Energy Management and Automated Analytics for Reduction of Energy Consumption

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***Abstract*— *This paper presents the basic principles of energy management and explores its viability within the community and those who are using electricity daily. It aims to confirm that an energy consumer can alter both their choices and behavior toward the energy consumption and reduce their electricity costs if they are equipped with the correct information. To implement this system, an energy management process was developed for the purposes of this research. The process was ultimately utilized to find a more cost and time efficient method to assist consumers to better understanding firstly reduce their electricity consumption whilst secondly proving that energy management is a viable concept for consumers to adopt. If consumers were able to reduce their consumption from this research, further investigation could be conducted to find better ways to help consumers reduce their electricity bills and lead more cost and energy efficient lives.*

***Index Terms*— *Cost reductions, energy awareness, energy efficiency, energy management, energy consumption.*

I. INTRODUCTION

Electricity bills are an inherent cost to any given household or business. It is a common customer complaint issue, not understanding their energy use and cost implications. Many customers would like more evidence and detail where energy is being consumed and how the bill can possibly be minimized. The energy management concept offers a solution to resolve this problem, providing a consumer with more regular information on prime consumption loads that increase energy use, so they can utilize this feedback to find ways to reduce their energy consumption costs. As well as reducing consumer's energy costs, the energy management concept can assist in the reduction of carbon emissions making for a more environmentally minded society.

The energy management concept presented can be applied across all energy markets be it residential, commercial or industrial. All three of these markets present different energy management challenges; however all still have potential to become more energy efficient. The average energy wastage in the residential market alone is 20% due to consumers not adopting energy efficient behaviors [1]. Various schemes have been adopted by government organizations within Australia to encourage large commercial building operators to construct their buildings for optimal energy efficiency operations [2]-[3]. There has also been research conducted within the industrial energy market to find potential for savings of $1.2 billion within industrial plant operations throughout Australia [4].

One of the greatest challenges with energy management from an end consumer perspective is obtaining a valuable return on investment money spent versus money saved. Not every site or premises has the potential to reduce consumptions even if the consumer invests a particular amount of funding in an energy reduction management system. This research project was aimed at finding a more cost and time efficient energy management process ultimately tailored toward low end energy cost consumers. There is less risk involved for a high energy consuming site or premises operator to justify investing time and funding into an energy management system to identify strategies to reduce energy usage. However, this is often not so clear cut for lower end consumers, where there is still potential for long term savings and improving energy consumption behaviors.

In this research, there are two main objectives to achieve. These are as follows:

i) To prove the viability of the energy management process as a concept to assist consumers in reducing their energy consumption. This will be achieved by offering a standard set of consumers more information regarding their existing separate load's energy consumption, and how to benefit by using different load demand strategies.
ii) Develop a more time and cost efficient process with which to deliver quality information regarding energy consumption to consumers. Reducing the cost of an energy management data collection and reporting process is an essential part of creating a more energy efficient society. If financial incentives are evident, more consumers will be willing to part-take and reduce their consumption. Correct implementation of energy management has future potential to reduce costs for domestic budgets and business operations.

This paper is organized as follows: the Introduction is in section I, Energy management principles and methodology is in section II, Experimental setup and measurement at field site is in section III, Results and discussion is in section IV. Finally, the conclusion is in section V.

II. ENERGY MANAGEMENT PRINCIPLES AND METHODOLOGY

A) Energy Management Background

Energy management has been a principle that has been adopted since the early 1970s. This time period saw a dramatic increase in energy supply costs and from it came a requirement for consumers to reduce on energy consumption [5]. As an example, during the latter part of the 1970's, the University of Michigan received funding from the Department of Education to perform energy audits of their site campus. As a result the university adapted to an energy saving mentality in order to find ways to reduce their consumption [6].

Since then, energy management technology has developed in order to assist consumers in becoming more energy conscious and reduce their consumption. The University of California Santa Barbara campus integrated an energy management system into their pre-existing energy information system in order to adopt energy management behaviors to reduce consumption [7]. The principle of utilizing technology to reduce consumption has also been adopted by other industries. Sysco Corporation, a large food corporation in the United States of America and Canada, utilized their own energy information gathering system to try and understand more about their energy consumption. As a result, they implemented their own energy managements system across 143 of their distribution sites, with one particular site reducing their energy consumption by 36% [8].

