RESEARCH SCOPING REPORT : VISUALIZING INFORMATION IN COMMERCIAL BUILDINGS

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ABSTRACT

New data acquisition technologies and information visualization methods provide great opportunities to monitor and display building performance data. Together they provide the building industry with the potential to give feedback to commercial building occupants, managers, and other parties, and to encourage energy-saving behaviors.

A great deal of research has been conducted to evaluate the potential for energy conservation using information feedback to influence occupant behavior in residential buildings. Results of these studies show that immediate energy feedback from meters or display devices can provide savings of 5-15%. However little research has been conducted on such feedback in commercial buildings, which present a greater challenge due to their greater complexity.

Researchers at CBE propose to contribute to this information gap by conducting research on effective visualization of building information in commercial buildings. The goals of this work are: (1) to identify the optimal methods for displaying building performance information, in order to influence commercial building occupants to reduce resource use; and (2) to identify methods to provide actionable information in order to assist building operators in achieving improved building performance; (3) to develop methods to include occupant feedback in these information displays, based on previous work conducted at CBE on occupant comfort and workplace satisfaction; and (4) to develop and test user interfaces for building data with various building stakeholders.

INTRODUCTION

Since its launch in 2000, the Leadership in Energy and Environmental Design (LEED) building rating system has become an key driver in the design of energy-efficient buildings. However a significant shortcoming of LEED is that as currently applied to new construction and major renovations, compliance with energy performance targets is based only on modeled energy use, with no requirement for documentation of actual performance in terms of resource consumption or indoor environmental quality. Initial research on actual energy performance in LEED buildings shows that modeled energy use in an unreliable predictor of actual performance (Diamond et. al., 2006).

Aggressive new energy policies will require far better building energy performance than currently required by LEED. For example, the U.S. Energy Independence and Security Act of 2007 (EISA

2007) will require new and renovated federal buildings to achieve carbon neutrality by 2030, and has set a goal of net-zero energy for all new commercial buildings by that date. The state of California has adopted policies requiring new residential construction to meet zero-energy targets by 2020, and commercial construction to be zero-energy by 2030.

In order to meet these goals in practice, commercial buildings will require continuous measurement and performance verification. Building managers will require access to accurate and useful information about building operations in order to effectively manage operations. To be most effective, information provided to facility managers must be actionable (Granderson, et. al., 2009). In addition, we propose that building occupants need to be engaged in ways that that allow them to positively contribute to the overall effective operations of a building. The potential benefits of engaging occupants of commercial buildings to improve building operations has been investigated in previous research from UC Berkeley (Federspiel and Villafana 2003).

A great deal of research has been conducted to evaluate the potential for energy conservation using energy information feedback to influence occupant behavior in residential buildings. However little research has been conducted on such feedback in commercial buildings. Researchers at CBE propose to contribute to this information gap by conducting cross-disciplinary research which will bring together diverse viewpoints, including building energy engineering, human-computer studies, and psychosocial behavioral factors. This report provides background on the nature of the problem, and our proposal for an initial phase of this research.

ADVANCES IN INFORMATION VISUALIZATION

Information technologies have advanced at a rapid rate, providing novel applications and methods for aggregating and visualizing information. Powerful information visualization websites such as those created by Martin Wattenburg of IBM’s Visual Communication Lab invite users to explore and customize data displays. One of Wattenburg’s early web applications is the *Map of the Market* he developed in 1998 for SmartMoney’s website. This tool provides a view of over 500 publicly traded stocks on a single screen, providing users with an overview of current trends and allowing them to quickly identify and drill down on relevant details. According to Wattenburg, financial professionals frequently use the site as a tool when discussing with colleagues stock market activities and trends (Note 1).

Adapting data visualizations to address non-technical audiences, media artists are exploring the idea of using building energy data to create *eco-visualizations* that make the invisible information of building performance visible to building users and the general public. Tiffany Holmes, a media artist and faculty member at the School of the Art Institute of Chicago, developed a public artwork project for the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign, that will dynamically display the building’s carbon footprint with a numerical value and graphical representations. The public art piece will also allow building occupants to commit to purchasing carbon offsets or taking actions to reduce their personal carbon footprint. (Holmes 2007) The project team is evaluating the results from the installation and will plans to release them for publication by the fall of 2009 (Note 2).

A pilot installation using energy *orbs* illustrates another non-conventional method of providing energy feedback to building users. In an effort to show building users the current energy demand and cost, a globe with internal glowing LEDs was programmed to change colors to represent off-peak (blue), peak (green), and super-peak (red). The device was also programmed to display flashing red for four hours preceding a super-peak period. The project report indicates that the orbs generated interest among customers who viewed them (Stein 2004). The energy orbs are an example of *calm technology*, a concept developed at Xerox PARC, which provides information at the periphery of users’ attention, allowing the information to be available without distracting from users’ central attention.

