

The Impact of a ZigBee Enabled Energy Management System on Electricity Consumption

Research-in-Progress

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ABSTRACT

The world currently faces an energy problem which is rooted in the inefficient use of energy resources. As a result, economies around the world are grappling to devise ways and means of solving this problem. This study postulates that the solution should consider reducing and managing consumption and use in order to be successful. As a result, this study explores the impact the implementation of an Energy Management System has on energy consumption and how it contributes towards sustainable environmental practices. The study is built upon the Design Science theory and is conducted within the boundaries of Energy Informatics. It will employ an experimental design, using Multiple Linear Regression to derive a model that predicts energy consumption. The study seeks also to derive optimized setting of the system through the use of Response Surface Methodology (RSM). The viability of the study will then be assessed by conducting a Cost-Benefit Analysis.

Keywords

Energy Informatics, Energy Information Systems, Energy Management, ZigBee, Green IS, Sustainability

INTRODUCTION

Society has an energy consumption problem which adversely affects global warming and also causes other global environmental problems (Watson, Boudreau and Chen, 2010). The consumption of energy is inescapable as it represents a fundamental input for modern economies and social life and is a critical enabler for economic development. Its use however, according to the Third World Academy of Science (TWAS) (2008), has been marked historically by four general trends: (a) Rising consumption, (b) The transition from traditional to commercial sources of energy such as fossil fuels, coal, etc., (c) Slow but steady improvements in the power of energy technologies and (d) A tendency towards fuel diversification and decarbonization.

These trends have steered humanity down a path where it now finds itself confronting an energy challenge of two critical dimensions. Firstly, current energy usage patterns have become unsustainable (Watson, Boudreau, Chen, Huber and Dick; 2008) and secondly, the large-scale use of fossil fuels threatens both the earth's climate and the health of the human-race (TWAS, 2008; Watson et. al., 2008). The fact is, a large majority of the energy needs of humanity are being supplied by fossil fuels (coal, oil, natural gas, shale, etc) which account for between 80 and 85% of the total global energy supply in 2004 (Herzog and Golomb, 2004). Fossil fuels are non-renewable resources (Food and Agriculture Organization of the United Nations, 2008), and not only is there an unlimited supply but their use also causes serious and harmful environmental effects (TWAS, 2008).

On the above premise, this study will investigate the use of wireless energy management systems in reducing electricity consumption which, next to transportation, is a major consumer of non-renewable energy sources. It will also investigate how these systems may be used to support sustainable business practices. This paper is a Research in Progress and will flow as follows: First the background to the study will be explored and its purpose outlined. The significance of the study will then be highlighted followed by the questions which will guide the research. Literature relevant to the study will then be explored followed by the methodology to be employed. The paper will then conclude with a brief summary.

BACKGROUND TO THE STUDY

The global situation

The global population grows by approximately 80 million every year (UN-water, 2009) thus pushing up the demand for energy and therefore diminishing an already limited supply of the commodity (as the population grows, so does the need for energy). According to the U.S. Energy Information Administration (2010), the global demand for energy is set to increase by 1.4 % annually up to the year 2035. This translates into a 49% increase over the demand in 2007, which stood at 85.7 million barrels per day (mb/d) of oil¹. Up to the third quarter of 2010, the average global demand for energy was 86.43 mb/d compared to 84.34 mb/d in 2009, representing the largest increase in the demand for energy in at least five (5) years. By the end of 2011, the demand had climbed to 89 mb/d. Analysis of the statistics further reveals that the global demand for energy almost always stays above its supply which is an important factor determining the price of oil.

Oil Prices

When oil prices increase it becomes a concern, as Crude Oil is the single most important element affecting the prices of energy products and services. This is due to the fact that oil holds the lion's share of the energy supply market (OPEC, 2011); one barrel of crude oil in the U.S, on average produces: 47% gasoline (which is used to power motor vehicles), 23% Diesel Oil, 10% Jet Fuel, 4% Liquefied petroleum Gas, 3% asphalt and 18% other products.

According to the U.S. Energy Information Administration (2010), Crude oil spot prices averaged \$103 as at December 2011. In April 2011, the prices reached its highest level since 2008 to peak at \$112. As a result, the oil import bill of developing nations roughly quadrupled, totaling approximately 5.5% of their GDP (U.S Energy Information Administration, 2011). Additionally, the oil import bills in sub-Saharan Africa increased by US\$2.2 billion in 2010 which is more than a one third over the increase in Official Development Assistance (ODA) over the year. These statistics undoubtedly points to the need for better management and efficient use of energy resources.