Society is now at a stage where information gathering and distribution can be automated to be more time and cost efficient. Digital technology in intelligent sensing platforms, combined with the internet of things (IoT) implementation and cloud data storage are examples of how information can be gathered. This provides the technological possibility to present energy use data to people in order to enable them to change electricity use with more quickly available energy consumption breakdown feedback. This could greatly improve the adoption of energy management strategies to reduce energy costs.

B) The Energy Management Process

The energy management process developed is based on a three step procedure. Step one is the monitoring phase which involves gathering sufficient data to quantify the energy consumption timeline and loads for a given site or premises. Step two begins once the data is captured. It is analyzed in order to compile and correlate into a format that can be understood by a regular consumer. Step three is when correlated data is then presented to a consumer, where they respond to implement appropriate control phase actions to reduce energy use. This three step process is then regularly repeated to assist a consumer in reducing on their energy consumption and have them operating their premises in the most energy efficient means possible [9]. A consumer does not have to spend every day monitoring their energy consumption; however gaining more knowledge over a longer period (e.g. a week, a month, a quarter or a seasonal basis) of time can certainly assist in helping people to develop domestic lower energy footprints and more cost efficient businesses.

C) Research Project Incentive

Justification for the project was to provide lower end energy users with a more cost effective method for implementing a reactive and effective energy management process. Time spent analyzing and correlating data was conducted for research purposes with the only cost to make this possible being the acquisition of monitoring hardware. The Efergy Engage Hub kit is a low-end cost consumer product that has one minute data logging capabilities which was utilized for the monitoring phase of this project. This data was then exported into an Excel spreadsheet for auto importation into MATLAB in order to correlate, format and present the data in a manner a regular consumer could easily understand. A consumer could then utilize this data to strategize better individual load management and implement control measures that were going to assist in reducing energy consumption.

Two consumer sites were utilized to test the methodology of the research project. Test site number one was a seven day a week business that had a café and sold grocery items. The business operating hours were from 7:00am ~ 5:00pm. The business owner was willing to participate in the energy management process as they considered electricity to be a significant overhead.

Test site number two was a three bedroom home occupied by a family of four. Similar to the business owner, the family of four also considered electricity as a significant cost toward the running of their household and wished to explore a possible means of reducing their consumption. The family spent approximately three times more than the average Queensland electricity consumer. Reduction of energy consumption would improve financial stability for the family.

One of the most significant common factors was both the business owner and the residential family had already contacted their energy provider seeking more information to better understand why their electricity consumption was so high. Contact with the electricity provider was primarily to obtain knowledge about possible reduction methods to better manage their energy consumption. After the contact, both consumers indicated that they felt there was a lack of information for regular energy consumers available to make better energy consumption decisions and justifications. An example of this for the cafe business would be understanding correlation in load demand and peak food order demand periods, versus lulls in use where it may be feasible to turn this device off for parts of the day.

Electricity is a commodity that society has become heavily reliant upon and to live or operate without it is not considered feasible for the majority of households and businesses. For many households and businesses alike, continuing electricity tariff rises in recent years, are now justification and necessity to better manage to reduce energy usage and costs. Providing an easily understandable report on energy loads and their demand allows energy management to be more optimally implemented to assist consumers to become more energy conscious. This in turn leads to more energy efficient behaviors which if implemented on a significant section of society has the added potential benefit of reducing the carbon impacts on our society. These principles all became particularly important when working with the owners of the test sites. The project attempted to find the correct information format that was going to appeal to them to motivate changed behaviors and strategies to reduce their electricity bill.

III. Experimental Setup and Measurement at Field Site

Lower end user domestic electricity customers and most small businesses are charged for energy usage based on metering installed in their mains or sub-mains board. Traditionally single-phase and three-phase supplies utilise a single phase moving disc meter per phase. These AC energy meters contain a spindle supported disc, which has a worm gear to drive a mechanical register similar in construction to an odometer in a car. The register's display is easily read for the utility company to record a subsequent total energy usage over a set period interval to calculate the customer's energy bill per phase. These AC meters record the amount of energy required per one revolution of the disc, or K_t which is given in units of watt-hours per revolution. The K_t for given meters is calibrated, and typically is around 7.2 in actual value. For such a disc power meter, the power per revolution P Watts is then given by:

