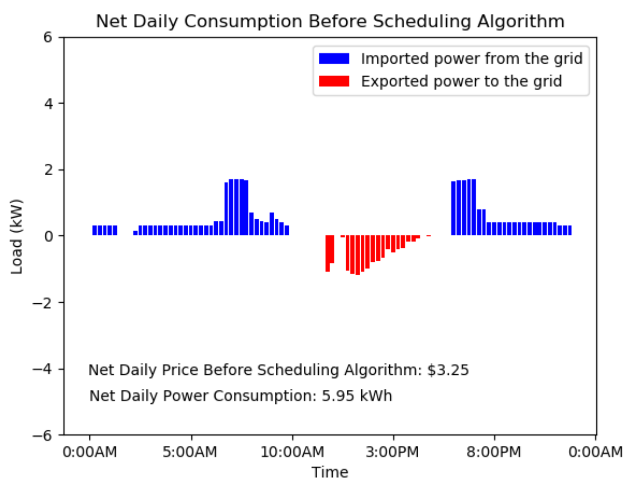

Figure 7.1: Net Power Consumption Before Scheduling Appliances

The optimization algorithm (NSGA-II) ran for 10,000 generations to determine the solution space of optimal times for the appliances to run. This solution space was then iterated through to maximize effectiveness of the selected objective function as detailed in Section 5.5.

The following solutions are examples of when the cost function is used to minimize energy prices over a single day, this can then be extrapolated to determine annual savings for the end-user. As can be seen below in Figure 7.2, the optimization algorithm determined that shifting the appliances starting times to the middle of the day when solar generation was more profitable than if they were to be moved to a cheaper time-of-use time (Section 5.5.1).

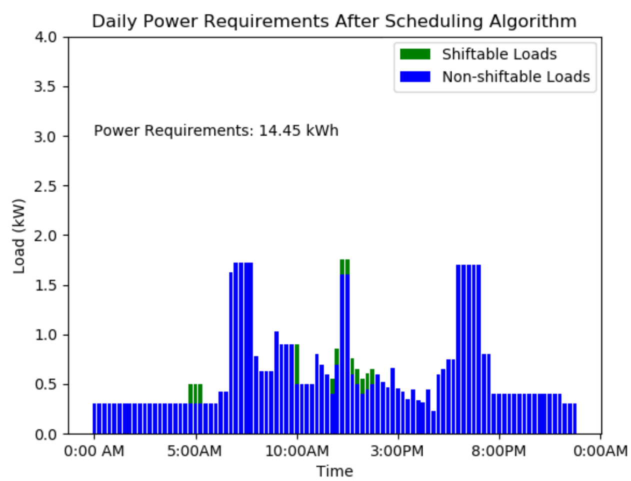

Figure 7.2: Load Profile After Scheduling Appliances

After the schedule was determined, the model then repeats the same process as outlined in 5.5.2 to determine the daily price and net power consumption for the model. This is shown in Figure 7.3. Where it can be seen that the daily price for energy was reduced from \$3.25 (5.6) to \$1.78, a 45% reduction in price. If this is then extrapolated out for an annual saving figure, where the original pricing of \$1,186.25 per annum is reduced to \$649.70.

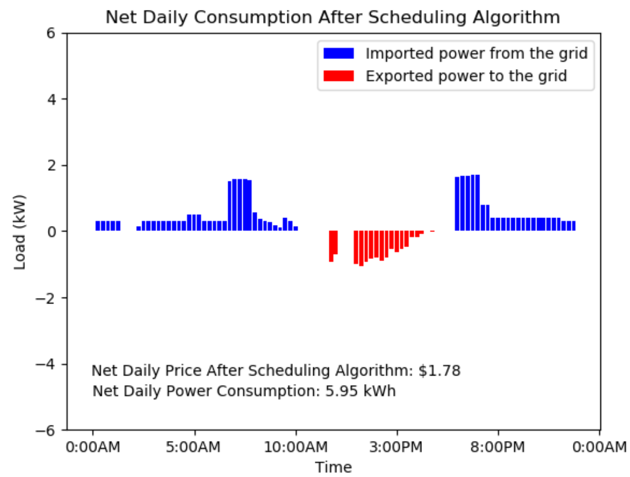

Figure 7.3: Net Power Consumption After Scheduling Appliances

The system also takes into consideration if it is more favourable for the appliances to be shifted to a cheaper time for energy use (possibly if the system does not include solar and/or on-site energy storage). This is exemplified in Figure 7.4, where the system determined shifting the appliances to the times where time-of-use pricing is must more cheaper than at peak times.

