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Green And Sustainable Technologies For The Built Enviornment

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Green And Sustainable Technologies For The Built Enviornment

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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 and the locations 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 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, Power Time Domain Reflectometry, 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 CO2 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. The residential sector, unlike the commercial and industrial sectors, is made up of multiple small energy users such as houses, mobile homes, and apartments. 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. We can create an environmentally conscious society and make people more willing to reduce energy usage by using green and sustainable technologies. Reducing energy consumption offers a ready-to-usesolution for reducing the effects of climate change and the potential of natural disasters and hazards.

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.

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 they 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. The standard feedback mechanism for residential electricity consumption has been the monthly bill. While this provides an aggregated use summary in kilowatt-hours (kWh), it does not provide information timely enough to empower consumers to make informed decisions about how and when to reduce their consumption. 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

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by the Figure is an interesting question that current RTMare 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.

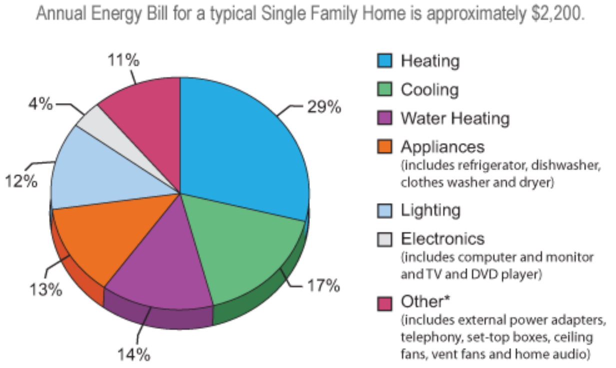


Fig.1.Energy Consumption ofA Typical Home

Study participants were self-selected by responding to a four-question survey sent to 2000 residential customers within the city limits of Omaha, Nebraska [19]. Homes were selected from a geographic area comprised of over 7000 homes that were already participating in an existing utility pilot study involving the wireless collection of electricity consumption data resolved to 15 minute intervals. In total, 214 respondents were willing to participate in the study. The project investigators contacted each chosen participant via phone or email, and set up an appointment and home visit of approximately one half-hour to install the device and explain its functionality. A website was also launched to address the questions or concerns of participants and provide additional energy saving tips. Participants could also contact a dedicated university call center run by the research team to deal with any monitor related issues. Out of the 214 initial respondents, a total of 151 homes participated in the study.

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.

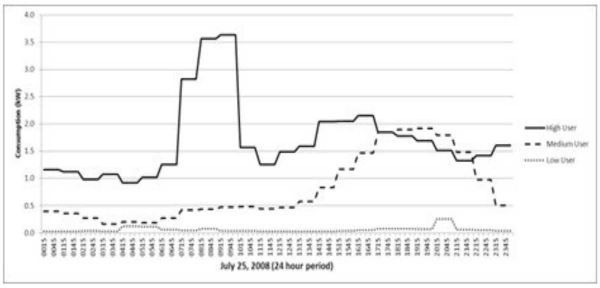


Fig. 2. Energy usage profile of a typical summer day (July 25, 2008); shows the high, medium, and low kW consumption patterns of participants with Aztech monitors.

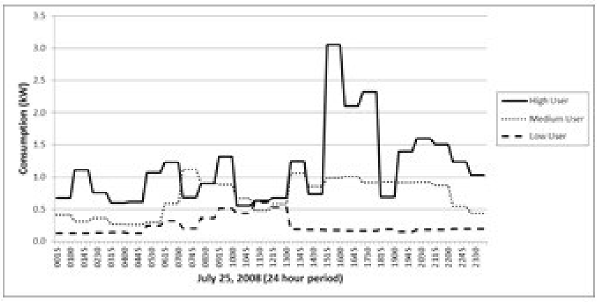


Fig. 3. Energy usage profile of a typical summer day (July 25, 2008); shows the high, medium, and low kW consumption patterns of participants with PCM monitors.

III. NON-INTRUSIVE ELECTRICL LOADS IDENTIFICATION AND 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. 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 the location of each node and the potential of energy saving of the connected loads. The goal of this approach is to be able to identify and locate 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. A block diagram of the proposed addressable power distribution and energy management system is shown in Fig.4.