Unfortunately the building industry has not been a leader in the information revolution. CBE's industry members, which represent a broad cross section of the industry, lament a number of control-related challenges including outdated control systems and the slow adoption of common data protocols. As a result, many building industry professionals say that they have limited resources for monitoring and improving energy and resource consumption in buildings. However, preliminary research conducted by CBE revealed a robust commercial interest in the development of energy measurement and display software, and several companies are developing and implementing new products to capitalize on this industry need. (Lehrer 2009) With increased commercial interest in energy efficiency and carbon reduction programs, combined with new availability of clean tech venture capital funding, we cab assume that this area will be rapidly evolving.

USING INFORMATION FEEDBACK TO INFLUENCE OCCUPANT BEHAVIOR

Since the 1970s a large number of studies have been conducted in North America and Europe to investigate the potential for use of improved energy feedback to encourage building occupants to reduce their energy consumption. The great majority of these studies have been conducted in residential buildings, and have used varying methods and/or combinations of feedback, commitment, goals, tailored information, and rewards. A frequently cited review of these studies indicates that immediate energy feedback from meters or display devices generally provide savings of 5-15%, and that historic feedback is may be more effective that normative feedback. (Darby 2006). However other reviews of feedback studies find that normative feedback that allows for comparison to other households is valuable to many customers (Roberts and Baker, 2003). As an example of one of the early energy feedback studies, researchers used simple paper displays posted in acrylic holders on kitchen windows to provide daily feedback of energy use to residents. Once-daily feedback was presented to the study group in terms of a percentage of an energy used compared to a predicted usage based climate and past energy use for each home. Compared to the control group, the feedback group reduced electrical use by 10.5% (Seligman and Darley, 1977).

A more recent study compared energy use in 17 homes that had been provided with commercially available *The Energy Detective* (TED) energy displays. The TED devices show current and cumulative energy use with 10W resolution, updated every second. The effect of the feedback provided by the TED was an average energy reduction of 7%. A follow up survey of occupants showed that respondents that expressed an interest in the devices saved 13%, compared to the 2.6% savings of respondents that showed less interest and motivation (Parker, et. al., 2008).

The large repository of such studies provides a useful resource, and have been evaluated and digested at great length by researchers of environmental psychology. A team of psychology faculty at the University of Gronigen (Netherlands) evaluated 38 peer-reviewed studies from 1977 to 2004, provided narrative summaries and a tabular presentation of findings, and made recommendations for improving intervention studies (Abrahamse, et. al. 2005).

One area that has been largely overlooked in these studies is an evaluation of what types of information would be of value to building users, and how best to present it. The studies mainly focused on the effect of the presence of feedback, not on the quality of the display; nor did researchers attempt to optimize the way information was displayed. This has been described as a surprising oversight, and overlooks educational theory that tells us the people have diverse preferences viewing information and learning. (Roberts and Baker, 2003).

Furthermore, with implementation of smart energy meters and other technologies that allow for more accurate and immediate feedback, and with the capability of using dynamic methods of displaying information, Current browser-based technologies provide extraordinary opportunities for engaging energy users and customizing displays for different groups or even individual users. Considering recent technological advances such as social networks and user-created content sites frequently described as "Web 2.0" , along with the capabilities offered by new types of sensor networks, we might reasonably question the relevance of the older feedback studies in today's technological context.

Computer-human interaction studies have demonstrated that subtle changes in computer interfaces can have an impact on how we perceive our experiences with technology, and provide insight in how we may best influence eco- or energy-related actions. One such study suggests that people prefer computer interfaces that demonstrate personalities types similar to their own. This study of 48 subjects tested interfaces that made recommendations with either dominant or submissive language styles. Subjects that used software with language styles with personalities similar to themselves found the experience more satisfying (Nass et. al. 1995). Another study found our interactions with computers may be subject to social norms that shape our interactions with other humans, and common norms of politeness influence may the behavior of computer users. For example, people tend to be less critical when making direct evaluations (in this case of computer products) as opposed to indirect evaluations (Nass et. al. 1994).

Faculty and students at the Stanford Persuasive Technology Lab are exploring the persuasive potential of new technologies, and have coined the term *captology* for "computers as persuasive technologies." Within the concept of captology, technology products can be considered persuasive elements by providing users with useful tools, media experiences, or by serving as social actors. These technology products may vary in their ability to persuade by the degree to which they are perceived as credible by users. (Fogg, 2003).

COMMERCIAL BUILDING VISUALIZATION PRODUCTS

Several software development are working to bring new visualization and social networking capabilities of Web 2.0 products for displaying building information in a compelling manner, providing features and interfaces tailored for building owners, operators, and occupants.

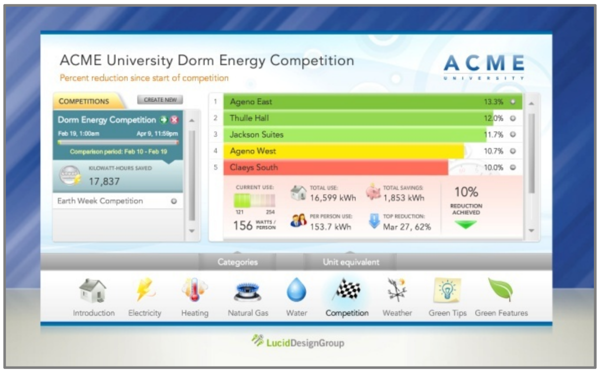
Distinct from conventional Building Automation Systems (BAS), these information displays typically do not provide detailed system operation such as equipment status or operation. Instead they have been developed primarily to visually display trend data, allowing for historical and normative comparisons. Many allow users to view energy and water use in terms of metrics that are the most relevant to their interests, including energy, cost and carbon emission equivalents. Some allow users to translate energy data into understandable common units, such as light bulbs, dollar cost, or pounds of carbon dioxide.

