University of Southern Queensland

Faculty of Health, Engineering and Sciences

An Analysis of Thermal Storage of Solar Energy

A dissertation submitted by

Benjamin Conway

in fulfilment of the requirements of

ENG4111 and ENG4112 Research Project

towards the degree of

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Abstract

An Analysis of Thermal Storage of Solar Energy

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Electrical and Electronic Engineering

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Keywords: Solar, Energy storage, Cost benefit

1. Introduction

The Project aims to evaluate and compare the efficiency of thermal storage of energy as opposed to direct capture techniques. With plans to develop a management system to maximize the cost benefit for the domestic end user. Specifically, regarding a grid connected solar powered home, with air conditioning, hot water system and pumped solar heating for the pool.

2. Background

Rising electricity prices in Australia (Figure 1) are a growing concern to the consumer and average household, especially by comparison to the consumer price index that household income is influenced by. A system to defend against these disproportionate increases is justified.

A major part of domestic electricity consumption is for heating, ventilation and cooling (HVAC). A project that seeks to maximize the energy efficiency of the household or business is one that has an increased potential in the current market. There are some products on the market which aid the consumer in making desirable energy choices, but none that take this approach.

3. Methodology

The analysis of thermal storage of solar energy took the approach of quantitative techniques. An existing home was used as the model for the project's potential feasibility. The decision to go this way, resulted in real world data, that is both relevant and accurate, mitigating the need for approximations and assumptions. It is also the way in which the completed project intends to interact with the supply it is monitoring and making decisions for, that is, in a real-time application of the findings.

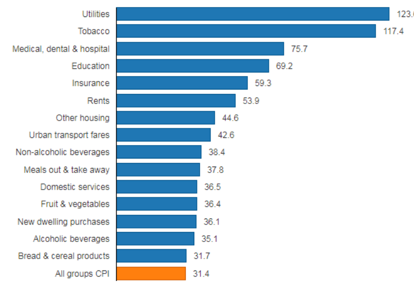

Figure 1 – Price rises over the last 10 years

4. Key Outcomes

The successful planning, preparation and implementation of the project has been an achievement. Through undertaking this research project, the modelling of an actual home energy system could be collated, analysed and its feasibility determined. The noteworthy observation has been that the components required are all readily available that are proven to make a measurable impact on the household HVAC efficiency.

5. Further Work

The realistic objectives were all able to be addressed in the timeframe. The extended objectives will not be able to be achieved during this period, and as such, are all options for ongoing work. There are plans to create a dashboard interface, and seek integration options with emerging peer to peer energy markets.

6. Conclusions

The message that should be taken away from this project is that there are numerous avenues by which independent households can benefit from utilising thermal storage.

7. Acknowledgements

I would like to thank Dr John Billingsley for providing keen insight into the direction that the project would eventually take. I would also like to thank my supportive wife, Taila Conway, who has been tireless throughout this year.

8. References

Cabeza, L. (2015). Advances in thermal Energy Storage Systems Methods and Applications, Woodhead Publishing.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Benjamin Conway

Student Number: [redacted]

Acknowledgements

I would like to acknowledge Dr John Billingsley for the support he has offered throughout this project as the supervisor. He has provided keen insight into the direction that the project would eventually take.

I would also like to thank my supportive Wife, Taila Conway, who has been tireless throughout this year, and also to my now 20-month-old Daughter, Piper, who has been on her best behaviour.

B. Conway

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Chapter 1 INTRODUCTION

1.1 Statement

This Project aims to evaluate the efficiency of storing energy thermally, and develop a management system to maximize the cost benefit to the domestic end user. Specifically, regarding a grid connected solar powered home, with split system air conditioning, hot water system and pumped solar heating for the pool.

The Title, 'An Analysis of Thermal Storage of Solar Energy' is to be defined by the following statements. The research project does not set out to develop new or improved ways of storing energy in its thermal form. Rather, it is to find ways to better utilize the solar energy generated in grid connected solar homes at the consumer level, albeit in the form of thermal systems, in the form of heating, ventilation and cooling, throughout the household.

The reasoning behind this is that there exist many solar generating households connected to the grid in the Australian market that underutilize the renewable energy being generated within the individual microgrids. This has a twofold effect, one, that the carbon offset achievable by the household is diminished, given that photovoltaic supply, is often inversely correlated to that of the systems demand. Secondly, the cost benefit from a financial perspective is not realized as a direct result of this inverse relationship. It was established early on that a Home Energy Management System would be the solution to implementing the solar storage in thermal capacity.

This project sets out to circumstantiate and develop this idea into a working prototype to help automatically oversee and manage the maximization of these two key benefits associated with the installation and implementation of a solar supply circuit within the average domestic user's household environment.

The conclusions drawn at the completion of research into this area are promising. The findings indicate that a feasible, cost effective solution to the problem exists. The working prototype was modelled and the results are in line with the scope set out to be achieved by the initial project offering.

1.2 Objectives

The main objective of this project is to investigate the feasibility of an energy management system that utilizes thermal storage of solar energy, specifically relating to grid connected solar powered homes.

The project objectives are to:

Programme: Version 1, 11th March 2018

1. Review existing home energy management systems and similar devices and evaluate them for their intended use.

2. Collect the essential data to make rationalized decisions on the best way to manage the household's energy.
3. Analyze field data to identify potential gains achievable by the system.
4. Develop a microcontroller program that has multiple digital and analogue inputs and outputs, for monitoring of the energy system and ability to implement the decision-making process.
5. Compare and conclude the foreseeable efficiency gains for a range of conventional systems.

If time and resources permits:

6. Provide a dashboard for the owner/consumer.
7. Extend the project to other energy consuming loads on the system.
8. Integrate with peer to peer energy markets to further increase potential.

Overall, the objective of this project is to fulfill the requirements of the Engineering Research courses of the University of Southern Queensland.

1.3 Idea Development

The notion that current proposed renewable and alternative energy systems lack the efficiency and output to truly create a 100% renewably supplied future currently exists. At ENG3902 Professional Practice – 1 in September 2017, a student presented a TEG system for energy generation, and I immediately thought that the application could be used in conjunction with existing PV arrays to improve efficiency. After some research, it was determined that there are already companies which have developed this idea, this project however will look to build upon this technology incorporating in instrumentation and intelligent control. The project will not seek to develop an alternative to the current ones, but simply seek to maximize the efficiency of the technology that we have available now.

There also exists a very one-sided growth rate between energy price and household expendable incomes. A reduction in electricity costs is a very topical one now. Most individuals are aware of energy saving methods, however, an automated way of managing power in the household is one that would be favorable.

The idea of storing solar energy in a thermal state is not a new one. There are many large-scale operations currently under way at a network supplier level that seek to store energy developed by a direct result of solar irradiation in one of its many capture techniques, and transform that energy type into a thermal one. Often this is achieved by heating large vessels of salt solutions, with the solar energy captured and then later harnessing that thermal store of energy to heat water, produce steam and drive turbines. This is an existing technology and one that is currently being researched and developed extensively, for this reason it is not the target scope of the Project.

Therefore, the general idea is one that sees the thermal storage of generated solar energy, in its quiescent sense. That is, in the household's state of dormancy, at a time when solar supply is in excess, utilize the HVAC systems of the household to store this energy for later use. Systems that are foreseen to be able to be capitalized on are, the household hot water system, pool heating and general air conditioning needs. This idea needs to be carefully thought out, as there is an unwanted consequence that has potential to arise where the household is consuming energy for the sake of consuming energy, effectively wasting it. That is not the intention of this project and steps will need to be taken to ensure that the storage methods are indeed demand loads that where possible could be forecast to be required as grid demand later in the day. The entire idea will be encompassed by the eventual development of a home energy management system that utilizes load shifting methods to increase efficiency within the system and return a positive cost benefit in a reduced timeframe for the consumer at the individual level.

1.4 Contextual Background

Rising electricity prices in Australia are a growing concern to the consumer and average household. A system to defend against these increases is justified.

A major part of domestic electricity consumption is for heating, ventilation and cooling needs. There are products available that automate devices in your home, notify you of your energy use, or even your energy supply if you have solar, but there is nothing that manages all of this in a neat package. A project that seeks to maximize the energy efficiency of the household or business is one that has an increased potential in the current market.

The electricity market is a hot topic recently and it would be a struggle to find someone unaware of this fact. There are large and rapid changes taking place in this industry, driven by the growing demand, the push for cleaner greener energy supply and those that are hopeful for a reduction in cost. Thus, the project would have to have foreseeable market trends accounted for so as not to become redundant in a short space in time. Techniques would need to be developed that are potentially somewhat unconventional. That might mean to decide to cool a room even though no one is present, knowing that it is probable that someone will be later when solar supply is not available, thereby limiting energy pull from the grid.

The project would involve instrumentation and measurement of the performance of the system, to trend and calculate the cost benefit achievable. Whilst also providing a means to implement the predicted best utilization of the energy.

The problem is a multi-faceted one, currently renewable energy technologies do not fill the void that is being created in the move away from fossil fueled energy production. Alternatives to these alternatives are going to be needed to increase efficiencies and minimize the growing consumer demand on the network. In the meantime, though it is necessary to maximize the efficiency of what we have available to us right now.

A typical grid-connected renewable energy system, currently sees return on investment figures based on the combination of, the savings in demand from the grid the installation offsets, and the income generated from the rebate provided by the energy supplier for exported power. This feed-in tariff is typically very small compared to the supplied energy tariff, 6-8 cents (Australian Solar Feed-in Tariff Information - Energy Matters, 2017) as opposed to 28.479 cents (General supply tariffs, 2017) per kilowatt hour.

A system that not only efficiently utilizes the energy it has available to it, but makes automated decisions on the most economical solution, is a system that has potential in a growing market.

Australia has a significant number of grid connected, solar powered homes and businesses. A large amount of their electricity consumption comes from heating, ventilation and cooling systems (HVAC). Hot water systems account for a large portion of this (Hot Water - Residential, 2017). The cost of electricity in Australia is a growing one, over the past ten years Utilities have increased by a factor of 123.6% (See Figure 1.1 – Price Rises over the Last Ten Years).

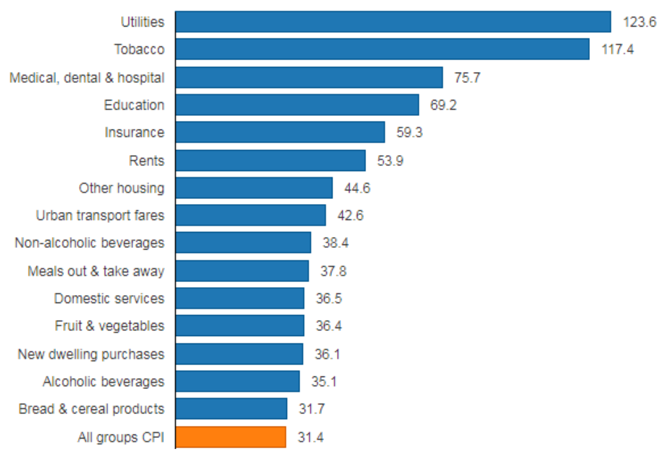

Figure 1.1– Price Rises over the Last Ten Years (Rising living costs are hitting some of us harder, 2017)

The growth in this CPI sub-group outweighs wage growth substantially as defined in Figure 1.2. This alone highlights the need to invest in technologies to help mitigate this heavily biased growth.

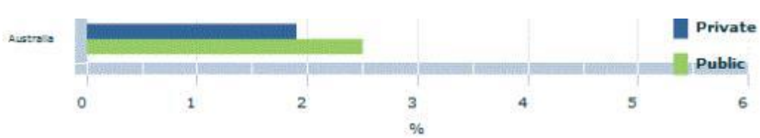

Figure 1.2 – Annual Change in Wage Price Index (6345.0 - Wage Price Index, Australia, Jun 2017, 2017)

A system that can make decisions autonomously on whether to draw from the network, feed in to the network, cool a room, heat water, supply to another system, or draw from another's system, is one that takes the guess work out of the situation. Often people want to be energy conscious and efficient but either lack the time or the understanding to do so, and a system that does this automatically would fit a perceived market gap.

1.5 Study Justification

The project is an ambitious one and makes moves to automate the power management of an end user. It will involve significant application of the learnings of the study thus far, as well as the implementation of a critical thinking mindset that sees solutions to the problems that may arise. I believe it is of appropriate difficulty level for a final year project, and that a solution to the problem is viable. Not only do I feel that it is viable I also think that the package could be marketable. Especially, given the recent price increases around the electricity supply to homes and business.

During a brief literature review conducted it was found that there are in fact products already on the market that manage household energy systems to varying degrees. However, there are few that can intervene in the energy pathways, and even less build predictive models to make pre-emptive decisions based on environmental cues.

The extension to the objectives, time permitting, include the relatively new concept of peer to peer electricity trading, currently in trial with one Australian company in the form of blockchain-based software (Gifford, 2017). This technology has the potential to disrupt the energy supply market in the same way that Uber has done the Taxi industry. The difference being the grid that interconnects the energy network is operated by the same provider that is exposed to the potentially adverse effects of this idea. To extend the analogy it would be like the Taxi company owning the roads on which they conduct their business, this disruption could result in an undesirable situation for many. For this reason, the technology developed in this project could be viable for adoption by the energy suppliers to be ahead of the disruptive technology that is already in trial stages.

1.6 Measure of Results

As with any project, this project seeks to provide a solution to an observed problem in the community. The net gain of the project's worth needs to be able to be visibly quantifiable. For this reason, the return on investment will be the way in which this project's outcomes will be measured. That is, the project should seek to not only be competitive with other similar systems on the market but also see to it that the return on investment of the grid connected solar array be maximized.

The reason return on investment will be used as a measure, is because the problem at the outset is inclusive of the fact that there exist many solar supplied dwellings connected to the grid that are subjected to fixed tariffs and large capital costs to implement these systems. There is also a common perception that solar supplied dwellings are no longer feasible since the reduction of the feed-in tariff, and the capital versus return is not sufficient enough to justify the initial outlay. This perception at a time when the Australian government has committed to green energy targets (Cleanenergycouncil.org.au, 2018) is one that will hinder its efforts and, more than likely, shift the burden onto large private entities, ironically at a cost to those very same taxpayers, in the form of Government grants and subsidies to said companies.

The project will be measured in two parts:

i. Return on Investment of the implemented Home Energy Management System should be less than 12 months.
ii. The Home Energy Management System should see to it that the return time on the dwelling's solar system be decreased by better than 5%.

Chapter 2 LITERATURE REVIEW

2.1 Literature 1

2.1.1 Reference

Anon, 2017. *Rising living costs are hitting some of us harder*. [online] ABC News. Available at: <http://www.abc.net.au/news/2014-08-06/jericho-rising-living-costs-are-hitting-some-of-us-harder/5649824> [Accessed 25 Sep. 2017].

2.1.2 Summary

Rising utility rates have contributed to the cost of living annual growth exceeding the typical wage growth. In the last year alone utility costs rose by 6.6%, compared with average weekly earnings growing by 2.05%. These figures were backed by the Australian Bureau of Statistics (6345.0 - Wage Price Index, Australia, Jun 2017, 2017).

2.1.3 Evaluation

Figures like these justify the requirement for means by which consumers can reduce their out of pocket expenses to make stagnating wage growth go further. All indications are that, in the short to medium term at least, these costs are going to continue to grow.

This article provides a data rich insight into the living costs that are affecting Australian economics and specifically cites utility costs as a major outlay that predictions at the time of writing were only going to get worse. This leads to a better return on investment for any system seeking to capitalize on improving the efficiency of renewable energy, even if that is just at a cost basis.

2.2 Literature 2

2.2.1 Reference

Anon, 2017. *General supply tariffs*. [online] Ergon Energy. Available at: <https://www.ergon.com.au/retail/residential/tariffs-and-prices/general-supply-tariffs> [Accessed 25 Sep. 2017].

2.2.2 Summary

Ergon Energy general supply tariffs description and pricing.

2.2.3 Evaluation

The information pertains to the general supply tariff and highlights the fact that it is the most common tariff for residential customers. This alludes to the fact that using this tariff pricing guidelines may best portray the average Australian household.

This information is crucial to establishing and maximizing the cost efficiency of the final product. As Tariff costs increase the hypothesis is such that so to would the potential return on investment.

2.3 Literature 3

2.3.1 Reference

Anon, 2017. *Australian Solar Feed-in Tariff Information - Energy Matters*. [online] Energy Matters. Available at: <https://www.energymatters.com.au/rebates-incentives/feedintariff/#queensland> [Accessed 25 Sep. 2017].

2.3.2 Summary

Information on Australian solar feed-in tariffs.

2.3.3 Evaluation

Information as to the current and historical feed-in tariffs, or rebates, provided for excess solar being supplied from homes and businesses to the grid. This is information which will help quantify and gauge potential cost benefit analyses.

2.4 Literature 4

2.4.1 Reference

Anon, 2017. *Comparison of home energy management systems in Australia - Solar Choice*. [online] Solarchoice.net.au. Available at: <https://www.solarchoice.net.au/blog/comparison-home-energy-management-systems-australia> [Accessed 25 Sep. 2017].

2.4.2 Summary

Side by side comparison of home energy management systems in Australia. The article sets out to establish ways to maximize the value that solar and traditional storage techniques can deliver.

2.4.3 Evaluation

Provided extensive general knowledge on other products that have similar framework to what I am currently proposing. Potentially critical information as to whether the project is indeed worthwhile given the number of products that are currently available. This will be key to determining the suitability of the project topic going forward. It also introduced the acronym EMS (Energy Management System) and HEMS (Home Energy Management System).

The article sets out the two basic primary functions of an EMS, that is to, monitor and control.

Monitoring allows an EMS to see how the energy is being used and generated in the household in question. At a minimum, this will provide an overview of how the energy is being used in real time. Ideally, this will extend out to being able to replay historical data on demand, allowing for the monitoring of home energy consumption, solar and batteries, or a combination these three key elements.

Control allows an EMS to make changes to at least one element of the energy system within the home. This may be as simple as enabling a device to be switched on and off, or as advanced as automating the energy use management within the home to maximize the value of solar and or batteries.

The article then sets out a comparison of 13 of the most prominent HEMS's on the market at the time and compares them using a set of criteria. Which are as follows:

- System Type
- Description
- Primary Focus
- Monitoring Capabilities
- Control Capabilities
- and, Costs

2.5 Literature 5

2.5.1 Reference

Clauser, G., 2017. *4 Smart Energy Monitoring Systems to Help You Control Your Electricity Bill - Electronic House*. [online] Electronic House. Available at: <https://www.electronichouse.com/home-energy-management/4-smart-energy-management-systems-help-control-electricity-bill/> [Accessed 25 Sep. 2017].

