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Visualizing Energy Information in Commercial Buildings: A Study of Tools, Expert Users, and Building Occupants

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EXECUTIVE SUMMARY

The overarching goal of this research is to identify the optimal methods for visualizing building performance information in commercial buildings. The current phase consists of three research activities: (1) product reviews of building visualization software products; (2) a study of expert users regarding attitudes and practices regarding visualization of energy and other building metrics; and (3) a survey of workplace occupants to understand how they use building energy information, and whether improved access to this information will encourage energy conservation behaviors in the workplace.

Building Visualization Product Reviews

The authors reviewed seven software products available for visualizing energy consumption information in commercial buildings. Companies and product offerings in this space are evolving rapidly, so this report provides a snapshot of trends at the time of this investigation, which was largely conducted in the spring of 2010. The review found that these products show promise for providing feedback about energy and other metrics, and have been reported anecdotally to encourage energy conservation behaviors. These products support multiple users and provide a standard set of features that cater to the needs of both expert users and typical building occupants. Almost all tools surveyed also support tailoring of interfaces to meet specific user needs, however the degree of configurability varies between products. Many of the providers of these products report growing customer bases and claim that the use of these products has promoted energy conservation behaviors. However, more research is needed not only to assess the usefulness of these products but also to validate claims on positive outcomes of use.

Expert User Needs Assessment

The second primary task of this research was to understand and document the energy information practices, needs and preferences of an important category of users — industry professionals who are experts in energy monitoring and analysis. A combination of surveys and “contextual inquiries” was used to understand how these individuals use building energy information and what tools they currently use to visualize it. The purpose of the study was to understand their experiences as users, to learn how useful and usable current tools are, and to identify needs currently lacking from these tools.

The study revealed that access to reliable energy and performance data varies considerably between firms and individuals, and that current tools have numerous shortcomings. For many building managers and design professionals, the process of visualizing building information for analysis, benchmarking and diagnostics, remains a time intensive, do-it-yourself undertaking. Many people interviewed, including those with access to energy visualization tools, still rely on data exported from building management systems (BMS), and manipulated in spreadsheet programs. A desire for more end-use and historical energy data, and a nearly unanimous desire for better methods of communicating with building occupants were observed. Based on these observations, the research team concludes that industry professionals would be well served by software tools that conform to standard conventions described in human-computer interaction literature as “overview first, zoom and filter, then details-on-demand.”

Workplace Occupant Needs Assessment

The third primary task of this research involved a survey of workplace occupants to understand how they typically use energy information and whether access to this information influences their energy attitudes and behaviors. Commercial products for visualizing energy consumption for occupants are rapidly being adopted, however access to these products is limited, and occupants for the most part continue to receive building energy and operation information anecdotally and through other means. A majority of the survey respondents report that they already take actions to save energy, and that they would take more energy conserving actions if they got feedback on either the amount or cost of energy used. The primary motivations for saving energy at work are environmental and ethical concerns (“doing the right thing”), followed by saving money for the company.

Finally, this study offers a few suggestions for methods to display building information to occupants and expert users. Based on these findings, the research team is currently studying the potential benefits of using a web-based social network application to promote energy awareness, to improve communications between operators and occupants, and to positively influence energy-saving behavior of typical office workers. Results of this study will be reported as the second and final phase of this research.

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1. PROJECT BACKGROUND AND INTRODUCTION

Commercial buildings account for 19 percent of all energy consumed in the United States,¹ and are seen as an important opportunity for reducing energy consumption and associated greenhouse gas emissions. A number of factors are bringing into effect policies and technologies that will lead to improved monitoring of energy and other building metrics, and that may also encourage energy conserving behavior.

The United States Green Building Council (USGBC) established the Leadership in Energy and Environmental Design (LEED) rating system in 2000 to promote energy efficient design and operation of commercial buildings. LEED has become an important driver towards this goal; however, a significant shortcoming is that as currently applied to new construction and major renovations, compliance with energy performance is based largely on modeled energy use. Since modeled energy use may be an unreliable predictor of actual performance, this lack of performance data undermines the reliability of this rating system (Diamond et. al., 2006). In addition, the last few years has seen aggressive energy policies that will require far higher building performance standards than currently required by LEED. For example, the U.S. Energy Independence and Security Act of 2007 (EISA 2007) requires new and renovated federal buildings to achieve carbon neutrality and net-zero energy for all new commercial buildings by 2030. The state of California too has adopted policies requiring new commercial construction to meet zero-energy targets by 2030. To meet these goals, ongoing monitoring and commissioning of commercial buildings will be necessary.

These new goals and policies provide market opportunities for providers of energy efficient products and services, as well as for “greentech” or “cleantech” startups. Numerous software companies have developed new data acquisition and information visualization products that provide interesting ways to monitor and display building performance data to various building stakeholders. These products offer the possibility of simplifying complex energy monitoring tasks for expert users, as well as the ability to display energy consumption information to non-technical audiences such as commercial building occupants. The growing popularity of these technologies in recent years may be linked to previous research that points to the prevalence of a so-called “Prius effect” which describes the positive behavioral impacts of making energy consumption information visible to users (Darby 2006). The authors’ discussions with several providers of building software products reveal similar findings. Although this evidence is largely anecdotal, many of their customers report energy savings of 5-15%.

A number of intervention studies have shown that effective energy feedback can influence energy saving behavior among building occupants (Darby 2006). However, few studies have focused on determining what types of energy information are of value to building users, or on the optimal methods for the display of such information. Furthermore, most of these intervention studies have been conducted in residential buildings and consequently, may not be applicable to commercial buildings. Unlike residential buildings, commercial buildings have highly complex mechanical systems and house a variety of users — managers, operators and occupants — some of whom have little or no control over their energy impacts (Lehrer 2009). Also, the energy performance in commercial buildings is highly dependent on building systems, envelope, and other pre-established characteristics, and less so on decisions and actions of occupants and operators. It is unclear from the current literature how these

¹ US Energy Information Administration. 2008. “Annual Energy Review.”
<http://www.eia.doe.gov/emeu/aer/consump.html> (accessed December 30, 2009)

challenges impact the role of information interventions in producing energy savings. The motivation for this research stems from this gap.

1.1 Objectives and Method

This study is being carried out in two phases: (1) the discovery phase, and (2) the design and subject test phase. The discovery phase consists of three related research tasks. The first involves product reviews of commercial energy dashboards to understand their features and capabilities. The second is an expert user study to assess the information needs, preferences and practices of expert users such as facility managers, energy professionals, HVAC design engineers and architects, using a combination of surveys, contextual inquiries and interviews. The final research task involves an energy information survey of workplace occupants.

The objectives for the “discovery” phase of this research include:

- Understanding the range of features available in software tools currently available for displaying building energy information.
- Studying and documenting the energy information needs and preferences of expert users such as facility managers, architects and design engineers that are involved in monitoring and analyzing building performance and energy consumption.
- Learning what energy information is currently available to these professionals and the tools they use to access the building’s energy information.
- Understanding the energy attitudes and behaviors of typical building occupants, and whether access to information will encourage energy conserving behaviors.

The “design and subject testing” phase involves consolidating the results of the discovery phase findings to identify optimal methods for displaying building performance information to these stakeholders. For this work we will explore how a social media network may facilitate communication between workplace occupants and building managers. We will investigate how this platform:

- Makes the workplace occupants more inclined to report problems, give feedback on their comfort levels, satisfaction, etc.
- Enables workplace occupants to monitor, share, and compare their personal energy use.
- Encourages energy-conserving behaviors, particularly when social and emotional rewards for eco-behavior are built into its design.
- Provides greater opportunities to building managers to improve buildings’ energy performance by offering insights into occupants’ attitudes and behaviors.

This cross-disciplinary study considers diverse viewpoints—including building energy engineering, human-computer interaction, and psychosocial behavioral factors—to study the role of energy feedback in commercial buildings. It focuses on the kinds of energy information that are useful to various categories of building stakeholders, and investigates preferred methods for its display. Based on preliminary building user research, two broad categories of building stakeholders that would benefit from energy information feedback were identified. These groups have diverse information needs and practices and include: (1) expert energy information users, and (2) general building occupants. Table 1 shows the types of building information users included in each of these categories. Expert users are typically involved in energy monitoring and analysis. For these users, feedback on energy consumption patterns in buildings provides increased opportunities to assess and improve overall energy performance. In contrast, the general building occupants are not involved in energy management roles. They are typically consumers of energy in a building and have limited ability to influence the building

energy usage patterns. While they may impact energy use to a certain extent through their control of lights, thermostats, computers and/or other equipment, these users otherwise have no control over a building's major energy performance. The research, design and test schema for this study will focus on the information needs of these two categories of users.

Table 1: User Group Demographics

Expert Energy Information Users	Architects, design engineers, facility managers, building operators, building managers, building owners, green building consultants, commissioning agents, academics and researchers
General Building Occupants	Office employees, educators, visitors

This report documents the findings from the first phase of this research. Section 1 of this report has provided the background of this problem. Section 2 includes a review of several leading information visualization software products. Section 3 describes the findings from the expert user survey and contextual inquiries. Section 4 reports the findings from the survey of building occupants. Finally, Section 5 suggests ideas for effective visualization methods in commercial buildings, and describes the second phase of this work now underway.