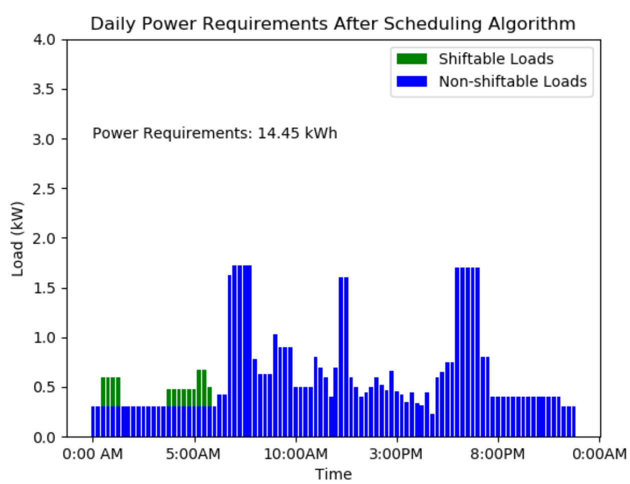

Figure 7.4: Load Profile After Scheduling Appliances

After the schedule was determined, the model then repeats the same process as outlined in 5.5.2 to determine the daily price and net power consumption for the model. This is shown in Figure 7.5. Where it can be seen that the daily price for energy was reduced from \$3.25 (5.6) to \$1.98, a 39% reduction in price. If this is then extrapolated out for an annual saving figure, where the original pricing of \$1,186.25 per annum is reduced to \$722.70.

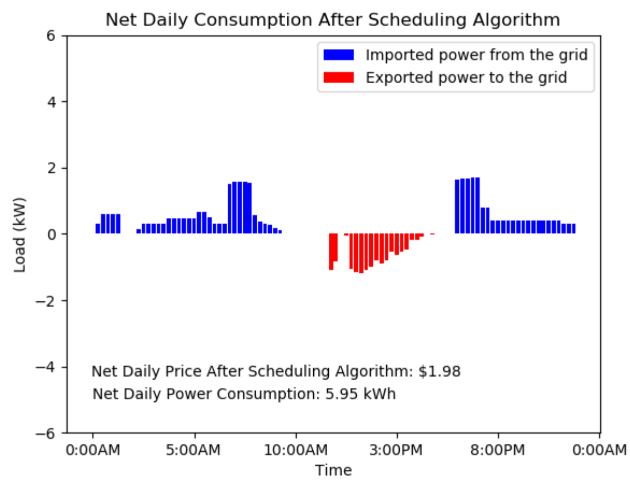

Figure 7.5: Net Power Consumption After Scheduling Appliances

7.3 Chapter Summary

The model developed in Chapter 5 was then applied with NSGA II, the multi-objective optimisation algorithm chosen for this project. Shiftable appliance's load profiles were extracted from the database aggregated from real world results. The output of NSGA II showed mainly two types of solutions that would be beneficial to the end-user finance wise.

The system either showed it would be more beneficial to consume the energy generated from a renewable source (eg, solar), rather than export it back to the grid for an incentive. When consuming on-site generation rather than exporting it showed an annual saving figure of 45%, where the original price of \$1186.25, was reduced to \$649.70.

The other type of solution the system determined was to shift appliances to a lower cost of power (eg, off peak period). When shifting appliances to the off-peak pricing period, this showed an annual saving figure of 39%, where the original price of \$1186.25, was reduced to \$722.70.

Chapter 8

Conclusions and Extensions

This chapter is a brief description of the insights determined from the results in the previous chapter. It is extended into ways that the model could be further developed and improved.

8.1 Conclusions

This project aimed to develop and construct a home area network capable of monitoring and controlling appliances in accordance with an optimized schedule. By utilizing a combination of existing Wi-Fi infrastructure within the average Australian household and an implementation of a multi-objective optimization algorithm NSGA-II (2.4.2); the project goals of reducing the daily energy cost were met with the addition of functionality for the end-user to control the system themselves or automated.

An initial background of the issues facing today's average Australian household was established. This was followed by a discussion of several current technologies that build the foundation on the functionality and capabilities of this project. An analysis of previous works completed of a similar nature from experts to give insight to how some decisions were made in this project. Following the analysis was the design considerations and choices that entailed the design and construction of the data collection node, similarly followed by the optimization model.

Results from extracting information from the database collated by the data collection nodes and theoretical models of solar energy generation, energy storage capabilities and the general household underlying load profiles were then made as inputs for the optimization model.

An insight into the types of schedules that the optimization model determined showed that often it was more favourable to the end-user to consume the solar generation at peak generation times rather than export solar energy to the grid for a incentive tariff. Showing a net daily reduction in price of 45% when appliances were shifted to start at peak generation times. When extrapolated to an annual price this showed a reduction in the original price of $1,186.25 to $649.70.

However in other simulated scenarios the optimization model determined that it is most favourable to the end-user to run the appliances when the time-of-use pricing is at it's lowest (off-peak). This scenario, which may be applied to systems without solar energy generation or energy storage capabilities showed a daily reduction in price of 39%, which when extrapolated reduced the annual price to $722.70.

The ability to automatically switch an appliance was not implemented at this stage of the project, as this was determined to be out of the scope of the project. The functionality of the system to retrofit to an existing appliance and communicate to the appliance would be seen as a major downfall in this projects suitability to be installed in existing buildings. However, this could be seen as a major benefit to an appliance manufacturer as the end-user of their appliances would be required to purchase their 'suite' of appliances to include the functionality to reduce energy bills.

