Integrating Energy Research in the Built Environment

Authors:

Dr. Avery Schwer, University of Nebraska, aschwer1@unl.edu
Dr. Mahmoud Alahmad, University of Nebraska, malahmad2@unl.edu
Dr. Dale K. Tiller, University of Nebraska, dtiller@mail.unomaha.edu
Patrick Wheeler, University of Nebraska, pwheeler@unomaha.edu
Adam Brumbaugh, University of Nebraska, abrumbaugh@unomaha.edu

Abstract — *North American electrical utilities face increased demand from the residential sector, and so have been sponsoring research to manage this growing demand to control the costs associated with power generation. This paper describes two ongoing projects at the University of Nebraska related to residential energy consumption. The first project evaluated the effectiveness of real-time electricity monitoring to reduce residential electricity consumption. Our project team installed three different electricity monitors in a sample of 151 houses, and compared electricity consumption in these houses with power consumed in a randomly selected sample of comparison houses. The second project evaluates a wide range of technologies that have been proposed for residential use in a living laboratory, the Zero Net Energy Test House (ZNETH). ZNETH is a house in Omaha NE that has been designed to produces more energy than it consumes. The house is nearing completion, and will be occupied by students sometime in the fall of 2010, when ongoing monitoring will commence to evaluate the performance of the innovative energy systems that have been installed in the house.*

Index Terms — *Energy use in the built environment, real-time monitoring, ZNETH*

REAL-TIME MONITORING

The existing power generation capacity available to the Omaha Public Power District (OPPD) is becoming insufficient to supply enough electrical power at peak times. Our team was contracted by OPPD to design and conduct a study to evaluate the effectiveness of real time monitoring as a method to decrease residential electrical energy and demand, in a sample of 151 residences in Omaha NE.

Several real-time power measurement devices are available to consumers. These devices offer electrical monitoring and display capabilities, and they are intended to provide users with information on electricity use such that this information prompts users to reduce their electrical power consumption. Different devices offer various monitoring and display capabilities and options: the goal of this work is to compare and contrast the effectiveness of three devices for reducing residential electricity consumption, that arise from changes in user behavior in response to feedback from the device.

The three devices included in the study were selected because they met several criteria. First, the devices had to be compatible with the Itron smart meters that are used throughout OPPD's residential service area. The devices also had to be relatively easy to install and use, offer quick feedback to the display in response to changes in power consumption inside the residence, all at an affordable purchase price. Six different devices (depicted in Figure 1) were initially considered for use in the study: two different versions of the the Aztech In-Home Display (Aztech), and the Power Cost Monitor (PCM) were selected for use in the study.

Figure 1. In-home energy displays from left to right: PCM, Aztech, Wattson, Ambient Orb, and Cent-A-Meter

The Aztech offers both cumulative and current kWh consumption and cost data. It is programmed to read the ERT digital signal generated by the Itron meter. The display updates in response to changes in power use with a 2-4 minute delay, and offers a range of statistical, graphical, and visual data on a residence's energy usage. The device is installed by plugging it in to a regular outlet in the house: once powered up, communication with the Itron meter is established by entering an identification number on the meter into the Aztec, which then searched for the signal from the meter. This step could take as long as 15 minutes, depending on the distance from the meter, but typically took around 5 minutes. The device includes a colored display bar along the top edge that can be programmed to display green, yellow or red, which is intended to act as a signal concerning the current residential or utility electrical profile. Two versions of the device were used.

In one sample of 50 houses (identified as AZ1), the colored display was programmed to change at specific times of day, to reflect intervals when utility demand is typically high. The display was green between the hours of 10:00pm and 7:59am M-F, (and remained green for 24 hours all Saturday and Sunday) when utility demand is usually low. It changed color to from green to yellow between the hours of 8:00am and 1:59pm (Monday to Friday). Finally, the display changed color from yellow to red between the hours of 2:00pm and 6:59pm (Monday to Friday), which are typically hours of peak electrical demand. By switching off or otherwise avoiding the use of electricity during times that the device display was red, homeowners would be helping the utility manage demand, and in jurisdictions with variable price structures based on time-of-use, they would help lower their own costs.

Another sample of 50 houses used a version of the Aztech device that had been programmed so the display color change occurred in response to historical electrical energy consumption data at that residence (identified as AZ2). The display was programmed to change color from green to yellow when the daily cumulative energy consumption reached 40% of the average daily summer consumption observed at that residence over the past three summers (historical data were provided by Omaha Public Power District): the display color changed from orange to red when the daily cumulative energy consumption reached 60% of the average historical summer consumption. The device was programmed to reset the color of the display to green each day at midnight. In this sample, color changes occurred at different times of the day in each house on each day. The signal from the device provided feedback to users on their own electrical use relative to past consumption patterns observed at that residence, rather than providing feedback about prevailing conditions at the utility.