Some emerging technologies [5][6][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 and locate energy consumption points with very minimal hardware additions to existing electrical circuitry in the built environment.

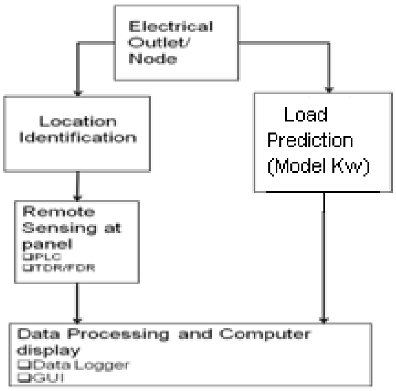


Fig. 4. Block diagram of the Proposed Addressable and Energy Management System using a bottom-up approach.

A. *Load Location Identification*

The identification of load locations is being investigated through Time Domain Reflectometry (TDR) [8], Power Line Communication (PLC) [9], [10] and Energy Harvesting [11],[12] with focus on TDR. TDR technology is based on sending shaped pulse waveform along the electrical conductor (wire) [13], [14], [15], [16]. The wave propagates down the conductor and sends back a reflected signal to the TDR source (in the electrical panel) when it experiences an impedance change on the conductor. The distance from the point of reflection back to the TDR gives a unique temporal signature that can be used to determine the status of the conductor. This concept is being investigated to identify the location of each node along the electrical network by continuously sending a unique waveform onto the conductor linking all the nodes. Once a node's characteristic is modified, i.e. a load is connected, the location will be identified using the corresponding reflected signal back to the TDR. The reflected signal will be predefined in a lookup table matching the distances of each node from the TDR source in the panel level. Fig. 5 shows the proposed model of the addressable power distribution system. This method of load location identification will eliminate the modification of existing nodes (outlets) in existing homes for the relative humidity, temperature, and holidays give better results and create a more reliable kW Model.

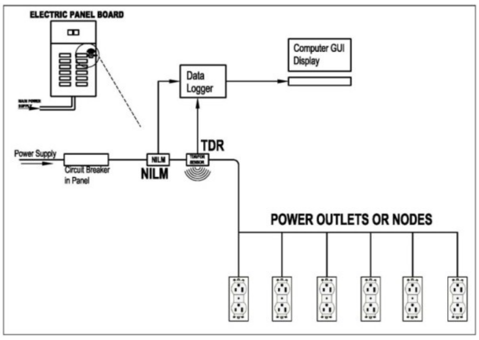


Fig. 5.Proposed Model of the Non-Intrusive Load Monitoring system.

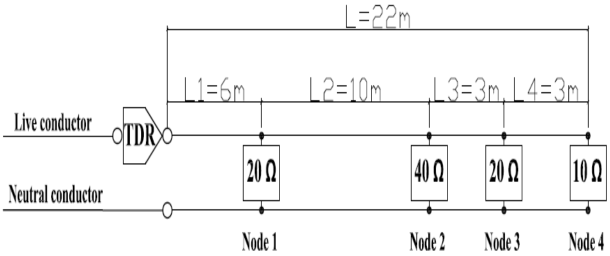


Fig. 6. #14 AWG conductor with characteristic impedance of 0.0104 ohm/m and VOP of 0.84 (Not drawn to scale).

From the simulated results shown in Fig.7, it can be seen that, the TDR will display a rise in signal amplitude when the change in impedance from one segment to the other is high and drops when the change is low. The various node locations are shown on the graph (fig. 7) as 6, 16, 19 and 22 meters, respectively from the TDR location.

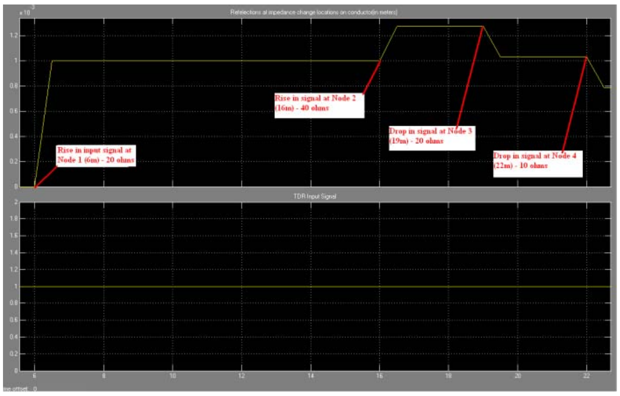


Fig. 7. Simulated TDR display of nodes with connected loads.