2.5.2 Summary

Discusses energy monitoring systems to help control electricity costs in the household. Stating that a connected smart home energy monitoring system makes it easy to view household electricity usage and save money.

2.5.3 Evaluation

This article provided an insight into the standalone products that are available, but exposed the notion that there are limited options for an all in one package. It also highlights the fact that not all homes are equal and thought and consideration should be given towards creating a base product, and tailoring options to suit the homes requirements. These options will be limited by individual household devices and budgetary constraints.

The four options discussed in this article range in price. They start at approximately $80 and extend out to $300. This information serves as a good indicator of where the target marketable price should be for a comparable product. It should also be noted that these systems are targeted at the monitoring aspect of the EMS, and leave the control over the decision-making process up to the end-user.

2.6 Literature 6

2.6.1 Reference

Anon, 2017. *Smart Homes Builders | carbonTRACK*. [online] carbonTRACK. Available at: <http://www.carbontrack.com.au/building-energy-management/> [Accessed 25 Sep. 2017].

2.6.2 Summary

Carbon Track intelligent energy management system home page. Provides a brief description on how the system integrates with the internet of things and smart home automation. This website covers extensively one of the preferred options on the market available today.

2.6.3 Evaluation

The product appears to be marketed more towards property managers, enabling them to manage property portfolios remotely, to reduce service costs. The system claims to have predictive and pre-emptive maintenance offerings. This utilization of the technology is not exactly aligned with the scope of this project but potentially highlights a much bigger target market than previously anticipated. The poll that they have conducted indicates majority are, interested in the energy efficiency of homes as parts of sales process, attracted to energy efficient homes when buying or renting, and would be willing to pay for this information to make better judgement calls. The system itself does not appear to be automated, it enables remote operation of devices and energy use monitoring in real time.

Continued reading into their product line uncovers the company's roadmap towards solar optimization. Stating that smart solar is more than just solar monitoring. Smart solar is the ability to monitor energy consumption patterns and habits, allowing the user to see the energy usage and potential for savings.

CarbonTrack states that, "The average household will often sell more than 50% of the solar energy produce back to the grid!" This statement is where the foreseeable gains to be made in thermal storage by this project are. The experimentation will seek to identify ways to capitalize on this, in conjunction with the general tariff rates provided by the utility provider, maximizing the cost benefit of a solar integrated household through thermal storage.

This system aligns itself well with the goals set out to be achieved by the project, however the estimated costings start at $1000 installed, and a subscription starting after the first 3 years of $6 a month to effectively access your own data (on?, 2018). This is where the microcontroller can prove its worth by coming in at a lower build price whilst providing many of the same functions for the household.

2.7 Literature 7

2.7.1 Reference

Anon, 2017. *10 Best Smart Outlets of 2017 | Smart Plugs and Electric Outlet Reviews*. [online] Safewise.com. Available at: <https://www.safewise.com/resources/smart-outlets-buyers-guide> [Accessed 25 Sep. 2017].

2.7.2 Summary

A review on the best smart outlet options currently available. A brief description of each and the advantages and disadvantages associated with each of them.

2.7.3 Evaluation

The reason this article was included in the literature review is because it emphasizes the way in which the plug-in devices in the home can be controlled. The document details that at present this is, relatively, an expensive way to control or even just monitor the energy use in an individual home. The outlet technology appears to require user input to mitigate any inefficiencies in terms of energy use. The devices that these systems would likely be in-line with are all smaller home appliances, and potentially fall out of consideration for this project.

Overall, the article provides a good knowledge base on the types of plug-in devices available. The noteworthy point in this article is that of the options available the lowest cost per unit mentioned is $35.

Even though there were devices that had the functionality to manage a household energy system, these options can become costly very quickly.

2.8 Knowledge Gap Identification

In reviewing the literature, the following could be synthesized into what is and is not known, summarized here:

- To conduct the research appropriately the typical household arrangement and design will need to be derived.
- The most recent technologies around this will need to be reviewed to ensure that it is not something already being done in this fast-moving space.
- If similarities are highlighted come up with something that is either a variation of, or entirely new concept in this space.
- Map all possible considerations for inclusion to the model. For example: Weather forecasts.
- Software/s to develop, model, construct and implement this project will need to be determined. This will more than likely not be one software package.

Chapter 3 METHODOLOGY

3.1 Procedures

The analysis of thermal storage of solar energy will take the approach of empirical techniques. The decision to go this way, results in real world data, that is both relevant and accurate, mitigating the need for any approximations. It is also the way in which the completed project intends to interact with the supply it is monitoring and making decisions for.

This process will allow for a seamless transition from the experimentation aspects, to the build of the finished product. This will result in a specialized solution for the dwelling being monitored, however the intention going forward would be to develop a system that integrates with a vast array of home energy arrangements. For this project however, that is outside the scope of the programme.

3.2 Project Planning

The project research was carried out in multiple key phases. By breaking the overall task down into key stages, milestones could be attributed to each and a measurable gauge of completion could also be administered. This was completed in conjunction with the Project Timeline set out in Appendix E.

3.2.1 Phase 1 – Project Preparation Phase

This phase encompassed the approval to commence the project proposed, the acquisition of resources perceived to be required, and the defining of scope of project. This would be a necessary requirement for the permissions needed to continue with the project. It involved interaction with appropriate Academic staff to find someone best suited to the project proposed.

3.2.2 Phase 2 – Modelling of Typical Home Energy System

A typical home energy system was needing to be developed and modelled. If not modelled, the data necessary to justify relevance was needed to be acquired at a minimum. To determine whether the project was relevant, and the level to which it was relevant, this phase would allow the researcher to identify the potential target market and therefore potential consumer base. There are multiple sources of information pertaining to household energy statistics within Australia, and a set of data that represented the current applicable average would likely be the best fit, especially to maximize the potential marketability.

3.2.3 Phase 3 – Data Collection Phase

This phase of the project entailed gathering information from a home or multiple homes that fits the renewable energy grid connected household model. A crucial phase in the process, as this data would form the basis for the analysis and allow conclusions to be drawn as a result. This data collection came in the form of dedicated data logging tools monitoring crucial feedbacks for the system to make appropriate decisions as to how to best manage the energy in the system.

3.2.4 Phase 4 – Modelling of Actual Home Energy System

The modelling of an actual home energy system will take the information obtained in Phases 2 and 3 and collate them to best represent the typical home. This will involve external measurements not limited to, the size of a living or bed room, the size of the hot water system, the weather patterns during the data collection phase, approximations of daily energy consuming activities, all of which needs to be in conjunction with and referenced to the data collected in Phase 3.

At this stage, model comparisons can now be conducted between what is found through research to be typical and the actual designs, made possible through the data collection phase. Algorithms will need to be developed to define rules around how to best manage the household energy. A microcontroller software implementation of this would be a worthwhile exercise in proof of concept and prototyping.

This phase is effectively the culmination of all the data, both researched and observed via experimental process in its raw form.

3.2.5 Phase 5 – Data Analysis Phase

At the data analysis phase, options and potential leverageable positions need to be determined. This is where the potential foreseeable efficiency gains can be calculated from. Dependent on time this section may encompass the extended objectives phase.

The data analysis can be conducted using either spreadsheet based software or a MATLAB based modelling software.

3.2.6 Phase 6 – Write-up and Preparation of Results

A draft dissertation will need to be prepared and submitted to the Academic Supervisor for review. The results will need to be presented at Professional Practice 2, at the Residential School as a part of ENG4903. A final dissertation will need to be compiled for submission after review of the draft by the Academic Supervisor. These are the necessary steps throughout the process to maintain direction and show visible signs of progress towards a desirable outcome. This forms assessment tasks along the way for added accountability.

3.2.7 Phase 7 – Extended Objectives

This phase will be time permitting, and will seek to quantify and conduct an analysis on the extended objectives of the project. These objectives were found to be time permitting due to an early assessment of time available and expected task durations. To keep the goals realistic and achievable these were made as potential objectives to compliment the overall main objective, rather than hinging the success of the project on them.

3.3 Consequential Effects

3.3.1 Sustainability Issues

The Engineers Australia code of ethics emphasizes the promotion of sustainability. Ensuring that engineers engage responsibly with all stakeholders, practicing in a way that upholds the safety, health and wellbeing of the community. The idea behind this mindset is to balance the needs of the present with those of future generations in the years to come (Engineersaustralia.org.au, 2018).

In line with this the outcomes of the project will be the determining of the feasibility of a household targeted power management system. This would have to have a quick return on investment to be beneficial to the purchaser of this product. The other added benefit, is that a consistent predictable reduction in demand from the grid allows energy providers to make better decisions when it comes to designing supply networks and the associated infrastructure. Which in turn, results in a lowered cost passed on to the end user. Therefore, having a doubling effect on the reduction in cost and improvement in time to see return on investment.

3.3.2 Ethical Responsibility

Bound by the Engineers Australia code of ethics, the responsibility is entrusted to the student to:

- Demonstrate integrity
- Practise competently
- Exercise leadership
- Promote sustainability

throughout the course of this project and a continuation of them into future endeavors (Engineersaustralia.org.au, 2018).

Ethically there are minimal considerations that need critical review. Even though the data gathering is going to be around the daily activities of a household, it is the student's own private residence and not that of a third party. This falls into the category of human beings undergoing observation by researchers. Acknowledgement will be made to the occupants of the house for their cooperation and assistance with the Project and if deemed necessary a formal consensual agreement could be obtained.

3.4 Safety Issues

3.4.1 Risk Assessment

The risk assessment conducted for the project (Table 3.1 – Project Risk Assessment) has been carried out with respect to the risk assessment tool pictured in Figure 3.1.

Likelihood	Consequence Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Almost Certain 5	5	10	15	20	25
Likely 4	4	8	12	16	20
Possible 3	3	6	9	12	15
Unlikely 2	2	4	6	8	10
Rare 1	1	2	3	4	5

Figure 3.1 – Risk Assessment Matrix (Risk Management Matrix Template - Virtren.com, 2017)

Table 3.1: Project Risk Assessment

Task	Hazard	Risk Score	Risk Mitigation	New Risk Score
Phase 1	Failure to gain approval.	9 (High)	Commence project proposal as early as possible.	3 (Low)
	Resources not available.	12 (High)	Almost all the tools required I already own.	3 (Low)
Phase 2	Improper posture when reviewing literature and gathering information necessary.	6 (Moderate)	Ensure ergonomic setup for extended held postures.	2 (Low)
Phase 3	Electric shock when setting up equipment.	12 (High)	Ensure all necessary personal protective equipment is worn, ensure tooling used is fit for purpose, and that all energy sources are isolated for the fitment of instrumentation equipment.	4 (Moderate)
	Hot water.	12 (High)	Ensure all energy sources are isolated, and pressure in the system is vented.	4 (Moderate)
	Inaccurate data collection.	9 (Moderate)	Wherever possible confirm recorded measurements against a known source or verifiable instrument.	3 (Low)
	Loss of data collection.	9 (Moderate)	Ensure a routine save and backup procedure is followed.	3 (Low)
Phase 4	Improper posture when reviewing data collected and gathering further information.	6 (Moderate)	Ensure ergonomic setup for extended held postures.	2 (Low)
Phase 5	Identification of the fact that there is not enough data to draw conclusions from.	9 (High)	Ensure adequate contact is maintained with the supervisor in a manner that makes this an unlikely event.	3 (Low)
	Data analysis takes longer than anticipated.	9 (High)	Ensure sufficient time set aside to complete data analysis. Where possible carry out all calculations that are perceived relevant ahead of time.	3 (Low)
Phase 6	Insufficient time available to appropriately document and present the results obtained.	9 (High)	Plan and predict time constraints ahead of time, to ensure time is utilised in a manner that, where foreseeable, mitigates this risk.	3 (Low)

3.4.2 Key Risks Identified

In analyzing the risk assessment completed prior to the onset of the tasks, the initial risk scores were deemed to vary from moderate to high. Safety issues brought about by hazards in the environment ranked highest in the assessment. Water and electricity at hazardous temperatures and voltages, respectively, even with risk mitigation techniques scored highest overall. This is because the likelihood could be decreased by isolating all energy sources, but the outcome from an event occurring still results in the same consequence.

The project will require access to and monitoring of voltages and systems that are potentially life threatening. As a qualified Electrician, this should not be an issue if appropriate risk mitigation tools highlighted in the risk assessment are followed, see Table 3.1 – Project Risk Assessment.

The risk scores have been deemed to be of a level that is as low as reasonably achievable.

3.5 Consumer Market Analysis

To set benchmarks around price points and ability to deliver on key objectives a consumer market analysis would need to be performed to enable a comparative analysis to be completed. The following table is one that has already been completed in the highly competitive Home Energy Management System space.

Table 3.2: Energy Management Systems Comparison (on?, 2018)

	Overview			Monitoring capabilities				Costs	
Platform name	System type	Brief description	Primary focus (solar, battery, or home)	Household energy consumption (to what level of detail?)	Solar production & consumption	Battery state of charge, charging & discharge	Control capabilities	Out-of-pocket costs	Ongoing costs
AlphaESS	Battery-integrated system	Part of all-in-one system solution provided by AlphaESS to help get the most from the solar and battery storage. Can be programmed and tailored for customer needs and remote controled for micro grid and other applications	Home / Small Business (Embedded in AlphaESS battery storage unit)	1s interval data for controlling purpose, 5mins data uploaded to cloud server. Free lifelong service, free upgrades.	1s interval data for controlling purpose, 5mins data uploaded to cloud server. Free lifelong service, free upgrades.	Detailed data available on battery charge/discharge , self - consumption, and what is imported/ exported.	Ethernet, CAN, cloud based, Zero export; Can control devices in home as long as they have AUX control capability	Included in AlphaESS all-in-one package	None.

Platform name	Overview: System type	Overview: Brief description	Overview: Primary focus (solar, battery, or home)	Monitoring capabilities: Household energy consumption (to what level of detail?)	Monitoring capabilities: Solar production & consumption	Monitoring capabilities: Battery state of charge, charging & discharge	Control capabilities	Costs: Out-of-pocket costs	Costs: Ongoing costs
carbonTRACK	Meter board system (Can be installed without solar or batteries)	An 'intelligent', holistic energy management system that integrates solar, batteries and energy consumption to maximise energy performance and value for residential, SME and C&I customers	Elimination of wasted energy consumption, optimisation of solar and storage management, preemptive alert capability	Detailed household consumption data displayed in 15 minute intervals down to device level	Detailed data in respect of total solar generation, solar generation consumed & solar generation exported; displayed in 15 minute intervals	15 minute data on all of the above	-Remote GSM circuit level & power outlet switching -ZigBee, Z-Wave, ModBus & RS485 communication capability -Smart Meter integration -DC measurement-hierarchical switching / demand response -Green circuit switching -TOU tariff optimisation -Spot price trading	From $337 installed	From $3/mo from 13th month
Enphase Home Energy Solution	Inverter-integrated system	Enphase's Home Energy Solution coordinates between solar, batteries and home energy demand to maximise overall system performance & value	Solar, battery & energy management	Integrated household consumption data displayed in 15 minute intervals	-Breakdown of solar generated, consumed & stored and grid imort/export displayed in 15 minute intervals. -Supports single and multi phase systems	15 minute data on all of the above	-TOU tariff optimisation -Additional features under development	Around $600 installed (battery costs excluded)	Nil
Geli	Battery-integrated system	A software platform that integrates with and manages a wide range of energy storage products to maximise the value of solar PV generation for the homeowner, retailer, and distribution provider	Solar + storage management software	Reads home energy smart meter	Data displayed in real time	Data displayed in real time	-TOU & solar self-consumption optimisation -Aggregated dispatch for virtual power plant services	Bundled with energy storage kits (available from select installers)	Varies depending on retail channel
Redback Technologies	Inverter-integrated system	An Aussie-designed 'smart inverter' that provides a faster return on investment by increasing self-consumption through intelligent software.	Solar, battery and smart home`	-Multiple circuit load profiles in 1 minute increments, 24 hours per day. -Consumption of solar production and grid power purchased	One minute data intervals	Users can chart 5 different battery parameters: State of charge (SOC), voltage, current, power, status. Battey SOC widget provided for quick view	-Internet of Things (IoT), -Inbuilt relay control -TOU optimization -Battery and appliances can be turned on and off through the app or portal	Included free of charge with Redback Smart Hybrid Inverter	Nil

Platform name	Overview			Monitoring capabilities			Control capabilities	Costs	
	System type	Brief description	Primary focus (solar, battery, or home)	Household energy consumption (to what level of detail?)	Solar production & consumption	Battery state of charge, charging & discharge		Out-of-pocket costs	Ongoing costs
Reposit Power	Meter board system (Can be installed without solar or batteries)	Reposit gets the most out of your solar battery system and improves return on investment. Enables GridCredits exports at $1/kWh at selected times and includes Time of Use (TOU) battery charging optimisation which reduces your consumption at times of peak energy rates. Also includes comprehensive home and solar energy monitoring. Australian designed and manufactured.	Home, solar and battery, energy trading, weather predictions, smart-grid participation.	-Monitoring on smart device app or web browser -24 hour look-ahead household consumption predictions -Individual monitoring of unlimited numbers of circuits if required -Supports single and three phase homes 1 second live data	-Monitoring on smart device app or web browser -24 hour look-ahead weather and solar generation predictions -Supports monitoring of unlimited number of individual solar systems both single and three phase 1 second live data	-Monitoring on smart device app or web browser -Dynamic automated battery charging to avoid peak rates -Supports combination of multiple battery systems both single and three phase 1 second live data	-Virtual power plant network response -Time of use (TOU) tariff battery charge optimation -circuit relay control capable -Hot water control capable -Internet of Things (IoT) control capable -DRED control capable -Ethernet, USB, ZigBee, WiFi -CSV data export	From $600	None
SMA Energy Meter	Inverter-integrated system	3 phase energy meter (63A/phase) for monitoring consumption of residential systems	Home / Small Business	Yes, 1 second polling	Yes	N/A	None	~$500	None.
SMA Sunny Home Manager	Inverter-integrated system	A learning system which is the brains behind the SMA Smart Home. Able to provide predictive energy generation and load recommendations. Integrates with Smart Home appliances which implement EEBUS. Compatible with Smart WiFi sockets to increase PV self consumption and reduce grid energy costs	Home / Small Business	5 min average but as detailed as 1 second with upgraded software packages	Yes, and for 3rd party inverters with an additional energy meter (see next row)	Yes	Full system control for SMA PV and battery inverters including: -Setting up battery charge from the grid during off-peak electricity tariffs -Export limitation for PV systems Tariff windows for automated "economical" optimisation of energy use -Automated load control with Smart Sockets	~$500	None, unless Sunny Portal Professional packages are activated.

