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Abstract—Energy conservation is among society's greatest challenges, and the built environment has a concentrated impact on our natural environment, economy, and health. Fundamental understandings of how energy is consumed, monitored, and controlled are key prerequisites for an energy conservation process. This paper evaluates the effectiveness of real-time energy monitors (RTM) to influence behavior change in residential consumers. A methodology for remote identification of load types along the electrical circuitry where they (load) are being consumed is also presented. The load type and status (on, off, standby) are determined both remotely and in a non-intrusive manner using Non-Intrusive Load Monitoring Methods. A bottom-up approach to real-time energy monitoring by integrating virtual and physical domains to increase user awareness on where, when, how and why aspect of energy to make inform decisions regarding energy consumption, optimization and conservation is proposed. A virtual 3-D environment is developed to display actual space/zone/building real-time power consumption information and to allow users to easily locate equipment/loads that are in standby/inefficient and causing energy waste in the real/physical environment. The proposed system using wireless ZigBee based monitoring system is demonstrated via a prototype board virtually integrated with a real world test environment. The results establish a promising tool in this filed.

Keywords-Green Sustainable Design, Energy Consumption, Energy Conservation, Real Time, Load Monitoring, Wireless, Sensor Networks, Building Automation, Non-Intrusive Load Monitoring.

I. INTRODUCTION

According to United States Green Building Council (USGBC), the built environment in the United States accounts for 72% of electricity consumption, 39% of energy use, 38% of all CO_2 emissions, 40% of raw materials use, 30% of waste output (136 million tons annually), and 14% of potable water consumption [1]. U.S. homes use about one-fifth of the total energy consumed in the nation and about 60% of that is in the form of electricity. Research has shown that these residential energy consumers waste almost 41% of the power supplied to their homes [2]. The large amount of usage and waste indicates that the residential sector has significant energy savings potential. To this end, the development of smart buildings or home automation technologies promises to make our living environment safer, more convenient, comfortable and more efficient. Some of the most important functions of smart buildings include environment monitoring, building security, monitoring and control of power systems etc. In addition to these, reducing energy consumption in buildings offers a ready-to-use solution for reducing the effects of climate change and the potential of natural disasters and hazards.

Data communication systems and information technologies are essential components of modern smart buildings. The use of occupancy sensors and building automation sensors are two ways of using data communication systems to create a smart built environment. Occupancy sensors are simple devices that sense whether an occupant is in a space or not and transmit a signal wirelessly to energize or de-energize the equipment being controlled by these sensors, such as lights or ventilation systems. Building automation systems use the information from the sensors to provide significant reduction in energy usage and cost by offering automatic control of indoor environment conditions.

To influence the electrical energy consumption, energy efficiency programs in the U.S. emphasize the use of energy saving technologies and design practices because energy saved is, quite literally, energy found. A reduction in energy consumption will occur as a result of changing old habits as it is essential to influence human behavior since when it comes to energy, it is the habitual behavior that influences our energy consumption. This need has opened ample opportunities for research on creative methods that encourage more energy efficient lifestyles. In addition, the use of modern building automation systems has become essential in order to provide occupancy comfort while improving energy and equipment efficiency as well as reduce operation costs.

This paper will address this behavior change to conserve energy and provide a case study conducted to determine the effect of real-time monitors to influence behavior change and educate homeowners on where energy is being used and how Information Technologies can save wasted energy. The ultimate aim of this research is to enable the user to be empowered to make conscious decisions to make green, sustainable choices.

The paper is outlined as follows: the effectiveness of real-time energy monitors (RTM) is discussed in Section II; Section III explains components of a non-intrusive data acquisition system. A Real Time Power Monitoring system as

is described in Section IV along with a demonstrated prototype of the proposed system. Section V discusses areas for further research. Section VI concludes the paper by discussions and remarks.

II. BEHAVIOR CHANGE AND ENERGY CONSUMPTION

When it comes to human consumption behavior, information is power. In the area of feedback systems, several real-time monitors in the market present an opportunity to decrease energy consumption. The use of real-time feedback presents an opportunity to decrease residential energy consumption by 10%-20% [3]. As can be seen from Fig. 1, lighting, heating, and cooling take up 58 percent of the annual energy bill for a typical household. The question posed by the Figure is an interesting question that current RTM are trying to address. However, current RTM devices available in the market monitor and display overall energy consumption for the entire home only and do not have the capability to adaptively determine wasted energy consumption on behalf of the resident. Users are thus responsible for both determining the location of wasted energy and taking the necessary actions to reduce that waste.

