# Occupant participation in energy conservation

**Jean Wineman, Erin Hamilton**

University of Michigan, Ann Arbor, Michigan

ABSTRACT: The performance of energy efficient buildings and building systems relies not only on intelligent design and use of appropriate building technologies, but is also largely dependent on the ways in which these advances in 'smart' green building systems integrate with occupant use patterns to enhance overall life quality and support long-term behavioral transformation toward energy conservation practices.

Research has shown that while approximately half of the energy used in the home depends on the physical characteristics of a house and its equipment, residents and their behavior influence the balance (Janda 2011). Differences in individual behavior have been shown to produce large variations – in some cases as much as 300% - in energy consumption, even when controlling for differences such as housing, appliances, HVAC systems, and family size (Keesee 2005; Hawk et al. 1989).

This paper reviews our understanding of existing energy use patterns and adoption/utilization of energy conservation practices in residential and workplace settings. Our intent is to explore the critical human and social dimensions of sustainable building/community design, and to understand those characteristics that enhance inhabitant life quality and support long-term energy conservation practices. The paper reports on an initial phase of a project exploring how the use of embedded energy feedback technology is used to inform and support occupant energy conscious behavior.

KEYWORDS: Occupant Interface, Feedback, Energy Consumption

## INTRODUCTION

Buildings consume 72% of the electricity produced annually in the United States; this share is expected to rise to 75% by 2025 (EPA 2009). The character, composition and capacity of the building envelope and its relation to HVAC systems, is one of the most significant factors in defining the overall environmental performance and energy use of a building (Wigginton 2007; Wigginton and Harris 2002). As a great deal of the operational energy consumed by a typical building is dedicated to the provisions of comfort (heating, cooling, ventilation, humidity control, and lighting), designing multifunctional building envelopes and systems of operation that reduce HVAC demand, yet respond to occupant comfort and health has been identified as a research priority by the USGBC (USGBC 2008). While efficient equipment and advanced building envelope technologies can reduce this energy load, further energy conservation can be achieved by involving occupants *directly* in the control of comfort provisioning. Research has shown that while approximately half of the energy used in the home depends on the physical characteristics of a house and its equipment, residents and their behavior influence the balance (Janda 2011). Differences in individual behavior have been shown to produce large variations – in some cases as much as 300% – in energy consumption, even when controlling for differences such as housing, appliances, HVAC systems, and family size (Keesee 2005; Hawk et al. 1989). Social scientists have long recognized that motivations to consume or conserve energy are societal issues, arguing that deep social change is necessary to achieve real and lasting energy reduction in buildings (Keesee 2005).

When advances in envelope design/construction are combined with sensing and feedback-informed occupant control, significant reductions in overall building energy use can be achieved. The advance of digital technology integration into the physical components of building systems has the potential to promote the engagement of non-expert occupants with building system operation, and the internalization of sustainable patterns of behavior (Velikov and Thün 2010).

This paper begins with an exploration of the social issues involved in household energy consumption through a summary of a variety of behavioral interventions aimed to promote household energy conservation and durable behavior change. Results show that combinations of methods that provide targeted information about energy consumption, goal-setting and feedback are likely to result in more durable behavior change, including energy conservation behaviors. The paper concludes with a description of the initial phase of a project that examines the role of technologically integrated feedback in engaging building occupants in energy conservation behavior.