Platform name	Overview			Monitoring capabilities				Costs	
	System type	Brief description	Primary focus (solar, battery, or home)	Household energy consumption (to what level of detail?)	Solar production & consumption	Battery state of charge, charging & discharge	Control capabilities	Out-of-pocket costs	Ongoing costs
Solar Analytics	Meter board system (Can be installed without solar or batteries)	Empowering people to navigate the changing energy landscape. Sophisticated analytics with a beautiful and engaging dashboard connects users to their solar and home energy use. Solar Analytics provides insights to improve performance and increase the value of their systems. Easy to install and use, local support backed by a team of experts. Australian made.	Solar, energy consumption & battery	5 second live data, up to 6 circuits per device	-Expected vs actual production analysis -Live production and consumption monitoring -System fault diagnosis and notification -Real time data display -Fleet Management capabilities	-30 min data state of charge -30 second data for charging & discharging -Ongoing development to expand brand range	-Solar self consumpion optimisation -TOU optimisation -Peak demand minimisation -In beta: relay switches and DRED controls -In development: solar and load forecasting	$399 (RRP)	$6/ month
SolarEdge Monitoring Platform	Inverter-integrated system	The SolarEdge cloud monitoring site & application performs remote monitoring on the go, for maximum solar energy harvesting. (Demo login available for interested users to view publicly available SolarEdge PV sites around the world.)	-Residential & Commercial solar PV -DC optimised inverters -battery & backup ready inverters -Home automation -Module level data Monitoring -Weather data -Module diagnostics	-Free lifetime PV system monitoring -From 5 minute interval data is available -Monitoring of total consumption of solar production, grid power purchased, and what is imported/ exported	-Detailed data can be viewed daily/ weekly/ monthly & annually -48 hour look-ahead weather predictions & recording -For the installers, it supports monitoring of unlimited number of individual solar systems both single and three phase	-Detailed data available on battery charge/discharg, self - consumption, and what is imported/ exported.	-Ethernet, GSM-SIM card with data package, WiFi, ZigBee, ModBus & RS485 communication capabilities -app enabled for mobile & tablet - -available From iOS & Android stores -device control product suite can turned on/off From the app	-Free lifetime monitoring for all single & three phase inverters -Free App from iOS & Android stores -If export monitoring is required, then you will need a Modbus meter, which is approx $330	None
Sonnen	Battery-integrated system	Global leading domestic solar energy storage product since 2010. Maximises self-consumption for the owner via intelligent, predictive energy management as well as direct and smart load control.	Solar, battery, home, self-learning + weather data	Total household loads Up to x3 Z-Wave smart sockets monitoring appliances directly per sonnen unit (multiple sonnen units can be installed) Solar PV inverter output.	Real time data of PV production, loads, grid import, grid export, self-consumption (autonomy) value.	Real time data of battery charge, battery discharge, overall state of charge, self-consumption (autonomy) value.	-Z-Wave control of X3 appliances and X1 relay control for larger circuits per sonnen unit (Multiple sonnen units can be installed) -Peer to Peer trading through sonnenCommunity -tariff optimisation -Full DRED control -control circuits can be remotely controlled via smartphone app or via user online portal	All of the intelligent self-learning monitoring and control is included free with the sonnen system, plus the ability to offer peer to peer trading.	None

From the Energy Management System comparison, the following can be stated:

At $330 Solar Edge Monitoring Platform is the cheapest option, for add-on home energy management solutions, limited to the market reviewed. However, this system is limited to the monitoring of the system and does not appear to have any form of control over the system itself.

CarbonTrack at $337 installed and an ongoing cost of $3 per month is the next best priced system. This system does allow both monitoring and switching capabilities to the occupant of the household. However, the price stated is the starting price, which allows for energy monitoring only. Further investigation found that estimated costs were more likely to be priced in at $999 installed with a $6 per month ongoing cost, this system would have the ability to control large loads remotely, helping to optimize energy savings (on?, 2018).

The results of the comparison show that, largely the consumer market for solar integrated home energy management systems, largely employ the use of batteries, which are often a large additional expense, and often neglect those dwellings that do not offer the battery storage technology. Another point to make is that majority of the systems on the market offer monitoring only with either non-existent influence over the system or at least very limited functionality. For this project, the target market will only be those dwelling with already installed solar installations, and the assumption made that battery integration is not a feasible inclusion for most, due to added capital costs. Initial indications, whilst outside the scope of research, do highlight the benefits that battery integration provide the customer, for things such as arbitrage trading, and tariff optimization techniques. The key learning here is that the competitors in the market, whilst they don't take on the same approach as this research aims to exploit, they have been found to be priced over and above $1000 for what will be considered a comparable product going forward.

3.6 Return on Investment

Return on investment is a financial ratio used to calculate the benefit an investor will receive in relation their investment cost. Commonly, this is calculated by dividing the net income projected or achieved by the original capital cost. The higher this ratio is found to be, the greater the benefit to the investor. Maximizing this ratio is a way to ensure any investment will prosper and provide the best earning potential to the affected party (Corporate Finance Institute, 2018).

It was found that a typical 3kW system costs near $5000 with approximately $2300 of the total fee already reduced because of government rebates. A system of this size will produce on average 12.9kWh per day. With a conservative figure of 30% of production kept in the household itself, an expected return on investment will take place over a 10-year period with energy markets and tariffs set where they are today. This is calculated using $500 as the overall reduction in energy costs and credits due to feed-ins. As the cost of energy fluctuates so too will this expected return on investment. Almost counterintuitively as the expense of energy grows, so too does the value of energy not being demanded by the household, leading to further savings and therefore decreasing the projected length of time over which the asset will become cost positive (Strine Environments, 2018).

It is this area that the prototype developed will seek to exploit and take advantage of the significant disproportionality between demand and feed-in tariffs, currently a 3-to-1 ratio. It should be stated here, that in the event a product of this nature was to be brought to market in scale, energy providers may combat this by decreasing this ratio. That can come in one of two ways, either increase the credits offered for feed-in or decrease the costs on the demand tariff. Whilst this would decrease the return on investment of the research project prototype, it would still work toward combating the rising costs of energy.

Chapter 4 EQUIPMENT and EXPERIMENTAL TECHNIQUES

4.1 Resource Requirements

Resources required to complete the project include, but are not limited to:

- Dedicated suitable household
- Dedicated data logging equipment (Figure 4.1) with multiple analogue inputs, and potential for remote connectivity.
- Arduino controller and/or available commercial grade microcontroller.
- Suitable Arduino 'add-ons' to cover the scope of the objectives.
- Software to interface with controller.
- Thermal probes for hot water, pool water and internal ambient air temperature.
- Flow meter, or at a minimum, flow switch on the hot water system and pumped solar water heating.
- Voltage probes for measuring supply voltage.
- Current clamps for measuring current draw/feed-in.

Figure 4.1 – DataQ Data Logging Instrument (Instruments Techno Test inc. | Our products -, 2017)

A DataQ is a data acquisition system that are available for a wide range of special and general-purpose applications. The DataQ system, a DI-730EN, employed for this task supports voltage input ranges from as little as 10mV up to 1000VDC, with an ethernet interface to a personal computer loaded with the appropriate software, known as WinDaq. The DataQ features 1000V input-to-output and channel-to-channel isolation, and is perfect for measuring voltages, currents and temperatures. The instrument offers 14-bit 150kHz waveform recording over 8 channels (Dataq.com, 2018).

4.2 Resource Analysis

4.2.1 Sourcing

Table 4.1: Plan to Source Resources

Item	Source
Dedicated suitable household	Researcher's home
Dedicated data logging equipment (Figure 4.1) with multiple analogue inputs, and potential for remote connectivity	Already owned
Arduino controller and/or available commercial grade microcontroller	Electronic supplier
Suitable Arduino 'add-ons' to cover the scope of the objectives	Electronic supplier
Software to interface with controller	Supplied with purchase
Thermal probes for hot water, pool water and internal ambient air temperature	Electronic supplier
Flow meter, or at a minimum, flow switch on the hot water system and pumped solar water heating	May not be required
Voltage probes for measuring supply voltage	Already owned
Current clamps for measuring current draw/feed in	Already owned

From the table, it is easy to establish that all resources, that are not already owned, will be sourced from an electronics supplier.

4.2.2 Availability

The local electronic supplier is well stocked and most items are readily available. They are open seven days a week and order most of their components through a wholesaler that offers overnight delivery on majority of their stock.

However, the components were eventually purchased online as there was a wider range available and the lead times were found to be negligible. This was key to reducing the initial risk score, that was assessed as being high. With the consequences of not being able to source components a potentially large problem.

4.2.3 Costs Involved

Having already acquired many of the components, majority of the cost for the data acquisition phase of the project was kept to a minimum. The costs incurred came about as the microcontroller was developed and the realizations made as to the best way to proceed in the build. These parts are commercially available and as a result were competitively priced. Table 4.2 shows a tabulated cost breakdown.

Table 4.2: Breakdown of Costs

Item	Quantity	Cost ($)
ZMPT101B AC Voltage Sensor	1	16.50
4 Channel Relay Module	1	6.86
UNO R3 Starter Kit	1	64.99
CD4051BE Multiplexer	5	5.30
DS18B20 Temperature Sensor	1	3.88
Waterproof Temperature Sensor	1	12.99
ACS712 20A Current Sensor	5	36.00
	Total	$146.52

Note that an entire Starter Kit was purchased and the CD4051BE multiplexer was purchased in a pack of 5. These two items standout as immediate opportunity to reduce costs incurred going forward.

4.2.4 Budget

Budget is to be kept within the realms of reasonable, as the product is intended to be cost competitive with existing similar designs but also provide the end user with a short return on investment.

Through the process of literature review, the initial indications are that a product targeted at the $100 market would see it enter the market as a competitive option versus the available products now. As a result, this can be deemed as a desirable price point to which to aim for.

The overall cost came in at $146.52 to acquire all the components to build the prototype. Although, a large portion of that cost was incurred in the purchase of the Arduino UNO Starter Kit. If this build was to be mass produced there are quite a few components in the kit that were unnecessary specifically for this build. The lowest cost found for the UNO R3 standalone was $22.00, and would see the entire build come in at just over $100.

This pricing is significant in terms of the measure of success of the project. The lower this cost can be kept the more likely the return on investment targets will likely be achieved.

4.2.5 Funding

This research project was entirely self-funded. As a result, there are a limited number of acknowledgements to be made. Also, there is little cause for concern for structuring any agreements over intellectual property that has been uncovered throughout the experimentation.

4.2.6 Lead Times

All items required are currently held by the local electronic supplier, or are with 2-3 business days freight away.

The longest lead time for any component required for the build was 7 days from order, with standard shipping applied.

As the build of the final product, is more of a proof of concept rather than the major objective of the project it was deemed acceptable to incur lead times of this length. If this item was to be refined and produced for a consumer market 7-day lead times could prove to be a hurdle without adequate logistical management and/or commercial agreements in place for the prioritization of supply chains to support the expected demand.

4.2.7 Alternatives

There are alternatives to both, the desired controller to be utilized, as well as the option of a secondary local supplier. As a last resort purchases may have to be made online, however, initial investigation into this indicates that due to the popularity of the controller being used, parts will be readily available in most cases.

Arduino was chosen as the platform to prototype this project on for several reasons. Arduino is an open source electronics platform, specifically designed for the prototyping of flexible easy-to-use hardware and software (Core Electronics, 2018).

Arduino can sense the environment it is immersed in by receiving a variety of sensors, and then can affect its surroundings through various capabilities. The Arduino programming language and the Arduino environment are both based on well-known coding platforms (Core Electronics, 2018).

Raspberry Pi was tabled as an alternative option for the prototype development platform. It is a general-purpose computer rather than a microcontroller, and typically operates on the Linux system. It is generally more complicated to use than Arduino. Raspberry Pi is best utilized in applications were a fully-fledged computer is required for complex tasks and heavy calculations. As opposed to the Arduino, that is better suited for conducting simple repetitive tasks (Core Electronics, 2018).

This comparison enabled the project to continue toward development on the Arduino platform. Prospects and further works may see it that the Raspberry Pi lend itself more toward the tasks required to be completed, however, at this early stage that will not be necessary and would be outside the scope of this research project.

4.3 Experimental Techniques

“An experiment is a question which science poses to Nature, and a measurement is the recording of Nature’s answer.” (Planck, 1949)

There exist two techniques when it comes to science, that is, observational and experimental, with many scientific disciplines being more observational than experimental in nature. There tends to be a multitude of variables that are not always possible to control and manipulate. Typically, these relate to natural phenomena, and as a result the experimental conditions are somewhat out of the control of those conducting the experiment. However, the basis of scientific method still reigns true, in that, observations inspire hypothesis, which in turn result in further observation (Emotionalcompetency.com, 2018). As such, the project would become a series of observations, developing data sets, which then in turn remodeled the understanding of the household energy system. This went on to eventually refine the experimental process down to a small number of analogue inputs needing only to be monitored.

Through research it was determined what minimum requirements made an energy management system able to function in a way that provides an opportunity to make use of thermal storage of solar energy. The two primary functions of an energy management system are to monitor and control (Solar Choice, 2018).

The process of monitoring sees that the system recognizes how the energy is being used, with some having the ability to recall and display historical data. Ideally the management system will have the ability to monitor consumption, solar output and in some cases also monitor the battery storage system. This could be achieved using an array of handheld monitoring equipment that was already made available, including but not limited to, handheld current clamps, temperature thermocouples, voltage probes and associated cabling.

The control function is what allows the system to be referred to one that can manage the energy. This can be as simple as allowing the user to disable a device that is consuming energy at an inefficient time, or as complex as, automatically managing and recognizing the energy flow through the system. Ultimately making decisions that increase the efficiency of the network it is monitoring. Ways of doing this are maximizing the value of solar and stored energy, by tariff arbitrage, and tariff use optimization. The capability to manipulate the home energy system being monitored, would eventually come as the result of the acquisition of a 4-channel output relay module integrated into the microcontroller circuitry.

Ultimately the experimental technique and design processes have been developed to satisfy the goals of the project.

Chapter 5 EXPERIMENTAL DESIGN

5.1 What is Experimental Design

The process by which an experimental process is planned to be carried out occurs at the Experimental Design phase. Typically, this will decide upon the variables that are to be monitored and often deliberately changed to observe the effect that it has on the process (Itl.nist.gov, 2018). A typical schematic of Process Design is shown in Figure 5.1. This process seeks to create an efficient procedure by which the experiment can be expected to take place.

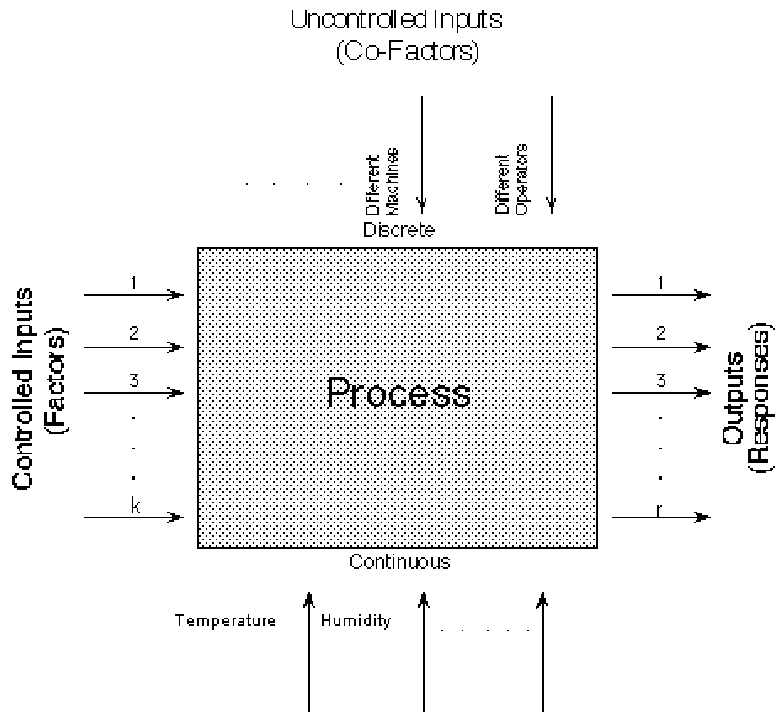

Figure 5.1 – Typical Schematic of Process Design (Itl.nist.gov, 2018)

5.2 Variables to Monitor

5.2.1 Necessary Variables

As previously stated in Experimental Techniques, the variables to monitor had to be such that the results of the data collection phase would allow the extension and extrapolation to form conclusions from the data.

There was also experimentation in determining the final variables that would be monitored. As seen in the data collected the signals being sampled started out very basically and were built upon from there. Using the experimental technique conclusions to steer the direction that this would take. The variables proposed to be monitored, by their very nature fall into the category of ‘Continuous’ in the Process Design Schematic.

That is not surprising given that the system will run in a real-time scenario where inputs will be monitored at a regular sample rate and decisions on the management of the energy be made in real-time also.

Through deliberate reduction in meeting the number of analogue signals able to be recorded consecutively, 8 variables were found to be necessary in being able to model the home energy system, allowing further analysis to take place.

They are as follows:

- Mains Supply Voltage
- Phase 1 Current
- Phase 2 Current
- Solar Supply Current
- Pool and Heating Current
- Hot Water System Current
- Ambient Temperature
- Pool Temperature

The analysis of these values at a minimum would allow the project to continue to progress.

The pool temperature variable was discussed with the supervisor as being too dynamic with the entire surface area of the pool exposed to the ambient conditions. Especially, such that it was to be the major source of thermal energy storage. As such, before the experiment could be undertaken a pool cover was purchased to help regulate the temperature of the body of water. This became a major influence of the results achieved. The figure below demonstrates the benefits that can be achieved with a pool cover, and this has proven to be highly accurate from the observations made throughout the experimentation.