The purpose of this part of the research is to investigate the effectiveness of the feedback methods of different devices on lowering residential consumption rates. It was hypothesized that consumers interested in reducing costs might respond to information about their energy consumption by engaging in energy saving behaviors during periods of higher demand.
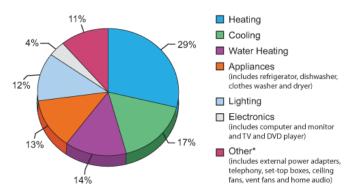

Fig.1.Energy Consumption of A Typical Home

Participants were grouped as low, medium, or high energy consumers and the results exhibited a shift in their peak-time energy consumption. Fig. 2-3 show the consumption data collected on July 25, 2008, a typical summer day in Omaha, NE. Peak usage occurred at different times in the day for different participants using these feedback devices. The study gave the real time energy consumption in 15 minute intervals. Direct feedback was provided via two surveys conducted during the course of and at the end of the study. The survey looked at whether the real time monitors had any influence on participants desire to conserve energy.

III. NON-INTRUSIVE ELECTRICL LOADS PREDICTION

Previous research has shown that feedback can be useful for short-term energy saving. Our survey results support this notion, as participants reported greater interaction with the device during the beginning of the study.
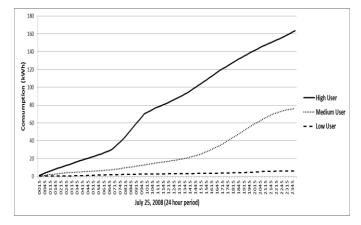

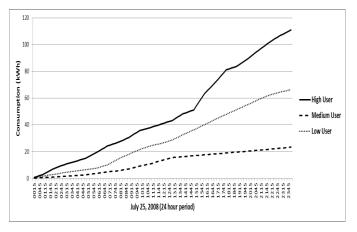Fig. 2. Cumulative kWh for participants with Aztech monitors.

Fig. 3. Cumulative kWh for participants with PCM monitors.

Since all of the feedback methods depended on the energy saving behaviors of the participants in order for energy savings to occur (reducing loads required manual switching), this study supports the need for more innovative ways to reduce residential energy consumption. Moreover, The American Council for an Energy-Efficient Economy (ACEEE) found that feedback devices alone are unlikely to maximize energy savings [4]. Hence, there is a need to focus on creative and promising methods to encourage energy efficient lifestyles. Toward a smart, built environment, this research presents a fresh methodology to addressing energy needs using a bottom-up approach. The focus will be on consumption and conservation at the electrical node, where an electrical node is a point on the electrical wiring system at which electrical current is taken to supply utilization equipment (load). To this end, we develop non-intrusive and novel methods to identify each node and the potential of energy saving of the connected loads. The goal of this approach is to be able to identify energy consumption points with very minimal hardware additions to existing electrical circuitry in the built environment. Information from these investigations is then

used for modeling, simulation and analysis to enable innovations in building information modeling (BIM), energy consumption performance and conservation, energy recovery using impulse saving behavior at the residential level and enables demand side energy management at the commercial/utility level.

Some emerging technologies [5-7], employ a lot of hardware additions to existing circuitry to achieve the intended goal of this research. The ultimate goal of this research is to be able to identify energy consumption points with very minimal hardware additions to existing electrical circuitry in the built environment.

In the past, different application-specific methods have been investigated to understand, among other things, how loads affect power consumption, power quality, efficiency, reactive power compensation, and system planning. The purpose of the load prediction aspect of this research is to understand the characteristic–load consumption. In this paper, a neural network (NN) methodology is employed to predict electrical loads for typical commercial and residential applications. The neural network provides a kilo watt (kW) Model. This model employs past trained data and serves as a baseline using past trained data to reflect an increase or decrease in energy use. Fig. 4 shows block diagram for pattern recognition in the Neural Network.
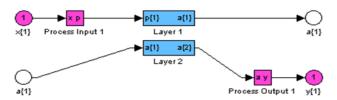

Fig. 4. block diagram for Neural Network Simulation

Each neural network represents one pattern (load). Some loads have the same signature and confusion of load identification could be avoided using more signatures like reactive power and harmonics. Fig. 5. shows pattern recognition for a sample load using the Neural Network shown in Fig. 4.
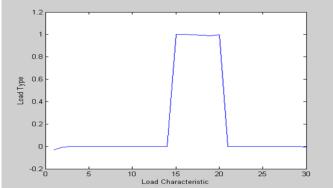

Fig. 5. Load Type (Printer, Laptop...Etc.) vs. Load Characteristic (watt)

The neural network or model will predict the amount of energy used in the future. Tests were conducted to determine the sizing possibilities for the Model. When combined, the data for the relative humidity, temperature, and holidays give better results and create a more reliable kW Model. A comparison between the predicted and measured data is given in Fig. 6.