Since this system is fully scale-able to the limits of a local Wi-Fi network (65,000 nodes), the possibility of savings to the end-user is a very favourable decision to install this system. For example, an ideal scenario where this system would be installed would be in large commercial buildings/systems where a plethora of automated appliances are installed, however unlikely being utilized to run at the most favourable time of the asset owner.

8.2 Future Extensions

The large range of applications for this project allows it to be extended in many ways. The existing functionality could be further investigated as follows:

- Alternate multi-objective optimisation algorithms,
- Forecasting future power usage in correlation with events (e.g. weather, human movements, holidays),
- Predictive analytics from past data,
- Retofittable capabilities to existing appliances.

A list of ways functionality could be extended include, but not limited to:

- Data scraping capabilities to determine weather patterns for area,
- Analysis of machine learning/AI integration into the optimization method,
- Implementation of machine learning/AI into network,
- Pilot program with potential future clients for feedback on product.

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Appendix A

Application Screenshots

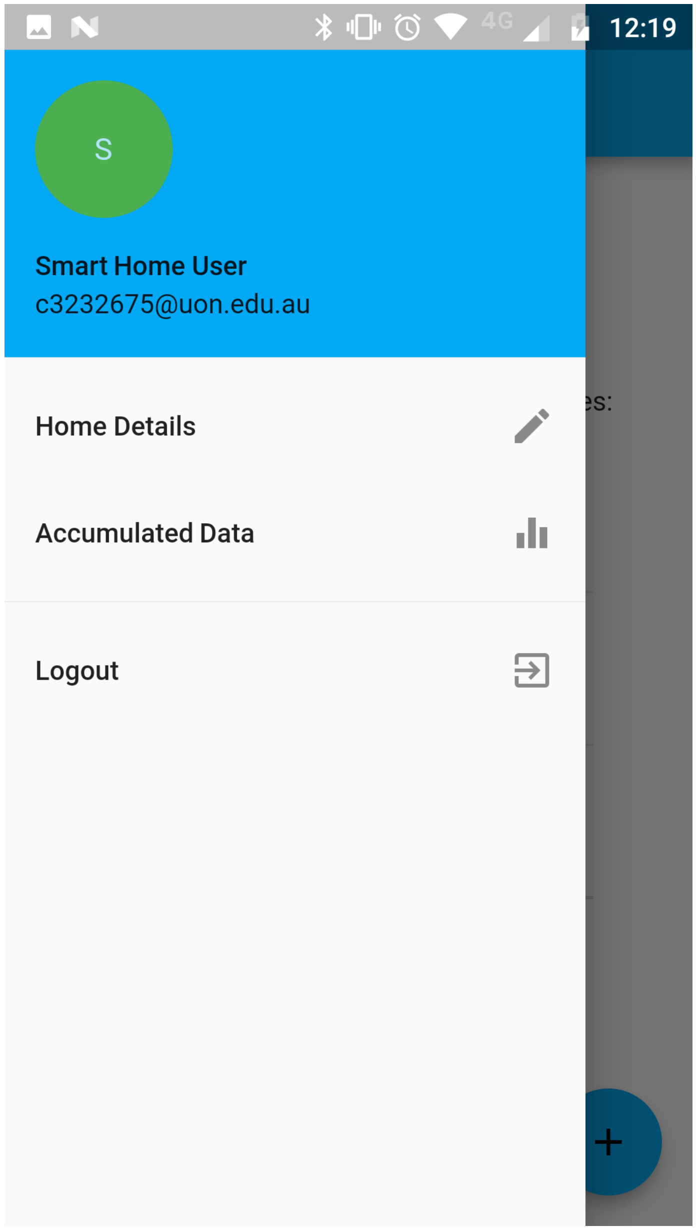


Figure A.1: Navigation Pane of Flutter App

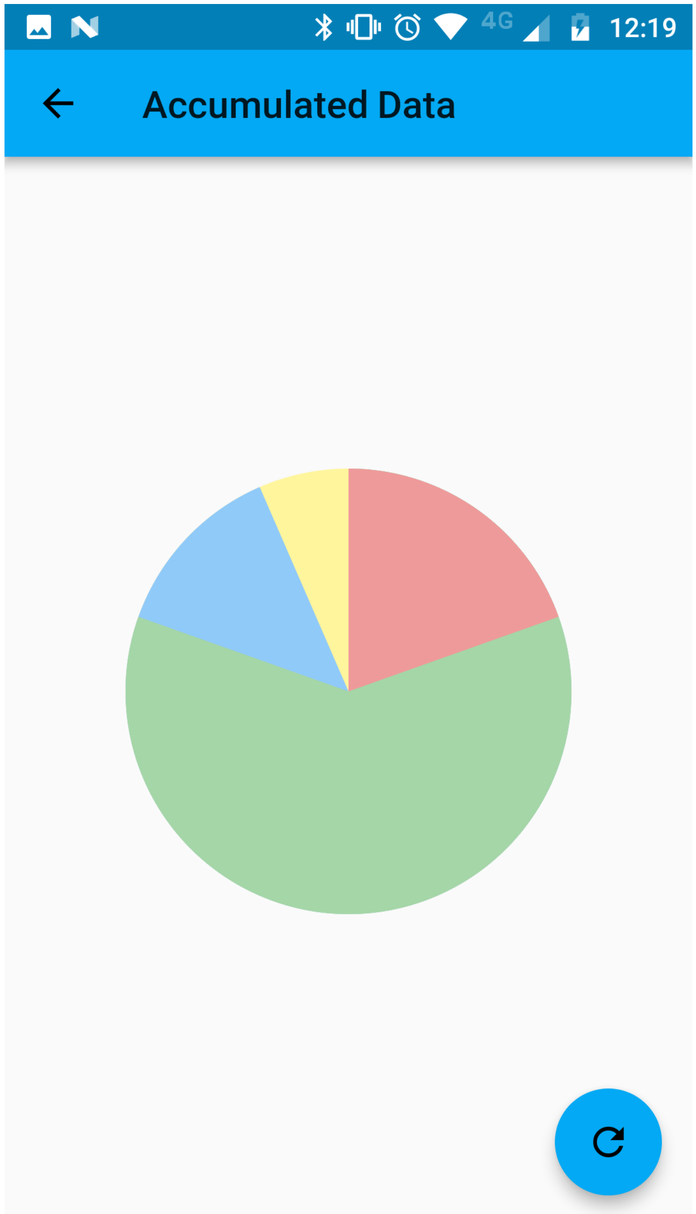


Figure A.2: Accumulated Data Example of Flutter App

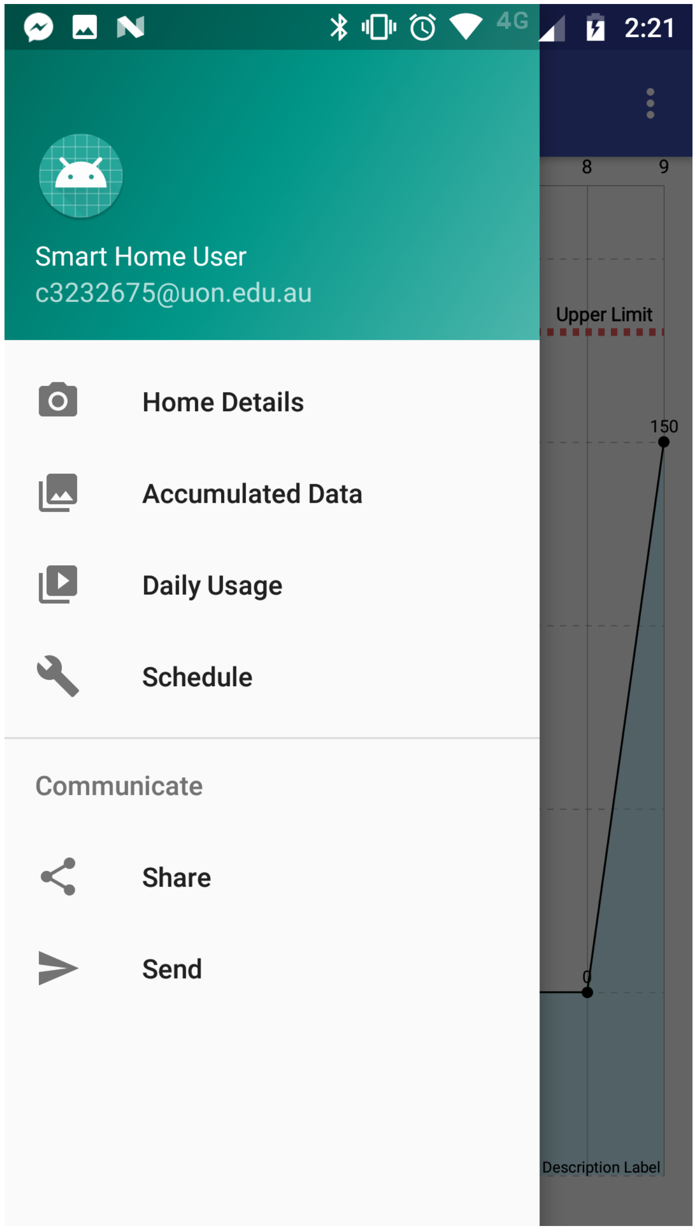


Figure A.3: Navigation Pane of Android App

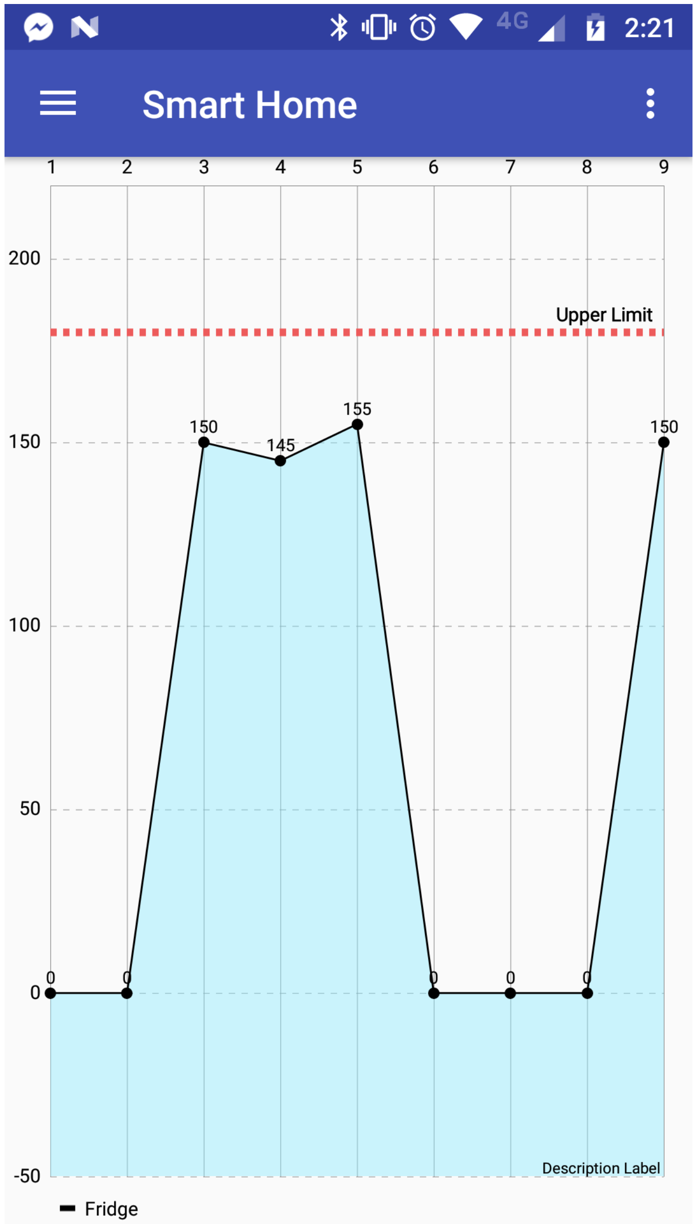


Figure A.4: Accumulated Data Example of Android App

Appendix B

Circuit Diagrams and Datasheets

YHDC **Product Specification** Date:2015-8-7

Product Name	Current transformer	Model	SCT013-000

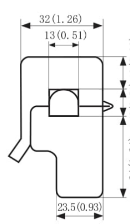