## 1.0 INFORMATION STRATEGIES

A common approach when attempting to influence behavior change is the dissemination of information. Interventions that emphasize information as the main predictor of environmentally responsible behavior do so with the assumption that a deficit in environmental awareness precedes the absence of the environmentally desirable behavior. In this theorized behavioral change system (Hungerford and Volk 1990), knowledge is expected to result in changes in awareness or attitudes about environmental issues, which in turn is expected to result in some action taken. From this perspective, information-based strategies can be particularly beneficial, especially considering a number of householders lack basic knowledge about energy conservation. A 2010 national online survey of household energy use revealed most participants were confused as to the most effective means for reducing household energy consumption (Attari et al. 2010). The majority of respondents reported they believed curtailment activities (like turning off their lights when not in use or lowering the thermostat) were more effective than efficiency improvements (like installing more efficient light bulbs and appliances). In contrast, efficiency improvements actually offer the highest potential for energy savings. However, it is generally acknowledged that curtailment behaviors can have significant impact on home energy emissions, as it is estimated that householders' adoption of simple everyday conservation behaviors could save up to "123 million metric tons of carbon emissions per year or about 7% of US national emissions" (Osbaldiston and Schott 2011, 281). Additionally, in contrast to technological efficiency, energy savings through behavioral change has the potential to spread across multiple contexts as energy-aware users begin to interact more conservatively in the environments they frequent every day.

### 1.1. Type of information

There are several categories of information or knowledge with respect to creating awareness of environmental issues (Kaiser and Fuhrer 2003). The first type is referred to as Declarative knowledge, which essentially seeks to create awareness of the environmental issue by defining the problem. Informational interventions that focus solely on declarative knowledge generally only result in increased levels of knowledge, which does not translate to behavioral change (Abrahamse et al. 2005). Declarative information about an environmental issue often must be accompanied by some Procedural information about how to achieve a particular conservation goal (Kaiser and Fuhrer 2003).

Understanding the purpose of different types of information is useful for knowing how to interject information into a basic model of behavior change involving three phases: the detection phase, decision phase, and implementation phase (Pelletier and Sharp 2008). For a person who is unaware that a problem exists (at the beginning of the detection phase), procedural information about how to reduce household energy conservation would be useless. Similarly, more declarative information about the nature of a problem would not motivate a person who is in the decision and/or implementation phases of behavior change (p. 212).

Research has shown that people desire access to procedural guidance with respect to energy conservation. In a 1996 study, 83% of respondents indicated that accurate information of how to reduce the electricity consumption of their appliances would help them to reduce their household's electricity bills (Mansouri, Newborough, & Probert, 1996, p.260). In addition to desiring information at the point of purchasing a more efficient appliance, householders desire procedural knowledge about how they might more effectively change their daily behavior to conserve energy, suggesting that householders derive pleasure in the self-interested pursuit of exhibiting their competency or efficacy in these tasks (Parnell and Larsen 2005).

### 1.2. Form of information

In a review of 41 intervention studies, Ester and Winett outline a number of characteristics pertaining to the effective dissemination of information. A cited weakness of this strategy is the pervasive use of the written medium alone and the use of information as the singular point of intervention. Informational interventions are strengthened when the information is about specific behaviors (i.e., procedural information that highlights simple, yet detailed behaviors to try to conserve energy), convenient behaviors and salient to the receiver of the message (emphasizing the importance of message tailoring, where applicable) (Ester and Winett 1982).

In general, results have shown that information strategies are useful for increasing knowledge about an issue, but information strategies alone rarely account for actual behavior change or energy savings. Approaches utilizing an information-based intervention can be effective for reducing household energy consumption, especially when used in conjunction with other approaches including goal-setting and feedback (Abrahamse et al. 2005).

## 2.0. USER FEEDBACK

### 2.1. Form of feedback

For the everyday householder, feedback about energy consumption is an important component in attempts to conserve energy. Yet the effectiveness of this type of information is often far from ideal in terms of optimizing users' energy conservation. In general, there are three types of household energy feedback: 1) direct feedback in the home (in the form of electricity meters), 2) indirect feedback in the form of a monthly utility bill about total energy used and 3) inadvertent feedback, which is a by-product of technological, household or social changes. Direct feedback involves the greatest potential for energy reduction, specifically offering the highest savings potential when linked to an individual appliance (Darby 2000).