2. DATA VISUALIZATION TOOLS FOR BUILDING PERFORMANCE

New information visualization methods and tools are being applied in business, science and academia for understanding trends and relationships in large, complex data sets. These innovations provide users with interactive capability for filtering, sorting, and visualizing information and take advantage of what Ben Shneiderman describes as the powerful “bandwidth of human vision.”²

In the building industry, a growing number of companies are providing products that enable the visualization of building performance data, primarily related to energy and water use and renewable power generation. Many of these companies have been started within the last few years, and we can expect additional companies to enter this market in coming years. In addition, many established IT companies such as Google, IBM, Cisco, Microsoft and Intel have developed energy software products to managing commercial building energy, though there are indicators that some of these products have not been commercial successes³. There are several drivers contributing to the adoption of information displays in commercial buildings. Owners of green buildings want to exhibit their accomplishments and gain innovation points under the LEED rating system. Design teams share such goals and also want the ability to easily view building performance, to compare against predicted performance and for benchmarking. Increased public scrutiny of green building results, combined with controversy in the research arena, has increased interest in measured energy performance of buildings (Diamond 2006, Turner & Frankel 2008, Brown 2009).

Further, in addition to the typical visualizations provided by many commercially available energy products, many firms are experimenting with the design of novel visualizations that often described as *tangible* and *ubiquitous*. A case in point is the work of a global engineering design firm, Arup, which is exploring innovative visualizations of energy use in commercial buildings (Figs. 1-2). Such efforts illustrate the growing interest in not only measuring energy performance, but also in using this information in interesting ways to instigate energy conserving behaviors among building occupants.

² Ben Shneiderman lecture at Center for Information Technology Research in the Interest of Society (CITRIS), UC Berkeley, 3/3/10.

³ Retrieved 9/2/11 from <http://www.greentechmedia.com/articles/read/as-predicted-cisco-getting-out-of-building-management/>.

Figure 1: Conceptual Design for a Screen Showing Energy Performance of a Single Zone



Source: ARUP

Figure 2: An Interactive Wall Showing the Carbon Emissions of an Average Person's Activities.



Source: ARUP

A preliminary phase of this research reviewed several commercial building information products (Lehrer 2009). These products are designed for monitoring energy and water use, for educating occupants about building features, and may also have some usefulness for macro-scale diagnostics. They include features and interfaces that are tailored to the needs of different categories of users such as building occupants, managers, and operators. To make the data more accessible to non-technical users, they often include graphical displays that translate energy information into equivalent units such as the cost of energy or CO₂ produced, or into familiar concepts such as hours of light bulb use. In contrast to conventional Building Management Systems (BMSs) or Energy Management and Control Systems (EMCSs), they primarily offer visual representations of real-time and historic energy and water use, with no control capabilities.

The complexity and cost of such systems vary considerably. At one end of the spectrum are products such as the “Building Dashboard” from Lucid Design Group, that can be purchased as an entry hardware and software package for two buildings for under \$10,000.⁴ On the other end, a major building controls supplier offered a potential customer a proposal to provide a user-friendly energy monitoring system for a large mixed-use building at a cost of over \$170,000 (the building already had an installed BMS).⁵

This section reviews seven building visualization products that are being adopted by a growing number of commercial building owners. These products were selected for review because they had established customer bases and because they provide visually interesting displays of information and/or offered user interfaces appropriate for a range of users. The companies and product offerings in this space are evolving rapidly, so this report provides a snapshot of trends at the time of this investigation, which was largely conducted in the spring of 2010. For a more comprehensive review of energy information systems, see Granderson et. al. 2009.

⁴ Retrieved 3/4/10 from <http://www.luciddesigngroup.com/starter.php>

⁵ Personal correspondence with ZGF Architects, 2/24/10

2.1 Pulse Energy

Pulse Energy is a software company located in Vancouver, B.C. that develops energy management software.⁶ Pulse Energy provides a suite of three applications that include: (1) the Pulse Dashboard view, an educational tool for general building occupants; (2) the Pulse Management view, which provides detailed trend data for facility managers; and (3) the Pulse Reporting view, for portfolio managers to compare building performance, calculate GHG emissions or financial data, and demonstrate the savings as a result of conservation or efficiency projects (Figs. 3-4).

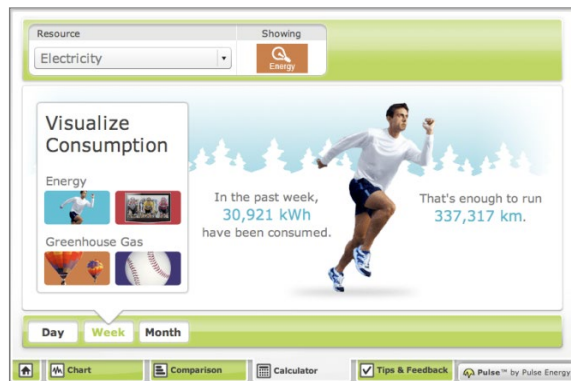
The Pulse Dashboard view translates energy consumption and greenhouse gas (GHG) emissions into units intended to be understandable to a general audience, for example, a distance to be run, the weight of baseballs, or the number of balloons that can be filled with the equivalent amount of GHG. In addition, the dashboard offers the users tips on energy conservation and allows them to send feedback on what additional information might motivate them to reduce resource use. The Pulse Management view is a more detailed interface that allows expert users to set alerts and identify operational improvements through comprehensive energy trend analysis. Expert users also have the ability to customize the look-and-feel of the Dashboard viewed by occupants.

The Dashboard and Management tools include current load profiles and baseline comparison profiles. The baseline profiles normalize for weather and other variables so that occupants can accurately determine the impact of energy conservation measures. Further, these tools allow trend data to be configured to display the energy profiles of electricity and water in varied temporal granularities.

Pulse Energy management reports that its installation base has increased by a factor of ten during a recent year of operation. Some of the firm's prominent clients include the Government of British Columbia, the University of British Columbia (UBC) in Vancouver, and a number of 2010 Olympic venues. At the UBC, the company staff played a key role in organizing competitions among buildings and facility managers to promote the use of the software and reduce energy use. As a result of these initiatives, the UBC campus estimates energy savings of 10-15%, which they attribute to the use of the software. Pulse Energy's online energy management software supported the Venue Energy Tracker that was set up at the Vancouver Olympic Games. The Venue Energy Tracker recorded total energy savings of 906 MWh during the games and marked the first time that Olympic venues monitored and publicly reported energy consumption during the events. As a result of continued success in demonstrating energy savings in the UBC campus and other projects, Pulse Energy in 2010 received a grant of \$2.6 million by Sustainable Development Technology Canada, to develop and demonstrate an intelligent energy management platform to improve the energy efficiency of commercial and industrial buildings.

⁶ This section is drawn from a combination of personal correspondence during 2010 with Pulse management and the company's website (<http://www.pulseenergy.com>).

Figure 3: Pulse Energy Dashboard Visualizing Energy Consumed in terms of Distance Run



Source: <http://www.pulseenergy.com/>

Figure 4: Historical Trending of Electricity Use at Wurster Hall, UC Berkeley



Source: <http://www.pulseenergy.com/>

2.2 Quality Attributes

Quality Attributes Software is headquartered in Ames, Iowa, and provides software solutions intended to reduce energy cost, energy consumption, and carbon emissions in commercial buildings.⁷ Quality Attributes provides a suite of two products for energy monitoring and verification: (1) iEnergy Software suite geared towards facility managers, architects, executives, building owners and operators; and (2) GreenTouchScreen for general building occupants and visitors (Figs. 5-8).

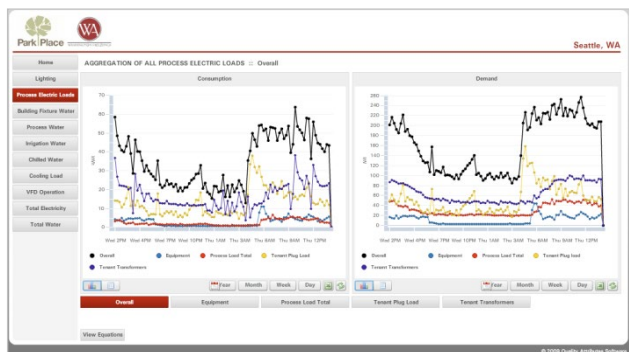
The iEnergy suite consists of three products: (1) iBuilding Application to monitor, measure and manage a single building's operations; (2) iCampus Application to monitor a group of buildings in the same geographical location; and (3) iEnterprise Application to track and assess a portfolio of buildings that may be widely dispersed geographically. Each of these applications graphically visualizes both real-time and historical energy data in a single-screen dashboard format. They offer a variety of interactive views and data reporting capabilities that can be tailored to meet users' needs. The iCampus application also supports ranking buildings by their total and normalized consumption making it easy to spot the best and worst performers in a campus. To facilitate behavioral changes and long-term energy reduction, the application encompasses a competition module between buildings. The iEnterprise is similar in functionality to the iCampus but is designed to function on a larger scale.