Characteristics:Openning size 13mm*13mm,1m leading wire, standard Φ3.5 three-core plug output.
Current output type
Purpose: Used for current measurement, monitor and protection for AC motor,lighting equipment, air compressor etc.
Patent No.: ZL 2015 3 0060067. X

Technical Data

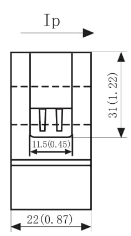
I_{PN}	Rated input	0-100A
I_{PM}	Max. detection input	
I_{OUT}	Rated output	0-50mA
X	Accuracy	±1%
ε_L	Linearity	±3%
N	Turns ratio	1:1800
Φ	Phase shift	≤180'
R_L	Max.Sampling resistance	10Ω
V_{PN}	Work voltage	660V
f	Work frequency	50-1KHz
T_A	Operating temperature	-25..+70℃
T_S	Storage temperature	-40..+85℃
Vd	Dielectric strength, 50 Hz, 1 min	3KV

Fire resistance	UL94-V0
Material of core	Ferrite
Mounting type	Suspension
Weight	55g

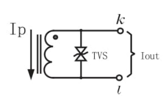
Dimension (mm(in). 1 mm= 0.0394 inch)



Front view

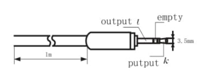


Side view



current output type

Schematic diagram



(can provide other wiring way)