The PCM display updates more quickly to changes in power use, with a latency of 2-5 seconds. The display offers both cumulative and current kWh and cost information as well as visual cues on how much power is being used. The fast response allows users to pinpoint the impact of individual energy users such as microwaves and clothes dryers. Installation requires placing a collar with an optical reader on the electrical meter that transmits data to an indoor display unit. The outdoor collar and batteries required for operation may limit wide application of the device.

PARTICIPANT SELECTION

All participants in the study were self-selected, having responded to a letter mailed by the OPPD soliciting volunteers for a study investigating the effects of real time feedback on residential electricity consumption. The response rate to the mailing was just over 10% (2,000 letters were mailed, 214 positive responses were received, and 152 devices were installed).

All installations were handled by a team of researchers, who scheduled appointments to deliver the real-time monitor to homeowners, explain the operation of the device, and answer any questions the respondent might have about the function of the device. Installations occurred over the months of May, June and July 2008. Scheduling appointments to install the devices was the most difficult aspect of this study.

All participants resided in an Omaha neighborhood that supported the operation of a wireless network that collected electrical power consumption data, resolved to 15 minute intervals, from individual meters installed at all houses in the neighborhood. This infrastructure automates the process of reading residential electrical power meters, periodically transmitting data to OPPD, who in turn provided the data to the research team on a monthly basis. Power consumption data were not always available for the complete sample of houses over the whole monitoring period, for a variety of reasons (power outage after a storm, failure of the fixed area network to collect and/or transmit data), however the number of such failures was relatively low. In the end, data were available from 47 houses equipped with the AZ1, 50 houses equipped with the AZ2, and 47 houses equipped with the PCM.

This area also included an additional 95 houses whose power consumption data are used by OPPD for load forecasting. Data from these residences were also provided to the project team by OPPD for use as a comparison sample, against which power consumption in the houses equipped with the real-time monitoring and feedback devices were compared. Each residence with a power monitoring device was matched with a randomly selected house from this sample of 95 comparison homes, and the power consumption over the same 30 day period was calculated and compared against the power consumption in the house equipped with the device.

MID-TERM MAINTENANCE

Once the devices had been installed and running for several months, the project team returned to each house to verify continuing operation of all devices. Several issues came up during these visits. It was important that the Aztechs display the correct time for the color change to occur at the proper time: by the time of the mid-term visit the devices were not displaying the correct time . This was due to the time change that occurred in the autumn, when clock time was changed to standard time from daylight saving time. In 37% of the Aztech's, a long duration power failure (greater than 5 hours) resulted in the loss of all data and programmed settings **.** The only setting that the device would remember was the ID number from the meter. Finally, the utility rate charge had changed since the time the devices were originally installed, and so the new rate had to be entered into all devices. As a result of these factors, 11% of the participants made the decision not to continue the study . In this occasion, an exit survey was distributed to the participants for them to complete. Each original participant that withdrew from the study was replaced with another participant.

FINAL REMOVAL

Once data collection was complete, and it was time to remove the devices, contacting participants to arrange for the removal was again an issue. After spending two months attempting to schedule appointments to remove devices, the team decided to make unscheduled visits, which proved to be a very effective strategy. At the end of the study, all but **N** devices were retrieved.

PRELIMINARY RESULTS

Figure 2 depicts the mean power consumption in houses with power monitoring devices, compared to power consumption over the same time period in randomly matched houses drawn from the comparison group of 95 homes in the first 30 days after the devices were installed in each residence.

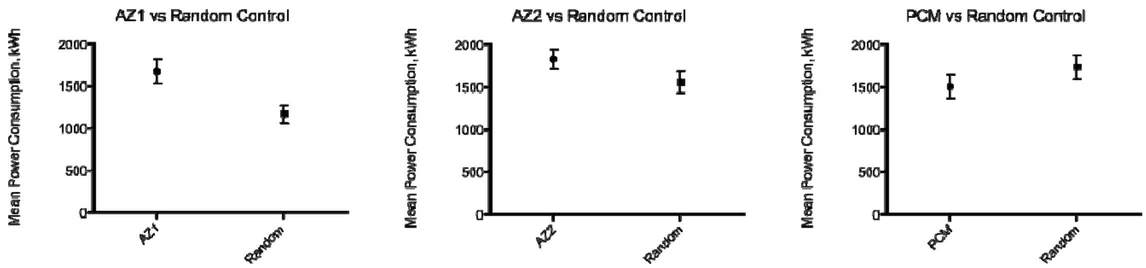

Figure 2. Mean power consumption (kWh) 30 days after device installation versus mean power consumption in randomly selected control houses (error bars are standard error of the mean)

Inspection of Figure 2 shows that the mean power consumed over the 30 day period immediately following the installation of either variant of the Aztech power monitoring device was higher compared to the power consumed over the same 30 day period in houses in the randomly selected control group. The mean power consumption over the 30 day period immediately following the installation of the PCM device was about 15% less than the mean power consumed over the same 30 day period in houses in the randomly selected control group. Although this reduction was similar in magnitude to results reported by investigators, our analysis showed that this was not a statistically significant reduction in power consumption..