In January of 2009, CBE conducted interviews with management representatives from four software companies that offer commercially available building feedback products: Lucid Design Group, Agilewaves, Small Energy Group, and Quality Automation Graphics. The objective of this preliminary investigation was to understand the main capabilities of the products, the types of visualizations they provide, and any energy savings results that have been reported by users.

Although each company had implemented a relatively modest number of sites, the managers interviewed report that their products are being rapidly adopted by clients, and expect to see continuing growth in the future. In the section below we provide an overview of the interview findings. (Installation numbers given represent those at the time of the interview, and have likely increased since that time.)

Company: Lucid Design Group, Oakland CA; http://www.luciddesigngroup.com
Contact: Michael Murray, CEO

Lucid Design Group's Building Dashboard has been implemented in commercial buildings, multi-unit residential buildings, and notably to monitor energy saving competitions among dormitory residents. The company' products have been developed primarily for use by building occupants, and secondarily by facility managers. The firm has installations at over 30 sites, including commercial buildings, multi-unit residential buildings, and dormitories. Installation and setup costs range from $10,000 to $50,000, using software and/or data acquisition gateways which send energy, gas, and water data to Lucid's servers. The company reports that some dorm competitions resulted in savings in the range of 5-25%, and that the most successful competitions used outreach methods to involve dorm residents, as the feedback systems alone tended not to be sufficient (Figure 1).



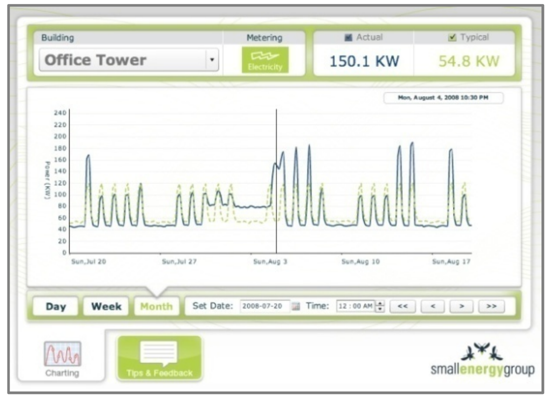


Figure 1. Sample interface from Lucid Design Group, showing results of dorm energy competition (left). Time series data interface for a prototypical office building from Pulse Energy (right).

Company: Small Energy Group, Vancouver B.C.; http://www.pulseenergy.com/
Contact: David Helliwell, President

Pulse Energy provides a suite of three products which include: (1) the Occupant Engagement Dashboard, an educational tool for occupant feedback; (2) the Facility Manager Application, which provides detailed trend data for facility managers; and (3) the Executive Reporting Application, which offers various outputs for management and carbon reporting requirements. The Dashboard and Manager tools include current load profiles and baseline comparison profiles. The baseline profiles correct for weather and other variables so that occupants can accurately determine the impact of energy conservation initiatives. At the time of our interview the firm had completed approximately 15 buildings, and reported that an additional 80 buildings would be added in the near future, including those at the University of British Columbia (UBC) in Vancouver. The company reported that some clients have made significant energy savings which they attribute to the use of the software. As an example, facility managers of Buchanan Tower at UBC worked with Small Energy Group staff to identify possible savings, and reduced average energy use by 15kW, a 25% reduction in the base load, during both day and night.

Company: Agilewaves, Menlo Park, CA; http://www.agilewaves.com
Contact: Peter Sharer, President

Agilewaves reports that it has completed approximately 24 installations including single-family residences, multi-unit residence buildings and commercial buildings. The company describes its products as a flexible platform that can monitor gas, electricity, water, and other metrics, and can provide both hosted and hybrid solutions. They are working on integrating their products with BAS products to provide messaging and some control functions, and their products are compatible with BAS software from Crestron, AMX, Honeywell and Johnson Controls. At the time of the interview many of the company's installations had not been monitored long enough to report energy savings, however one homeowner reported savings of 50% attributed to the software, and another user reduced water consumption by a third (Figure 2).

Figure 2. Sample user interface designs for schools by Agilewaves (left) and Quality Automation Graphics (right).

Company: Quality Automation Graphics, Ankeny, IA; http://www.qagraphics.com
Contact: Dan McCarty, President

Quality Automation Graphics has a history of designing user interfaces for building control clients such as Johnson Controls and Tridium. Unlike the three products described above, QAG's data visualization products are not hosted solutions. The company provides software that is installed on clients' servers, and managed by clients' IT staff. The system relies on a Lynxspring gateway, which connects to the buildings' BAS, and is installed by the client's contractor or controls provider. The system is based on open source products and works will all BACNet, MSTP, or LonWorks BAS. It utilizes a Flash front end with HTML, with a MySQL database. Clients can purchase the Flash files (fla) and/or the source code files (swf).