GreenTouchScreen is an educational tool designed to promote awareness about a building's sustainability measures. It is a web-based interactive kiosk software that displays real-time energy data, and enables historical and normative comparisons of buildings' performance. The product has been customized and installed in multiple locations, including noteworthy installations at the Cold Climate Housing and Research Center in Fairbanks, Alaska; Building B3 in the Department of Energy in Las Vegas, Nevada; the King County Office Building in Seattle, Washington; Great River Energy in Elk River,

⁷ This section is drawn from a combination of personal correspondence during 2010 with Quality Attributes staff and the company's website: (<http://www.qualityattributes.com>)

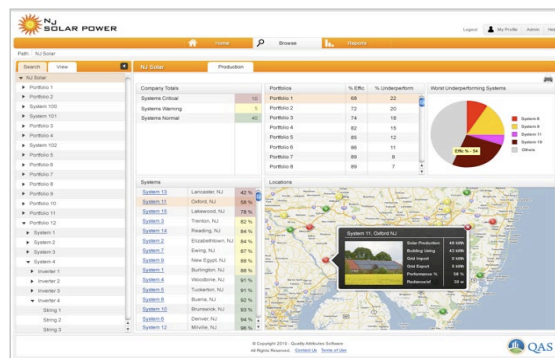
Minnesota; Allsteel Inc., San Francisco Showroom in San Francisco, California; and the Broward County South Regional Library in Penbrooke Pines, Florida.⁸

Figure 5: iBBuilding Application Used at Park Place, Seattle WA



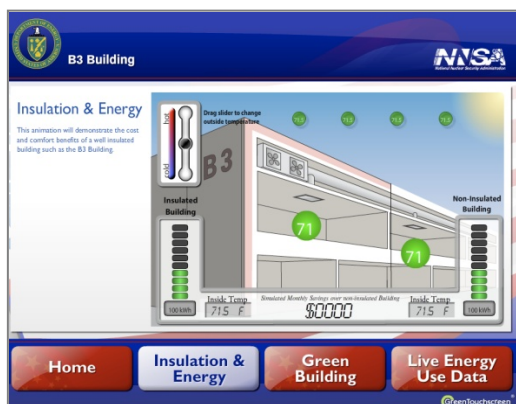
Source: <http://parkplace.ibplatform.com/>

Figure 6: iBEnterprise Application Used at NJ Solar Power



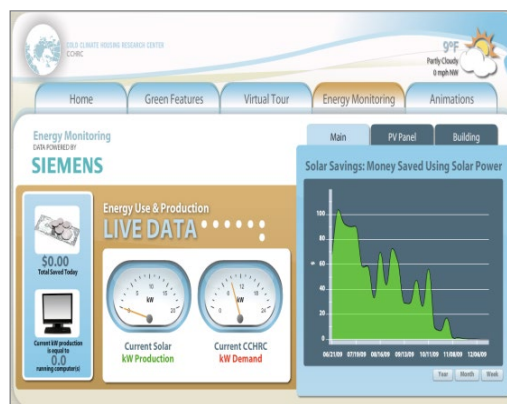
Source: <http://www.qualityattributes.com/asp/products/iBEnterprise.aspx>

Figure 7: Animation Showing Green Features in Dept. of Energy Bldg B3, Las Vegas, NV



Source: <http://lasvegasb3.doe.greentouchscreen.com/>

Figure 8: GreenTouchScreen at Climate Housing and Research Center in Fairbanks, AL



Source: <http://cchrc.greentouchscreen.com/>

2.2 Noveda

Noveda Technologies of Branchburg, New Jersey, provides a range of energy-monitoring software products geared for facility managers and general occupants.⁹ These include: (1) the Sun Flow Monitor that allows for real-time monitoring, diagnostics and reporting of the building's solar energy performance; (2) the Energy Flow Monitor, which monitors a building's energy and natural resource use; and (3) the Facilitmetrix, which combines the functionalities of the Sun Flow Monitor and the Energy Flow Monitor to track renewable and conventional energy use, as well as HVAC system performance; and (4) the Carbon Footprint Monitor, which monitors a building's impact on the environment, and can

⁸ Information on the total number of installations was unavailable at the time of this report.

⁹ This section is drawn from a combination of personal correspondence during 2010 with Noveda management and the company's website: (<http://noveda.com/en/>).

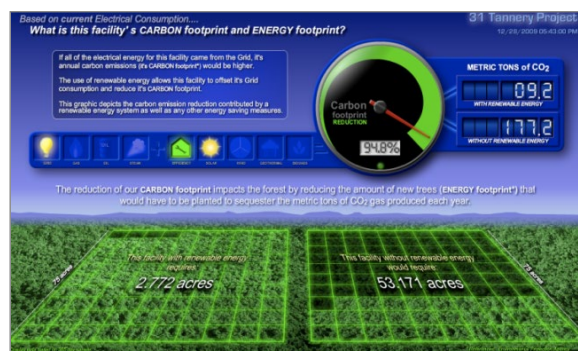
evaluate the savings due to energy conserving measures. Besides allowing the users to monitor consumption by end-use in real-time, all these tools store historical data on building energy consumption and facilitate comparative benchmarking against previous utility bills or energy reduction targets (Figs. 9-10).

Figure 9: Noveda Sun Flow Monitor



Source: <http://noveda.com/en/page/87?l1=3&l2=4>

Figure 10: Noveda Carbon Flow Monitor



Source: <http://noveda.com/en/page/87?l1=3&l2=4>

At the time of this study, Noveda software had been installed in approximately 60 commercial buildings. Noveda management points to the 31 Tannery Project in New Jersey, which the company claims to be operating with net-zero electrical purchase. The project utilizes Noveda's tools for monitoring and visualizing the building's energy performance, and reports that these monitoring and diagnostic tools promoted positive behavioral changes among building occupants and has contributed to reductions in energy use estimated at 5-15% and a significant decrease in greenhouse gas emissions (RealComm Edge 2008).

2.4 Lucid

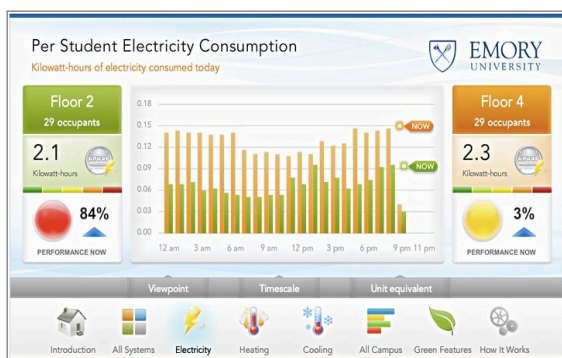
Lucid of Oakland, California, was one of the earliest providers of energy visualization products for residential and commercial buildings.¹⁰ Lucid Design Group employs the name *Building Dashboard* for its products, which include interactive websites and web-based touchscreen kiosks to display building performance information mainly to occupants and visitors. The Building Dashboard is available in versions for use in companies, schools and homes. All versions provide real-time, historical and normative comparatives of energy use data. Some versions also represent consumption data in commonly understandable units such as usage in dollars, equivalent hours of light bulb use and CO₂ emissions. Although the Building Dashboard is primarily an educational tool geared to non-technical audiences, add-on applications such as the Data Downloader for data archival are available for expert energy monitoring and analysis (Figs. 11-12).

At the time of this study, Lucid reported having approximately 50 installations of the Building Dashboard in a range of institutional, commercial and residential settings. Driven by the goal to change the way

¹⁰ This section is drawn from personal correspondence 2009-2010 with Lucid management and the company's website: (<http://www.luciddesigngroup.com>).

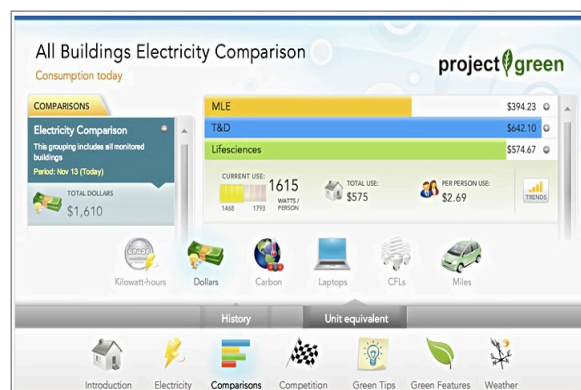
building occupants think, act and consume, Lucid cites examples of installations including college dormitory energy completions that have resulted in energy savings of 10% to 56%.

Figure 11: Per Person Consumption – Lucid Building Dashboard for Students



Source: <http://www.luciddesigngroup.com>

Figure 12: Normative Comparisons – Lucid Building Dashboard for Companies



Source: <http://www.luciddesigngroup.com>

2.5 Agilewaves

Agilewaves is a software solutions company located in Menlo Park, California.¹¹ The company offers two types of energy monitoring and reporting software: (1) the Building Optimization System (BOS) for facility managers, owners and building operators; and (2) the Resource Monitor for residential consumers. The BOS is a web-based system that monitors a building's electric, gas, and water usage in real time. It also enables trend analysis, historical and normative comparisons, and cost and carbon footprint projections. Both these systems receive data feeds on energy use in varying granularity from the building's existing BMS. The BOS also includes alerts that can be configured to suit individual users' needs. Besides energy diagnostics, the Resource Monitor also enables tracking of temperature and humidity, output from solar PVs, performance of solar or geo-thermal systems, and indoor air quality (Figs. 13-14).

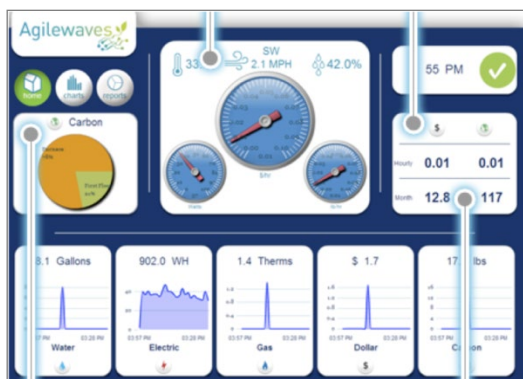
A panel of energy efficiency experts at the California Energy Commission evaluated the Agilewaves proposal for "Performance Measurement & Benchmarking for Net-Zero Energy Buildings."¹² Included in these findings, the Energy Commission noted that the Agilewaves Building Optimization System "has the potential of reducing energy use by 30% in retrofitted and newly constructed buildings." One of Agilewaves' clients, Evergreen Partners LLC, reported that the Agilewaves interface deployed at its Johnston Square Apartments in Baltimore provides a central point for command-and-control for building performance and by doing so, offers opportunities to cut operating costs. The installed based of this product was not available at the time of this study.¹³

¹¹ This section is drawn from a combination of personal correspondences during 2010 with AgileWaves management and the company's website: (<http://www.agilewaves.com>).