PURPOSE OF THE STUDY

Many solutions to this problem are being explored. However most of the attention, so far, has been on finding alternative sources of energy. While these solutions are worth pursuing, Watson et al. (2010), conversely, perceives the problem as one that stems from a lack of information thus putting Information Systems at the heart of the solution. This they noted, gives rise to the IS sub—field of energy informatics. Energy Informatics is the field concerned with “analyzing, designing and implementing systems to increase the efficiency of energy supply and demand systems” (Watson et al. 2010). They noted that many organizations, in a bid to improve profits and productivity, indulge in environmentally unsustainable practices, which result in wastage, unused resources and energy inefficiency. Energy informatics and more specifically Green Information Systems, they argue, best address these practices. Green IS, a concept directly related to green IT, refers the use of more environmentally friendly technologies to provide information to support and create more environmentally sustainable practices (Watson et al. 2010). As a result, this study takes an IS focus towards solving the electricity consumption problem and will be built upon the Green IS paradigm as purported by Watson et al (2010). Specifically this study aims to:

1. Examine how the use of an Energy Management System within the business environment will impact energy consumption.
2. Conduct an investigation into the cost and benefits associated with the implementation and use of ZigBee enabled Energy Management systems.
3. Determine the optimal settings for the devices within the system and that will yield the best results.

SIGNIFICANCE OF STUDY

This study will have implications for both practice and theory.

On a practical level, the study should show the extent to which consumers could reduce their energy consumption which should result in both economic and environmental benefits. The amount of greenhouse gases being released into the atmosphere will automatically be reduced and thereby reducing overall carbon footprint. Regulation is heavily dependent on information (Afsah, Laplante And Wheeler, 1996) and this research will add to the information repository from which regulations regarding energy will be formulated.

¹ Oil is one of the world's most widely used energy sources and as a result it is used to measure the movement in the demand and supply of energy

The study will also contribute to the subfield of Information Systems known as Energy Informatics through the implementation of the principles it proposes and the subsequent addition to the body of knowledge within the sub-field. As a result it promotes the use of Green IS for sustainable development.

RESEARCH QUESTIONS

This research will be guided by the following research questions:

1. What is the impact of a ZigBee enabled Energy Information and Management System on electricity consumption?
2. What are the cost and benefits associated with the implementation of a ZigBee energy management and information System?
3. What is the optimal mix of device settings to minimize energy consumption?

LITERATURE REVIEW

This section will explore previous research conducted in the field of wireless energy management systems and Design Science. This review will show that, to the best of our knowledge, there is a lack of research on energy management systems combining Energy Informatics, Green IS and Design Science approaches. It will be divided into two major sections. First it will explore literature relating to energy management systems, ZigBee and the use of ZigBee in Energy Management Systems. The second section will take an in-depth look at Design Science and Design theory which forms the theoretical underpinnings of this study. Finally, we summarize by providing the link between the existing literature and this study.

Energy Informatics

The proposition of the energy informatics subfield was put forward by Watson et al (2010) out of recognition of the role IS can play in reducing energy consumption. The core idea behind this subfield is that supplying consumers with information about their energy usage can lead to changes in usage patterns and decreases in overall consumption. This idea is expressed succinctly by Watson et al (2010) as:

ENERGY + INFORMATION < ENERGY

The contention is that “high level granularity data about the distribution and consumption of data will enable the development of information systems for reducing energy consumption”. It involves the collection and analysis of data that will support the optimization of distribution and consumption networks. To support this idea, Watson et al (2010) present an incorporated framework consisting of all the elements an energy supply and demand system. The major technological components of this system are: flow networks, sensor networks and sensitized objects. These technological components, they argue, should be present in any efficient and intelligent energy system. We now describe these components and how they are incorporated into this study.