The company reports that it has completed approximately 35 installations of its Energy Efficiency Education Display at commercial and institutional buildings including several schools and libraries. Although installations have ranged from $5000 to $50,000, the company's basic package with data gateway hardware, a flat panel touchscreen, CPU and embedded software costs approximately $15,000.

USING SOCIAL NETWORKING PRODUCTS FOR ENERGY CONSERVATION

The Web 2.0 phenomenon includes the rapid adoption of new social-networking websites, and the integration of social networking features into existing sites. Facebook now has over 200 million active users, with users over 35-years old representing the fastest growing demographic , according to company's statistics (Note 3). Such social-networking sites have been used for peer-to-peer diffusion of ideas, to generate interest in social causes, and are now being adapted as persuasive technologies to encourage energy and resource conservation.

A number of intervention studies have demonstrated that public commitment can be an effective means to promoting energy-conserving behavior. One such study tested the effects of public commitment among 23 commercial/industrial building owners in Michigan. A group of "mild commitment" building owners were told that their participation in the program would be announced via a full-page advertisement in a local newspaper. The participation of "strong commitment" building owners would likewise be announced in advertisements, however the ads would include the actual savings of the firms. Although both groups saved more natural gas than a control group, the mild commitment group saved more energy than the strong commitment group. There was no significant reduction in electrical energy use, possibly because owners resisted lowering light levels for product or display areas. Although the study included only a small number of sites, it concluded that the "simple public acknowledgement of energy conservation efforts appears sufficient to bring about energy conservation" (Shippee and Gregory 1982). A study of 90 homeowners in Oregon compared the results of subjects that either received energy questionnaires, made commitments to reduce electrical usage, and/or were offered monetary incentives. Approximately 74% of the homeowners in the commitment and combined groups reduced their energy consumption, and saved more energy that other groups, including the incentive group (Katzev and Johnson 1984).

The New York software development firm Efficiency 2.0 has created websites for *Climate Culture* and *America's Greenest Campus* programs, and is currently working with utilities and other customers to implement online software to will allow residential customers to share information about their energy use, and compare it with other households. The company's *Personal Energy Advisor* will allow users to track energy use, and to establish and track energy and water savings targets. The company plans to provide data views in terms of cost, carbon, peak usage, and other metrics.

Based on information provided through surveys, the *Personal Energy Advisor* will also make tailored suggestions to help customers reduce their water and energy use and associated costs. The company also plans to integrate its software with social media software will enable users to compare their household energy usage with other homes in the same area, connect with other users through blogs, messaging, and groups. At the time of this writing the company is working on contracts with major utilities that represent approximately two-million residential customers, and expects to see conversion rate of 2-5% of these customers into active users, or 40 to 100 thousand users (Note 4).

USING PERFORMANCE FEEDBACK IN COMMERCIAL BUILDINGS

The majority of intervention studies conducted on energy feedback have been conducted in residential buildings. (The paper by Shippee and Gregory, 1982, is one of the few exceptions.) The reason for this research inclination is clear: in residential buildings, building occupants exert complete control over building controls, and their actions greatly impact energy use. For example, a study of ten identical homes built by Habitat for Humanity, having identical appliances and equipment, found that energy use varied by a factor of 2.6 to 1 (Parker et. al. 1996). Another study of 11 solar homes in Sacramento, California also revealed a wide diversity of energy use. One home had a negative energy cost by producing more energy that it consumed, whereas the most energy intensive home in the study had an annual energy cost of close to $1200 (Parker et. al. 2008). Residential buildings also readily lend themselves to psychosocial studies by the fact that a few individuals in each home (in many cases a single person) are responsible for energy decisions and can easily act on their preferences (Figure 3).

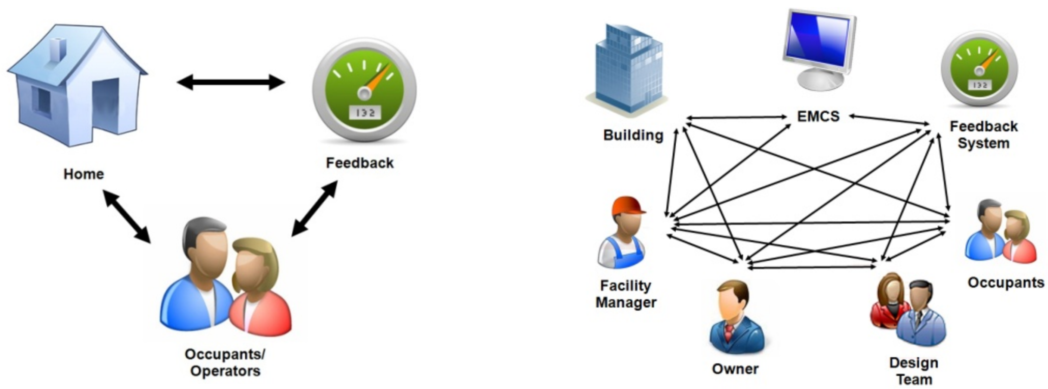


Figure 3. Relative complexity of residential (left) and commercial buildings (right) with respect to the study of using feedback to influence occupant behavior.