¹² Personal correspondence with Carol Morrison of Agilewaves, January 2010.

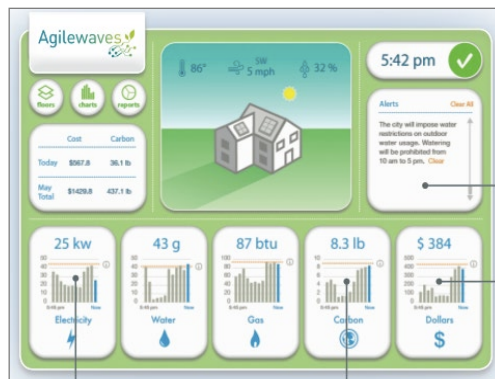
¹³ Agilewaves declined to share information on individual projects and the number of installations due to non-disclosure agreements with clients.

Figure 13: Agilewaves Building Optimization System



Source: <http://www.agilewaves.com/>

Figure 14: Agilewaves Resource Monitor



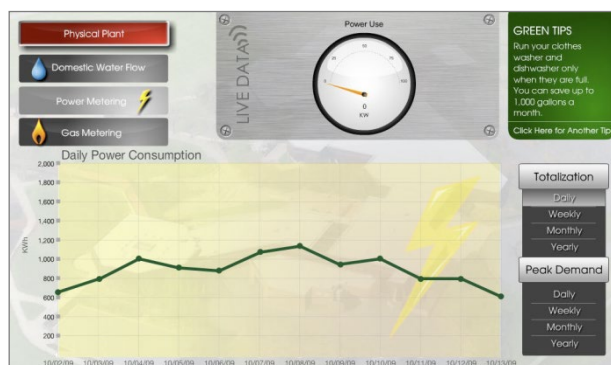
Source: <http://www.agilewaves.com/>

2.6 Quality Automation Graphics

Quality Automation Graphics of Ankeny, Iowa provides design of custom graphical user interfaces and interactive products.¹⁴ The company's Energy Efficient Education Dashboard (EEED) is primarily an educational tool that is targeted to building occupants and visitors. It displays real-time and historical energy data and also educational animations that highlight a building's energy conserving features. In addition, the system supports a "competition module" that ranks buildings within or outside a campus based on normative comparisons. Unlike the other products reviewed here, the EEED is not a hosted solution. Instead the software is typically installed on the customer's servers and is managed by the clients' IT staff. This allows customers to decide how the system is integrated into an enterprise network. The customer retains control of the EEED and configures not only some aspects of the look and feel of the dashboard, but also its functionality and how it accesses data from the building automation system (Figs. 15-16).

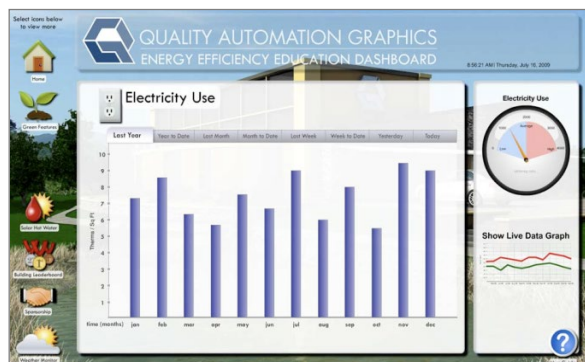
¹⁴ This section is drawn from a combination of personal correspondences during 2010 with QA Graphics employees and the company's website: <http://www.qagraphics.com>.

Figure 15: EEED Showing Live Energy Data, Daily Power Consumption and Energy Tips



Source: <http://www.qagraphics.com/energy-efficiency-education-dashboard/energy-dashboard.html>

Figure 16: Monitoring Electricity Use with EEED



Source: <http://www.qagraphics.com/energy-efficiency-education-dashboard/energy-dashboard.html>

At the time of this study, QA graphics had customized and installed over 85 EEEDs for schools, universities, restaurants, government buildings, commercial buildings, and libraries. Although the company is not able to provide direct energy saving statistics, company representatives report having received positive feedback from customers.

2.7 Prophet Suite

Prophet is a software visualization product that offers customers a holistic view of building performance and allows users to create customized screens and visualizations using a Flex interface.¹⁵ It can be configured for both expert users and building occupants, and to be functional across multiple performance metrics including electricity, water, and gas. The software is available with coordinated hardware including for monitoring and control. The system is compatible with several BMSs including Siemens Apogee, Tridium, and JCI Metasys, and is based on the Niagara development platform (Figs. 17-18).

Prophet was developed with the goal of giving customers control over the design of screens and also data analysis. The product suite allows administrators to configure user accounts and manage access rights and privileges. In addition, users can organize building data in a hierarchy that meets users' individual needs, by campus, building, floor, room, equipment load, etc. The system also allows for data aggregation and normalization can be combined to provide an overall view of building metrics.

Prophet also provides an extensive "widget" library that simplifies the creation of graphical building dashboards and interactive components such as HVAC equipment, floor plans, server room layouts, etc. This allows users to "drag and drop" the elements needed to create screens tailored to specific uses. The company also provides standard screen templates and conducts an annual competition for the most useful and innovative interface designs created by users. One unusual capability not found elsewhere in the review is the ability for users to include live video feeds into screen views if desired.

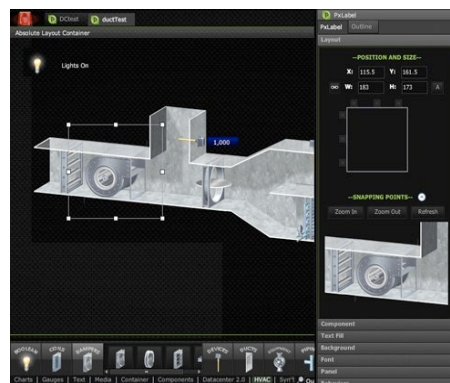
¹⁵ This section is drawn from a combination of personal correspondences with Controlco employees during 2010 and the company's website: <http://www.controlco.com/software-it.html#prophetSuite>.

Figure 17: Prophet Suite Dashboard Builder



Source: <http://prophetsuite.com>

Figure 18: Interactive Components to Build Graphical Representations of HVAC Equipment



Source: <http://prophetsuite.com>

2.8 Summary of Product Reviews

All of the energy visualization tools that were reviewed support multiple users and offer a standard set of features to suit the needs of both expert users and the typical commercial building populations. Products such as Lucid's Building Dashboard, Quality Attributes' GreenTouchScreen, and QA Graphics' EEED are primarily marketed as educational tools for informing about building resource use, carbon footprint reduction and other broad sustainability measures. These tools are targeted to diverse audiences including building occupants and visitors, and are intended to raise awareness of building performance and to encourage energy conserving behaviors.

Products such as Noveda's Facilimetrix, iBEnergy from Quality Attributes, BOS and Resource Monitor from Agilewaves, and Prophet are designed for expert users who may have advanced knowledge about energy monitoring and analysis. Most of these tools support complex energy data modeling and analytics. Single screen "dashboards" such as the Pulse Dashboard are designed to support both sets of users, and combine educational and data visualization elements.

Almost all tools surveyed support tailoring of interfaces to meet specific user needs. The degree of configurability, however, varies across tools. While most tools provide the basic interface framework with which users interact through simple on-screen selections, newer tools such as Prophet allow users to build highly customized interfaces using a library of widget interface elements.

In general, the products reviewed allow users with administrative privileges to control both the content and the look and feel of the information presented. They determine the level of information that is displayed to the users lower in the access hierarchy. In most cases, users with minimal access rights typically see only a public version of the dashboard; administrators and users higher on the hierarchy can both visualize the data and with some systems also perform analyses.

Many of these product providers report expanding customer bases and claim that the use of these products has promoted significant energy conserving results. However, additional research is needed to verify these claims, and to understand exactly how these savings may be due to the use of these data visualization tools.

3. A STUDY OF EXPERT USERS

The second primary task of this research is to understand and document the energy information practices, needs and preferences of an important category of users—industry professionals who are experts in energy monitoring and analysis. A combination of surveys and contextual inquiries was used to investigate how these experts use building energy information and what tools they currently use to visualize this data. This study sought to understand their user experiences, to learn how useful and usable commonly used tools are, and what information needs are not being met by these tools.

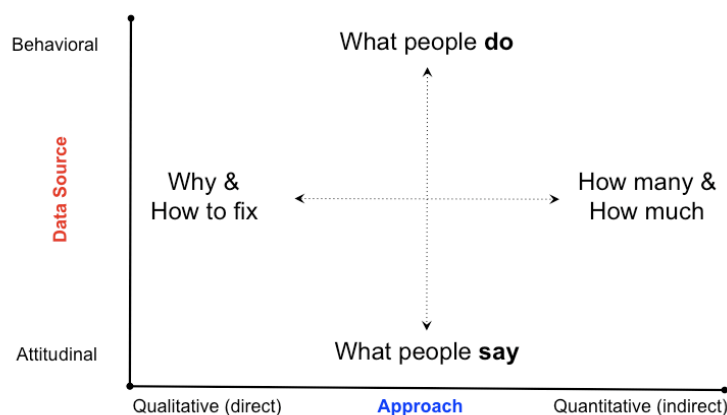
This section describes the research methods and findings from the expert user study. Section 3.1 provides an overview of user experience research methods. Section 3.2 describes the expert user questionnaire. Sections 3.3 through 3.5 describe the findings of the expert survey. The findings reported in this section were presented at the American Council for an Energy-Efficient Economy (ACEEE) 2010 Summer Study on Energy Efficiency in Buildings and are included in the conference proceedings (Lehrer & Vasudev 2010).