B. *Load Prediction*

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. 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.

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. 8.

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.

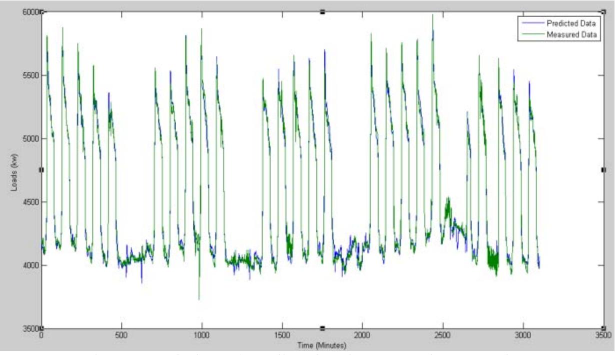


Fig. 8. Deviation of Predicted and Measured Energy data

IV. INTERACTIVE REAL-TIME MONITORING AND CONTROL

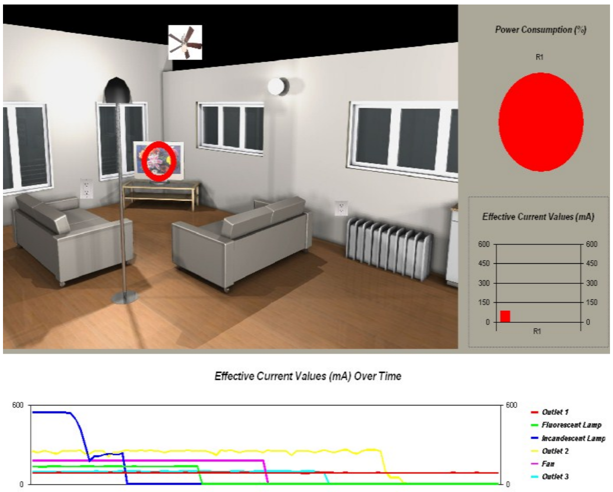
Much previous research has been devoted to improving ways to inform residents of their energy usage. To alleviate the information burden and guesswork about energy waste, we propose an interactive real-time monitor and controller (RTMC) system as shown in Fig. 9.This system achieves real-time energy 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.

A prototype of this RTPMC system has been designed and tested. Fig. 9 shows the board built to simulate six loads.

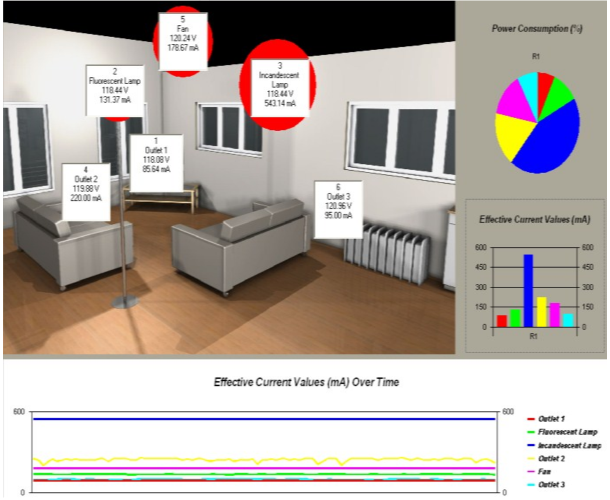
We integrated the output of the board with a virtual environment model to illustrate our physical/virtual system. The virtual environment is built, using Visual Basic, for the prototype that emulates a room in a house. It provides the user with a simple interface that combines the actual layout of the 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. 9.The RTPM System Prototype Board.

Fig. 10 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.



(a)On/Off Load Demonstration



(b) Real- time power consumption

Fig. 10. 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.

V. 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. We plan to wireless energy sensing and actuation nodes (WESAN's) for the purpose of energy monitoring in the future.