Flow Network – According to Watson et al. (2010), these are the connected components that “support movement of continuous matter or discrete objects”. They contend that, due to the vital role these components play in economic activity, increasing their efficiency is a necessary step towards creating a sustainable society. In this study we focus on electricity consumption thus making the electricity wiring of the building our flow network. Maximizing the gains from flow network requires optimization of flows. According to Watson et al (2010), in order to dynamically optimize flows, a flow network must incorporate the use of controllers to enable the state of the flow to be changed. In our study, we use relays thermostats and dimmers to change the state and intensity of electricity flow.

Sensitized Objects – are objects with the capability to sense and report data about its use (Watson et al., 2010) In our study electrical appliances used within our test area are fitted with ZigBee enabled appliance modules allowing them to monitor and report their electricity consumption for appropriate action. These objects, according to Watson et al (2010), are essential for managing demand. They also contend that there needs to be remote control of the state of the sensitized objects in the system. All the sensitized objects of our system including relays, dimmers and sensitized appliances are remotely controllable through the use of a ZigBee enable Gateway.

Sensor Network – This refers to a set of spatially distributed devices that reports the status off a physical item or environmental condition (Watson et al. 2010). In this study we use occupancy sensor and temperature sensors to detect the state of the surrounding environment. The state of the surrounding will then be used to determine what actions should be taken. Watson et al (2010) also note that a variety of technologies are being used to support sensor network. These include such wireless technologies as Bluetooth and ZigBee. ZigBee is the technology of choice for this study as it is specially designed for sensor networks and includes a profile suited for energy management.

ZigBee

ZigBee is an IEEE 802.15.4 standard based protocol that provides the network infrastructure created by the ZigBee Alliance for wireless sensor applications (Daintree networks, 2008). It also establishes a set of specifications for wireless Personal Area networks (WPA). ZigBee support all the major requirements for sensor networks, which include long battery life, low cost, small carbon footprint and mesh networking capabilities to support communication between a large number of interoperable devices (Daintree networks, 2008).

We have so far seen few studies that assess the impact of a ZigBee sensor network on electricity consumption (Han & Lim, 2010; Dey, Abowd & Salber, n.d). None of the few, however, provides empirical data to substantiate or to test a hypothesis. Han and Lim (2010) designed smart home device descriptions and standard practices for demand response and load management “Smart Energy” applications needed in a smart energy based residential or light commercial environment. In another study, Dey, Abowd & Salber (n.d) discussed the requirements and presented a software solution for dealing with context in a smart environment. Han and Lim (2010b) in yet another study developed a new routing protocol called DMPR (Disjoint Multi Path based Routing) to improve the performance of their ZigBee sensor networks. The paper also introduced the proposed home energy control system’s design that provides intelligent services for users. The solution was demonstrated using a real environment.

This study will improve of these prior studies by assessing the design of an Energy Information and Management System within the context of the Energy Informatics subfield. According to Watson et al (2010), designing such a system requires breaking away from the dominant social sciences paradigm and embracing a solution sciences approach which incorporates fields such as management science design science and policy formation. This study will be approached from a design science perspective.

Design Science

Design Science is a paradigm in IS research for which there has been a struggle to establish a central definition. It was birthed out of attempts to differentiate Information Systems as a design science as opposed to a natural or behavioral science (Osterle et al 2011). Design has been the core principle in disciplines such as engineering and computer sciences. It is “the use of scientific principles, technical information and imagination in the definition of structure, machine or system to perform pre-specified functions with maximum economy and efficiency” (Walls, Wideyer and El. Sawy., 1992). On this basis, Gregor and Jones (2007) notes that design is implicit within the anatomy of IS as it involves the design and delivery, use and impact of technology within organizations and society. As a result design should be considered an important topic within the information systems paradigm (Walls et al 1995). While Researchers such as Osterle et al. (2011) and Walls et al (1992) lament the predominantly behavioral approach IS has taken and thus proposing a design approach; others have taken a slightly different view. March and Smith (1995) for example reconciles the two views of IS by arguing that artificial phenomenon can be both created and studied. Congruently, Hevner et al. (2004) argues that research in the IS field is comprised of two complementary but distinct phases: behavioral science in which the problem is understood and design science in which a solution is created and applied to the problem. Design science therefore revolves around the creation of an artifact to solve an identified organizational need (Osterle et al. 2011). This, according to Venable (2006), has the potential to increase the relevance of IS research to practice (March and Smith, 1995; Hevner et al., 2004).