3.1 Background on User Experience Research

The goal of user experience research is to provide insight into the users—who they are, what they do, and what they want (Kuniavsky, 2003). User experience (UX) research methods can provide both qualitative and quantitative measures of users’ attitudinal and behavioral responses to the product or service in question. While attitudinal UX research methods may be described as “what people say” and documenting their stated beliefs, its behavioral counterpart focuses on “what people do” with minimal interference from the method itself (Rohrer 2008). Both these techniques can be carried out in either a qualitative or a quantitative manner. Qualitative UX studies gather data directly, whereas quantitative studies typically gather data indirectly through an instrument such as a survey or data mining. The choice of a particular UX research technique depends on the purpose and motivations of the study. A diagram of these considerations is shown in Figure 19.

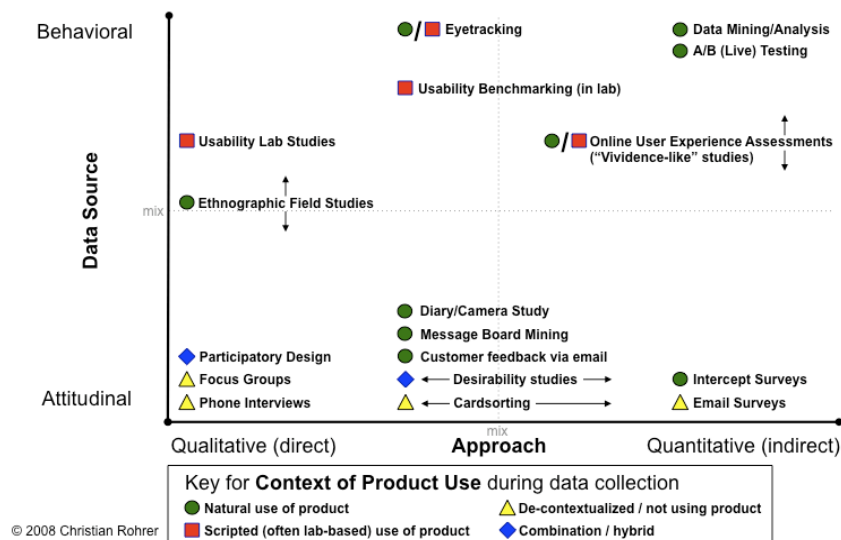
Figure 20 illustrates how numerous UX research techniques fit into this diagram. The chart includes a third variable, “context of product use,” that describes how participants use a product or service during the study, and may influence the outcomes of UX research (Rohrer 2008).

Figure 19: UX Research Methods Spectrum



Source: Christian Rohrer, <http://www.useit.com/alertbox/user-research-methods.html>

Figure 20: Matrix of UX Research Techniques



Source: Christian Rohrer, <http://www.useit.com/alertbox/user-research-methods.html>

In this study the research team was interested in both attitudinal and behavioral responses, and therefore used a combination of surveys, phone interviews and contextual inquiries to capture a mix of quantitative and qualitative perspectives to understand users' practices and information needs concerning viewing and analyzing building performance information. The context of product use in the contextual inquiries (noted as ethnographic field studies in the chart above) was *near natural*, that is, the subjects were asked to demonstrate the tools they used commonly in their work. The following section describes the research methods and the findings from the expert user study.

3.2 Expert User Survey Development

An expert user survey was developed to gather information from user groups who are highly familiar with energy monitoring and analysis, and who may be able to influence (to varying degrees) energy performance in commercial buildings. Such groups typically include building managers and operators, architects, engineers, commissioning agents, green building consultants, and others. The survey questionnaire consisted of multiple-choice and open-ended questions, divided into three sections. The first section asked users about sources and types of building performance information currently available to them, and the frequency of their use of this information. The questionnaire used conditionally branching pages so that users of energy management systems (described in the questionnaire as having control capability) and/or energy visualization tools (having no control capability) were asked additional questions specific to their use of these tools. The second section asked respondents to rate the usefulness of several types of energy information. The final section included background questions on the test subjects' demographic information and computer use patterns. This questionnaire is included in Appendix A.

3.3 Respondent Demographics and Energy Information Sources

Via email invitations a group of building industry professionals was invited to participate in the survey, using email lists that had been compiled by UC Berkeley's Center for the Built Environment for communications and outreach purposes. The survey results are viewed as a convenience sample, not statistically representative of a larger population, however they are still useful for qualitatively assessing information practices and preferences of expert users. A total of 70 complete responses to this survey was received; the distribution of job titles is shown in Figure 21. Respondents who indicated "other" (19%) included design and construction managers, project managers, utility program managers, and individuals with building or sustainability responsibilities. The ages of respondents were roughly evenly split between the four survey choices: < 30, 30-40, 40-50, and 50-60.

Figure 21: Primary Job Function of Respondents. (N=70)

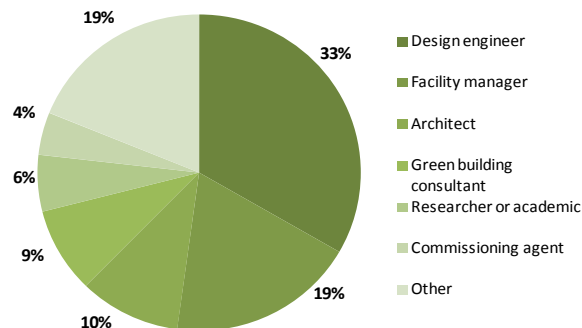
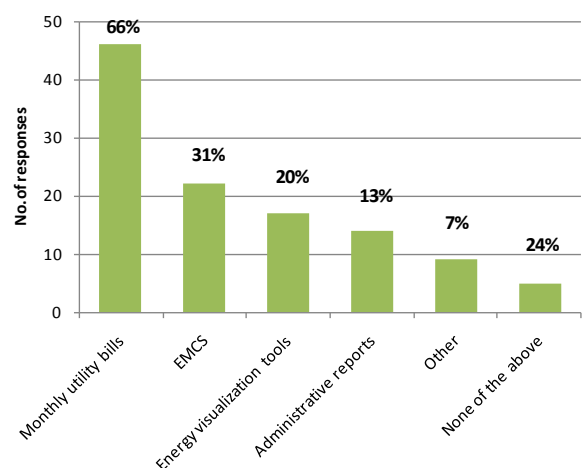


Figure 22: Information Sources Currently Available to Users. (N=70)



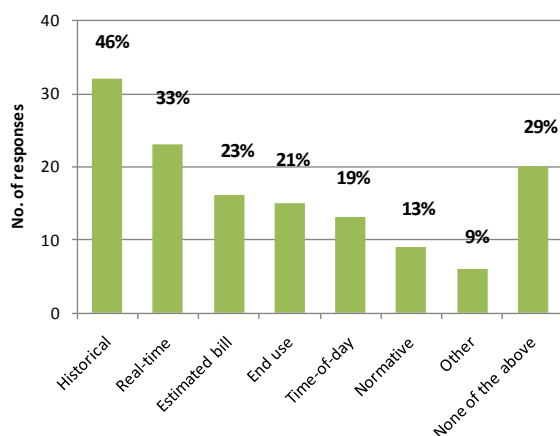
Multiple checkboxes, responses do not add to 100%.

Approximately three-fourths of the respondents currently have access to some building energy information (Fig. 22). The most common source, cited by 66% of respondents, is from monthly utility bills, followed by energy management systems, energy visualization tools, and administrative reports. Respondents were asked about the types of information available to them, for example historical, normative, end use, real time, or time of day (Fig. 23). Close to half of the respondents have access to historical energy use, and 33% have real-time energy data. In addition, respondents were asked how often they view building energy or performance data, and learned that they do so infrequently. Of the 51 respondents that have access to energy information, 39 people (76%) view this information once a month or less, six people (12%) view it a few times a month, and only six people (12%) view it one or more times a week.

Branching pages in the survey inquired further about the use of EMCSs and energy visualization tools. Respondents were asked about the types of systems used (by text box entry), frequency of use, most useful aspects, and shortcomings. Of the 23 respondents that use EMCSs, close to half indicated that they use multiple products. The most commonly cited products include those from Siemens, Johnson Controls, and Automated Logic; included also were Alerton, Invensys, Adura, Tridium, and Barrington. The useful features that respondents listed most frequently include trending, real-time information,

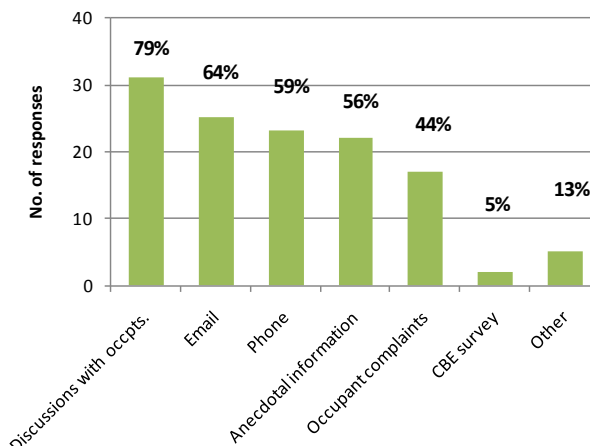
information on individual HVAC units or devices, and graphical displays such as charting and views of zones and floor layouts.

Figure 23: Information Types Currently Available to Users. (N=70).