The real-time monitored kW will be compared to the model kW (baseline). The difference between the two should reflect the potential energy savings. In other words, the Model kW will make it easier for engineers to define acceptable performance thresholds.

In future studies, it is hoped that the proposed methods will lower energy spending by 15-25% spanning the lifecycle of most home electronics. The load location identification method can be combined with the kW Model to detect the energy saving potential and also locate the source of the savings. This can be accomplished using only minimal additional hardware and software.
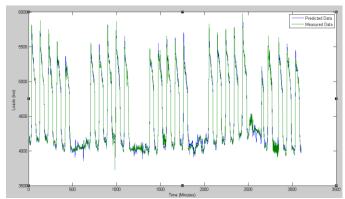

Fig. 6. Deviation of Predicted and Measured Energy data

III. INTERACTIVE REAL-TIME MONITORING AND CONTROL

Much previous research has been devoted to improving ways to inform residents of their energy usage. To alleviate the information burden and guesswork about energy waste, we propose an interactive real-time monitor and controller (RTMC) system as shown in Fig. 7. This system achieves real-time energy monitoring by integrating virtual and physical domains to increase user's knowledge to make informed decisions regarding energy consumption, optimization and conservation. Using an innovative design and integration of physical and virtual domains, users will have easy access to the amount of energy they consume and the exact locale of this consumption. The system has been demonstrated via a prototype board coupled with a virtual system. This energy monitoring system is based on an instantaneous impulse savings behavior that provides users with the ability to reduce energy usage in real time for the entire home by pressing a button. The system's user friendly interface with Go-green save-energy button is based on an adaptive system that monitors and controls real energy consumption at every energy consumption location or node. A node is defined as a point on the wiring system in the building at which electrical current is taken to supply utilization

equipment (loads) [17]. Common nodes include receptacle, lighting switch, dedicated load, etc. This energy monitoring system will effectively determine non-critical and wasted energy in home and provide users with the ability to turn off wasted energy with the Go-green save-energy button. This will result in total power consumption for the home to be at its optimal level while also maintaining occupant comfort.

The physical system will consist of wireless nodes controlled by a central hub. Wireless nodes will transmit power consumption data from energy consuming devices to the central hub. This central hub will process all the information and bring the virtual and physical systems together. The hub will determine which devices could be turned off to save energy with data received by either a combination of occupancy sensors, temperature sensors, and lighting sensors, or by input from the user's personal preferences. By pressing the Go Green button the user can turn off all of the unneeded devices and save energy without the need of unplugging them manually. The hub will display the power consumption data in a format the user can easily comprehend with KW usage and dollar usage of the devices.

Wireless Data transmission is being pursued using Xbee radios shown in Fig. 8. These radios use the Zigbee protocol's for wireless communication. They are low power radios that can monitor the current and voltage and act as an actuation device for each node with the help of triacs. This will make the nodes low in power consumption to maximize energy saved for each node. The low power of the radios does decrease their effective range but this is overcome by their ability to 'hop' data transmissions between each other until the data reaches the main hub for processing. The actuation system will use triacs to change the state of nodes with data from the central hub. This system will be small enough to be retrofitted into existing nodes in the form of an outlet cover or built into new buildings in the form of a new outlet box that fits existing outlet box sizes.
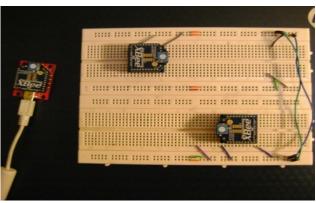

Fig. 8.Xbee Wireless Radios.

A prototype of this RTPMC system has been designed and tested. Fig. 7 shows the prototype board built to simulate six different loads.
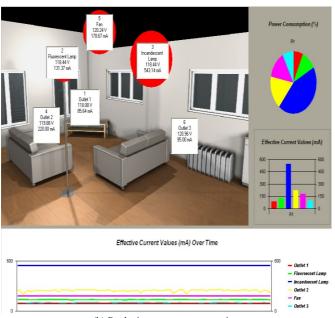
We integrated the output of the board with a virtual environment model to illustrate our physical/virtual system. The virtual environment is built, using Visual Basic, for the prototype that emulates a room in a house. It provides the user with a simple interface that combines the actual layout of the room with real-time power consumption at every electrical node. Each load in this room is associated with one of the loads in the RTPMC prototype. When power is consumed at a load location, a red circle with a thickness proportional to the power consumption of that load will show up, indicating which load is consuming power in real time.