Compared to residential buildings, the energy performance in commercial buildings is more dependent on building systems, envelope, and other pre-established characteristics, and less so on decisions and actions of occupants and operators. Facility managers may have the ability to make changes and adjustment to system operations, but only within the limitations of standard building operations. For example, few facility managers will opt to save energy by selecting thermostat settings likely to make large numbers of people uncomfortable (although some people will be willing to do so in their homes). In addition, the effects of individual occupants' behavior are highly diffused by the large populations typical of commercial buildings.

In spite of these challenges, when we consider the vast amounts of energy consumed in commercial building operations, (over 6.5 quads annually, according to CBECS data) it is still incumbent on the building science research community to investigate the potential for, and identify best practices for, using information feedback to conserve resources in commercial buildings. In addition, commercial buildings may offer great opportunities for energy savings through low- or no-cost actions. Students in Prof. Cris Benton's "Secret Life of Buildings" course at UC Berkeley achieved energy savings of 27.5% in a campus building by using data visualization to analyze energy use patterns, and then changing fan schedules, with no apparent impact on occupants (Note 5, and Figure 4).

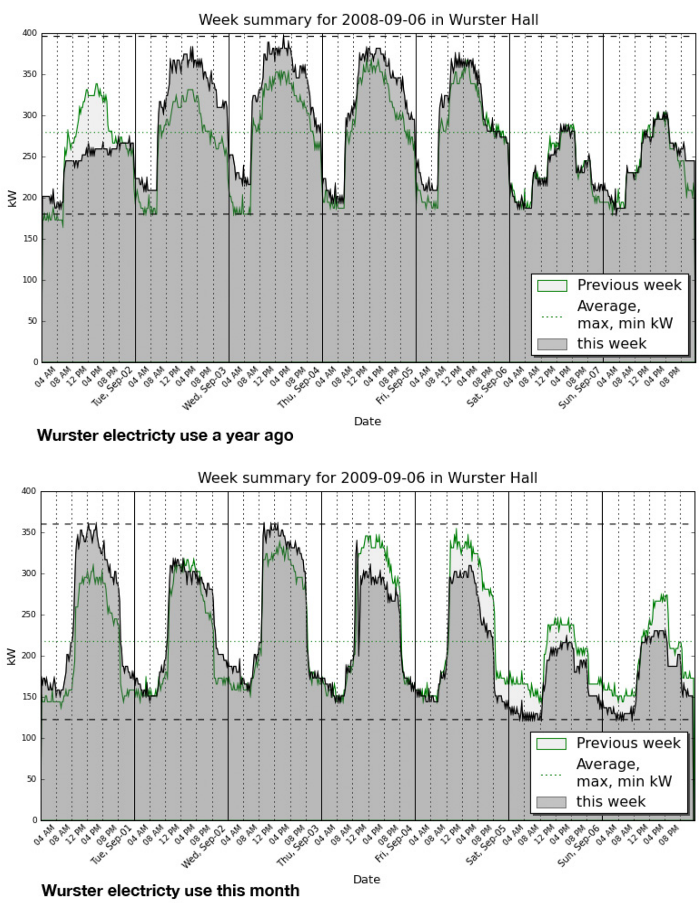


Figure 4. Students used data visualizations in UC Berkeley's Wurster Hall to understand energy patterns, and recommended fan schedule changes that reduced overall building energy use by 27.5% .

TYPES OF BUILDING METRICS FOR INFORMATION DISPLAYS

The range of data available for information visualization has been summarized into five primary categories; (1) real-time energy consumption; (2) historical consumption; (3) disaggregated consumption; (4) tariff, load management, or time-of-day consumption; and (5) normative consumption (Roberts and Baker 2003). Several studies show value in both historical feedback, "How does my energy consumption compare to previous periods?" and normative feedback, "How does my energy use compare to that of other people?" (Ibid.). The types of displays can be further broken down by the style of data plotting, and analysis methods for providing performance indicators, normalization, and benchmarking (Granderson, et. al. 2009).

Much research at CBE has focused on the response of building occupants to indoor environmental conditions in commercial and institutional buildings. One study hypothesized that building operations may be improved by effectively gathering and acting on information from occupants, and a research team developed an interface to allow occupants to submit and track maintenance requests (Federspiel and Villafana 2003). CBE has also developed an Occupant IEQ Survey tool that allows for the capture of detailed information about occupants' response to buildings. Such information is useful for both building diagnostics and benchmarking purposes (Zagreus et. al. 2004). This resource has now been expanded to include benchmark quality data for over 400 buildings in North America, primarily office buildings, but also including banks, hospitals, schools, and laboratories. Although the results of the of the survey have been used primarily by building owners and researchers, there may be value in using the survey data in comprehensive building information displays. Making such data available in an easily understood format may provide an additional metric for evaluation of building performance not currently available in products currently available.