ZNETH

The second initiative investigating residential energy consumption is the ZNETH house. This house is an 1,800 ft^2 (about 167 m^2) two story structure with another 1,000 ft^2 (about 93 m^2) in the basement. It has four bedroom three and a half baths. Construction is now nearing completion. This section describes the features and educational impact of the first phase of this ten-year research program, which has the goal of reducing the impact of new residential construction on the environment. The ZNETH will be used as a framework for research and education in the area of sustainable construction design and practices. This goal is accomplished through the following four objectives: 1. Design a ZNETH house in Omaha, Nebraska that produces more energy than it consumes; 2. Build a full scale ZNETH house using selected technologies and students from a variety of disciplines; 3. Monitor the house during occupation using automated monitoring, controls, diagnostics and soft-repair technologies, and; 4. Educate students, industry and the community on sustainable options through interactions with objectives 1, 2, and 3.

The interdisciplinary research and educational experience was present throughout the project with student involvement from both undergraduate and graduate programs. Programs that were directly involved include Construction Engineering, Construction Management, Architecture and Architectural Engineering. A number of other programs were peripherally involved during construction as part of course projects or service organizations.

Several courses used the ZNETH design as the central focus of their courses. Two Architecture classes used it as a design project. Two sophomore level Architectural Engineering courses used it for an entry level design project. Interdisciplinary Charrettes were organized to simulate real world situations and used to provide feedback for the final design. Over 100 students were involved in the project prior to breaking ground.

ZNETH BUILDING ENVELOPE

Construction Engineering and Construction Management students were involved in construction of the building envelop as part of a course or as a service project. Graduate students were project managers and organized construction, scheduled crews and ordered materials. Other student groups and courses used the ZNETH property for service learning exercises. The basement walls are 12 in (about 30 cm) Insulated Concrete Forms (ICF), as are three walls on the first level. The fourth wall on the first level, and all the walls on the second level, are 2 X 6 wood-framed walls.

The insulation in the wood framed walls is open cell soy-based foam on the first level, and closed cell soy-based foam on the second level. Soy-based insulation is applied using water, does not off-gas, and is moisture resistant, making it more environmentally friendly than some other alternatives (EMEGA, 2010). Typical residential construction is wood framed 2 X 4 walls. Typical fiberglass insulation in the 3.5 in (about 9 cm) cavity provides and R value of 11. Open cell soy-based insulation in the same space provides and R value of 12.6 or R3.6/in (about 2.5 cm). The equivalent space using closed cell would provide an R value of 23.8 or R6.8/in. This results in an R37.4 for the 2 X 6 walls using closed cell insulation. In addition the closed cell provides some additional structural support that allows 24 in (about 61 cm) spacing between studs reducing the amount of wood in the structure.

The ICFs selected were 12 in. (about 30 cm) wide configuration called Fox Blocks by Airlite Plastics Company (2008). They include a 6 in (about 15 cm) concrete core with 5.25 in (about 13 cm) of Expanded Polystyrene. The R-value of this configuration is 21.64 with an infiltration rate of .05 to .10 air changes per hour. This compares favorably to traditional 2 X 4 framing with batt insulation at an R-value of 11. The ICF wall system will not degrade over time and the materials are non-toxic and stable in high moisture environments. In addition, the ICF include a sound transmission class of 45 to 50 which indicates high sound insulating properties.

The exterior walls were covered with an Exterior Insulation Finishing System (EIFS) system. EIFS is a composite building system that incorporates insulation, waterproofing and a finish surface. It consists of a layer of expanded polystyrene (EPS) – 2.5 inches thick (about 6cm). The EPS is coated with a cementicious adhesive with an embedded fiberglass reinforcing mesh. This is covered by the finish coat that is applied with a trowel or spray to create a stucco-like finish. The Oak Ridge National Laboratory (Oak Ridge National Laboratories, 2008) found this system was more energy efficient and moisture resistance than wall systems with brick, stucco or cement fiber siding.

CONCLUSION

Future research in the field of real-time monitoring will further develop the usefulness of these devices in conserving electricity. This study showed a potential for decreasing energy consumption, but future studies should target more specific demand needs. With evidence shown for energy savings in residential applications, there seems to be the need for further investigation in small business and even commercial applications. This research would determine whether or not using RTMs in small commercial applications would provide any energy reduction. If small businesses are able to shift their demand in any significant manner it would be a large step in reducing the projected building of additional capacity at the utility. The study would further educate the public by having RTMs present in places of work and on display in the ZNETH project.

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