Standard three-core pligs schematic diagram

http://www.yhdc.com

Figure B.1: Current Transformer Datasheet

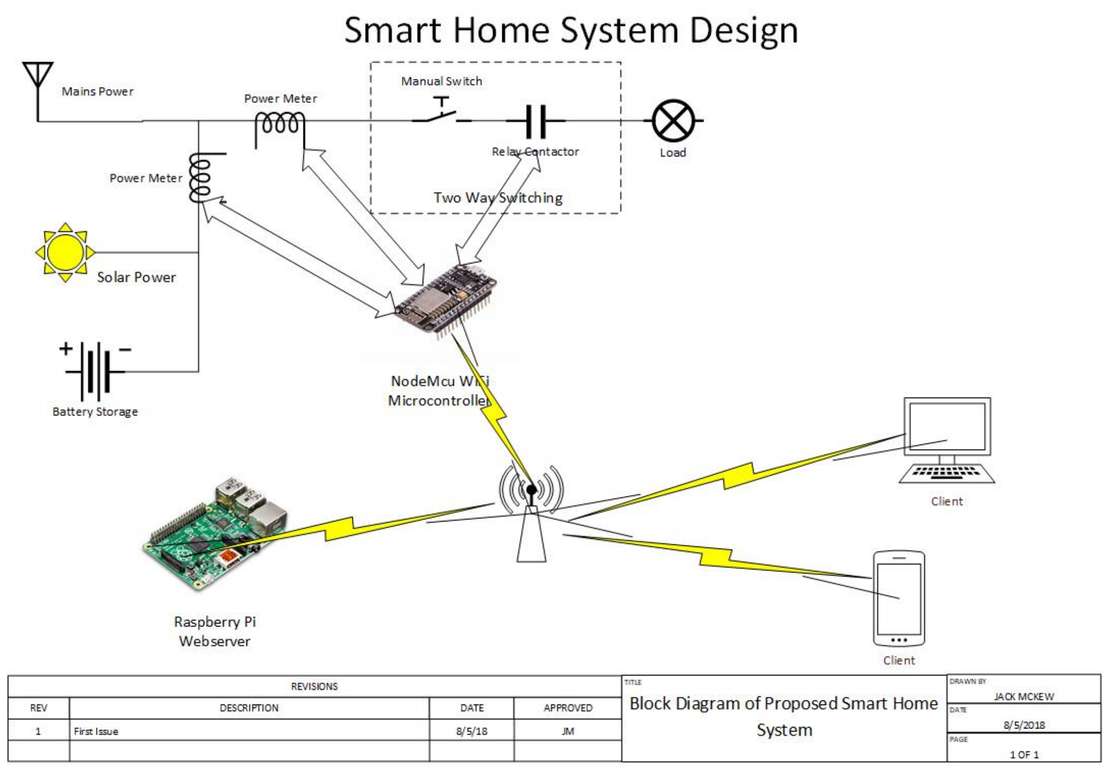


Figure B.2: Block Diagram of Data Collection Device