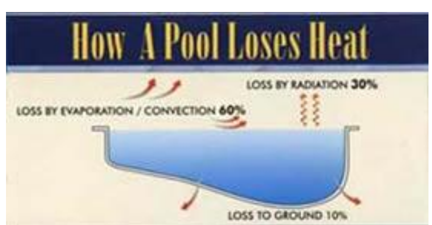

Figure 5.2: How a Pool Loses Heat (Northernpools.co.nz, 2018)

It is not yet known to what extent the addition of the pool cover will have on the energy costs, however, the effect it has had on reducing the amount of water lost to evaporation would indicate that it is doing its intended job.

5.2.2 Complimentary Variables

The list of complimentary variables is quite extensive. The end goal of the project is to create a device that is relatively simple to install and as a result have been deemed not necessary, but should be considered nonetheless, especially for further works. They are as follows:

- Pool Heater Flow
- Roof Temperature
- Hot Water System Flow
- Hot Water System Temperature
- Pool Pump and Heater Pump Currents Separately
- Weather Forecast
- Peer-to-peer Market Options

5.3 System Constants

5.3.1 Pool Dimensions

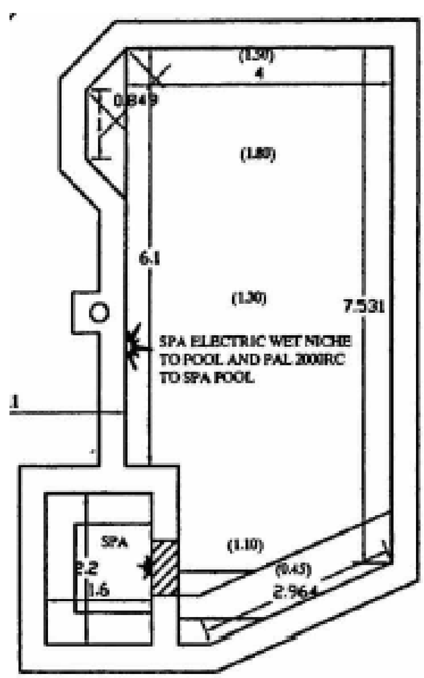

Figure 5.3 – Pool Dimensions

5.3.1 Pool Volume

Table 5.1: Pool Volume

Section	Dimensions (mm)	Volume (L)
Spa	2200 x 1600 x 1300	4576
Shallow End	2500 x 2964 x 450 to 1100	2871
Deep End	4000 x 6100 x 1100 to 1800	35380
	Total	42827

5.3.2 Pool Surface Area

Table 5.2: Pool Surface Area

Section	Dimensions (mm)	Surface Area (m^2)
Spa	2200 x 1600	3.52
Shallow End	2500 x 2964	3.71
Deep End	4000 x 6100	24.4
	Total	31.63

5.3.3 Heater Pump

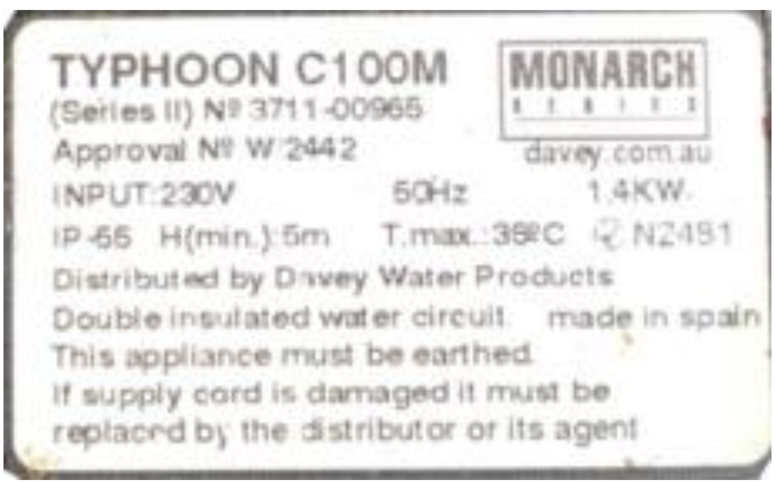

Figure 5.4 – Heater Motor Nameplate

Input: 230V Frequency: 50Hz Power: 1.4kW

5.3.4 Pool Filtration Pump

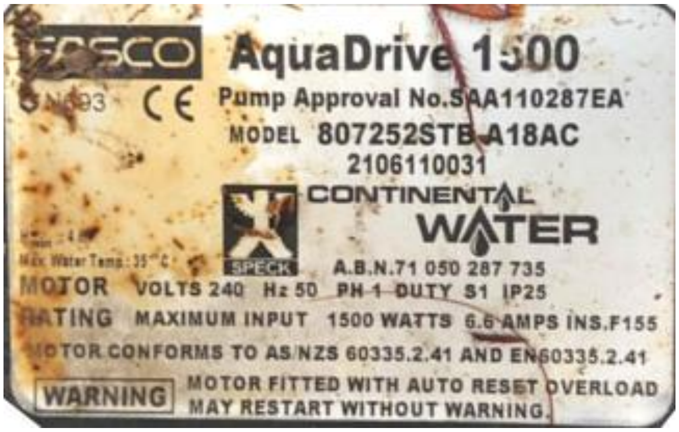

Figure 5.5 – Filtration Pump Nameplate

Input: 240V Frequency: 50Hz Power: 1.5kW Current: 6.6 Amps

5.3.5 Grid Connected Photovoltaic Array

Figure 5.6 – Inverter Nameplate

Output: 240V Frequency: 50Hz Power Out (Rated): 5kW

5.3.6 Hot Water System – Dux Proflo 315TI

SPECIFICATIONS	315T1
Storage Capacity (L)	321
Hot Water Delivery Rating (L)	315
Twin Element Boost Capacity (L)	-
Element Sizes (kW)	3.6
Net Weight Empty (kg)	93
Relief Valve Pressure (kPa)	1000
Max Inlet Pressure (kPa)	800

Figure 5.7 – Hot Water System Details

Input: 240V Frequency: 50Hz Power: 3.6kW Volume (Rated): 315L

5.3.7 Tariff 11

Table 5.3: Tariff 11 Details (Ergon.com.au, 2018)

Tariff 11 Residential	**Price (exc. GST)**	**Price (inc. GST)**
All usage Anytime		
All usage	25.298 cents per kWh	27.8278 cents per kWh
Daily supply charge	88.948 cents per day	97.8428 cents per day

Figure 5.8 – Tariff 11 Meter

5.3.8 Tariff 33

Table 5.4: Tariff 33 Details (Ergon.com.au, 2018)

Tariff 33 Controlled Supply	**Price (exc. GST)**	**Price (inc. GST)**
All usage	21.05 cents per kWh	23.155 cents per kWh
Daily supply charge	0.00 cents per day	0.00 cents per day

Figure 5.9 – Tariff 33 Meter

5.3.9 Solar Feed-in Tariff

Table 5.5: Solar Feed-in Tariff (Ergon.com.au, 2018)

Solar feed-in tariff options	
Solar flat feed-in tariff for regional Queensland. This amount is not subject to GST. (cents per kWh exported)	9.369
44 c/kWh solar flat feed-in tariff. This is not available for new solar PV connections. This amount is not subject to GST. (cents per kWh exported)	44.00
Solar time-varying feed-in tariff from 3:00pm to 7:00pm for Peak period. This is not available for new solar PV connections. This amount is not subject to GST. (cents per kWh exported)	13.606
Solar time-varying feed-in tariff for Off-peak period (all other times). This is not available for new solar PV connections. This amount is not subject to GST. (cents per kWh exported)	7.358

Chapter 6 EXPERIMENTAL PROGRAMME and RESULTS

6.1 Phases

6.1.1 Phase 1 – Project Preparation Phase

The approval to commence the proposed project came in conjunction with feedback from the Supervisor, John Billingsley and consultation with the examiner Chris Snook. After having to amend the initial project specification to make it 'more defined and less vague'. At this stage, a Project topic and objectives were decided upon and accepted by all parties concerned.

Acquisition of resources and collation of resources already held began soon after. Initial quotation and price points were gathered on all outstanding resources, however unless they were required for the data collection phase they were not obtained at this point.

This satisfied the phase sub set of objectives, initially planned for completion by the end of Week 1. That is, to gain approval to commence the proposed project, and the acquisition of resources.

6.1.2 Phase 2 – Modelling of Home Energy System

To model a home energy system and what form that may take came about within the literature review. Tariffs, average household consumptions, and other similar ideas were all reviewed to derive a conclusion from this. Sources such as Ergon, the local area energy supplier, were a good source of information for wider community data (Figure 6.1 – Household Electricity Use Comparison).

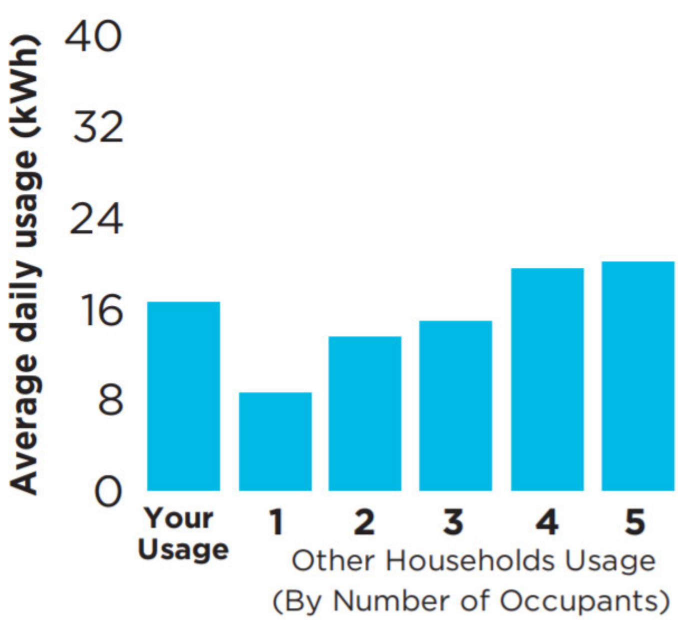

Figure 6.1 – Household Electricity Use Comparison (Ergon.com.au, 2018)

This shows that the consumption is representative of a typical 3 to 4-person occupancy as far as household usage compares. The Australian Bureau of Statistics suggests that the average number of persons per household remained stable in the 2015-16 data obtained, at a figure of 2.6 (Abs.gov.au, 2018).

This meant that the household in question represented a typical Australian residence according to these two sources, given that its occupancy at the time of experimentation was 3 persons. This information allows for the extrapolation of data processed to be extended out to include most of the applicable Australian residences.

6.1.3 Phase 3 – Data Collection Phase

The data collection phase had the heaviest reliance on adhering to the results of the Project Risk Assessment (Table 3.1). It was strictly followed especially around conductors, ensuring, where able, the energy source was isolated and means of sampling where placed downstream of a circuit breaker.

Each sensing device was calibrated by comparing against either a known value or another sensor of a similar type to ensure the integrity of all data collected. This is an essential step as it needed to be able to be extrapolated on in the latter stages of analysis, obviously incorrect data multiplied out by a year could have implications on the accuracy of the results. It should be noted that it was deemed not critical but only desirable to have highly accurate feedbacks for the eventual microcontroller system, and that some drift, within reason, would be acceptable for use in the proposed EMS. This decision was a result of the fact the controller would be working with real time measurements.

Figures 6.2 and 6.3 show the method used to collect the information of the household energy usage over a period. The data acquisition tool has provisions to monitor up to 8 voltage inputs at a time at varying sample rates with the ability to collect both real-time data points or time weighted root mean square (RMS) data points. It was during this process that the researcher determined that there was a two-phase feed into the residence and provisions had to be made to accommodate this oversight. The solution to this came in the form of an additional current sensing device.

Figure 6.2 – Data Collection Station

Figure 6.3 – Data Collection Method

Initial results indicated lower than expected solar outputs in full-sun and upon inspection it was found that the parallel connector on the roof was open circuit. As a result, this component was replaced and a dramatic improvement in solar output was observed. Even though this was not an intended benefit of monitoring the system, it highlights the fact that without monitoring, the end user often has little to no comprehension of how their energy system is performing. It also needs to be stated that this data was continued to be used throughout the rest of the research. The decision made based on that if there were foreseeable gains made with 50% of the array producing no output, then the cost benefit would likely be doubled because of this find.

The temperature inputs were fed back into the recorder using thermocouples. The temperatures were calibrated using a Fluke 87V True RMS multimeter to ensure the recorded value was accurate. Figure 6.4 shows the calibration method for the pool temperature thermocouple. Note that, the figure portrays a thermocouple entering the water and is in no way a hazardous source of voltage.

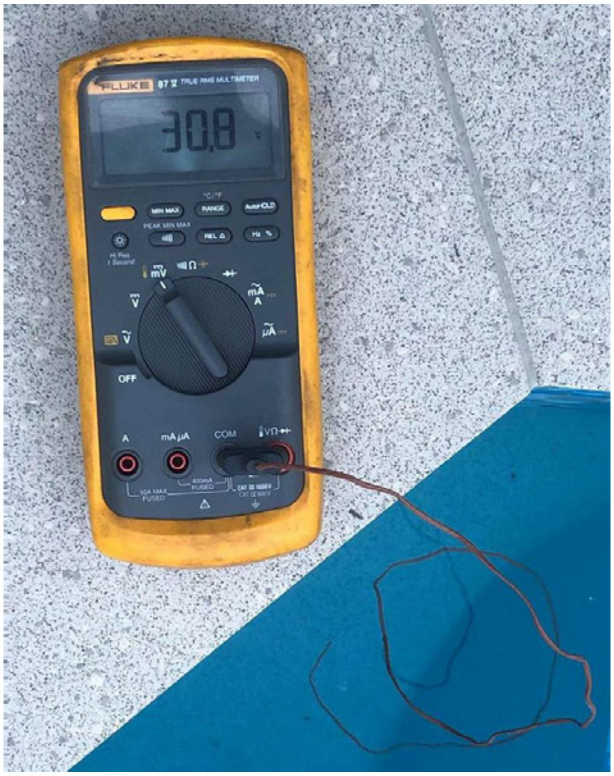

Figure 6.4 – Pool Temperature Calibration

An example of the output of this data collected can be seen in Figure 6.5, with channel 2's scaling displayed in Table 6.1 as an example of the setup that went into tuning each of the DataQ monitoring channels specific to the sensor. Channel 2 was the Phase 1 Current, being collected using a Fluke i410 Current Clamp. The current clamp outputs 1mV per 1 Amp sensed. Note here the acquisition method is set to RMS, the justification for this is that, had the data collected been in real-time a sinusoidal waveform equivalent would have been recorded and further post-processing would have had to take place. This way the capabilities of the DataQ as an effective means of data acquisition could be shown to be relevant, as well as reducing the amount of time taken and processing power to manipulate large sets of data. This RMS acquisition method was applied to all alternating current voltages and currents.

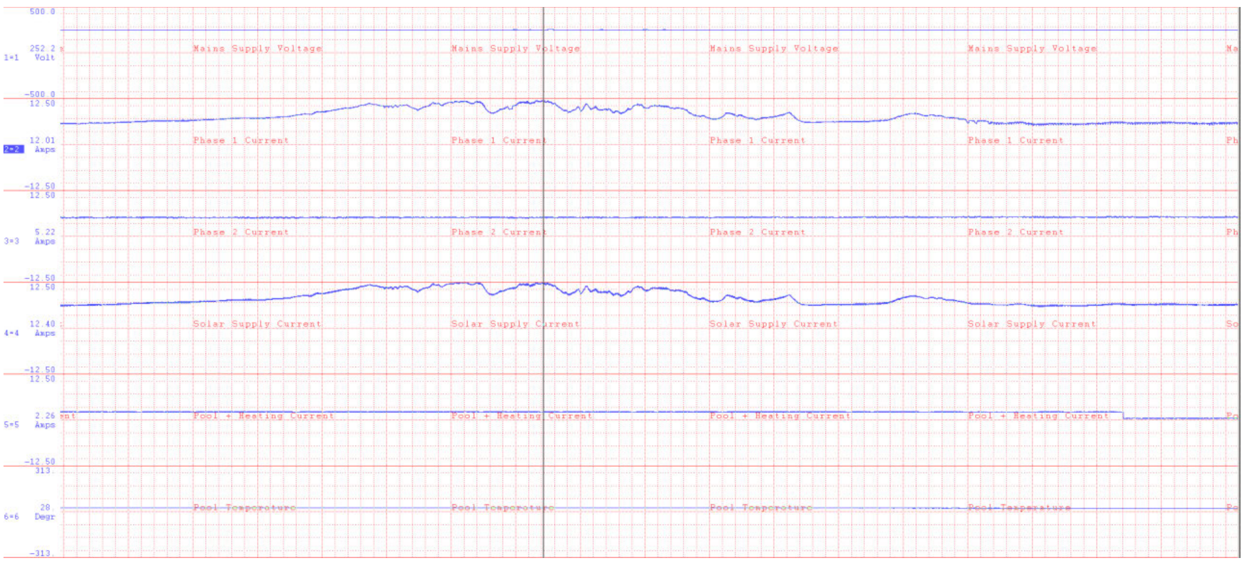

Figure 6.5 – Sample of Data Acquisition Data

Table 6.1 – Channel 2 Settings

Playback channel	*2*
Acquisition channel	*2*
Sample rate (Hz)	*100.0025*
Sample rate divisor	*1*
Effective sample rate (Hz)	*100.0025*
Acquisition method	*RMS*
Input type	*Linear*
Gain	*10000*
Input level top	*.10000*
Input units	*Volt*
Input level bottom	*-.10000*
Dynamic range top	*100.00*
Engineering units	*Amps*
Dynamic range bottom	*-100.00*
User annotation	*Phase 1 Current*

The ambient temperature was also trended to give an indication of the weather at the time of recording. This is one of many external environmental factors that may be incorporated into the final design. An example of the weather the week this recording was taken was taken from the Bureau of Meteorology after the fact (Figure 6.6 – Example of Weather Observation). In the final design, a reliable source of weather prediction would likely be called upon to assist in making forward projections about the way in which the energy is utilized.