One of the central problems with the majority of feedback householders receive is the lack of itemized information that details the usage of each appliance, according to certain times of day. This has been likened to trying to shop for groceries and only receiving a bill for the total sum rather than for each individual product (Fischer 2008). In an extensive literature review of several international studies utilizing feedback to promote household energy conservation, Fischer highlights numerous characteristics of successful feedback. The medium and mode of presentation is particularly important. Computerized feedback with multiple options available according to the user's choice presented in an aesthetically appealing format (a balance of text and graphics) has been shown to be an important characteristic. Detailed, appliance-specific breakdowns of information presented very frequently are also effective. (Note: No studies with feedback offered less than monthly have been effective. Daily and more frequent feedback have shown the greatest results in energy reduction.) Additionally, studies have shown the importance of combining frequent, appliance-specific feedback with procedural information about ways to reduce energy consumption (Brandon and Lewis 1999).

### 2.2. Feedback and goal-setting

Testing the combined effect of feedback and goal-setting, Becker (1978), asked 40 families to set a difficult energy conservation goal of 20% and 40 families to set an easy goal of 2%. Within each of these groups, half of the families received feedback (three times per week) and half only received feedback at the end of the intervention. Twenty families served as a control group who only received information about energy conservation. The combined effect of feedback and goal-setting was supported, as only the 20% goal combined with the feedback condition statistically differed in energy conservation from the control group.

Building on the work of Becker (1978), McCalley & Midden (2002) tested the efficacy of product-integrated feedback and goal-setting on household energy conservation in a simulation study wherein participants could enter an energy conservation goal into a washing machine interface and receive energy feedback in real-time. Expanding on Becker's work, participants were either assigned a conservation goal or were responsible for self-setting a conservation goal. The results of the study conclude that product-integrated feedback, when combined with a means for the user to set an energy conservation goal, offers an effective means for energy conservation.

In summary, while a number of techniques offer effective results, no single approach has been shown to affect durable conservation behavior change. Rather, the research suggests that interventions adopting a combination of tactics, including detailed, specific declarative and procedural information and goal-setting with frequent, specific feedback are likely to result in the greatest conservation effects (Abrahamse et al. 2007)

### 2.3. Feedback and technology

With advances in the research have also come significant advances in material and computer technologies that define the nature of the feedback systems available. The research has been evolving to include emerging technologies of iPhone applications, social networking sites, and Internet energy dashboards. Advances in technology have now opened doors to the study of the effectiveness of fine-grained energy information that allows consumers to increasingly connect energy use to specific sources in the environment (Froehlich 2009). Much research has focused on the nature of the feedback, often manipulating variables such as frequency, content, access, and even information about social norms.

As a follow-up to a study that involved users in setting goals and receiving feedback on a simulated washing machine interface, Midden and Ham (2006) explored the effect of social, in addition to factual, feedback via a robotic agent displayed on the machine interface. The social feedback via the robotic cat, which gave visual positive and negative feedback to users, resulted in the strongest persuasive effect on energy conservation. Exploring the ways less overt modes of feedback might influence user energy conservation, Maan et al. (2010) employed ambient lighting changes to provide users with subtle, less cognitively demanding, cues about positive and negative energy performance. The results indicated that the feedback through ambient lighting had a stronger persuasive impact than factual numerical feedback.

The North House Project (Velikov and Bartram 2009) explored both the technical and the human dimensions of energy consumption. The project involved the development and construction of a prototype high performance, energy producing home which incorporated advanced technologies that not only functioned to manage building energy, resources, and comfort, but also make it possible for inhabitants to actively participate in the operation of the home in order to achieve their environmental goals.

The ALIS (Adaptive Living Interface System) developed for the North House project, incorporates multiple modes of graphic user interface to provide occupants with energy systems control and feedback, as well as architecturally integrated devices that signal resource use in haptic and ambient ways. In addition the system provides social motivation tools to foster sustainable patterns of living.

The ALIS was integrated with automated building controls and sensing systems that optimized energy and water use in the home. ALIS provided feedback and control through an array of interfaces that used web browsers on both building embedded displays and home computers; a mobile application; and ambient feedback displays embedded in the house (such as the Ambient Canvas described below). The ALIS allowed users to control all aspects of the interior environment (ie. override automated systems) including lights, temperature, humidity, ventilation, as well as privacy, daylight, and glare through the interior blinds and exterior shades. Feedback and control could be personalized for individual users. Users had the opportunity to set personal milestones and challenges, and the system also included a community interface to encourage collaboration/competition.