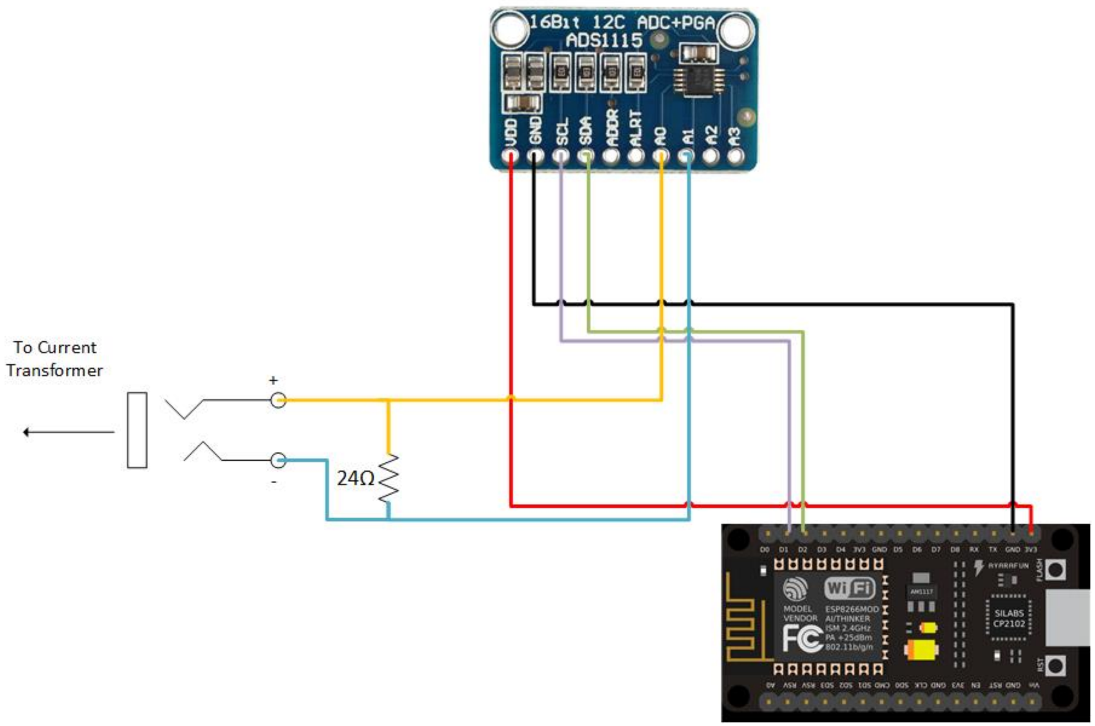


Figure B.3: Circuit Diagram of Data Collection Device

Appendix C

Load Profiles

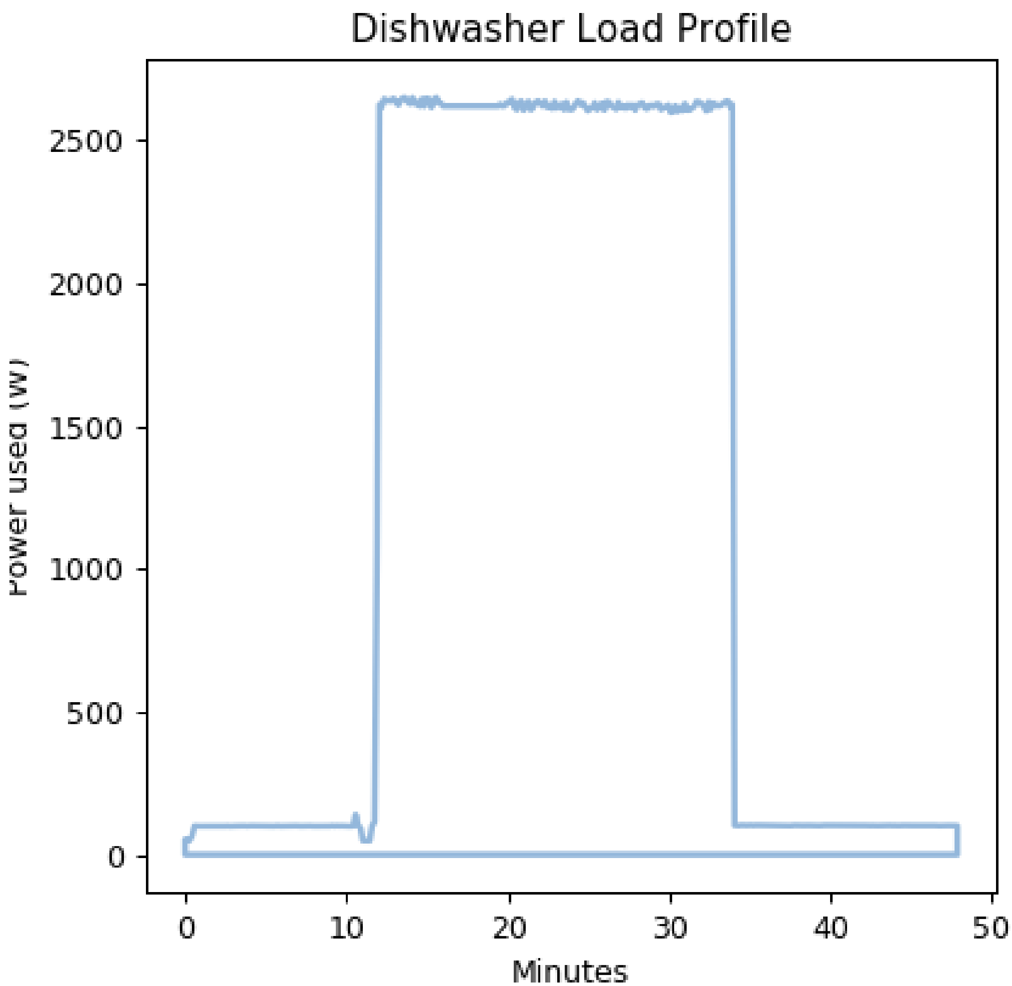