Rockhampton, Queensland
May 2018 Daily Weather Observations

Date	Day	Temps		Rain	Evap	Sun	Max wind gust			9 am					
		Min	Max				Dir	Spd	Time	Temp	RH	Cld	Dir	Spd	MSLP
		°C	°C	mm	mm	hours		km/h	local	°C	%	8th		km/h	hPa
1	Tu	17.0	28.1	0			ESE	43	10:29	22.8	59		SE	19	1021.6
2	We	19.1	29.4	0			ESE	33	12:52	22.5	60	8	SE	11	1021.4
3	Th	19.6	28.7	0.2			ENE	30	14:35	22.4	77	7	ESE	13	1020.0
4	Fr	20.1	30.0	0.2			NNE	26	16:53	24.4	69		SE	9	1020.3
5	Sa	16.9	31.1	0			E	30	11:51	24.2	74		SSE	9	1022.3
6	Su	18.3	29.2	0			ESE	44	09:50	23.8	64	7	SE	26	1023.9

Figure 6.6 – Example of Weather Observation (Bom.gov.au, 2018)

This phase called for a review at the end of week 8. At this point a discussion was had with the researcher's supervisor around progress to this point and assistance was offered where possible.

6.1.4 Phase 4 – Modeling of Actual Home Energy System

The model of the actual home energy system took place in the form of a comparison between a typical household researched in Phase 2, and the results obtained from Phase 3 data collection. They were found to be within the realms suitable for comparative analysis, and the project was deemed able to be continued.

The programming of a physical microcontroller designed specifically to maximize the thermal energy storage has been completed. As per the plan this was intended to happen by the end of Week 14. This didn't take place until a few weeks after this point, and as there were other areas that were not expected to be done at this point, making good progress it was not of concern. The decision-making process was collated at this point, and initial indications were that there would be a foreseeable cost benefit to have the system impose on the energy demand not considered to affect the resident.

The idea being that solar energy can be stored as thermal energy, which in turn will reduce the premises energy bill and increase potential earnings.

The end of Phase 4 was scheduled for Week 15. It was now that the second of three supervisor reviews scheduled was held.

6.1.5 Phase 5 – Data Analysis Phase

The potential efficiency gains and applications of the microcontroller have now been reviewed, and there is a likely benefit to be achieved by the project.

Table 6.2 shows a summary of a portion of data collected at 12:40pm on the 27th May.

Table 6.2: Summary of Data Window

Type	Load		Amps	kW	kWh	Cost ($)
Supply	Solar	Average	3.36	0.83	0.29	0.03
		Peak	13.56	3.42	1.04	0.10
		Minimum	1.29	0.32	0.10	0.01
Demand	Pool + Heating	Average	1.41	0.35	0.12	0.03
		Peak	8.48	2.11	0.60	0.15
		Minimum	0.15	0.04	0.01	0.00
	Hot Water System	Average	2.90	0.72	0.25	0.05
		Peak	4.05	1.02	0.87	0.18
		Minimum	0.11	0.03	0.11	0.02

This table shows that the average solar supply is higher than both the pool and heating demand and the hot water system demand. With a peak value being more than the two major demand types combined. This opens the opportunity to enable load shifting techniques, to ensure the load profile for demand remains within the realms of the solar supply input. Thereby, utilizing thermal storage within the household's existing systems of the solar supply being generated. This is achievable via a technique known as load shifting.

Load shifting involves shifting energy consumption to another time, typically when prices are lower, or in this case to a time where solar supply is sufficient. Hence, creating a thermal store of the solar supply, rather than regeneration into the grid, which in turn increases the cost effectiveness of the solar output (Eex.gov.au, 2018).

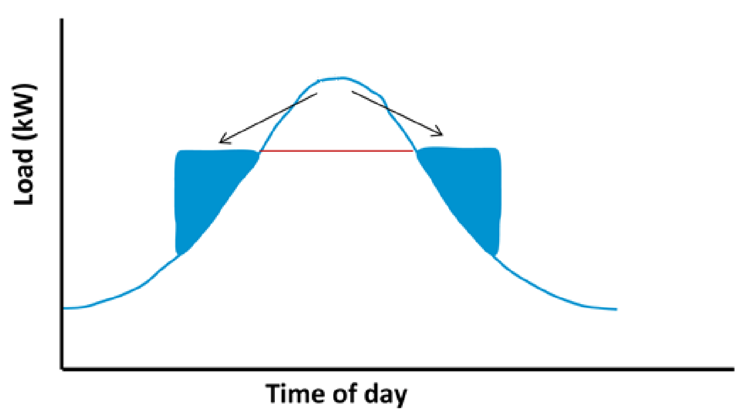

Figure 6.7 – Load Shifting Example (Eex.gov.au, 2018)

Load shifting can be achieved through rescheduling activities, switching off unnecessary equipment or, and effectively the major point of this project, switching the load over to onsite generation (Eex.gov.au, 2018).

Through research, it was found that the essence of what the prototype would be implementing once developed was indeed load shifting technology. The initial plan to store solar energy in its thermal form within the household eventually culminated in the form of the development of a system that would do exactly that. However, to make it cost effective and a product that would be viable in today’s marketplace, it would need to include other methods of energy management.

6.1.6 Phase 6 – Write Up and Preparation of Results

The preparation of the write up of results has seen a continual effort made to keep up to date and track progress throughout the year. The progress report was written in alignment with the standards set for the final dissertation so that the report can simply be added to and amendments made post feedback.

A draft dissertation has been submitted and feedback received on how to improve the write-up has been made. These recommendations were all taken on board and the final document will hopefully reflect the recommendations offered by the Supervisor.

6.1.7 Phase 7 – Extended Objectives

In terms of extended objectives, little has been done to achieve majority of them. However, the goal to extend the project onto other loads on the system has begun at the data collection phase. The hot water system, pool pump, pumped pool heating and cumulative demand data has been gathered. This would allow for this objective to begin to take shape. A power study using the nominal power rating of the devices on the system would be relatively simple to conduct, especially with cooperation of the occupants of the household providing some information about what consumption is being used at the time.

The decision to extend the control of the circuits allowable within the microcontroller’s system was made because, by not limiting the project scope to the pool water heating and including household systems such as hot water, the target market is increased dramatically. The research findings also indicate that on average the largest demand in the average dwelling in Australia is that of the hot water system.

6.2 Microcontroller

6.2.1 Design

The design of the microcontroller became a straightforward process once the analogue inputs required to be monitored were known. This microcontroller’s specific objective was to enable the maximization of the solar energy through thermal storage autonomously. The seamless flow from data collection to microcontroller design is due to the experimentation, and failures, in selecting what were necessary variables to monitor. This is also an indication that the project followed a research methodology in that the outcome was not known before the onset of the task, and that the findings developed as the project progressed.

The decision-making process was collated as a part of Phase 4, based on the early indications that there would be a foreseeable gain achieved through the implementation of such a device. The prevalent indicator was the visible disparity between the timings of demand on the network and the time at which solar supply was greatest. This observation was drawn from the current monitoring devices.

After some deliberation, it was decided to use an Arduino platform for the task at hand for several reasons. The Arduino, is a microcontroller, which means that it excels at controlling small devices, like sensors, motors and lights. It is also a desirable platform for prototyping on. Compared to some other products on the market, this platform leant itself to be aligned with the project undertakings. Section 4.2.7 has already covered this in greater detail.

6.2.2 Hardware

The hardware was all sourced online and consisted of everything required to complete the task. The only item that was not straightforward in its ease of use was the CD4051BE multiplexer. This was required to increase the number of analogue inputs available to the Arduino R3 inputs that it was originally limited to.

A schematic of the design was prepared by hand after searching through the Arduino forums for a recommended option (Forum.arduino.cc, 2018) and not having any success, for an all in one solution to the problem. Figure 6.8 shows the schematic of the intended build for the project and Figure 6.9 shows the completed build of the microcontroller ready to be programmed.

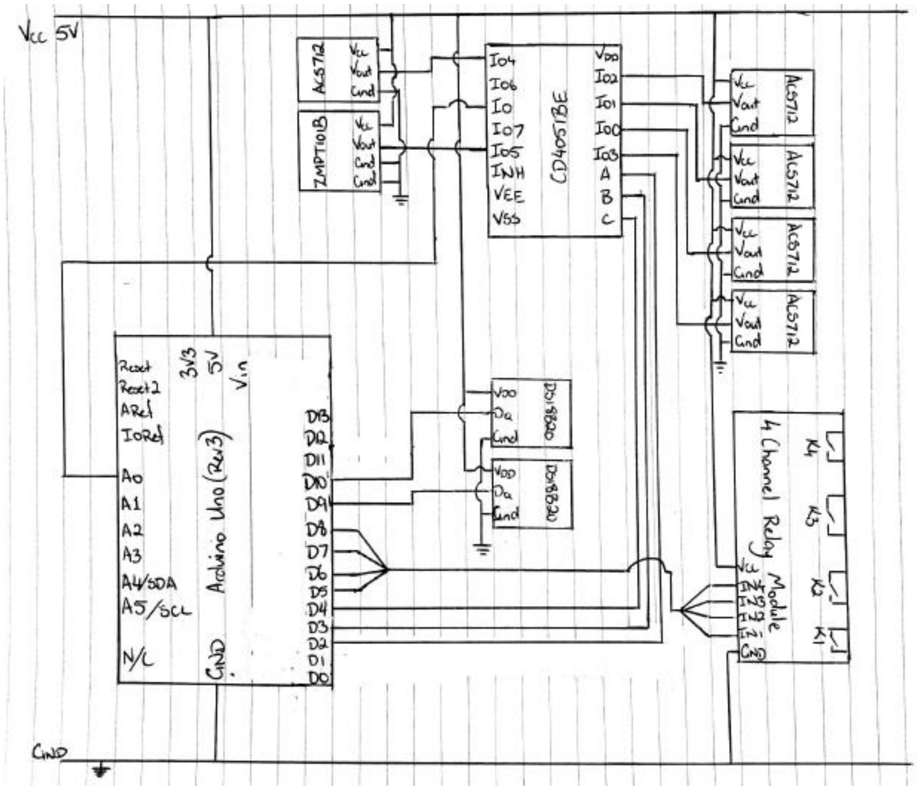

Figure 6.8 – Microcontroller Schematic

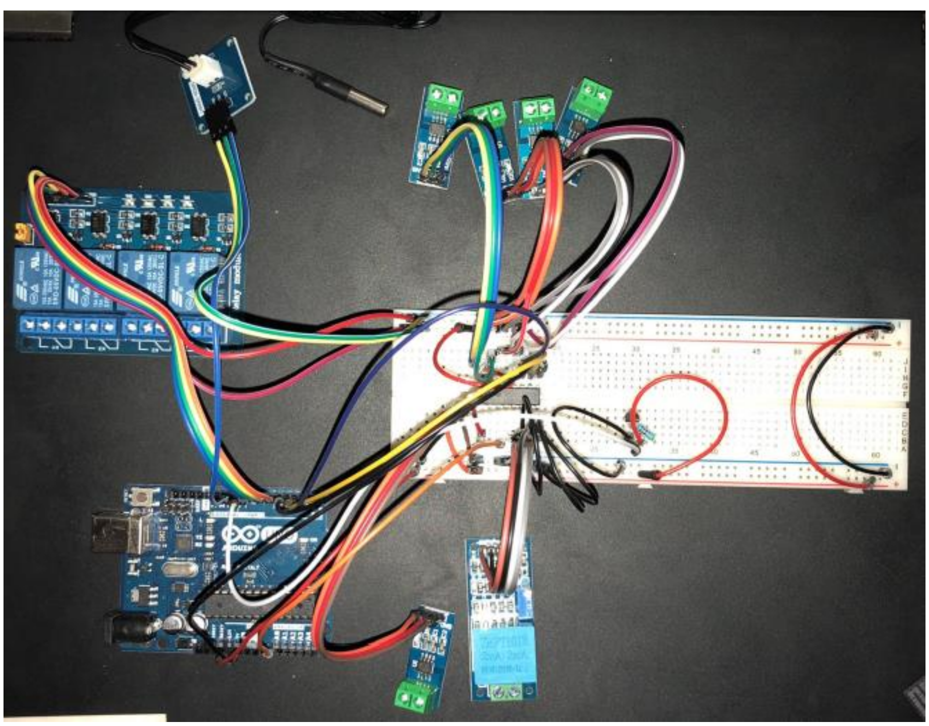

Figure 6.9 – Completed Microcontroller Build

Note that, the process to confirm calibration and adjust feedbacks took place at the data collection phase, so too did the process at the microcontroller build stage. The ACS712 current sensors were of note as having a large offset when initially powered on. The modules have a potentiometer built into them for this reason after a secondary literature review, many forums indicated that this observation was not uncommon.

6.2.3 Software

See Appendix C for the raw code used to create the logic around the microcontroller's influence over the home energy network. The logic was written as a proof of concept and a marketable product would require further review.

The software consists of a main program and multiple sub routines. This allows the microcontroller to make real-time decisions over the passing or blocking of energy use throughout the home by controlling its main circuits. Using the same analysis techniques of that of the analysis phase, to follow, the software processed whether the solar supply was being generated and made effort to limit the use of HVAC circuits until a time where solar generation was occurring at a level sufficient enough to support the load.

This implementation served as only a proof of concept rather than a fully working product and the final build would need to also consider things such as, the weather forecast. For example, if there were cloudy conditions expected for an extended period, the system would need to allow the hot water system to run on the mains circuit to ensure the household had hot water available. With the shut-off of the energy being determined and controlled by the thermostat, already installed in systems supplied in Australia.

This would not be the case for the pool heating however, as the pool heating pump is temperature differential controlled. That is, if there is not a gain in temperature to be made by pumping water from the pool up through the roof mounted heating then the pump simply would not run. This process can easily be controlled by the microcontroller without the need for such integration with weather forecasts and the like.

Figure 6.10 – Roof Mounted Heating

Chapter 7 ANALYSIS AND DISCUSSION

Appendix D gives an example of the raw data captured by the data acquisition tool. An example has been used as there were millions of lines of data sampled over the course of a few days of recordings.

Table 6.2 gave a summary of a window of data collected over a 3-hour period beginning at 12:40pm on the 27th May. Figure 7.1 shows the corresponding weather observations for the region at the time as reported by the Bureau of Meteorology.

Date	Day	Temps		Rain	3 pm					
		Min	Max		Temp	RH	Cld	Dir	Spd	MSLP
		°C	°C	mm	°C	%	8th		km/h	hPa
27	Su	15.6	24.9	0	23.9	51	8	ESE	20	1019.6

Figure 7.1 – Rockhampton, Queensland Weather Observations (Bom.gov.au, 2018)

The summary given in Table 6.2, came about through a heavy reduction in data sample points from that of the originally recorded data. The formula to filter out excessive data is as follows;

=INT(A6)=A6

returning a value of TRUE or FALSE and then filter spreadsheet for True to rationalize the data by a factor of 100. Another formula had to be written that would index and reference a value based on a maximum from another column, and an example of this is shown here;

=MAX(Data!E6:E10491)*(INDEX(Data!B6:B10491,MATCH(MAX(Data!E6:E10491),Data!E6:E10491,0)))/1000

These formulas would not need to be carried across to the microcontroller portion of the project, but were critical for filtering through such a large sample size.

Fortunately, the data acquisition software allowed a root mean square (RMS) value to be sampled as opposed to instantaneous sample points which would have resulted in seeing the alternating current sinusoidal form in the recorded data. This was done by calibrating the channel for RMS and selecting the RMS window size to be considered for the output. This would need to be carried across to the Arduino program if real time data analysis and decision making was going to be achieved.

The two demand loads analyzed, were that of the pool filtration and heating pumps, and that of the hot water system. Note that each of these are on separate tariffs, and this sample window has been used for reference as it contains data for both. Table 7.1 below summarizes the collation of the data window in terms of load currents and corresponding demands and costs associated.

Table 7.1: Net Values Achieved

	Net Values			
	Amps	kW	kWh	Cost ($)
Average	0.95	0.24	0.08	0.06
Peak	-1.03	-0.28	0.43	0.24
Minimum	-1.04	-0.25	0.02	0.02

Table 7.2 displays the outcomes because of recording the two separate phase currents. Note that both a Solar Supply Current and Phase 1 have been merged to create the Phase 1 Resultant. The reason being, is that the AC current clamp used gave no indication of whether the current being measured was being drawn from the grid or being fed back into the grid. As such a negative in this data is representative of the energy generated from the photovoltaic (PV) cell exceeding that of the demand on Phase 1. This ability to distinguish between energy demand and energy returned to the grid, is a function that the microcontroller would have to provide to function adequately.

Table 7.2: Outcomes by Phase

		Amps	kW	kWh	Cost ($)
Phase 1 Resultant	Average	-2.26	-0.56	-0.19	-0.02
	Peak	0.74	0.18	-0.05	0.00
	Minimum	-13.16	-3.32	-0.91	-0.09
Phase 2	Average	5.41	1.34	0.46	0.12
	Peak	6.37	1.61	1.32	0.33
	Minimum	5.08	1.25	1.32	0.33

In this data set it was observed that the resultant of Phase 1 saw that the demand was completely offset by that which was being produced by the solar array at the time. However, in the absence of PV array, the demand on Phase 1 alone would have resulted in 7 cents per hour cost. This detail is critical as it is evidence that the project had the ability to achieve its intended goals. It also the significant difference between the feed-in tariff financial returns to the end user as opposed to the cost when the power is in demand. At present that is the factor of a 270% variation between the two tariffs.

The figure below is a graphical representation of the results achieved in this timeframe. It highlights the significant amount of surplus energy of Phase 1 that could be put to more efficient use, that is either to heat the pool water, the hot water system or general heating ventilation and cooling of the dwelling. It also highlights the relatively constant baseload of the premises on phase 2 that constitutes majority of the light and power circuits used throughout the house by its occupants.