A clear distinction has however been made between routine design and Design Science Research (DSR) (Venable, 2006; Viashnavi and Kuechler, 2008; March and Smith, 1995; Hevner et al. 2004). According to Aier and Fischer (2011), the popularity of DSR increased when Hevner et al. (2004) published a seminal article on the subject matter. They describe routine design as the mere application of knowledge to existing organizational problems in contrast to DSR which addresses previously unsolved problem in a unique and innovative way or previously solved problems in a more efficient and effective way. Its central theme, according to Wang and Wang (2010), is to make design work and knowledge partly formalizable, partly empirical and partly teachable. March and Smith (1995) adds that the aim of DSR is to create artifacts which may be of four types: models, constructs, methods and instantiations. This, according to Vahidov (2006), is in contrast to a simple research project which produces only specific instantiations in solving a problem.

Design Science Research and Theory

There also exists a level of contention as to the role of theorizing in Design science research. From a process point of view, Hevner et al (2004) is also ambiguous. The IS Research Framework (p. 80) that they present combines the Theorize (theory) and Build (artifacts) activities of March and Smith (1995) into a single Develop/Build activity and the Justify (theory) and

Evaluate (artifacts) activities (March and Smith, 1995) into a single Justify/Evaluate activity. Thus, they “combine behavioral-science and design-science paradigms” (Hevner et al, 2004, p. 79). They merged Develop/Build and Justify/Evaluate activities then constitute IS Research and produce both artifacts for “application in the appropriate environment” (outcomes of build and evaluate) and “additions to the knowledge base” (outcomes of develop and justify) (Hevner et al, 2004). Hevner et al. (2004) did not explicitly make mention of new or revised theories as a research contribution. However, as part of Research Rigor, they did mention that the researcher needs to be skilled in the “selection of appropriate means to justify the theory or evaluate the artifact.” March and Smith (1995) is however, more explicit is in separating the function of design science and theory. They argue that theory is not an intrinsic part of design science but that design knowledge is rather expressed in models, methods, constructs and instantiations (Hevner et al., 2004). Venable (2006) however adds better theories to this classification, arguing that design science research in IS must produce better theories as an outcome of the research. In fact venable (2006) postulates that theory and theorizing are pivotal to design science research and that theory should be the primary output of design science research.

This research and Design Science

This research will undertake the design of the solution based on Design Science framework presented by Hevner et al (2004). This framework was chosen as it is considered the most widely accepted design science framework in use by IS professionals (Venable 2006, Peffers et al, 2006). There is however one potential limitation, it focuses primarily on technology-based designs (Hevner et al., 2004). This therefore excludes designs focusing on organizations, policies and work practices as the designed artifacts. This limitation however does not affect this study due as it focuses on the design of an optimized wireless energy management system which is a technology-based artifact.

Their frameworks presents seven (7) guidelines for conducting design science research in the IS arena. These guidelines and how this study conforms to them are outlined below.

1. Design as an artifact: Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation. This study will produce a wireless sensor network that evaluates and manages the consumption of energy (Energy Management System).
2. Problem Relevance: The crisis in Japan, rising oil prices, unrest in the Middle East and North Africa, and a just recently ended economic recession all combine in creating an energy crisis for the world.
3. Design Evaluation: The utility, quality, and efficacy of a design artifact must be rigorously demonstrated by means of well executed evaluation methods. Hevner et al. (2004) suggests several methods for design evaluation: observational, analytical, experimental, testing and descriptive. This study utilizes testing method in which the ZEMS will be simulated within the test environment. The design will be evaluated on the amount of energy consumed after optimization This will be done by comparing pre-test to post-test data.
4. Research Contributions: Effective design-science research must provide clear and viable contributions in the areas of the artifact. This research contributes to the energy sector by providing empirical evidence on ZigBee’s contribution to energy conservation. It will also add to the knowledge base by providing a framework for testing and evaluating ZigBee based smart energy applications.
5. Research Rigor. The design of experiment approach that this project takes has been proven to produce reliable results.
6. Design as a search Process: The search for an effective artifact requires utilizing available means to a desired end while satisfying laws in the problem environment.
7. Communication of Research: Design science research must be presented effectively both technology-oriented as well as management-oriented audiences. It is hoped that this research will assist energy policy makers in making decision with regard to energy conservation and also in designing and testing the technology in similar environment.