Figure C.1: Dishwasher Load Profile

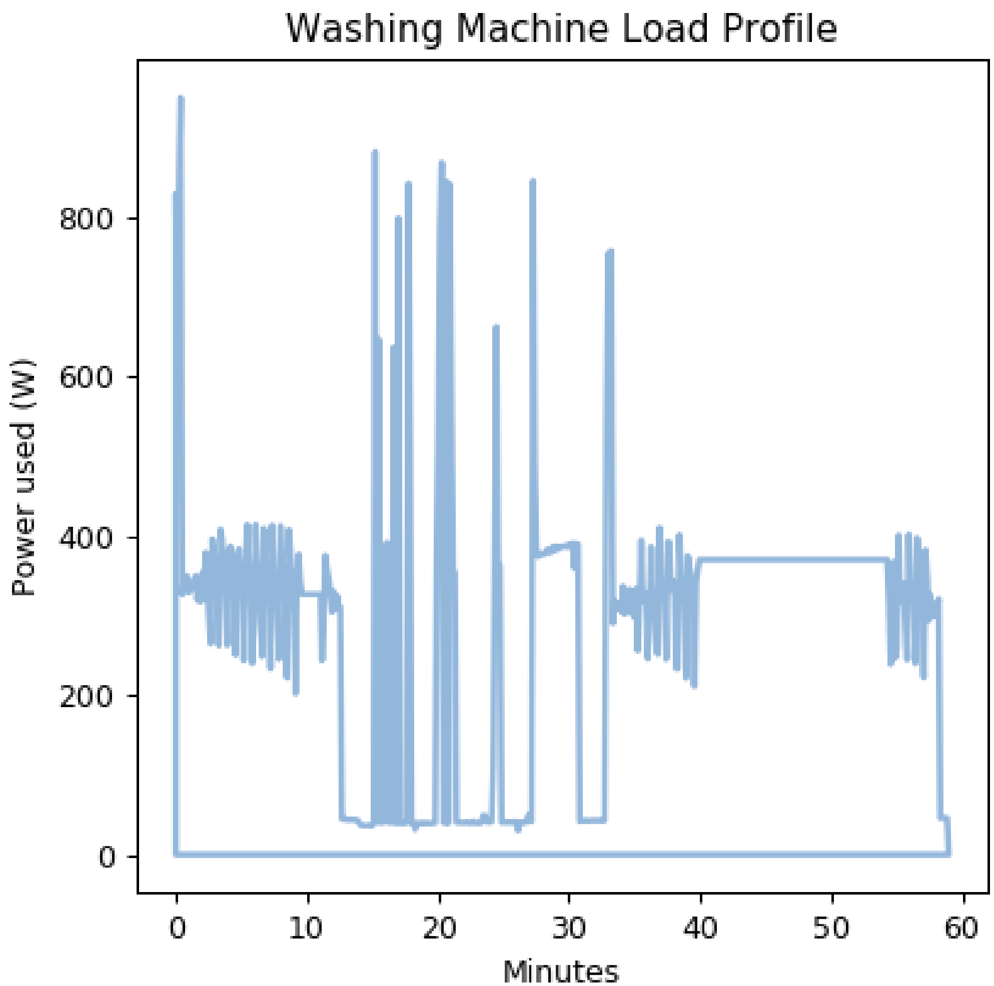


Figure C.2: Washing Machine Load Profile

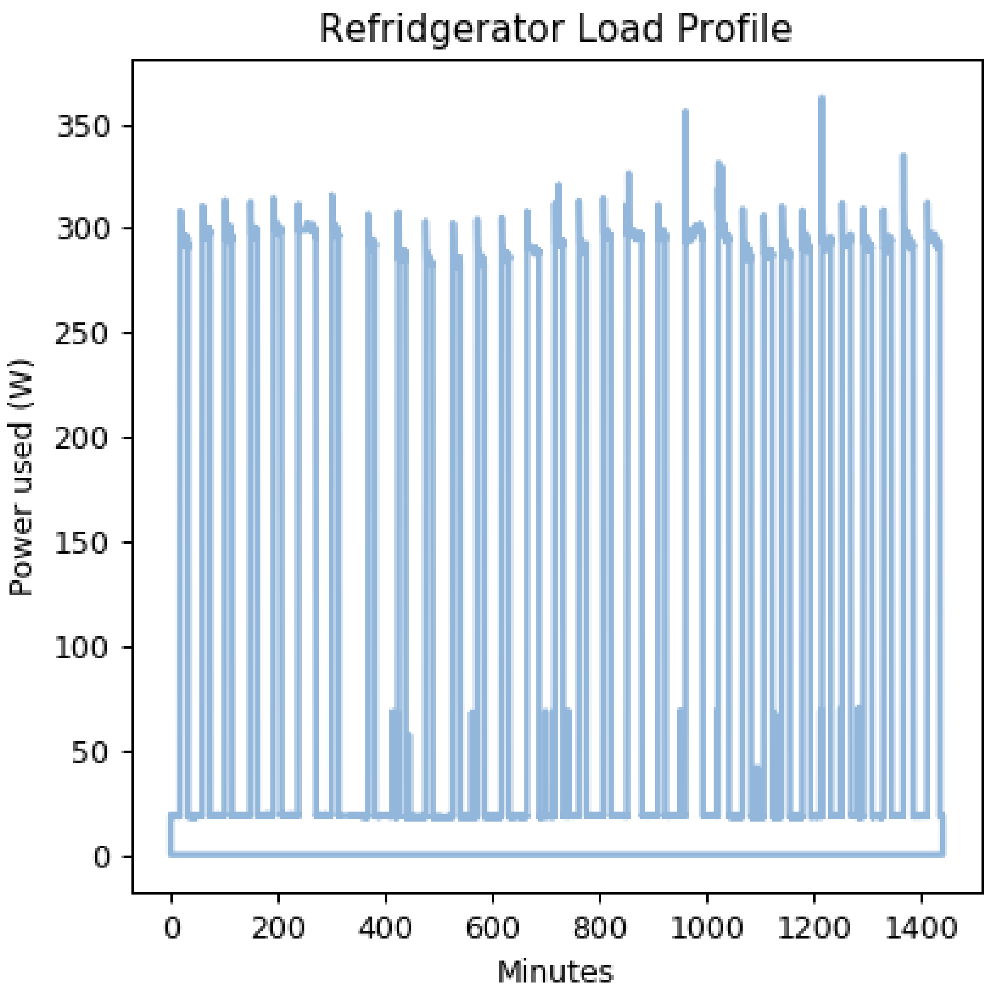


Figure C.3: Refrigerator Load Profile