An additional feature of ALIS, described by Velikov and Bartram (2009), was the Ambient Canvas. “In an age of information overload, there is increasing interest in the cognitive value of “calm technology,” that is, technology and information that inhabits the periphery of human attention, and that provides attunement to conditions without requiring attentive focus” (Weiser and Brown 1997). The Ambient Canvas is an information display that was embedded in the kitchen backsplash of North House that provided ambient feedback (through color changes) on levels of energy consumption. This subtle feedback system promotes awareness of resource use to assist and influence sustainable decision-making.

A continued pressing area of research in need of advancement is the development of new forms of occupant interface, such as those developed for the North House project, to enable meaningful information exchange between systems and users. In order for building systems to realize the potential of embedded intelligence promised by advanced sensing and computational integration, it is critical that users are able to interact with systems in didactic, real-time, and projective modes. User interface systems support tasks to help occupants control building systems (through touchscreen development, smartphone applications, web applications and community networks). 'Tools' should integrate with use patterns (coordinated with online tools, messaging, calendars, etc.) and provide meaningful performance feedback that supports long term behavioral transformation.

An example of a current research project on the use of embedded intelligence to inform and support occupant energy-conscious behavior is described below.

### 3.0. THE INTEGRATED RESPONSIVE BUILDING ENVELOPES (IRBE) PROJECT

The Integrated Responsive Building Envelopes (IRBE) study (Lynch and Thün 2011) explores the development and implementation of environmental sensing/feedback systems and occupant responses/behavior related to energy control systems and daylight strategies in a test-bed office building on the UM campus. To optimize sustainable system performance, a portion of the project (with involvement of the authors on the research team, and K. Velikov from the North House project) explores how users interact with sustainable systems and ways to augment sustainable behavior through educational materials. The project examines ways in which integrated controls and feedback mechanisms in buildings can be designed to support and even transform behavior of building inhabitants toward more sustainable patterns of living and building use habits.

The first step of this project was the administration of a survey to all occupants of exterior offices in the building to understand how they perceive and interface with energy control systems and daylight strategies in the building. The survey included a set of questions related to satisfaction with environmental features and performance (including natural and artificial lighting, glare, environmental control features (opening windows, thermostats, etc.) and so forth), as well as occupant knowledge related to the building and its energy conscious features.

We also conducted walk-throughs of office use. During the same time period as the survey was administered, members of our research team walked through selected portions of the building recording occupancy, behavior (for example use of space heaters, lights left on in unoccupied spaces, weather appropriate clothing), and operation of building control systems (open windows, thermostat settings, position of window blinds, etc.). Any other occupant interventions for environmental control (blocking vents, covering windows, use of portable space heaters/fans or other devices, individual desk lights and so forth) were noted. We also recorded temperature, light, and humidity readings for each office. These methods (survey, walk-throughs, measurement) will be administered in summer, fall, and winter to assess any seasonal effects. To date we have administered the fall walk-through and survey.

Walk-through results indicated that all window blinds were in the fully down position, except for less than 10% of offices. Occupants appeared to adjust the position of the blind slats to adjust environmental conditions. 70% of blind slats were fully opened on the North side (20% partially or fully closed); a similar percentage on the West side had blind slats either fully open or partially open (31% partially or fully closed). 40% of blind slats were partially or fully closed on both the East and South sides of the building. Since the walk-through took place between 10 am and noon, the position of the blind slats on the East and South sides of the building may have been influenced by sunlight.

The majority of occupants turned overhead lights on when they occupied the office. This ranged from all overhead lights on in occupied offices on the East and North sides; 88% in occupied offices on the West side; and 75% of occupied offices on the south side. 44% of unoccupied offices on the North side had lights on; 25% unoccupied offices on the South side; 19% on the West side; and none on the East side (although some of these offices may have been only temporarily unoccupied).