$$P = \frac{3600K_t}{t} \tag{1}$$

where, t = time in seconds for the disc to complete one revolution. As an example if K_t = 7.2, and one revolution was completed in 12.96 seconds, the power for that given period is 2000 watts. If this continued in like fashion over a complete hour, the meter read-out register would show 2 kW increase in consumption. These traditional disc AC meters are now being replaced by electronic wattmeters, which use digital time integration algorithms to calculate the customer's power usage, as well as active, reactive and monitor different loads for multi-tariff operation. These calculations are also be mimicked in in other energy metering device software or MATLB script. For this project, voltage and time integration period are considered constant values and are accounted for by the back end computer system built by the Engage Hub Kit manufacturer. The current, however, varies from site-to-site and it is this value that needs to be measured in order to perform the data analysis process for the purposes of this research project. This value is found from the current transformers pictured on the right hand side of figure 1. The sensors are placed around the mains cables of the given site or premises, one sensor for each supply phase to the property.

These sensors are then plugged into the transmitter, the device on the left side of figure 1, so that the data can be wirelessly transferred to the Engage hub, which is the central point of the data capturing system. The hub device is shown in the center of figure 1. The data is then transferred at a frequency of 433-MHz. For transmission, the hub is situated within a 50 meters radius from the transmitter. Both test sites had their mains supply within sufficient range of the local area network.

Figure 1. Efergy Engage Hub Kit.

The Engage hub is then plugged into the local area network via an Ethernet cable which in this case was a standard internet router. It utilizes this connection point to transmit all of the data to a server where the data can either be used by a third party software developed for energy monitoring platforms, or alternatively it can be downloaded by the individual user. For the purposes of this project, the data was downloaded into Microsoft Excel so that it could be imported into MATLAB for analysis purposes.

The Efergy Engage system logged data in one minute intervals. This data was analysed in MATLAB to provide output which can be promptly returned back to the consumer.

Visiting the consumers at their sites introduced them to physically compare the data of individual appliance's energy consumption and assisted the consumers in seeing how particular appliances and cyclic or non-cyclic use contribute toward their bill. These comparisons allowed them to alter their behavior for consumption that can be minimised or avoided, while understanding some of critical base-load consumptions that cannot be altered. This understanding provides them with a means to become optimally energy efficient for their chosen domestic lifestyle, or business operation.

The implementation of this piece of hardware refers back to one of the main objectives of this research project which was to find a more cost efficient and robust energy management process. The Engage Hub Kit allowed greater data capturing capabilities which was critical during the data analysis phase of this project. Developing computer programs through MATLAB was another aspect of the project that also referred back to the core objective of cost efficiency. By leveraging from computer technology and the automated data analysis process capabilities of MATLAB, time and manual tasks could be reduced in order to rapidly find the correct information that would appeal to a consumer to likewise make improvements quickly when easily warranted. It was proposed for this research that improving this reporting turnaround time and its cost efficiency that will ultimately lead more consumers to undertake energy management processes to achieve more optimal energy efficient outcomes.

IV. Results and Discussion

A) Data Monitoring Results

The results were split into two parts to indicate whether or not the energy management process implemented actually assisted consumers in reducing energy consumption. This was due to on-going findings from data discovered throughout the duration of the research project. Initially, as the data became available it was utilized across both test sites to see if any reductions were apparent as a result of the feedback the energy consumers were receiving. Figures 1 and 2 and table-I show the average daily consumption throughout the course of the investigation period. This was initially taken as a general trend of reduction in energy consumption.

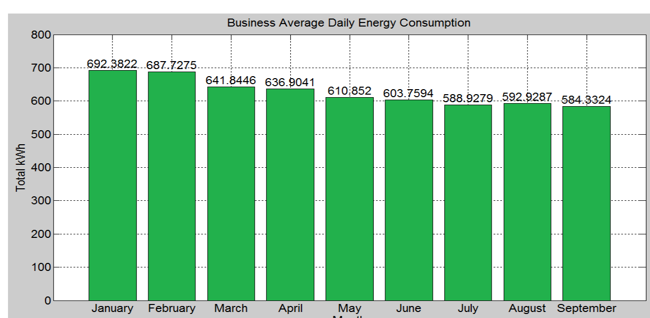

Figure 2. Average Daily Energy Consumption for Business's.

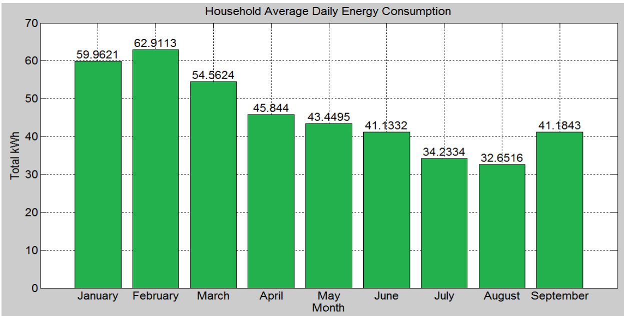

Figure 3. Average Daily Energy Consumption for Household's.