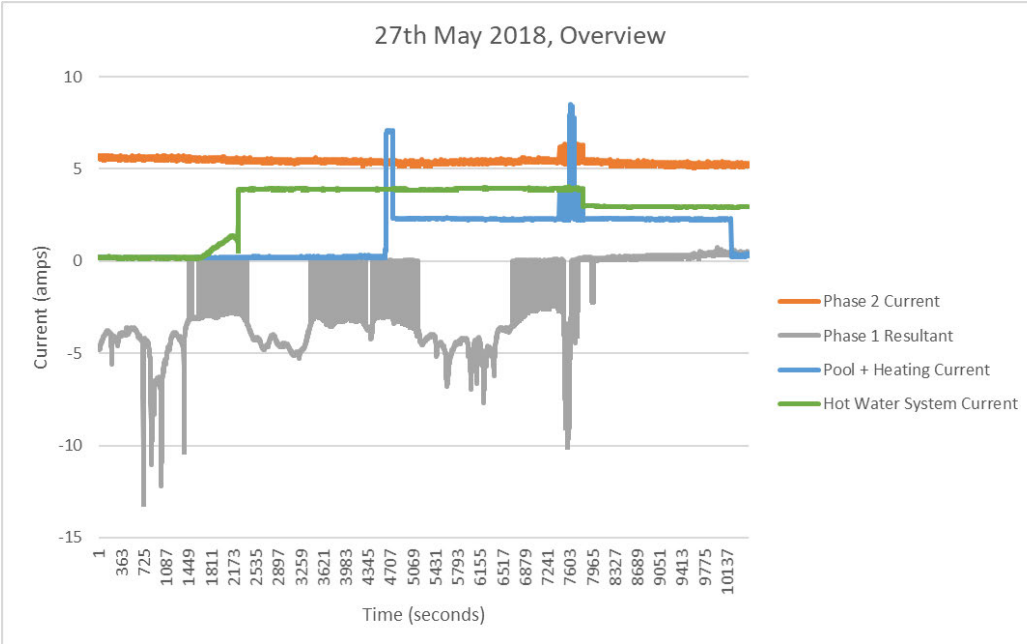

Figure 7.2 – 27th May 2018, Overview

The following graphic displays the supply verse demand loads of the property, with emphasis on the applications using thermal energy as a means of storage. The data has been filtered to show what the two definite target areas of the scope of the project has now been condensed to.

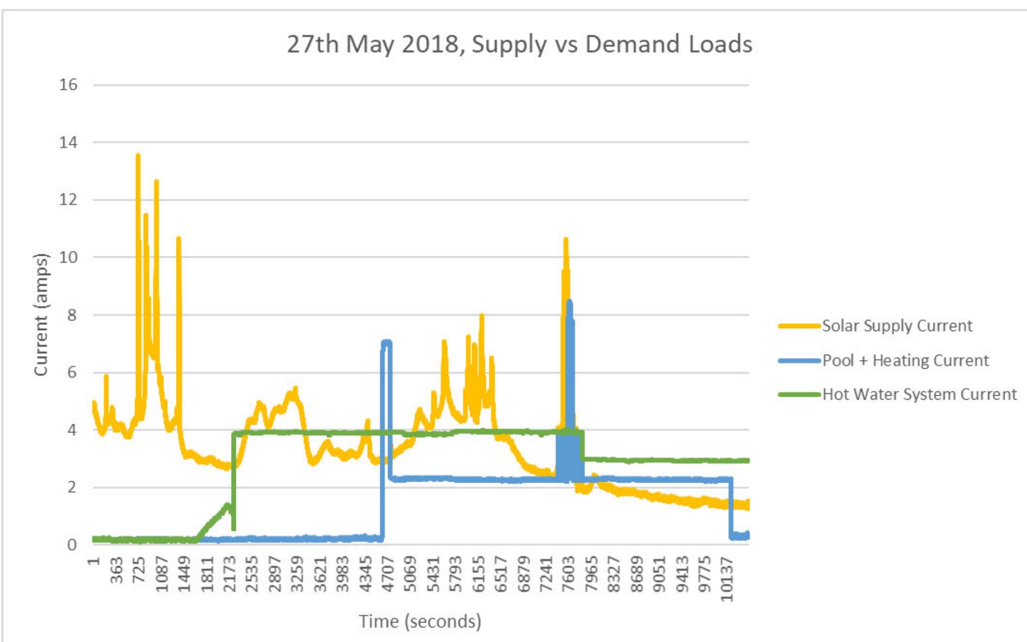

Figure 7.3 – 27th May 2018, Supply versus Demand Loads

This data in conjunction with the following figure allows the following analysis to be made about the data collected. With an average 'peak sun hours per day' of 5.82 and an average of 0.19kWh feed-in, at a time that could be considered as a conservative peak sun period, this results in 1.11kWh daily average surplus. Multiplied out by the solar feed-in tariff, over a year this results in $37.81 credit from the utility provider. However, using this surplus energy to heat the pool, hot water or air conditioning the home, sees a reduction over the same time in cost, multiplied out by the demand tariff 11, by $112.31. It should be well noted that this data is taken at a time when there was both pool filtration and heating current as well as hot water system current for a large portion of the data. One would suspect that this is not representative of the average household usage from these two load types, however it strongly supports the basis of the experiment and initial hypothesis made.

Australian Solar Radiation Figures			Best Average Performance			Seasonally Adjusted			Sun Tracking	
			Tilt	Peak Sun Hrs / Day		Tilt	Peak Sun Hrs / Day		Peak Sun Hrs / Day	
Location	Longitude	Latitude	Angle	Best Month	Worst Month	Angle	Best Month	Worst Month	Best Month	Worst Month
Darwin NT	12°25'S	130°52'E	20°	Aug=7.22	Jan=5.03	15°→50°	Aug=7.64	Jan=5.21	Aug=9.64	Feb=7.56
Cairns Qld	16°54'S	145°48'E	20°	Oct=6.14	May=4.39	15°→50°	Oct=6.14	May=4.69	Dec=8.36	May=5.47
Halls Creek WA	18°14'S	127°40'E	25°	Sep=7.30	Dec=5.99	15°→50°	Jul=7.81	Jan=6.43	Nov=9.94	Feb=8.94
Townsville Qld	19°18'S	146°48'E	25°	Sep=6.47	Jun=4.94	15°→50°	Sep=6.53	May=5.25	Dec=8.97	May=6.19
Tennant Creek NT	19°36'S	134°06'E	25°	Sep=7.03	Jan=5.64	15°→50°	Sep=7.03	Feb=6.25	Dec=9.47	Jun=7.58
Port Hedland WA	20°23'S	118°37'E	25°	Oct=7.61	Jun=5.72	15°→50°	Nov=7.73	Jun=6.47	Nov=11.28	May=8.00
Rockhampton Qld	23°23'S	150°29'E	30°	Oct=6.28	Jun=5.36	15°→50°	Nov=6.59	May=5.81	Nov=9.08	May=6.97
Longreach Qld	23°26'S	144°16'E	30°	Sep=7.25	Jun=6.17	15°→50°	Nov=7.55	May=6.58	Nov=10.81	May=7.94
Alice Springs NT	23°49'S	133°54'E	30°	Mar=7.39	Jun=6.22	15°→50°	Jan=7.43	May=6.64	Jan=10.64	Jun=8.03
Brisbane Qld	27°25'S	153°05'E	30°	Jan=6.22	May=4.50	15°→50°	Jan=6.61	May=4.81	Jan=8.50	May=5.50
Oodnadatta NT	27°34'S	135°25'E	30°	Mar=7.53	Jun=5.42	15°→60°	Dec=8.09	Jun=6.06	Dec=11.50	Jun=7.06
Geraldton WA	28°48'S	114°47'E	30°	Dec=7.64	Jun=4.81	15°→60°	Dec=8.27	Jun=5.36	Dec=11.75	Jun=6.19
Kalgoorlie WA	30°47'S	121°30'E	30°	Dec=7.19	Jul=3.61	15°→60°	Dec=7.74	Aug=3.94	Dec=11.06	Jul=5.14
Forrest WA	30°50'S	128°07'E	30°	Jan=7.47	Jun=4.81	15°→60°	Dec=7.99	Jun=5.50	Dec=11.42	Jun=6.36
Perth WA	31°56'S	115°58'E	30°	Jan=7.61	Jun=3.86	15°→60°	Dec=8.06	Jun=4.39	Dec=11.47	Jun=5.03
Williamtown NSW	32°48'S	151°50'E	35°	Jan=6.03	Jun=3.95	15°→60°	Dec=6.96	Jun=4.31	Dec=9.47	Jun=5.14
Sydney NSW	33°56'S	151°10'E	35°	Dec=6.32	Jul=3.80	15°→60°	Dec=6.93	Jul=4.11	Dec=9.11	Jul=4.56
Mildura Vic	34°15'S	142°05'E	35°	Dec=7.36	Jun=4.14	15°→60°	Dec=8.07	Jun=4.58	Dec=11.56	Jun=5.22
Albany WA	34°57'S	117°48'E	35°	Jan=6.67	Jun=3.57	15°→60°	Dec=7.14	Jun=3.94	Jan=9.56	Jun=4.47
Adelaide SA	34°58'S	138°32'E	35°	Jan=7.86	Jul=3.22	15°→60°	Jan=8.18	Jul=3.56	Jan=10.94	Jul=3.94
Wagga Wagga NSW	35°15'S	147°28'E	35°	Dec=7.14	Jun=3.61	15°→60°	Dec=7.91	Jun=4.75	Dec=11.50	Jun=4.75
Canberra ACT	35°19'S	149°12'E	35°	Jan=7.18	Jul=3.58	15°→60°	Jan=7.65	Jul=3.83	Jan=10.00	Jul=4.28
Mt Gambier SA	37°45'S	140°47'E	35°	Jan=6.71	Jun=2.88	15°→60°	Jan=7.08	Jun=3.14	Jan=9.67	[illegible]
Melbourne Vic	37°50'S	144°58'E	35°	Jan=6.50	Jul=3.13	15°→60°	Jan=6.86	Jun=3.39	Jan=9.42	[illegible]
Laverton Vic	37°53'S	144°45'E	35°	Jan=7.00	Jun=3.02	15°→60°	Jan=7.11	Jun=3.36	Jan=9.53	Jun=3.75
East Sale Vic	38°06'S	147°06'E	35°	Jan=6.24	Jun=2.81	15°→60°	Jan=6.53	Jun=3.17	Jan=8.72	[illegible]
Launceston Tas	41°36'S	147°12'E	40°	Feb=6.58	Jun=2.67	15°→65°	Jan=6.92	Jun=2.94	Jan=9.42	[illegible]
Hobart Tas	42°50'S	147°30'E	40°	Jan=6.17	Jun=2.67	20°→70°	Jan=6.53	Jun=2.92	Jan=8.75	[illegible]

Figure 7.4 – Australian Solar Radiation Figures (Rpc.com.au, 2018)

Additional times and days recorded show a similar trend to this critically analyzed example. The other typical scenario sees a significant energy demand for hot water system current, at times where solar supply is at a minimum. Figure 7.5 highlights this between the hours of 4:00PM and 7:00PM on this day. This only further justifies that making use of the solar energy at a time when it is being produced and storing it as thermal capacity will return a cost benefit to the end user.

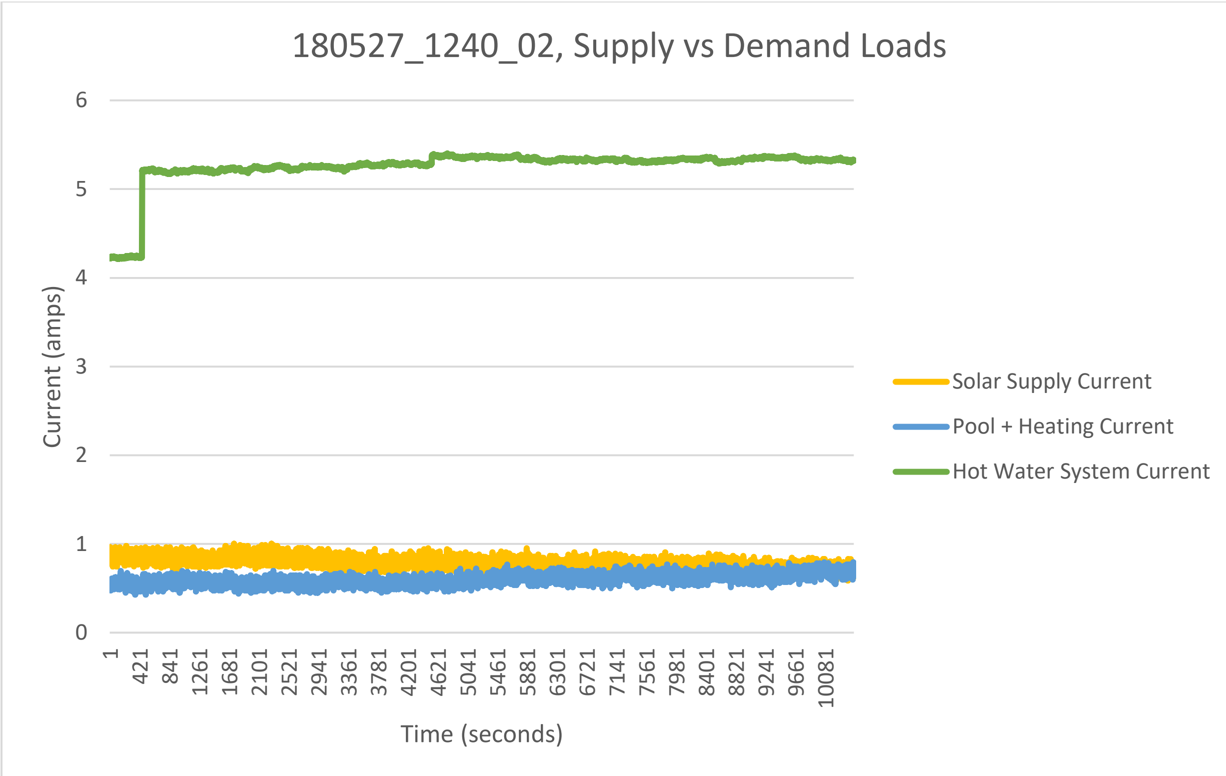

Figure 7.5 – Excess Demand at Minimum Solar Supply

With the aid of the data collected the decision system by which the microcontroller would work to was able to be deduced. For the initial prototype, these decisions were relatively straightforward, however adaptation and personalization of the systems to better suit individual household requirements would not be difficult with the hardware already incorporated into the system. Initially this personalization may take the place of software changes, but longer term would see to it that users would be able to define parameters by which the system would operate from a graphic user interface, whether that be an app with remote connectivity, or a mounted panel within the household itself. See that flow diagram below explaining the operation of the microcontroller.

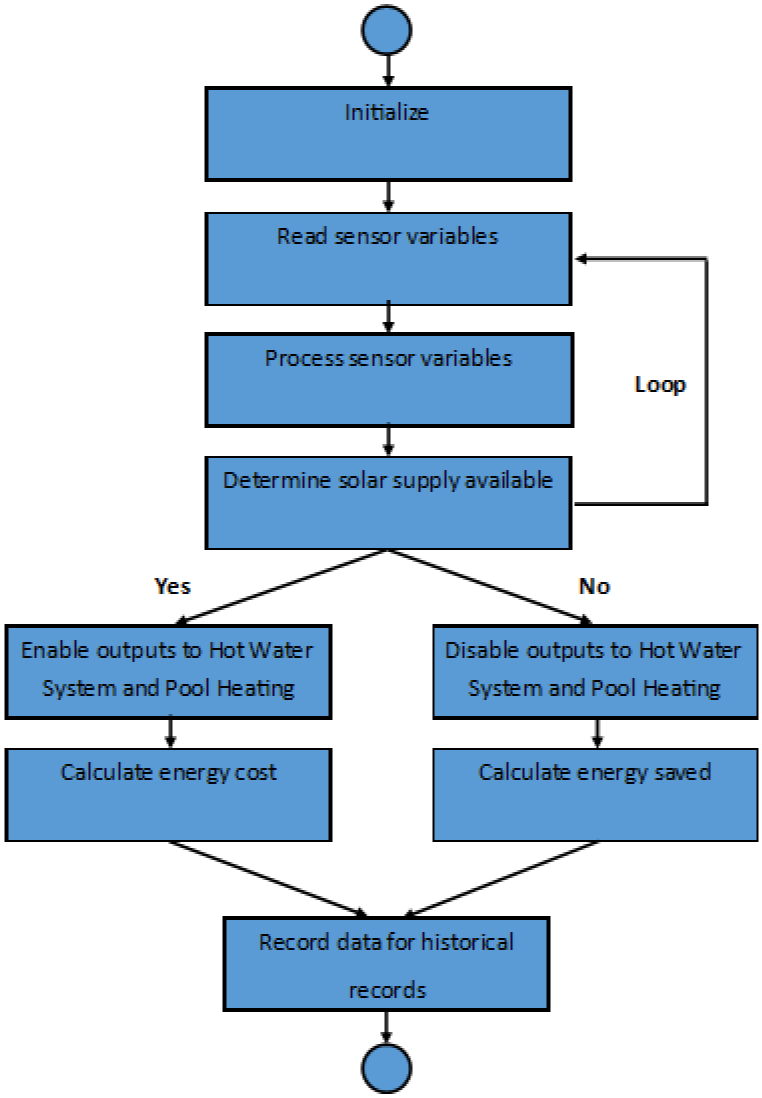

Figure 7.6 – Microcontroller Flow Diagram

A measure of results was set out at the early stages of the project and they are as follows:

i. Return on Investment of the implemented Home Energy Management System should be less than 12 months.
ii. The Home Energy Management System should see to it that the return time on the dwelling's solar system be decreased by better than 5%.

With the results obtained the prototype has the potential to see positive returns in approximately 6 months. This being based on a $100 build cost with negligible internal power consumption and running costs, and an expected saving, because of better management of the household energy, of $186 per annum indefinitely. Therefore, delivering on the measure by a full 6 months.

Secondly, the prototype having completely paid itself off in only 6 months, then shifts its target onto reducing the time to cost positive on the initial capital invested in the solar system itself. This would see approximately an additional $225 benefit to the occupant for the life of the system, helping to reduce a 10-year investment return period to one closer 7 years. This results in a 4.5% gain over and above the expected 10% that a standalone system typically offers. Whilst this does not quite meet the target from conception, it does go close to it, and considering the inexpensive nature of the build is rather impressive.

Chapter 8 CONCLUSIONS

8.1 Conclusions

The project set out to review existing home energy management systems and similar devices, evaluating them for their intended use and their suitability to provide solution to the hypothesized problem, with the main objective being to investigate the feasibility of an energy management system that utilizes thermal storage of solar energy, specifically relating to grid connected solar powered homes. A review at the time of commencement found that there were many products on the market that sought to provide the end user either information or control over their energy usage, however none met the requirements to be able to solve the problem at hand.

The essential data required to make rationalized decisions on the best way to manage the household's energy was collected in the very early stages of the project. It was found that no less than 8 inputs were required to make use of an effective energy management system. These analogue inputs were voltage, current and temperature.

The field data collected was analyzed and potential gains achievable by the system were then identified. With the result of this being the difference between a $37.81 credit or a $112.31 debit because of the equivalent energy purchase. A potential conservative cost benefit of $74.50 annually, to store the energy thermally as opposed to either feed-in to the grid or demand energy at another time. It should be stated that the total realized potential cost benefit is in the order of $186.80.