METHODOLOGY

This study will employ a design of experiments methodology in order to determine the level of impact of each factor on energy consumption as well as to derive a model for predicting energy consumption and, the optimized settings. The study will be conducted in three phases:

Phase One: Design and Implementation of Energy Management System

This phase consists of the implementation of the ZigBee enabled Energy Management System within the test environment and the collection of pre-test. The system will consist of several devices:

- Five (5) ZigBee occupancy sensors placed at various places with the test area will determine the level of occupancy within the room. This will allow the lights and AC's to be switched off or adjusted based occupancy level.
- Fourteen (14) ZigBee appliance modules which act as power strips in which appliances and electrical devices such as computers, printers, etc are plugged in order to monitor and control their energy usage. The amount of appliance modules is in direct proportion to the amount of electrical devices in the test area.
- One (1) ZigBee Gateway. This unit retrieves energy information from all other devices on the network and provides energy management capabilities such as trend analysis, energy consumption forecasting and device setting control and monitoring.
- One (1) ZigBee panel meter. This device will be attached to the main electrical panel to monitor overall energy usage of the area. The test area consists of one panel therefore only one panel meter is needed.
- Five Light Dimmers (5) to regulate light intensity. There are five circuits controlling light units within the test area. Each dimmer will be placed on a circuit.
- One (1) ZigBee enabled thermostat which turns the Air Conditioning unit on/off/down/up depending on the policy settings and occupancy levels of the area. There is one A/C unit controlling the temperature of the room. As a result only one thermostat is needed for this study.

Upon installation of the system, energy consumption data, recorded in Kilo-Watt per hour (Kw/h), will be collected for daily for two weeks. This will be compared to pre-test data in order to determine the level of impact the system has on energy consumption. Alternative methods were also considered, such as, controlling the building with energy management system as opposed to controlling with energy management system. However seeing that objective of the study to see how much the intervention impacts what currently exists, we thought it best to use the selected methodology.

Test Environment

Even though vendors have done their own testing, there is no empirical data on testing in a real world environment. This project will test the performance of ZigBee in a normal office setting. This test bed is an office which is a part of a larger complex comprising of three adjoining office buildings.

The test area was fitted with its own individual electrical meter and therefore pretest electricity consumption will be taken daily for two weeks. The building has no energy manager or any form energy management system. All energy management efforts are carried out manually by turning on/off lights and air-conditioning as required.

Phase Two: Design of Experiment

This phase of the project will involve conducting several experiments:

Experiment 1 – Multiple Linear Regression Analysis (MLRA)

The aim of this experiment will be to determine which factors are the most significant contributors to electricity consumption. The factors to be considered are:

- Dimmer settings
- Occupancy Sensor Time Delay Settings
- Thermostat setting
- Occupancy
- Distance between occupants and sensors

This will involve measuring the values for each variable each day over a one month period. This data will then be used to conduct the MLRA. This will determine the extent to which each factor contributes towards energy consumption and will also produce a model for predicting energy consumption given the significant factors. The result of this section will then be used to carry out experiment 2.

Experiment 2: Response Surface Methodology (RSM)

In this experiment the optimal setting of the network will be determined. This will be done through the use of Response Surface modeling (RSM). The significant factors highlighted in experiment one will again be monitored for a period of two months and the optimum setting derived.

Phase Three

In this phase of the project the optimized setting will be put to the test in order to determine level of impact the optimized system has on energy consumption. In doing so, the system will be monitored for two months taking variable readings daily. This will be compared to the pre-test data to determine the impact of the intervention.

Cost Benefit Analysis

A Cost Benefit Analysis (CBA) will be carried out in which several factors, all expressed in US dollars (US\$), will be considered in executing the CBA, they include:

Benefits:

Amount of energy saved per month in electricity cost

Saving in retrofitting

Cost:

Cost to purchase equipment

Cost of installation

Office downtime

CONCLUSION

Statistics show that energy consumption has been increasing over the last five years and will continue to rise. As a result the countries constantly face rising oil and energy bills. This research explores cutting the cost of energy by reducing the amount that is used. The study will use the design science framework to an IEEE 802.15.4/ZigBee automatic energy management environment in contribution to energy conservation. The project will yield the level of reduction to be obtained from the implementation of such system. It will also present a Cost-Benefit Analysis in order to determine the viability of implementing such a system.

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