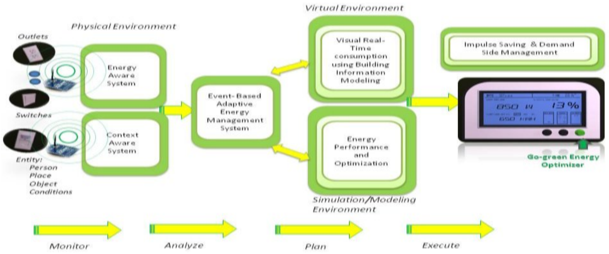


Fig. 11.Future vision for energy monitoring and control systems in smart homes.

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 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.

VI. 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 enabled by the TDR and Model technologies 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 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.

VII. REFERENCES

[1] U.S. Green Building Council (USGBC),"Green Building Facts." U.S. Green Building Council, www.usgbc.org/ShowFile.aspx?DocumentID=5961, last accessed 2/3/2011.

[2] Williams, Eric D., & Matthews, H. Scott., "Scoping the Potential of Monitoring and Control Technologies to Reduce Energy use in Homes," Proceedings of the 2007 IEEE International Symposium on Electronic & Environment, May 2007, pp. 239-244.

[3] Wallace, James (2007). "TED the energy detective." http://www.currentcost.net/ 2818000.shtml, last accessed 11/18/2010.

[4] Karen Ehrhardt-Martinez, Kat A. Donnelly, & John A. "Skip" Laitner, "Advanced metering Initiatives and Residential Feedback Programs: A Meta-Review of Household Electricity-Saving Opportunities," American Council for an Energy-Efficient Economy, report Number E105, June 2010.

[5] Intelli-plug, http://www.ethicalsuperstore.com/products/oneclick/energy-saving-intelli-plug-dsk-105/#product_ethics, 2008.

[6] Sticord plugs, http://www.homeqn.com/entry/sticord-power-saver-plug-promises-to-conserve-energy, 2010.

[7] Vulcan Surge Protector, http://vulcantechnology.com/products/.

[8] Martin Hartebrodt and Kabitzsch, K. (2004)."Fault Detection in Fieldbuses with Time Domain Reflectometry", IEEE Africon.

[9] IEEE Power Engineering Society, (2004).IEEE Guide for Power-Line Carrier Applications.

[10] Yu-Ju Lin, Haniph A. Latchman, Richard E. Newman, and SrinivasKatar (2002). " A Power Line Communication Network Infrastructure For The Smart Home" IEEE Wireless Communications Vol. 9, No. 6.

[11] Banting John, Fredrick and Mcbee Bruce W. (2010). " Power Line Energy Harvesting Power Supply" US Patent Application Publication No. US 2010/0084920 A1.

[12] Shichuan Ma, Yaoqing (Lamar) Yang, Hamid Sharif, Yi Qian, and Mahmoud Alahmad (2010)." Energy Harvesting and Its Challenges in Smart Grid ". unpublished.

[13] Martin Hartebrodt and Kabitzsch, K. (2004)."Fault Detection in Fieldbuses with Time Domain Reflectometry", IEEE Africon.

[14] Guangming Song, Fei Ding, Weijuan Zhang, and Aiguo Song (2008)."A Wireless Power Outlet System for Smart Homes" IEEE Transactions on Consumer Electronics, Vol. 54, No. 4.

[15] You Chung Chung, Nirmal N. Amarnath, Cynthia M. Furse, and John Mahoney (2009), "Capacitance and Inductance Sensors for locating of open and Short Circuited Wires", IEEE Transaction on Instrumentation and Measurement, Vol. 58. No. 8.

[16] Paul K. Kuhn, Cynthia Furse, and Paul Smith (2006). "Loacting Hidden Hazards in Electrical Wiring" Aged Electrical Systems Research Application Symposium.

[17] Mark W. Earley, Jeffrey S. Sargent, Joseph V. Sheehan, E. William Buss, "National Electrical Code Handbook," NEC 2008, NFPA, pp 29.

[18] The MathWorks, http://www.mathworks.com/, Accessed 7-21-2010

[19] M. Alahmad, Andrea Wilkerson, Josh Eiden, "Collaboration with Industry to Promote Energy Conservation and Education", Proceedings of the Annual American Society for Engineering Education (ASEE), Austin, Texas, June 14-17, 2009.