Taking this return on investment and incorporating it into average return times on the 3kW system discussed earlier, sees that a $500 per annum return is increased to $725, not inclusive of the $100 prototype costing, sees a 10% return on solar array capital increased to approximately 14.5% per annum, constituting a decrease in total reclamation of capital in 3 less years. In a system that typically has an expected life of 25 years, this sees an additional 12% of the systems life positively geared.

A microcontroller on the Arduino platform was purchased and developed making use of the very same inputs used in the data collection and analysis phase. The microprocessor was then given the ability to monitor the home energy system and the ability to implement a decision-making algorithm through digital output relays to influence the household consumption. The entire build cost was calculated to be $103.53 and as a result the return on investment, again conservatively speaking, would be 6.5 months, not factoring in installation costs, or sales margins. However, the point here is that the return on investment on the additional capital integrated into an existing grid connected solar array, takes negligible time to become cost positive, and start working to improve the return on investment time into the solar array itself.

A conclusion of the foreseeable efficiency gains has now been made, as well as a comparison to existing similar systems on the market and therefore completes the programme requirements set out at the commencement of this project, dated 11th March 2018.

In conclusion, the overall project objective has been to fulfill the requirements of the Engineering Research courses of the University of Southern Queensland. This dissertation is an embodiment of the progress and completion of the steps taken to achieve this ambition.

8.2 Further Work

As part of the programme extended objectives desired to be achieved are as follows:

- Provide a dashboard for the owner/consumer
- Extend the project to other energy consuming loads on the system
- Integrate with peer to peer energy markets to further increase potential cost benefits

Each of these provide objective provide opportunity for ongoing work with this research project. However, the integration with peer to peer energy markets would be a move away from the cost benefit of thermal storage of solar energy and more towards combating extensive return on investment periods often encountered with consumer level solar panel system installs.

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Appendix A Project Specification

Project Specification

For: Benjamin James Conway

Title: An Analysis of Thermal Storage of Solar Energy

Major: Electrical and Electronic Engineering

Supervisor: John Billingsley

Enrolment: ENG4111 – EXT S1, 2018

ENG4112 – EXT S2, 2018

Project Aim: To evaluate the efficiency of storing energy thermally, and develop a management system to maximize the cost benefit to the end user. Specifically relating to a grid connected solar powered home, with split system air conditioning, hot water system and pumped solar heating for the pool.

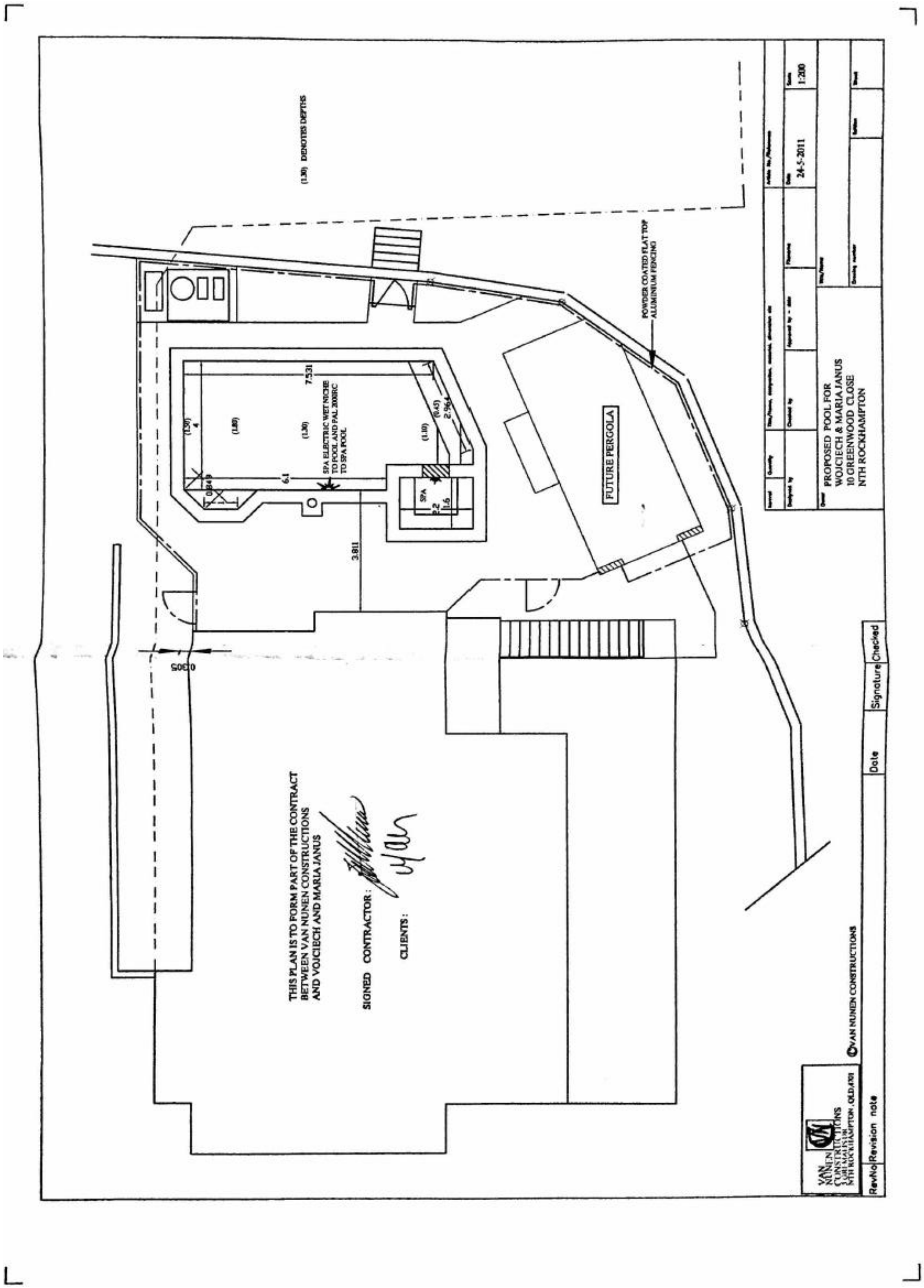
Programme: Version 1, 11th March 2018

9. Review existing home energy management systems and similar devices and evaluate them for their intended use.
10. Collect the essential data to make rationalized decisions on the best way to manage the household's energy.
11. Analyze field data to identify potential gains achievable by the system.
12. Develop a microcontroller program that has multiple digital and analogue inputs and outputs, for monitoring of the energy system and ability to implement the decision-making process.
13. Compare and conclude the foreseeable efficiency gains for a range of conventional systems.

If time and resources permits:

14. Provide a dashboard for the owner/consumer.
15. Extend the project to other energy consuming loads on the system.
16. Integrate with peer to peer energy markets to further increase potential.

Appendix B Pool Plan



Appendix C Arduino Program

```
/*

*/

void setup() {

}

void loop() {

}

// ZMPT101B AC Voltage Sensor

#include "EmonLib.h"             // Include Emon Library
EnergyMonitor emon1;             // Create an instance

int i = 0;
float tenvals = 0.0;
float minval = 1000;
float maxval = 0.0;

void setup()
{
  Serial.begin(115200);

  emon1.voltage(2, 109, 1.7);  // Voltage: input pin, calibration, phase_shift
//  emon1.current(1, 111.1);       // Current: input pin, calibration.
}

void loop()
{
  emon1.calcVI(20,2000);         // Calculate all. No.of half wavelengths (crossings), time-out
//  emon1.serialprint();          // Print out all variables (realpower, apparent power, Vrms, Irms, power factor)

//  float realPower       = emon1.realPower;        //extract Real Power into variable
//  float apparentPower   = emon1.apparentPower;    //extract Apparent Power into variable
//  float powerFActor     = emon1.powerFactor;      //extract Power Factor into Variable
//  float supplyVoltage   = emon1.Vrms;             //extract Vrms into Variable
//  float Irms            = emon1.Irms;             //extract Irms into Variable

 float Vrms = (emon1.Vrms - 3);
 if (Vrms < 0) { Vrms = 0.0; }

 tenvals += Vrms;
```

```
 if (minval > Vrms) { minval = Vrms; }
 if (maxval < Vrms) { maxval = Vrms; }

 i++;

 if (i == 10)
 {
  Serial.print("Avg: ");
  Serial.print(tenvals/10);
  Serial.print(" (");
  Serial.print(Vrms);
  Serial.print(") Min: ");
  Serial.print(minval);
  Serial.print(" Max: ");
  Serial.println(maxval);

  i = 0;
  tenvals = 0.0;
  minval = 1000.0;
  maxval = 0.0;
 }
  delay(100);
}

//DS18B20 Temperature Sensor
#include <OneWire.h>

// OneWire DS18S20, DS18B20, DS1822 Temperature Example
//
// http://www.pjrc.com/teensy/td_libs_OneWire.html
//
// The DallasTemperature library can do all this work for you!
// http://milesburton.com/Dallas_Temperature_Control_Library

OneWire  ds(9);  // on pin 9 (a 4.7K resistor is necessary)

void setup(void) {
  Serial.begin(9600);
}

void loop(void) {
  byte i;
  byte present = 0;
  byte type_s;
  byte data[12];
  byte addr[8];
  float celsius, fahrenheit;
```

```
if ( !ds.search(addr)) {
  Serial.println("No more addresses.");
  Serial.println();
  ds.reset_search();
  delay(250);
  return;
}

Serial.print("ROM =");
for( i = 0; i < 8; i++) {
  Serial.write(' ');
  Serial.print(addr[i], HEX);
}

if (OneWire::crc8(addr, 7) != addr[7]) {
    Serial.println("CRC is not valid!");
    return;
}
Serial.println();

// the first ROM byte indicates which chip
switch (addr[0]) {
  case 0x10:
    Serial.println("  Chip = DS18S20");  // or old DS1820
    type_s = 1;
    break;
  case 0x28:
    Serial.println("  Chip = DS18B20");
    type_s = 0;
    break;
  case 0x22:
    Serial.println("  Chip = DS1822");
    type_s = 0;
    break;
  default:
    Serial.println("Device is not a DS18x20 family device.");
    return;
}

ds.reset();
ds.select(addr);
ds.write(0x44);        // start conversion, with parasite power on at the end

delay(1000);     // maybe 750ms is enough, maybe not
// we might do a ds.depower() here, but the reset will take care of it.
```

```
  present = ds.reset();
  ds.select(addr);
  ds.write(0xBE);         // Read Scratchpad

  Serial.print("  Data = ");
  Serial.print(present, HEX);
  Serial.print(" ");
  for ( i = 0; i < 9; i++) {           // we need 9 bytes
    data[i] = ds.read();
    Serial.print(data[i], HEX);
    Serial.print(" ");
  }
  Serial.print(" CRC=");
  Serial.print(OneWire::crc8(data, 8), HEX);
  Serial.println();

  // Convert the data to actual temperature
  // because the result is a 16 bit signed integer, it should
  // be stored to an "int16_t" type, which is always 16 bits
  // even when compiled on a 32 bit processor.
  int16_t raw = (data[1] << 8) | data[0];
  if (type_s) {
    raw = raw << 3; // 9 bit resolution default
    if (data[7] == 0x10) {
      // "count remain" gives full 12 bit resolution
      raw = (raw & 0xFFF0) + 12 - data[6];
    }
  } else {
    byte cfg = (data[4] & 0x60);
    // at lower res, the low bits are undefined, so let's zero them
    if (cfg == 0x00) raw = raw & ~7;  // 9 bit resolution, 93.75 ms
    else if (cfg == 0x20) raw = raw & ~3; // 10 bit res, 187.5 ms
    else if (cfg == 0x40) raw = raw & ~1; // 11 bit res, 375 ms
    //// default is 12 bit resolution, 750 ms conversion time
  }
  celsius = (float)raw / 16.0;
  fahrenheit = celsius * 1.8 + 32.0;
  Serial.print("  Temperature = ");
  Serial.print(celsius);
  Serial.print(" Celsius, ");
  Serial.print(fahrenheit);
  Serial.println(" Fahrenheit");
}

//CD4051BE Multiplexer Code
  //MUX Code
  /*
```

```
 *
 */

int r0 = 0;      //value of select pin at the 4051 (s0)
int r1 = 0;      //value of select pin at the 4051 (s1)
int r2 = 0;      //value of select pin at the 4051 (s2)

int s0 = 2;
int s1 = 3;
int s2 = 4;
int count = 0;   //which y pin we are selecting

void setup(){
  pinMode(s0, OUTPUT);
  pinMode(s1, OUTPUT);
  pinMode(s2, OUTPUT);
}

void loop () {

  for (count=0; count<=7; count++) {

    // select the bit
```

```
    r0 = bitRead(count,0);    // use this with arduino 0013 (and newer versions)

    r1 = bitRead(count,1);    // use this with arduino 0013 (and newer versions)

    r2 = bitRead(count,2);    // use this with arduino 0013 (and newer versions)



    //r0 = count & 0x01;      // old version of setting the bits

    //r1 = (count>>1) & 0x01;      // old version of setting the bits

    //r2 = (count>>2) & 0x01;      // old version of setting the bits



    digitalWrite(s0, r0);

    digitalWrite(s1, r1);

    digitalWrite(s2, r2);



    //Either read or write the multiplexed pin here


  }
}

//ACS712 20A AC Current Sensors
/*
Measuring Current Using ACS712
*/
const int analogIn = A0;
int mVperAmp = 100; // 100 for 20A Module
int RawValue= 0;
int ACSoffset = 2500;
double Voltage = 0;
double Amps = 0;

void setup(){
 Serial.begin(9600);
}

void loop(){
```

```
RawValue = analogRead(analogIn);
Voltage = (RawValue / 1024.0) * 5000; // Gets you mV
Amps = ((Voltage - ACSoffset) / mVperAmp);


Serial.print("Raw Value = " ); // shows pre-scaled value
Serial.print(RawValue);
Serial.print("\t mV = "); // shows the voltage measured
Serial.print(Voltage,3); // the '3' after voltage allows you to display 3 digits after decimal point
Serial.print("\t Amps = "); // shows the voltage measured
Serial.println(Amps,3); // the '3' after voltage allows you to display 3 digits after decimal point
delay(2500);

}
```

Appendix D Raw Data Example

Samples per sec. = 800/1								
Time	Mains Supply Voltage	Phase 1 Current	Phase 2 Current	Solar Supply Current	Pool + Heating Current	Hot Water System Current	Ambient Temperature	Pool Temperature
sec	Volt	Amps	Amps	Amps	Amps	Amps	Degr	Degr
0	2.49E+02	4.77E+00	5.66E+00	4.93E+00	1.83E-01	2.06E-01	3.57E+01	1.83E+01
0.01	2.49E+02	4.77E+00	5.66E+00	4.92E+00	1.83E-01	2.06E-01	3.57E+01	1.83E+01
0.02	2.49E+02	4.76E+00	5.68E+00	4.93E+00	1.83E-01	2.04E-01	3.57E+01	1.83E+01
0.03	2.49E+02	4.76E+00	5.68E+00	4.92E+00	1.83E-01	2.05E-01	3.57E+01	1.83E+01
0.04	2.49E+02	4.76E+00	5.68E+00	4.93E+00	1.83E-01	2.05E-01	3.57E+01	1.83E+01
0.05	2.49E+02	4.76E+00	5.68E+00	4.92E+00	1.83E-01	2.05E-01	3.57E+01	1.83E+01
0.06	2.49E+02	4.75E+00	5.68E+00	4.92E+00	1.83E-01	2.08E-01	3.57E+01	1.83E+01
0.07	2.49E+02	4.74E+00	5.68E+00	4.91E+00	1.83E-01	2.11E-01	3.57E+01	1.83E+01
0.08	2.49E+02	4.72E+00	5.68E+00	4.92E+00	1.83E-01	2.12E-01	3.57E+01	1.83E+01
0.09	2.49E+02	4.72E+00	5.68E+00	4.91E+00	1.83E-01	2.11E-01	3.57E+01	1.83E+01
0.1	2.49E+02	4.71E+00	5.68E+00	4.91E+00	1.83E-01	2.10E-01	3.57E+01	1.83E+01
0.11	2.49E+02	4.72E+00	5.68E+00	4.91E+00	1.71E-01	2.11E-01	3.57E+01	1.83E+01
0.12	2.49E+02	4.72E+00	5.68E+00	4.92E+00	1.71E-01	2.10E-01	3.57E+01	1.83E+01
0.13	2.49E+02	4.72E+00	5.68E+00	4.92E+00	1.83E-01	2.11E-01	3.57E+01	1.83E+01
0.14	2.49E+02	4.72E+00	5.69E+00	4.93E+00	1.83E-01	2.09E-01	3.57E+01	1.83E+01
0.15	2.49E+02	4.72E+00	5.68E+00	4.92E+00	1.71E-01	2.08E-01	3.57E+01	1.83E+01
0.16	2.49E+02	4.72E+00	5.68E+00	4.92E+00	1.83E-01	2.08E-01	3.57E+01	1.83E+01
0.17	2.49E+02	4.72E+00	5.66E+00	4.91E+00	1.83E-01	2.06E-01	3.57E+01	1.83E+01
0.18	2.49E+02	4.74E+00	5.66E+00	4.93E+00	1.83E-01	2.06E-01	3.57E+01	1.83E+01
0.19	2.49E+02	4.76E+00	5.65E+00	4.93E+00	1.71E-01	2.08E-01	3.57E+01	1.83E+01
0.2	2.49E+02	4.75E+00	5.65E+00	4.94E+00	1.71E-01	2.08E-01	3.57E+01	1.83E+01

Recording 180527_1240_01_csv

Appendix E Project Timeline

	Semester 1 - ENG4111																				Semester 2 - ENG4112														
						Recess												Recess													Recess				
	Week Number																																		
Task/Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Phase 1 - Project Preparation Phase																																			
Approval to commence proposed project	X																																		
Acquisition of resources	X																																		
Phase 2 - Modelling of Home Energy System																																			
Literature Review		X	X	X	X																														
Phase 3 - Data Collection Phase																																			
Data Collection						X	X	X																											
External environmental factors; e.g. Weather						X	X	X																											
Review 1								X																											
Phase 4 - Modelling of Actual Home Energy System																																			
Collation of data obtained								X	X																										
Determine algorithms for decision making process										X	X																								
Program microcontroller to suit needs												X	X	X																					
Review 2														X																					
Phase 5 - Data Analysis Phase																																			
Determine potential efficiency gains achievable															X	X	X																		
Potential for application of microcontroller																		X	X	X															
Analysis of physical data from trial phase																					X	X													
Potentially Phase 7																					X	X	X	X	X	X	X	X	X	X	X	X	X		
Phase 6 - Write up and Preparation of Results																																			
Draft dissertation preparation				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
Review 3																													X						
Present at Professional Practice 2 - ENG4903																															X	X			
Final dissertation compiled for submission																																	X	X	X
Phase 7 - Extended Objectives																																			
Create a dashboard for the owner/consumer																					X	X	X	X											
Extend the project to other loads on the system																									X	X	X	X							
Integrate with peer to peer energy markets																													X	X	X	X	X		

Appendix F Supervisor Correspondence

F.1 Supervisor Assignment

From: Chris Snook
Sent: Friday, March 9, 2018 4:52 PM
To: John Billingsley <John.Billingsley@usq.edu.au>
Subject: ENG4111_in_2018 : Proposal_Benjamin_Conway.pdf

Dear John

Mr Benjamin Conway (ONL Elec) has requested one your topics :

95 Alternative Energy

(see attached)

If you are willing and able to supervise this student please reply to this email

with APPROVED, otherwise feel free to make alternate suggestions.