RELATED INFORMATION DISPLAY AND FEEDBACK RESEARCH STUDIES

For our discussion of methods for studying information visualization in commercial buildings, it is worth noting several past research activities at UC Berkeley. As noted above, CBE researchers developed and tested a pilot implementation of an interface for building occupants (Federspiel and Villafana 2003.). The goal of the project, dubbed the Tenant Interface for Energy and Maintenance Systems (TIEMS), was to collect information from tenants, provide them with feedback about building operations, and provide more accurate information for facility managers in order to improve building operations. The system allowed tenants to submit and track service requests, see current indoor temperatures, and to be informed about building maintenance activities. The system was built upon the GEMnet (GSA Energy and Maintenance Network) system used by GSA for energy and maintenance management and was tested in two buildings with a small number of users. The system was designed to help facility managers by reducing the number of redundant maintenance requests, and by associating relevant temperature information with requests. Also, by displaying current temperature to tenants when they submit a request, the system may have the effect of reducing the number of such complaints, since studies of complaint databases show that many temperature complaints occur when temperatures are within ASHRAE-specified limits. Unfortunately the TIEMS field trial was conducted with a small number of lead users who input phone complaints from other tenants, and was not provided directly to tenant populations. In spite of this limitation, the trial determined that users will actively use a web-based interface, and that such a system can improve the quality of information in a maintenance database.

Faculty and graduate students at UC Berkeley also developed, prototyped and tested a residential control and feedback interface as part of a multi-year program developing technologies to enable demand-response (DR) capability in California residences (Peffer 2009). The goal of the project was to create an interface that would allow homeowners to select thermostat settings and understand the implications in terms of cost and energy use with dynamic energy pricing.

Considering that most programmable thermostats are already too complex for most users, incorporating the added complexity of dynamic-pricing into a user-friendly thermostat is indeed a challenge.

The DR-enabled thermostat, called the Demand Response Electrical Appliance Manager (DREAM), was developed with substantial user input, first through personas, page flows, and paper and electronic prototypes, and was later tested through heuristic evaluation. Simple paper mockups of the interface were tested with subjects that were given sample tasks to complete while thinking aloud, as the project team observed. The results of user tests were incorporated into a series of iteratively developed electronic prototypes.

The design of the final prototype consisted of two parts: a dial-like interface, similar to the Honeywell Round thermostat familiar to many homeowners, and a rectangular section, with tabbed navigation common on web-based interfaces. The dial component shows temperature, thermostat settings, and selections for fan, cooling and heating, much like a traditional round thermostat. The rectangular portion of the interface displays information about costs, equipment settings, electrical usage, and other information. Users can also select tabs to change preferences for temperatures, equipment operation schedules, view current and daily electrical use, and to preview cost forecasts that result from their selections. The electrical use can be viewed via a bar chart that compares energy usage of major end uses such as air conditioning, washer, dryer, and major kitchen appliances (Figure 5).

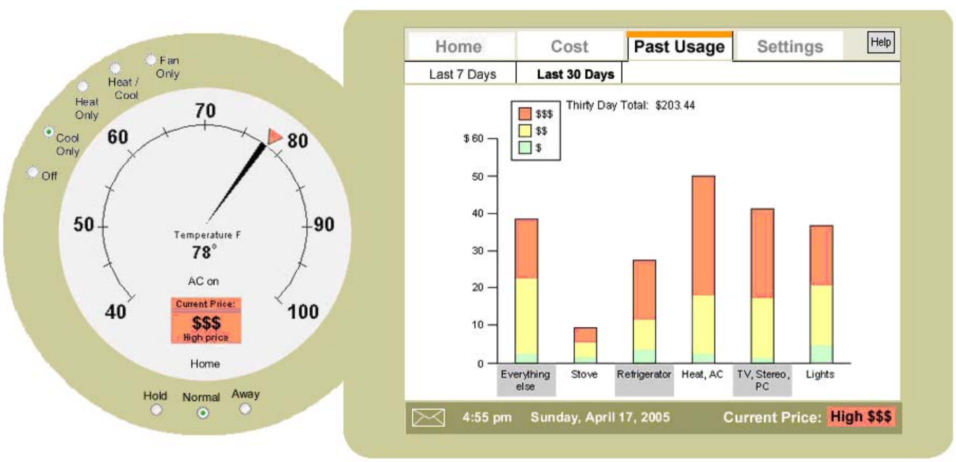


Figure 5. Prototype of DR-enabled thermostat, dubbed the Demand Response Electrical Appliance Manager (DREAM).

A simplified version of the prototype interface underwent a final round of testing with 53 subjects at UC Berkeley's Experimental Social Science Laboratory (Xlab). Test subjects observed a simulation and were able to change settings, and then completed a survey about their impressions of the interface. The features of the interface that subjects found to be most useful were those that provided information about specific appliances. The features deemed most useful by subjects included an iconographic display of the energy cost of appliances at various price points, a bar chart with time-of-day electrical costs, and a tool that could be used to set energy-saving goals.