Table-I. Overall Energy consumption reductions for a period.

Month	Average per day (kWh)	Reduction (vs January) (%)	Average per day (kWh)	Reduction (vs January) (%)
January	692.38	0	59.90	0
February	687.73	0.67	62.91	-5.03
March	641.84	7.30	54.56	8.91
April	636.90	8.01	45.84	23.47
May	610.85	11.78	43.45	27.46
June	603.76	12.80	41.13	31.34
July	588.93	14.94	34.23	42.85
August	592.93	14.36	32.65	45.49
September	584.33	15.61	41.18	31.25

B) Utility Data Results

After initial control measures were implemented as a result of the information the consumers were receiving, a review process was undertaken to confirm the cause of any reductions. Further analysis concluded that the percentage reductions could not have been due only to behavioral changes, as no significant control measures were implemented to reduce consumption by this degree. This was especially in the household where the winter months of June, July and August saw total reductions of 31.34%, 42.85% and 45.49%, respectively. This prompted additional research to find which appliances could possibly have been causing such a dramatic reduction over this period of the research project.

As refrigeration units need to reject heat in order to produce a cooler environment [10], climate control and refrigeration were investigated. The seasonal ambient temperature range can have a significant bearing on refrigeration cycle duration and frequency of operation. Higher ambient temperatures naturally decrease the efficiency of the refrigeration unit [11]. Figure 3 represents the average load profile for the month of January vs. the month of June. The resulting trend clearly indicates a difference in the base load consumption during the hours the business is closed. On average, the base load drops nominally 2 kW.

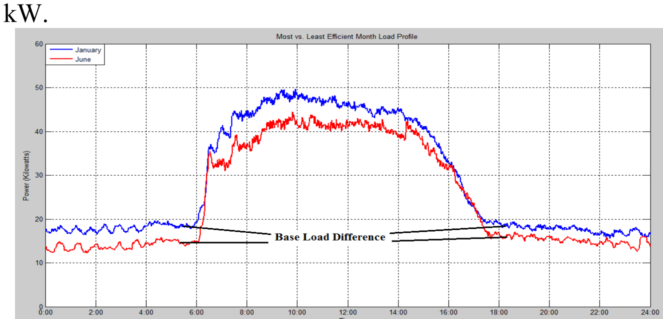

Figure 4. Business's Load Profile January versus June.

Given the test locations were in a tropical region, the favorable seasonal winter impact of operational ambients on the number of refrigeration units in the business, and significantly reduced domestic air conditioning load also contributed to the recorded reduction in energy consumption.

For this reason, a second source of additional energy use data was utilized to assist in finding whether or not these two different electricity consumer types were becoming more energy conscious as a result of the information they were receiving. Both consumers had previous electricity bills available from their utility providers. These have within the information of the average daily consumption for the given billing period, as well as a comparison to the average daily consumption of the same time billing period for the previous year. This annual trend measurement tool provided greater accuracy in proving the viability of the energy management process. It is a more accurate indicator of energy behavior changes of a consumer in response to the test data reports during a time when they were actively undertaking an energy management process. Table-II represents the average daily energy reductions of 2014 vs. 2015 from the data given by the energy provider. The business and household saw an average daily reduction of 7.78% and 3.07% respectively which is much more indicative of how an energy management process can influence an electricity bill. The results also aligned with the responsiveness of the consumer as the business owner discussed that they felt more energy conscious and motivated to adopt behavioral changes to reduce consumption. The household consumers also felt they had become more energy conscious however it was clear that this was not to the same degree as the business owner.

Table-II. Comparison of average daily energy consumption reduction in 2014 and 2015 for business and households.