If needed, his email to sort out precise details is = [redacted]umail.usq.edu.au

At this stage, however, the pressure is just to get him allocated.

If he has not made acceptable progress in formulating a topic by the time the Project Specification is submitted then we might consider bad things for him.

Regards

Chris

9/03/2018

From: "John Billingsley" <John.Billingsley@usq.edu.au>

To: "Chris Snook" <Chris.Snook@usq.edu.au>

Sent: 9/03/2018 11:00:30 PM

Subject: RE: ENG4111_in_2018 : Proposal_Benjamin_Conway.pdf APPROVED

I have been discussing somewhat similar projects with him and Matthew Harawira. But I am sure there are ways to make them different.

Cheers

John

From: Chris Snook
Sent: Saturday, March 10, 2018 10:53 PM
To: John Billingsley <John.Billingsley@usq.edu.au>
Subject: Re[2]: ENG4111_in_2018 : Proposal_Benjamin_Conway.pdf APPROVED

Ok - I'll assign him to you but insist on a new title asap

Thx

C

John Billingsley <John.Billingsley@usq.edu.au> Mar 11

to me, Matthew

Matthew and Benjamin,

Now that you both have chosen a project in this area, we have to separate the titles and separate the topics.

In the fog of discussions, the following aspects have been mentioned:

Cheap wind generator

Solar energy storage as heat, rather than electric charge,

Monitoring of multiple energy sources and sinks

And probably others that I have forgotten!

Using ‘reply all’, please indicate your aptitudes and choices – and maybe new themes like Ardduino that you want to explore.

Let’s carve up the topics to get two projects that do not overlap too much.

Cheers

John

John Billingsley <John.Billingsley@usq.edu.au> Mar 11

to Matthew, me

That sounds appropriate. Reading an analogue signal on the Arduino is easy, storing the values in non-volatile memory so that they can survive switch-off needs a bit more thought. Otherwise just using the Arduino as a go-between ADC to do the greatest part on a PC requires the least thought.

Benjamin is electrical and I gather that he wants to do something much more elaborate concerning strategies for feed-in and demand tariffs etc.

I think there can be good separation if the proposals are well written. An appropriate title might be "An analysis of thermal storage of solar energy".

Whenever you upload something that needs me to do something, please send me an email so that I do not have to keep monitoring the course web-site.

Cheers

John

F.2 Topic Discussion

ERP2018 - Alternative Energy

Benjamin Conway <[redacted]umail.usq.edu.au> 9/24/17

to John.Billingsl., bcc: bconway

Hi John,

I am an Electrical/Electronic Engineering student looking to complete my Research Project in 2018.

I have found your project entitled: Alternative Energy and was hoping that this topic was still available, or whether it was even applicable given that I am not a mechatronics student?

Regards,

Benjamin Conway

[redacted]

John Billingsley <John.Billingsley@usq.edu.au> 9/25/17

to me

Give me more details about what you actually want to do!

There are heaps of possibilities, but as the researcher you will have to lead the way.

Cheers

John

From: Benjamin Conway [mailto:[redacted]umail.usq.edu.au]
Sent: Sunday, 24 September 2017 1:48 PM
To: John Billingsley <John.Billingsley@usq.edu.au>
Subject: ERP2018 - Alternative Energy

Benjamin Conway [redacted]umail.usq.edu.au> Mar 8

to John

Hi John,

Sorry for the delay in getting back to you.

I would like to take what you have proposed and adapt it slightly to the house I am living in.

The home has pumped solar pool heating as well as gas heating for the spa, solar electricity system (5kW), as well as heating and cooling for the water system and house itself. I would like to develop a home energy management system that applies to certain constraints (eg pool and hot water system temperature regulation), and makes an automated decision on what to do with the power given that Ergon currently pays approximately 10c/kWh as a feed-in tariff, but charge 36c/kWh for demand.

Suggest that I use either an analogue input capable plc or microcontroller (eg raspberry pi, arduino or fuzzy logic) to make these decisions and refine the process to create the most efficient, in heating ventilation and cooling, as well as cost effective home.

Regards,

Benjamin Conway

John Billingsley <John.Billingsley@usq.edu.au> Mar 8

to me

Lots of interesting possibilities!

An Arduino has ten-bit analogue inputs and is easy to interface to a PC, so makes a good go-between. A Raspberry should give wifi connectivity without needing add-ons. The PC is probably the best environment I which to develop the strategy. If you have an old discarded one it will probably do the job.

You might find that it is more efficient if you put Ubuntu onto it.

If you want to make the system really smart, you might be able to interface the weather forecast!

The idea that I plugged is really only appropriate for new-build houses, but you could perhaps consider a floating expanded-polystyrene insulating pool cover, the solar method of heating your pool and circulation of warm pool-water into radiators in the house!

Cheers

John

From: Benjamin Conway [mailto:[redacted]umail.usq.edu.au]
Sent: Thursday, March 8, 2018 9:17 AM
To: John Billingsley <John.Billingsley@usq.edu.au>
Subject: Re: ERP2018 - Alternative Energy

Benjamin Conway <[redacted]umail.usq.edu.au> Mar 8

to John

I do have an old laptop that I could dedicate to this, I would need to familiarize myself with Ubuntu as I have never used it before.

There are a lot of possibilities, and in my brainstorming I had considered the weather forecast as well as the likelihood of people being home as to whether it was worthwhile on that day or at that time to utilize the system.

Just to be clarify, the whole idea is to utilize the water as a thermal battery where possible and efficient to do so? That energy can then be used elsewhere as a heat exchange. As I live in Rockhampton, for the majority of the year, this would be most practical in cooling the ambient air temperature of the home.

I have listed this project as my first preference and submitted to Chris Snook.

Cheers,

Benjamin

John Billingsley <John.Billingsley@usq.edu.au> Mar 8

to me

I'll have to look very carefully at the new specification to make sure that there is enough meat in it!

Not sure about using the pool for cooling, unless it is efficiently shaded. With just a pool blanket it will have quite a heat gain in summer. Monitoring its temperature can be part of the project. If water is plentiful you can run a fountain and get evaporative cooling!

Maybe the original wind generator would be safer for Rockhampton.

How much experience have you got of microprocessors like the Arduino?

Cheers

John

From: Benjamin Conway [mailto:[redacted]umail.usq.edu.au]
Sent: Thursday, 8 March 2018 11:57 AM

[redacted]umail.usq.edu.au Mar 9

to John

Hi John,

The pool would only be apart of the project for me, I would like to look at the heating of the hot water system using home solar power instead of using the grid at night.

Would be an all encompassing home energy management system by the time it was finished. The pool and solar water heating would just be a part of it.

The wind generator is something that I would be interested in also.

I have limited experience with Arduino and that's why I would like to use it. I use PLC's daily though.

Regards,

Benjamin Conway

John Billingsley <John.Billingsley@usq.edu.au> Mar 9

to Chris, me

We'll have to ask for Chris Snook's opinion!

Cheers

John

From: [redacted]umail.usq.edu.au <[redacted]umail.usq.edu.au>
Sent: Friday, March 9, 2018 9:11 AM

Benjamin Conway [redacted]umail.usq.edu.au> Mar 19

to John, Chris

Hi John,

Would you be happy for me to take up your suggestion of the new title as, "An Analysis of Thermal Storage of Solar Energy"?

As you have mentioned, I would be looking at the aspects of the efficiencies of using power as it was created from the home solar array, rather than having to pull it in from the grid. This extends to all systems that comprise the HVAC on the residence.

Regards,

Ben

Benjamin Conway [redacted]umail.usq.edu.au> Mar 19

to John, Chris

Hi John,

I have submitted a draft project specification, with supporting documents for your perusal.

If you would prefer I send them via email to yourself that will be easy enough going forward.

Thanks in advance, for any feedback given.

Ben

John Billingsley <John.Billingsley@usq.edu.au> Mar 19

to me

The title seems OK – unless you want to make it a ‘comparison’.

Cheers

John

From: Benjamin Conway <[redacted]umail.usq.edu.au>
Sent: Monday, March 19, 2018 7:12 PM
To: John Billingsley <John.Billingsley@usq.edu.au>
Cc: Chris Snook <Chris.Snook@usq.edu.au>

John Billingsley <John.Billingsley@usq.edu.au> Mar 19

to me

I think Chris will be happier if I use the Study Desk.

Cheers

John

From: Benjamin Conway <[redacted]umail.usq.edu.au>
Sent: Monday, March 19, 2018 8:56 PM
To: John Billingsley <John.Billingsley@usq.edu.au>
Cc: Chris Snook <Chris.Snook@usq.edu.au>

Benjamin Conway <[redacted]umail.usq.edu.au> Mar 21

to John

Hi John,

Have you had an opportunity to peruse these at all?

John Billingsley <John.Billingsley@usq.edu.au> Mar 21

to me

Not yet. Today's task!

Cheers

John

From: Benjamin Conway <[redacted]umail.usq.edu.au>
Sent: Wednesday, March 21, 2018 7:29 AM

[redacted]umail.usq.edu.au Mar 21

to John

Thank you John.

Much appreciated,

Benjamin Conway

On 21 Mar 2018, at 7:30 am, John Billingsley <John.Billingsley@usq.edu.au> wrote:

Not yet. Today's task!

Cheers

John

From: Benjamin Conway <[redacted]umail.usq.edu.au>
Sent: Wednesday, March 21, 2018 7:29 AM
To: John Billingsley <John.Billingsley@usq.edu.au>
Subject: Re: ERP2018 - Alternative Energy

Hi John,

Have you had an opportunity to peruse these at all?

<image001.png>

Benjamin Conway [redacted]umail.usq.edu.au> Mar 26

to John, Chris

Hi John,

I was just wondering whether you have had an opportunity to look at the Project Specification yet?

My interpretation was to simply upload the documents and await further instruction before submitting. Is this still the case?

Kind regards,

Benjamin

John Billingsley <John.Billingsley@usq.edu.au> Mar 26

to me

I looked at what you had uploaded some time ago!

I set the status to 'endorsed'.

Cheers

John

From: Benjamin Conway <[redacted]umail.usq.edu.au>
Sent: Monday, March 26, 2018 7:00 PM

John Billingsley <John.Billingsley@usq.edu.au> Apr 30

to me

It is a long time since I last heard from you. How are you progressing?

Cheers

John

From: John Billingsley
Sent: Monday, March 26, 2018 8:38 PM

To: 'Benjamin Conway' <[redacted]umail.usq.edu.au>
Subject: RE: ERP2018 - Alternative Energy

Benjamin Conway [redacted]umail.usq.edu.au> Apr 30

to John

Hi John,

Thank you for touching base.

I feel I am moving along well.

In terms of the plan, I am sitting at the 10-11 week projected mark.

I do have a question regarding a change that I plan to make? I have just purchased a solar blanket for our pool. Which should see the evaporation levels decrease, but more importantly the water heating efficiency increase, decreasing the amount of pumping up to the roof.

Would you have any concerns about this going forward in terms of skewing the data. I suggest that if I have to re-record I can simply leave the solar blanket off the pool for as long as required.

Cheers,

Ben

John Billingsley <John.Billingsley@usq.edu.au> Apr 30

to me

I would rely on a solar blanket being present – otherwise evaporation will dominate the heat loss in a way that is not proportional to excess temperature so is harder to compute.

Cheers

John

From: Benjamin Conway [redacted]umail.usq.edu.au>
Sent: Monday, April 30, 2018 6:40 PM
To: John Billingsley <John.Billingsley@usq.edu.au>

Benjamin Conway <[redacted]umail.usq.edu.au> May 29

to John

Thank you, John.

I re-recorded my data over the weekend just gone, with the addition of the heat blanket after seeing some positive results, not only in temperature storage, but also in reduction in loss of water to evaporation.

I don't know whether I'm supposed to update you on how I am travelling with workload, but in the lead up to exams with full-time work it should be said that I have a bit on. I am managing though.

Kind regards,

Ben

John Billingsley <John.Billingsley@usq.edu.au> May 29

to me

Now is the time that you can get good data! The idea is to warm a house with solar radiation – and it is only in winter that you would want to do it! So measuring the thermal yield at this time of year is what really matters.

I sympathise with 'end-of-semester-itis' – I am going to be pretty busy marking. But the amount of effort is up to you – I am a resource, not a whip-cracker. But please meet deadlines for reports to keep Chris happy!

Cheers

John

From: Benjamin Conway <[redacted]umail.usq.edu.au>
Sent: Tuesday, May 29, 2018 4:24 PM

F.3 Extended Abstract and Coversheet

Extended Abstract and Coversheet

Benjamin Conway <[redacted]umail.usq.edu.au> Sep 3

to John

Hi John,

I managed to be flagged as a late enrolment for ENG4903.

I have drafted my abstract for your review, it is well and truly late for submission at this point, but will submit once I receive your approval.

I am about to draft my 50 word biography, is this something that you would want to see before I submit it?

I hope to have my partial draft dissertation into you by the beginning of next week which corresponds with Review date #3.

See attached for my Extended Abstract and Coversheet.

Regards,

Benjamin Conway

John Billingsley Sep 3

to me

I think that it could be expressed much more clearly. The bar chart seems to take up more space than it warrants. But what you upload is up to you!

I thought that the essence was to compare the direct capture and storage of solar energy as heat, versus PV capture and use of stored electrical energy for heating.

Cheers

John

From: Benjamin Conway <[redacted]umail.usq.edu.au>
Sent: Monday, September 3, 2018 8:20 PM
To: John Billingsley <John.Billingsley@usq.edu.au>
Subject: Extended Abstract and Coversheet

Benjamin Conway <[redacted]umail.usq.edu.au> Sep 4

to John

Fair point, I have reworked it a bit in the hope that it reads more clearly. I agree the essence is to compare the two and that was not clearly stated in the abstract.

I reduced the bar chart in size, but don't have an alternative graphic to it that clearly shows the justification for the project that this one does.

If you are happy to sign off on the coversheet, I will submit them as soon as possible.

Cheers,

Ben

John Billingsley Sep 4

to me

Here is the coversheet with a signature

Cheers

John

From: Benjamin Conway <[redacted]umail.usq.edu.au>
Sent: Tuesday, September 4, 2018 9:12 AM

To: John Billingsley <John.Billingsley@usq.edu.au>
Subject: Re: Extended Abstract and Coversheet

F.4 Clarification

Dissertation - Raw Data

Benjamin Conway <[redacted]umail.usq.edu.au> Sep 12 (6 days ago)

to John

Hi John,

Hope all is well.

I am compiling the appendices at the moment and Raw Data is covered in Section 11 Dissertation Preparation.

11.10.3 Raw data

Ideally all raw data should be presented to enable future workers to confirm results and derive maximum benefit from the effort. However, with the use of computer-based data acquisition programmable field data loggers, the data volume is often vast so that reproduction in the dissertation is clearly impractical. It is left to you and your supervisor/s together to determine the appropriate level of raw data, part-processed data or processed data to present in the printed text. A fuller version of the data may be included as a supplementary file on the submission CD (refer section 12). On rare occasions, an examiner may wish to view raw data not directly presented in the dissertation. You are advised to maintain your raw data in an accessible and presentable form.

I have millions of samples of raw data, should I submit a snippet of it? Enough to take up an A4 sheet?

Regards,

Benjamin Conway

John Billingsley Sep 12 (6 days ago)

to me

Remember that there are two objectives.

One is to show me some good data to support or shoot down the hypothesis – and I am very happy to look at a file for that.

The other is to persuade the 'moderators', who will be trying to compare your performance against that of their own students, that you have done a good job. One A4 sheet should be enough!

So as far as the print-ware is concerned, put in enough to convince but not too much that would look like padding! A single graph can eat up a swag of data and just needs something like 'the data can be found at'.

Cheers

John

From: Benjamin Conway <[redacted]umail.usq.edu.au>
Sent: Wednesday, September 12, 2018 1:22 PM
To: John Billingsley <John.Billingsley@usq.edu.au>
Subject: Dissertation - Raw Data

Appendix G Initial Project Offer

Title:	Alternative energy
Course:	ENG4111/2 Research Project
Author:	John Billingsley
Keywords:	Mechatronics, energy.

Abstract:

The cost penalties of PV and wind generation are becoming all too obvious. Alternative alternatives are needed!

A major part of domestic electricity consumption is the result of heating and cooling needs. I have halved my water heating bill with two square metres of Colorbond, ten dollars-worth of irrigation hose and a solar fountain pump. A simple project can be based on insturmenting this system to quantify its performance.

A more significant proposal could perhaps influence the building industry. Again with irrigation hose on a Colorbond roof, I can heat a swimming pool to nearly 40 C. So instead of contemplating a photovoltaic system that charges a battery, this hot water can be circulated through pipes installed in any hew slab, in the same way that is done in every new build in the UK - see the 'Grand Designs' TV programme.

The slab has ample thermal capacity to store daytime warmth throughout the night with no need for any expensive battery, but could be augmented by off-peak electricity during any protracted cloudy period.

In summer, of course, the circulation can take place at night, when radiative cooling brings the roof well below the ambient air temperature, to cool the slab.

The project would involve instrumentation and measurement of the performance of a simple test setup - unless you are contemplating building a new house - with data-mining and analysis of the physical principles.