Researchers at Lawrence Berkeley National Laboratory have surveyed commercially available Energy Information Systems (EIS) products that provide displays of building performance data. A review of research and trade literature was conducted in 2003 for the purposes of creating a framework with which to categorize 17 representative IES products, and to describe the products' capabilities. The study described a wide range of product types, including EIS for basic building monitoring, demand response, enterprise energy management, and web-based control systems

(Motegi et. al. 2003). As the offerings of EIS suppliers have expanded since the publication of the 2003 survey, this work is currently being updated to include approximately 30 EIS products. A preliminary report on the current study cites a need to pursue standardization and usability in these products, and notes the convergence of visualization and display in these products (Granderson et. al. 2009). The current work will be concluded in a comprehensive report that will include evaluations of EIS products and case studies of these products in practice.

Several future research projects now in planning phases or soon to be underway will contribute to the collective body of knowledge on information visualization and feedback. ASHRAE Technical Committee 1.4, Control Theory and Application, has developed a scope of work statement (#1502-WS) for the study of methods for measuring and displaying building metrics including comfort and energy use. This project, "User Interface Design for Advanced System Operation," will be organized around the needs of a broad range of commercial building stakeholders, including facility managers, developers, and occupants. The work will also identify how building data should be optimized and incorporated into usable interfaces. The scope of work statement has been approved by the committee and will be issued for bid in fall of 2009 (Note 6).

In addition, a research team headed by Oberlin College and Lucid Design Group will conduct a four-year pilot study of energy and water information feedback in residences and commercial buildings in Oberlin, Ohio. This work will explore the use of dashboard displays, social networking sites, public kiosks, e-mail, text messages, at both the individual and community level scales. The study plans to identify which types of media work best for motivating users, and how to optimize these media. The project will be funded by a grant from the Great Lakes Protection Fund (Note 7).

CURRENT AND FUTURE RESEARCH ON INFORMATION VISUALIZATION AT CBE

CBE has begun the next phase of research on effective visualization of building information. The goals of this work are: (1) to identify the optimal methods for displaying building performance information, using building dashboards (simplified displays), touchscreens, and possibly other devices, in order to influence commercial building occupants to reduce resource use; and (2) to identify methods to provide actionable information in order to assist building operators in achieving improved building performance; and (3) to develop ways to include occupant feedback in these information displays, based on previous work conducted at CBE on occupant comfort and workplace satisfaction. We are conducting this work as a collaboration between CBE and the UC Berkeley School of Information, and we have received positive feedback from iSchool faculty on a draft of our research plan.

For the initial planning phase of this work, currently underway since spring of 2009, we are conducting a literature review to assess the potential for occupant feedback to reduce energy use in buildings. We are also involved in the review of commercially available building visualization products to understand capabilities and constraints of these types of hardware and software tools. A brief summary of this survey is included in this scoping study.

For the second phase of work, we will characterize subgroups of building stakeholders in order to investigate optimal ways to influence occupants to reduce energy and water consumption. The initial work will be conducted with a combination of surveys and interviews, the creation of user profiles, following a process commonly used by web and software developers. We will also rely on other common user experience techniques such as contextual inquiry (identifying users' work practices and information needs) and focus groups (Kuniavsky 2003). The project team will produce a report to summarize the results of the first two phases of this project.

The last phase of this project will involve the development and testing of prototypical building information displays. These prototypes will include interface features currently available on building software products, such as time series displays, monthly bar charts, and carbon and cost equivalents. In addition, we will develop new types of information displays with the potential for informing and impacting the behavior of occupants and other building stakeholders. We expect to create specific interfaces for distinct users; for example, a single screen "dashboard" view of information may be appropriate for office tenants, however facility managers will likely want the ability to drill down to find actionable information for diagnostic purposes.

These prototypes will be evaluated through usability tests, for which CBE can draw upon a number of test techniques, including task-based interviews, think-aloud usability tests. CBE has access to excellent resources on the UC Berkeley campus for these tests, including as the X-Lab test facility used in the DREAM interface tests described earlier. CBE will analyze the results to identify which interface elements are most effective, and with which sub-groups of building stakeholders. The results of these test will be reported in detail in a final report to CEC PIER; in addition CBE will submit the work for journal publication. A list of deliverables and an outline work schedule have been included in CBE's scope of work submitted to PIER, "Advanced Integrated Systems Technology Development."