Multiple checkboxes, responses do not add to 100%.

Figure 24: Occupant Feedback Sources. (N=38).



Multiple checkboxes, responses do not add to 100%.

Complaints about EMCSs include the inability to get usable performance data, inadequate integration with meters, lack of metering of end uses or devices that are not included in the BMS (such as total electrical use, lighting and plug loads), lack of effective historical comparisons, and the inability to format and save charts. Interestingly, many features listed as useful by some respondents are cited as lacking by others, so the features of the various products must vary considerably. Frequency of use of the EMCS information is varied — 14 users (54%) view it once a month or less, while eight (31%) view it once a day or more. As expected, facility managers and commissioning agents reported more frequent use of EMCSs.

Of the 18 respondents that use energy visualization tools (having no control capability), seven (39%) indicated that they use Excel or a spreadsheet program to manually manage data for visualization, something that was also observed during the contextual inquiries. Five users indicated that they use a building monitoring product such as Agilewaves, Fat Spaniel (PV monitoring software), or Obvious. The Energy Star Portfolio Manager was also listed by two respondents. The useful features cited by users include historical information, the ability to compare between selected time periods, the ability to make comparisons between buildings, estimated costs, graphing capability, and energy use intensity.

The list of shortcomings is similar to those noted for EMCS products and includes, for example, lack of integration with other systems, inability to combine multiple energy sources (e.g., electricity, gas, steam and/or chilled water), lack of real-time data, no access to raw data, lack of benchmarking capability, lack of end-use data, and the inability to identify anomalies. The frequency of use for visualization tools is somewhat less than that of the EMCS users, with 50% reporting that they use them once a month or less, and only one person using the system daily.

The fact that a significant overlap between the sets of comments is seen, both pro and con, regarding EMCS and energy visualization tools, seems to indicate that people in this sample are using both sets of tools in much the same way, and that many of these respondents may not make a great distinction between tools with control capability and those that only provide information.

3.4 User Preferences for Energy and Performance Information

To understand the gaps between the desired and currently available energy information, respondents were asked to rank six types of energy information for usefulness in saving energy, on a 5-point scale ranging from “very useful” to “not at all useful.” The information deemed most useful is end-use energy consumption cited by 71%, closely followed by historical energy consumption, and time-of-day use (Fig. 25). This finding reveals an information gap: even though end-use energy information had a high utility ranking, only 21% currently have access to it. Another interesting finding is the lower value users put on estimated energy bills. Ironically, many commercially available energy visualization tools stress the benefit of this feature in their advertising.

A prior pilot survey had revealed a high level of interest in end-use energy information. Consequently, this survey included a detailed question regarding the types of end-use data that would be useful (Fig. 26). Within this category, 91% of respondents felt that lighting load data would be most useful, closely followed by plug and process loads, cited as useful by 84% of respondents. In general, all types of end-use data were viewed as valuable.

Respondents were also asked about the usefulness of other types of information that are included in some newer energy visualization products (Fig. 27). The results show a high level of interest in building dashboard tools or simplified building report cards. As many systems are complex, and most users have little time to view this data, such a need seems obvious.

Figure 25: Comparative Usefulness of Types of Information. (N=70)

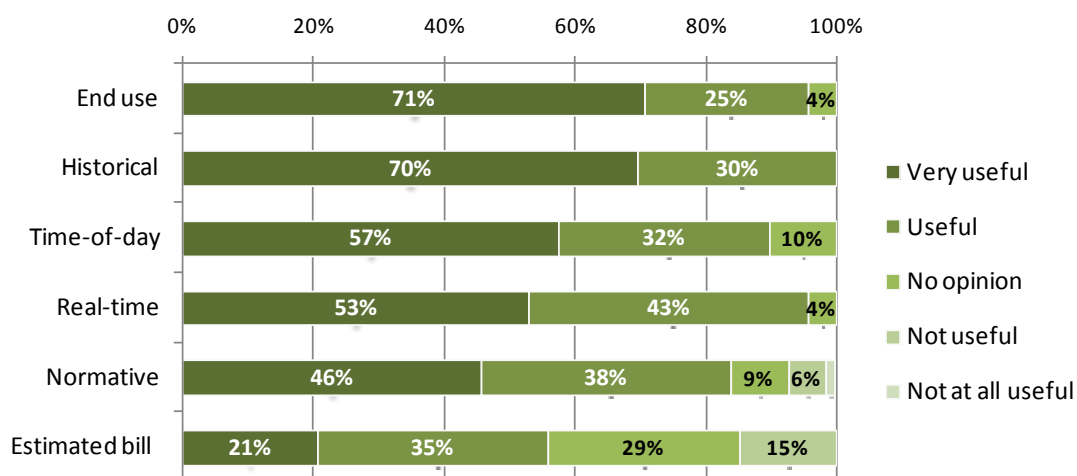
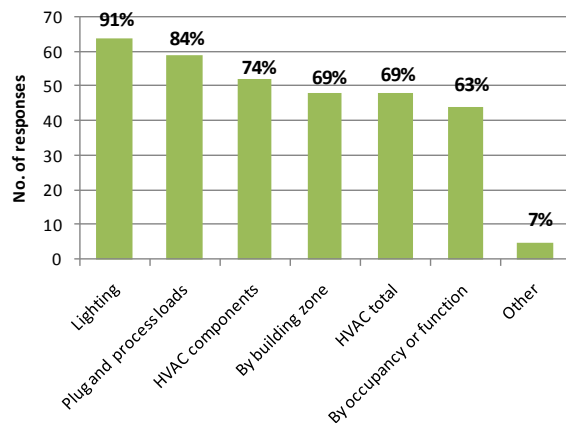
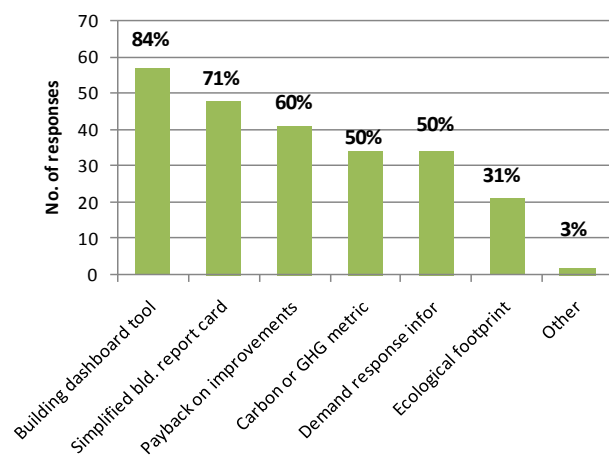


Figure 26: Usefulness of Types of End-Use Data. (N=70)



Multiple checkboxes, responses do not add to 100%.

Figure 27: Usefulness of Other Information. (N=70)



Multiple checkboxes, responses do not add to 100%.

3.5 Information Feedback from Occupants

As building occupants provide a valuable source of information about building performance (Zagreus et al. 2004), respondents were asked whether they get information from occupants regarding “occupants’ satisfaction, problems, or general building performance.” The results were evenly divided between those that do (38 responses; 54%) and those that don’t get such feedback (32 responses; 46%). Of the 38 people that do get occupant feedback, the most common source is from discussions with occupants or tenant representatives (79%), followed by email, phone, anecdotal information, and via complaints logged in a building management system (Fig 24). The survey also showed that 90% of respondents would like to have a more systematic way of communicating with building occupants. While there are a few tools available for this purpose (for example the CBE Occupant IEQ Survey) and some research has been done to test new approaches to occupant feedback (Federspiel & Villafana 2003), this points to an ongoing information need that is generally being overlooked. To help address this need, the authors have designed and will test a prototype social media application intended to facilitate communications between occupants and building operators (Lehrer and Vasudev, 2011).

3.6 Contextual Inquiry of Expert Users

Contextual inquiry is a method for understanding users by interviewing them in their workplaces and observing how they use interactive products. Previous research has used case study methods to document how facility managers use energy information systems to manage energy use in commercial buildings (Motegei et al. 2003, Granderson et al. 2009). For this study interviews were conducted with six subjects having a variety of information needs and practices. As there are many diverse users of building performance information, these case studies included design team members and other building industry professionals.

Each inquiry included a semi-structured interview to learn about the user’s background in energy management, current sources of energy information, frequency of use, and interactions with occupants. During the interviews, the subjects were also asked about shortcomings with the current sources of information, and additional building information that might be useful. In addition, the subjects were

asked to demonstrate the tools they used to view building information, with attention to the commonly used features.

The subjects selected for the contextual inquiry were asked to provide a broad range of perspectives on visualizing building performance data. Participants included:

- Engineering team members for a small office building with a zero-energy goal
- Architects in a firm that designs a large number of green and LEED-certified projects
- A mechanical engineer and principal with a mechanical engineering firm known for its high-performance building design
- A project manager for a major university campus
- A facility manager for a single building on a university campus
- Energy and resource consultants with an engineering firm who work with data for buildings, campuses, and entire communities

The following sections summarize the findings of these interviews in terms of the subjects' tools and practices, common limitations cited by these users, and a summary of key information needs that are not met by the tools they currently use.

3.7 Tools and Practices of Contextual Inquiry Subjects

Most of the interview subjects rely primarily on BMSs such as Metasys, Automated Logic, Barrington, and Obvius for energy monitoring. Although the expert survey findings indicate that many people have access to monthly utility bills, none of the interview subjects mentioned using monthly bills. The interviews confirmed the survey findings, which show that many people use multiple BMS and/or energy visualization products.