Thermostats in the building control banks of multiple offices, while individual occupants have control of individual air vents. None of the individual office air vents were turned off or blocked. Portable heaters were observed in 25% of North facing offices, and 10% of East facing offices. Portable fans were observed in several offices, but none were in use. Average office temperature recorded was 22.7; for East facing offices, recordings averaged about .5 degrees higher noted during the walkthrough (10 to noon). Average humidity readings were 50.2% for North and East facing offices, and 51.8% for South and West facing offices.

Results of the initial surveys indicate that the majority of occupants are satisfied with the operability of office control systems and generally satisfied with office environmental conditions. It appears that there is potential for educational intervention regarding energy conservation strategies related to building energy systems and the use of overhead lights.

A separate portion of the IRBE study involves the design and implementation of sensing systems integrated into the physical components of building systems. From the behavioral perspective, we will again study occupant energy behavior following the installation of these feedback systems. We will also provide educational materials regarding energy conserving behavior, and explore this intervention as a means to promote long-term sustainable behavior.

## CONCLUSION

Critical human and social dimensions of sustainable building and community design have the potential to support long-term energy conservation practices. Research suggests that interventions adopting a combination of tactics, including detailed, specific declarative and procedural information and goal-setting with frequent, specific feedback are likely to result in the greatest conservation effects. Feedback systems such as the ALIS introduced in the North House project offer exciting possibilities. The intent of the IRBE study is to begin to test approaches to the integration of new technologies within the building system that engage occupants with building system control and feedback, encourage energy conservation, and lead to durable behavior change.

## ACKNOWLEDGEMENTS

We are grateful to the Office of the Vice-President of Research, Taubman College of Architecture + Urban Planning, and the College of Engineering at the University of Michigan for the funding of this project. We are additionally thankful for the collaboration of interdisciplinary minds from the fields of Architecture, Engineering and Natural Resources who have come together to form the project team.

## REFERENCES

Abrahamse, Wokje, Linda Steg, Charles Vlek, and Talib Rothengatter. 2005. “A Review of Intervention Studies Aimed at Household Energy Conservation.” *Journal of Environmental Psychology* 25 (3) (September): 273–291.

———. 2007. “The Effect of Tailored Information, Goal Setting, and Tailored Feedback on Household Energy Use, Energy-Related Behaviors, and Behavioral Antecedents.” *Journal of Environmental Psychology* 27 (4) (December): 265–276.

Attari, Shahzeen Z, Michael L DeKay, Cliff I Davidson, and Wändi Bruine de Bruin. 2010. “Public Perceptions of Energy Consumption and Savings.” *Proceedings of the National Academy of Sciences of the United States of America* 107 (37) (September 14): 16054–9.

Becker, Lawrence J. 1978. “Joint Effect of Feedback and Goal Setting on Performance: A Field Study of Residential Energy Conservation.” *Journal of Applied Psychology* 63 (4): 428–433.

Brandon, Gwedolyn, and Alan Lewis. 1999. “Reducing Household Energy Consumption: A Qualitative and Quantitative Field Study.” *Journal of Environmental Psychology* 19: 75–85.