REFERENCE NOTES

1. Martin Wattenburg lecture at the UC Berkeley School of Information, "The Social Life of Visualizations," October 12, 2005.
2. Personal correspondence with Tiffany Holmes, May 22, 2009.
3. Facebook usage statistics taken on June 19, 2009, from http://www.facebook.com/press/info.php?statistics
4. Personal correspondence with Efficiency 20 CEO, Tom Scaramellino, June 10, 2009.
5. Personal correspondence with Prof. Cris Benton, September 25, 2009. Information on this project is at http://steel.ced.berkeley.edu/courses/fa09/arch244/?p=1172
6. ASHRAE's Dashboard Research project is available at: http://www.tedownloads.com/dashboard/
7. Information on the Oberlin study is at: http://new.oberlin.edu/home/news-media/press/detail.dot?id=524219

REFERENCES

Abrahamse, W., L. Steg, C. Vlek, and T. Rothengatter, 2005. "A review of intervention studies aimed at household energy conservation," *Journal of Environmental Psychology*, Volume 25, Issue 3, September, pp. 273-291,

Darby, S., 2006. "The effectiveness of feedback on energy consumption: A review for EFRA of the literature on metering, billing and direct displays," Environmental Change Institute, University of Oxford: Oxford, UK. pp. 1-21

Diamond, R., Opitz M, Hicks T, Vonneida B, and Herrera S., 2006 "Evaluating the site energy performance of the first generation of LEED-certified commercial buildings," Proceedings of the 2006 Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficient Economy, Washington DC, August, 2006. LBNL-59853.

Federspiel, C. and L. Villafana, 2003. "Design of an energy and maintenance system user interface for building occupants," *ASHRAE Transactions*, 109(2), pp. 665-676.

Fogg, B. J. (2003). Persuasive Technology: Using Computers to Change What We Think and Do. Morgan Kaufmann Publishers: San Francisco, CA.

Granderson, J., M.A. Piette, G. Ghatikar, and P. Price, 2009. “Preliminary findings from an analysis of building energy information system technologies,” proceedings of the national conference on building commissioning, June, pp 1-19. at http://www.peci.org/ncbc/2009/docs/Granderson_NCBC09P.pdf

Holmes, T.G., 2007, “Eco-visualization: Combining art and technology to reduce energy consumption,” Proceedings of the 6th ACM SIGCHI conference on Creativity & Cognition Washington, DC, pp. 153 – 162.

Kuniavsky, M. 2003, *Observing the User Experience: A Practitioner’s Guide to User Research*, Morgan Kaufmann Publishers: San Francisco, CA.

Katvez, R., and T. Johnson, 1982. “Comparing the effects of monetary incentives and foot-in-the-door strategies in promoting residential electricity conservation,” *Journal of Applied Social Psychology*, Vol 14, Issue 1, pp. 12-27

Lehrer, D, 2009. “Visualizing building information: using information feedback to educate and influence building managers and occupants.” *Centerline Magazine*, Center for the Built Environment, University of California, Berkeley, Winter. http://www.cbe.berkeley.edu/centerline/winter2009.pdf

Nass, C., J. Steuer., and E. R.Tauber, 1994. “Computers are social actors,” *Proceedings of the sigchi conference on human factors in computing systems: celebrating interdependence*, Boston, Massachusetts, United States, April 24 - 28, 1994 pp. 72-78

Nass, C., Y. Moon , B. Fogg, B. Reeves, and C. Dryer, 1995. “Can computer personalities be human personalities?” In *Conference Companion on human factors in computing systems* (Denver, Colorado, May 7 - 11, 1995). pp 228-229.

N. Motegi, M.A. Piette, S. Kinney, and K. Herter, 2003. "Web-based energy information systems for energy management and demand response in commercial buildings," Lawrence Berkeley National Laboratory. Paper LBNL-52510. http://repositories.cdlib.org/lbnl/LBNL-52510

Parker, D., M. Mazzara, J. Sherwin, 1996. “Monitored energy use patterns in low-income housing ins a hot and humid climate,” Proceedings of the tenth symposium of improving building systems in hot and humid climates, Ft. Worth, TX,

Parker, D.S., D. Hoak, and J. Cummings, 2008 “Pilot evaluation of energy savings from residential energy demand feedback devices,” University of Central Florida, Florida Solar Energy Center, Prepared for U.S. Department of Energy. p. 1-32.

Peffer, T. E., 2009. “California DREAMing: the design of residential demand responsive technology with people in mind,” Doctoral dissertation, Department of Architecture, UC Berkeley, Berkeley from http://repositories.cdlib.org/cedr/cbe/cit/Peffer2009_DemandResponse.

Roberts, S., and W. Baker, 2003. “Towards effective energy information. Improving consumer feedback on energy consumption.” A report to OFGEM. pp. 1-45.

Seligman, C. and Darley, J.M., 1977. “Feedback as a means of decreasing residential energy consumption,” *Journal of Applied Psychology*, *62*, 363-368.

Shippee, G., and W. L. Gregory, 1982. “Public commitment and energy conservation,” *American Journal of Community Psychology*, Volume 10, Number 1, February.

Stein, L: F., 2004. “California Information display pilot technology assessment.” Prepared for Southern California Edison. Boulder, Co.: Primen, Inc. pp. 1-39.

Mark Wattenburg's work can be seen at http://www.bewitched.com/research.html, and also at IBM's Visual Communication Lab website at:
http://www.alphaworks.ibm.com/contentnr/introvisualization

Zagreus, L., C. Huizenga, E. Arens and D. Lehrer, 2004. "Listening to the Occupants: a web-based indoor environmental quality survey," Proceedings of Indoor Air 2004; 14 (Suppl. 8): pp. 65-74. December.

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