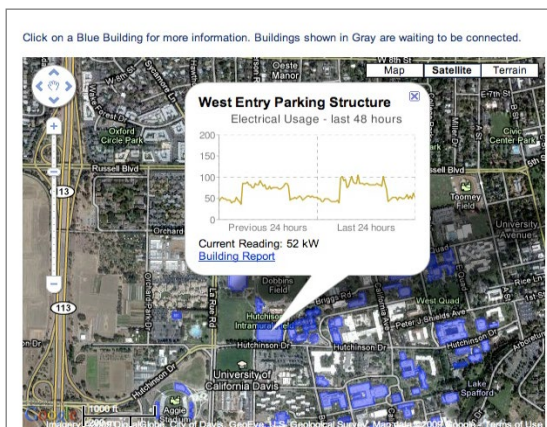
One example of the multiplicity of energy tool use is seen in the practices of the engineering team for a small commercial zero-energy building (ZEB). This team has monitored the building's performance to reach its net-zero goal since the initial occupancy. The project uses control and data systems that the design team describes as state-of-the-art, including a BMS system for HVAC control and monitoring, a web-based software tool to monitor electrical production of the rooftop PV array (required for rebate program compliance), a wireless lighting control system, and an additional product for monitoring overall electrical use.

Consistent with the survey findings, several interview subjects utilize web-based energy dashboards that provide simplified visualizations of energy profiles and trends. Although these tools have limitations (see below), some users describe them as useful for spotting anomalies in whole building energy use and for identifying high base loads. For example, the campus project manager interviewed uses a campus-wide "utilities consumption dashboard," which is publicly available online. Users can select a building from a campus map to view a pop-up window with a trend line of electrical use over the past 48 hours, along with the current power use (Fig. 28). Users can also view more detailed information, including the current demand compared to the previous day, averages, maximums, monthly utilization, and cost data. This subject uses this tool on a monthly basis to understand the energy profile of buildings, however his frequency of use may increase when he has a large number of renovation projects underway.

Of all the subjects interviewed, the architects are the most interested in comparing the overall performance of their projects against other benchmarks. They are using free, publicly available tools, including the Energy Star Portfolio Manager, and a pilot version of the web-based "Energy IQ" benchmarking tool now under development by Lawrence Berkeley National Laboratory. This promising tool allows users to benchmark existing or design-phase buildings against a wide array of energy metrics

for other buildings (Fig. 29). In addition to these energy-benchmarking tools, they also use the CBE Occupancy IEQ Survey to obtain information on occupant satisfaction in their completed projects.¹⁶

Figure 28: Campus Utilities Consumption Dashboard



Source: <http://facilities.ucdavis.edu/dashboard/>

Figure 29: Sample Interface From EnergyIQ



Source: <http://energybenchmarking.lbl.gov/>

3.8 Limitations of Current Tools

The interview subjects noted several shortcomings of the energy information tools they are currently using. The number of different systems in use, and the lack of integration between them were cited as significant problems. For example, none of the tools used by this group of subjects could combine multiple energy sources such as electrical, steam, and/or gas. This is well illustrated by the large number of systems required for the relatively small (6500 ft²) ZEB project described above. Another common limitation is the lack of effective visualization of end-use energy data. BMSs are the only source of end-use data, and most do not allow users to view cumulative energy use in a meaningful way.

Few of the energy tools used by this group of users provide capability for data analysis within the tool. For analysis and visualization, many users must download data from a BMS, and use spreadsheet programs, sometimes in conjunction with the Universal Translator tool,¹⁷ to create visually appealing visualizations and presentations (Fig. 30). This is a time-consuming task, and is typically only performed in special cases, such as for diagnostics or reporting building performance.

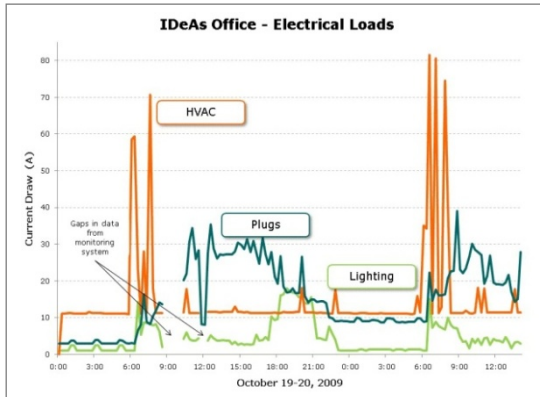
Several interview subjects also noted that simplified building dashboard products have significant limitations. Although they have included such dashboards on several projects, they feel that the energy data from these tools are typically too simple to be useful for building designers wishing to track their buildings' performance. Additionally, they find that these dashboards are rarely available online and do little to benchmark performance against comparable buildings. The university project manager interviewed noted several shortcomings with the dashboard-style campus utilities tool described above. Data is not normalized, so building-to-building comparisons can be misleading to non-expert users. The system has also been known to report erroneous data, and on several occasions failed to reflect major

¹⁶ Information on this survey resource is available at <http://www.cbe.berkeley.edu/research/survey.htm>

¹⁷ A free software tool designed for the management and analysis of data from building management systems available at <http://utonline.org/cms/>

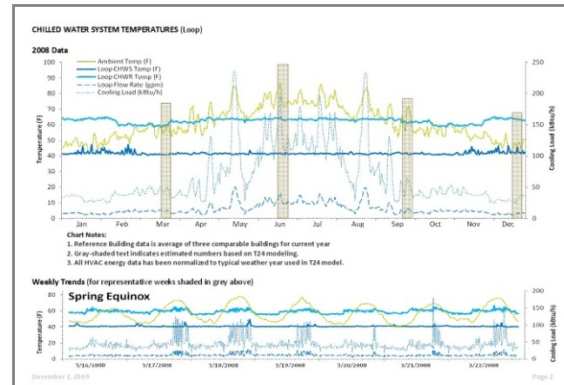
changes in occupancy. Such occurrences have raised concerns among users about the credibility of the tool.

Figure 30: Elec. Load Visualization Produced using Universal Translator



Source: IDEAs

Figure 31: Custom Data Visualization Proposed for Campus Buildings



Source: Bill Starr, UC Davis

3.9 Summary of Key Information Needs Noted in Contextual Inquiries

Although the interview subjects varied in terms of information needs and access to energy information, they reported a common number of unmet information needs that are summarized below. As part of the interview process, the subjects were asked to imagine and describe their ideal energy visualization tools; the responses to this question are revealing and some are included in this summary.

High-level overview with drill-down capabilities, including visualization of end-use energy information including lighting, plug loads, and HVAC components: The interview subjects report that they use energy information tools infrequently, confirming the survey findings. They require a visualization that provides a quick overview, with an ability to drill down for detailed information when needed. One group of subjects described an ideal visualization tool as a cross between a dashboard-style product with overviews of daily and weekly energy use, combined with the capability of the BMS system, including alarms to identify anomalies. In pursuit of an effective summary of building information, one interview subject had even charted out a proposal for a tiered building report that ranges from general building information to system-level detail (Fig. 31).

Integration of energy visualization features with data analysis: Many users rely on data downloaded from BMSs and manipulated in spreadsheet programs. The ability to filter and generate energy analyses in tabular or graphical form directly from the energy monitoring system would be a great time saver for these users.

Support for normalization and energy benchmarking: Several interview subjects cited the need to accurately benchmark between buildings, including normalized values and energy use intensity.

Compatibility with existing BMSs: The multiplicity of systems, proprietary BMS protocols, and lack of interoperability were common complaints. Some interview subjects described an ideal tool that would be based on open source products, and that could be built in a modular fashion with the flexibility of web-enabled tools.

Support for occupant interaction capability: Several of the interview subjects stated a desire to have better interaction with building occupants, a finding that supports the survey results. One group of

subjects believed that that they would benefit from an ability to record occupant discomfort with time and location data that could be compared to BMS data for diagnostics. (Such a system was piloted in a U.S. General Services Administration building, reported in Federspiel & Villafana 2003.)

3.10 Summary from Expert User Study Directions for Future Research

Although this research deals with a relatively small sample, one can begin to generalize about information preferences of expert users of building information. The survey research revealed that many users have access to monthly utility data, and many also have access to EMCS or data visualization data. Many users do not make a great distinction between information systems with control capability and those without, and that for most users viewing this information is an infrequent activity. Building operators and commissioning agents are more frequent users of this information (assuming they will not be ambivalent about the value of control capability.) A preference for historical energy data, and a desire for end-use data of many types, with lighting and plug/process loads ranking highest were also observed. The survey revealed a nearly unanimous desire for better methods of communicating with building occupants, and this finding was supported by the interview research.

The expert user study found that access to reliable energy and performance data varies considerably between firms and individuals, and that the current tools have numerous shortcomings. Many people cited the lack of integration of energy sources and control systems, and the inability to modify and save views. Both the surveys and interviews showed that many users, including those with access to building information tools, still use data exported from BMSs, and manipulated in spreadsheet programs for analysis, visualization, and presentation. For many people, the serious analysis of managing building data remains a time intensive, do-it-yourself undertaking.

Many users would also like access to an information dashboard overview, or simplified building report card, while many users need to drill down for detailed information. These professionals would be well served by software tools that conform to a convention described in human-computer interaction literature as “overview first, zoom and filter, then details-on-demand” (Shneiderman 1996).

Finally, the contextual inquiry research revealed that there is a range of reasons why these expert users seek building performance information. The facility managers and engineering professionals are interested in viewing current and cumulative performance and fine-tuning operations. The architects interviewed are less likely to be involved in operational details but are seeking lessons-learned for future design and general performance data that can inform the design of future projects.