Fig. 8 shows real time power consumption by means of read circles, Excess (wasted) energy consumption is also highlighted at two locations. Although these two loads are turned off, they still consume power (phantom load). The red indicators function as warning sign for users to take action to conserve energy and minimize waste.

Fig. 7.The RTPM System Prototype Board.

(b) Real- time power consumption
Fig. 8. The RTPMC Physical/Virtual Real-time Integration

This project distinguishes its approach by focusing on the user interface and experimentally verifying consumer behavior and achieving a significant energy saving. We are empowering users to make their own decisions in order to simultaneously save money and energy using the RTPMC system. The RPTMC learns the occupant's energy behavior and determines

the locations and magnitudes of wasted energy and provides this information in a user friendly approach to allow the user to take impulse action to sustain savings without having to estimate which action will best reduce energy use.

IV. FUTURE WORK

An event-based modeling and simulation of energy management systems is proposed to make the virtual model and the control logic a realistic resemblance of the actual system.

This will provide a platform to foster research and perform experiments used to mimic the procedural manner with which a human brain perceives and reacts to real-life events. Humans use concern, satisfaction, and perception to make appropriate decisions to balance between energy consumption and conservation and human comfort. The perception and direct/indirect interaction of humans with the electrical system
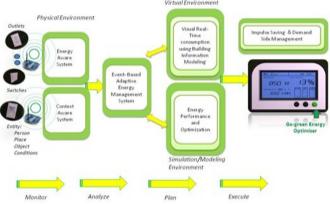

Fig. 9. Future vision for energy monitoring and control systems in smart homes.

through the load can be classified in an event-based model composed of:

- events, such as someone entering/leaving a room, a switch turning on/off, and a load being plugged into or out of an outlet;
- conditions/constraints, such as leaving lights on for security reasons, turning off the air conditioning (AC) if the temperature is less than a set point, and leaving on a computer that is in standby so as to prevent data loss;
- actions, such as changing the settings of the AC, increasing/decreasing fan speed, and shutting off phantom loads;
- states, such as on, off, speed 1, and speed 2 for a fan, or on, off, and dimmed for a light;
- data, such as the values of power consumption, voltage, currents, or power factor of the utilization equipment, the maximum power demand forecasted, the weather forecast, the electricity bill rates and tariffs and a fault diagnosed in some part of the electrical system; and
- transitions, such as a switch transitioning from state "on" to state "off," an occupancy sensor transiting from a state of working properly to a state of not working, and a motor

transitioning from transient state to steady state from speed 1 to speed 2, or from on to off state.

We use MATLAB [18] to model and simulate this event-based adaptive system. The control logic is based on state-machine theory. Using finite-state machines, the team will identify and classify each WESAN with its operating modes as states. The adaptive controller will then be modeled and simulated as an event-driven (reactive) system based on a hierarchy of super- and sub-systems. The entire electrical system is the main super-state/system. This state/system contains sub-states/systems for each level in the building. Each level is composed of zones, and each zone consists of nodes (WESANs). We will classify the data inputs to the nodes as deterministic or stochastic. Deterministic data include power consumption at certain states; whereas, stochastic data is power consumption that changes with time. For these data, the team will consider dynamic and static types of states. Transitions from one node state to another are determined by events and conditions. Each component of the wireless energy sensing and actuation system (WESAS) has a state which can be composed of one or more sub-states.

The main goal of this system is to minimize power consumption for the whole building. Power consumption can be expressed by Equation 1:

$$P(n+1) = f(X(n), U(n)) \qquad (1)$$

Where $P(n+1)$ is the total power consumption for the whole system at time step $n+1$, $X(n)$ is a matrix/array representing the current respective states of system's components at time step n, and $U(n)$ is the system input matrix/array at time step n (again including data, conditions and events). The control logic target determines what actions will be taken by each WESAN at time step $n+1$.

V. CONCLUSION

In this paper, smart home technologies are being introduced in the built environment in order to conserve energy and thus create a more sustainable future. The identification methods will reduce the need for hardware additions to the existing electrical circuitry in the built environment.

Preliminary findings from the simulations indicate that a sensor technology can be developed successfully with the capacity to upgrade the existing electrical systems in the built environment. This technology will not only reduce the costs associated with upgrading, but will increase the energy efficiency in the built environment and eventually reducing greenhouse gas emissions CO_2, NO_2, etc. in the electrical power generation process.

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