Study Site	Average 2014	Average 2015	Reduction (%)
Business	606.41	559.2	7.78%
Household	45.57	44.17	3.07%

C) Proof of Viability

As well as aiming at confirming the viability of the energy management concept, part of the project's outcomes also was to find a cost efficient solution to aid the consumer drive their energy management process. Both energy consumers indicated prior to the research project that they had not been receiving enough information regarding their energy consumption of their respective premises. As a result of the project energy use reports provided, they now felt more knowledgeable about their consumption. In terms of research costs, this project implemented an energy management process that was only cost efficient. The cost to implement not just the hardware to gather such data, but a digital processing unit as used for this project to develop energy use reports, adds an element of overhead for a consumer to implement an energy management process. Nonetheless, this research project assisted in proving the viability of energy management and the ability for consumers to react and adapt to more detailed energy consumption information to become more energy conscious. It confirmed that consumers are seeking to find ways to reduce their consumption and that these reductions can be realized through behavioral changes.

Figures 5 and 6 graphically represent the average daily consumptions for 2014 when an energy management system was not implemented versus 2015 when the energy management system project was undertaken. These figures represent the difference in energy consumption when more information was provided to consumers and assists in proving the viability of the energy management process.

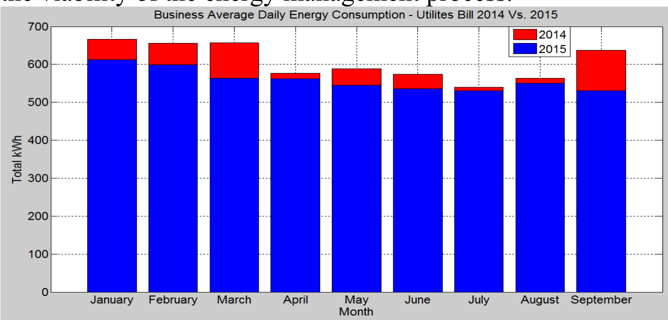

Figure 5. Business's Average Daily Consumption per Month.

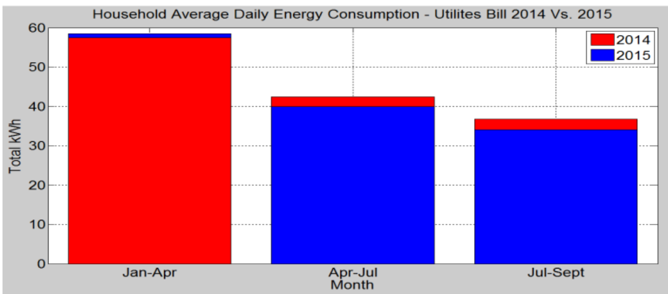

Figure 6. Household's Average Daily Consumption per Month.

V. Conclusion

In conclusion, it is clear from the findings that electricity is a commodity that is provided to society in order to make their lives better. It is becoming more costly for households and businesses alike to utilize electricity and people are seeking more ways to optimise its use and so reduce costs. Cost effective energy management principle based on effective and auto-reporting of load usage can be adopted by our society to reduce on their energy costs producing a more energy efficient society. In 2013, sadly 24,000 homes were disconnected from the network grid in Queensland because they could not meet payment due to rising electricity costs [12].

One of the significant hurdles for energy management processes within the energy market is that most reduction methods come with inherent upfront, and very commonly, on-going costs. This research project contributed to demand management strategies by offering rapidly accessible information to electricity consumers to make them more energy conscious and self-manage their energy consumption more optimally to reduce costs. The key principle to this is to provide rapid data collection and analysis in an acceptable format to consumers. One of the most substantial challenges of the engineering world, especially in the field of information distribution, is to design and implement technologies that can be simply and practically adopted by a standard consumer. The ability to rapidly access the needed behavior changing information is of value to a regular consumer; and without this better energy management strategies will not be adopted by these consumers. Further research is required into the current generation of SMART electronic energy meters, and their networking accessibility for consumption monitoring by the consumer, and not just the energy supplier for billing purposes. Examples of blue-tooth technology are already available with many PV array co-generation inverters that allow customers to see their daily and hourly solar energy production trends. This technology however has not as yet been transferred to utility based electronic energy meters to allow consumers to also monitor their energy use. Alternatives to this technology base, is a smartphone and tablet 'APP' that can interface with data from energy monitoring systems such as the Efergy Engage data logger, and produce energy consumption trending and 'alarms' for high energy use, or continuing energy use when not needed. Continuing work in this area may provide a much more cost effective technical solution to the outcomes of project, where knowledge of consumption trends can alter the consumers' behaviour and reduce energy costs.

Acknowledgements

This research was supported by the School of Mechanical and Electrical Engineering, Faculty of Health, Engineering and Sciences, University of Southern Queensland, Toowoomba, Queensland 4350, Australia. This work was also assisted for measurements by the families, the text sites are located in Mossman, Queensland, Australia.

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