Darby, Sarah. 2000. “Making It Obvious: Designing Feedback into Energy Consumption Sarah Darby Environmental Change Institute, University of Oxford.” In *2nd International Conference on Energy Efficiency in Household Appliances and Lighting*.
EPA. 2009. “Buildings and Their Impact on the Environment: A Statistical Summary”. Washington, DC.
Ester, Peter, and Richard A. Winett. 1982. “Toward More Effective Antecedent Strategies for Environmental Programs.” *Journal of Environmental Systems* 11 (3): 201–221.
Fischer, Corinna. 2008. “Feedback on Houshold Electricity Consumption - a Tool of Saving Energy.” *Energy Efficiency* 1: 79–104.
Froehlich, Jon. 2009. “Sensing and Feedback of Everyday Activities to Promote Environmentally Sustainable Behaviors.” *UbiComp*.
Ham, Jaap, and Cees Midden. 2006. “A Persuasive Robotic Agent to Save Energy : The Influence of Social Feedback , Feedback Valence and Task Similarity on Energy Conservation Behavior.” In *Social Robotics*, edited by S.S. et al. Ge, 6414:335–344.
Hawk, D., L. Schipper, S. Bartlett, and E. Vine. 1989. “Linking Life-Styles and Energy Use; A Matter of Time.” *Annual Review of Energy* 14 (1): 273–320.
Hungerford, Harold R, and Trudi L Volk. 1990. “Changing Learner Behavior through Environmental Education.” *Journal of Environmental Education*. Heldref Publications. http://psycnet.apa.org.proxy.lib.pdx.edu/psycinfo/1991-02699-001.
Janda, Kathryn B. 2011. “Buildings Don’t Use Energy: People Do.” *Architectural Science Review* 54 (1) (February 1): 15–22.
Kaiser, Florian G, and Urs Fuhrer. 2003. “Ecological Behavior ’s Dependency on Different Forms of Knowledge.” *Applied Psychology: An International Review* 52 (4): 598–613.
Keesee, M. 2005. “Setting a New Standard - the Zero Energy Home Experience in California”. Sacramento.
Lynch, Jerome, and Geoffrey Thün. 2011. “Integrated Responsive Building Environments.”
Maan, Saskia, Bo Merkus, Jaap Ham, and Cees Midden. 2010. “Making It Not Too Obvious: The Effect of Ambient Light Feedback on Space Heating Energy Consumption.” *Energy Efficiency* 4 (2) (December 3): 175–183.
Mansouri, Iman, Marcus Newborough, and Douglas Probert. 1996. “Energy Consumption in UK Households: Impact of Domestic Electrical Appliances.” *Applied Energy* 54 (3) (July): 211–285.
McCalley, L.T, and Cees J.H Midden. 2002. “Energy Conservation through Product-Integrated Feedback: The Roles of Goal-Setting and Social Orientation.” *Journal of Economic Psychology* 23 (5) (October): 589–603.
Osbaldiston, R, and J P Schott. 2011. “Environmental Sustainability and Behavioral Science: Meta-Analysis of Proenvironmental Behavior Experiments.” *Environment And Behavior* 44 (2) (April 19): 257–299.
Parnell, Rosie, and Olga Popovic Larsen. 2005. “Informing the Development of Domestic Energy Efficiency Initiatives: An Everyday Householder-Centered Framework.” *Environment and Behavior* 37 (6) (November 1): 787–807.
Pelletier, Luc G., and Elizabeth Sharp. 2008. “Persuasive Communication and Proenvironmental Behaviours: How Message Tailoring and Message Framing Can Improve the Integration of Behaviours through Self-Determined Motivation.” *Canadian Psychology/Psychologie Canadienne* 49 (3): 210–217.
USGBC. 2008. “A National Green Building Research Agenda”. Washington, DC.
Velikov, K, and L Bartram. 2009. “North House: Developing Intelligent Building Technology and User Interface in Energy Independent Domestic Environments.” In *26th Conference on Passive and Low Energy Architecture*. Quebec.
Velikov, K., and Geoffrey Thün. 2010. “Responsive User Control Systems for Developing User Intelligence.” In *Proceedings of ISES Renewable Energy Proceedings*, 763–771. Yokohama.
Weiser, Mark, and John Seely Brown. 1997. “Less [intrusion] Is More [useful].” *Computerworld*, February.
Wigginton, M. 2007. “Glass Architecture and the Interactive Building Envelope Principles and Precedent.” In *EU COST C13 Glass Architecture and the Interactive Building Envelope: Final Report*, edited by M. Crisinel, M. Eekhout, M. Haldimann, and R. Visser. London: IOS Press.
Wigginton, M., and J. Harris. 2002. *Intelligent Skins*. London: Architectural Press.