4. ENERGY INFORMATION SURVEY OF TYPICAL OFFICE OCCUPANTS

A building information survey for workplace occupants was developed and implemented to investigate energy attitudes and behaviors of occupants in commercial buildings, and to evaluate the potential for energy feedback to promote energy conserving behaviors. The survey questionnaire consisted of multiple-choice and open-ended questions, divided into two sections. The first section asked about people's energy use in their workplace environments: specifically, about their current sources of energy information, energy use sensibilities, and efforts to energy conservation. People were also asked about the kinds of energy information that might be useful for saving energy and the preferred methods for display. The second section asked about respondents' demographics, type of workspace, and energy awareness at home. (The questionnaire is included in Appendix B.)

4.1 Respondent Demographics and Current Sources of Energy Information

Past users of CBE's Occupant IEQ Survey were contacted by email to identify potential occupant survey sites. Five buildings were identified and a person familiar to people within the organization was employed to forward the survey link to occupants. Table 2 summarizes the buildings and survey responses.

A total of 170 complete responses to this survey were received. Approximately half the respondents were in the two youngest age groups: under 30 (26%) and 30-40 (26%). The remaining respondents were divided between the older categories: 40-50 (18%), 50-60 (20%), and over 60 (9%). There was roughly an equal number of male (47%) and female (53%) respondents. Most of the respondents work in enclosed private office spaces (29%), cubicles with partitions (28%), and in workspaces in open offices with no partitions (25%). Approximately three-fourths of the respondents report access to some sort of energy information. The most common source, cited by 39% of respondents is from a co-worker or manager, followed by company and external communications, and graphical displays (Fig. 32).

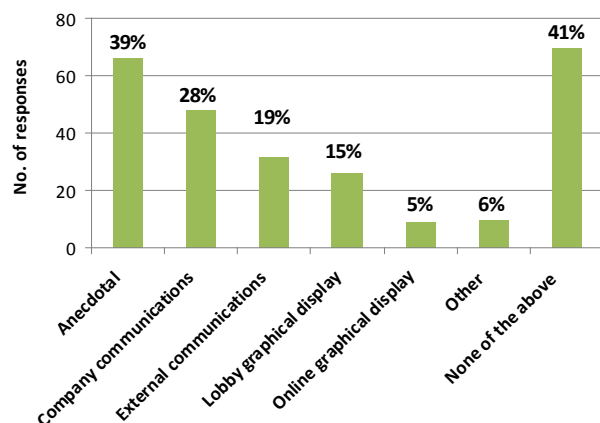
Table 2: Summary of Occupant Survey Participant Buildings

Building description	Location	Type	Responses
Campus design and construction management office	Davis, Calif.	Office	28
Urban design and landscape practice	Philadelphia, Penn.	Office	49
College preparatory K-12 school	Haverford, Penn.	Educational	56
Academic building with offices, classrooms, and studios	Berkeley, Calif.	Educational	35
Department of natural resources building	Madison, Wis.	Office	3

The survey asked users of graphical displays additional questions about the use of these displays, and learned that viewing this information is not a frequent practice. Out of the 35 respondents that view electronic displays, most (57%) access this information once a month or less, 9 people (30%) view it few times a month and only 4 (13%) one or more times a week. They were also asked how this information is useful to them (Fig. 33). Approximately two-thirds responded that they view this information out of a

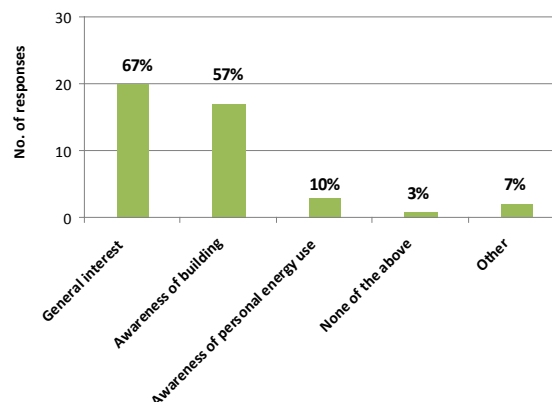
general interest. Some indicated that this information makes them more aware of their building (57%) and a few indicated that it makes them aware of their personal consumption patterns (10%). In terms of other useful information they would like to see in such a display, about three-fourths of respondents (75%) cite the usefulness of viewing building electrical use. Other useful information include building water use (43%), descriptions of green features (25%), carbon footprint (21%) and the amount of renewable energy generated (18%) by the building.

Figure 32: Current Sources of Energy Information (N=169)



Multiple checkboxes, responses do not add to 100%.

Figure 33: Usefulness of Energy Information in Electronic Graphical Displays (N=30)



Multiple checkboxes, responses do not add to 100%.

4.2 Self-Reported Energy Behaviors and Motivations to Conserve

The survey also included several questions about behavior and attitudes towards energy conservation in the workplace. A surprisingly large number of the respondents (91%) strongly agree or agree with the statement that they currently make an effort to save energy at their workplace (Fig 34). They report that they currently take energy-saving actions including turning off the ceiling lights (73%) and desk lights (66%), turning off equipment (62%), using energy-saving settings in equipment (59%), adjusting blinds and/or windows (48%), purchasing energy efficient equipment (18%), and adjusting thermostats (11%) as additional efforts to control energy use in their workplaces. (Although such high levels of self-reported energy saving may not reflect actual behavior, it at least shows the respondents attitudes towards such actions.) A question regarding the motivations for these energy saving actions was also included in the survey (Fig. 37). The most frequently cited reasons are to benefit the environment (92%), "because it is the right thing to do" (86%), and to save money for the company (63%). Also, 40% would take actions in order see the results represented in an energy information display.

Many respondents indicated (strongly agree or agree) that they would make more of an effort to conserve energy if they had knowledge of the amount (80%) and costs (73%) of energy they were consuming (Figs. 35 & 36). This clearly shows that information feedback has great potential value in supporting energy conservation efforts and by doing so can play an important role in lowering their carbon footprints.

Figure 34: Response to: “I currently make an effort to conserve energy in my workplace.” (N=171)

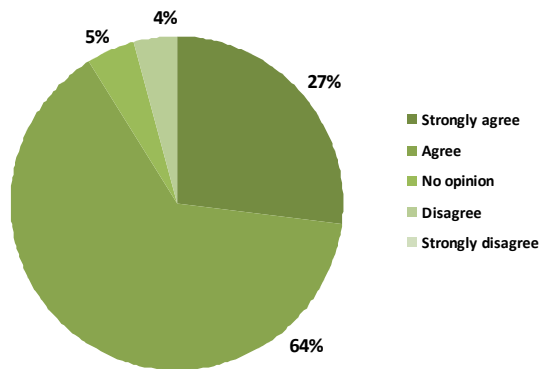


Figure 35: Response to: “If I knew more about the *amount* of energy consumed in my workplace, I would make more of an effort to conserve energy.” (N=171)

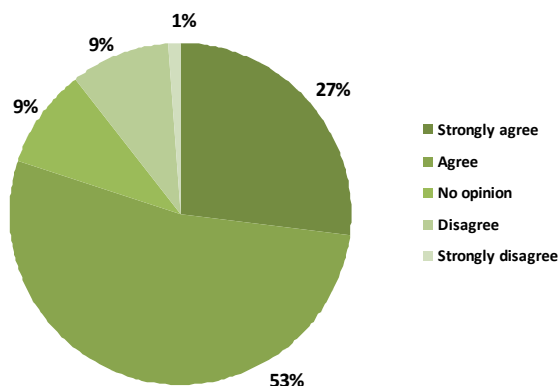
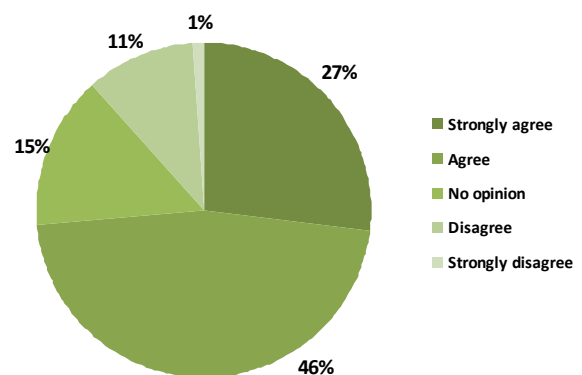


Figure 36: Response to: “If I knew more about the *cost* of energy consumed in my workplace, I would make more of an effort to conserve energy.” (N=170)

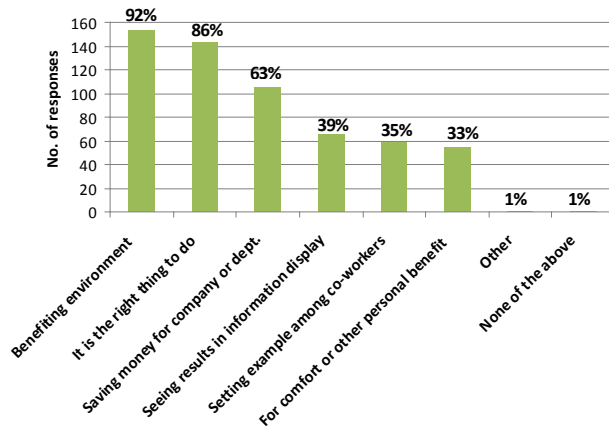


4.3 Preferences for Representing Energy Information

The survey further asked respondents which methods of representing energy use in the workplace would be most useful (Fig. 38). The results highlight a strong need to visualize both the amount (75%) and related costs (70%) of energy use in the workplaces. People also responded that showing energy information in terms of pollution created or prevented (58%) and commonly understandable units such as light bulbs and homes powered (43%) would be useful.

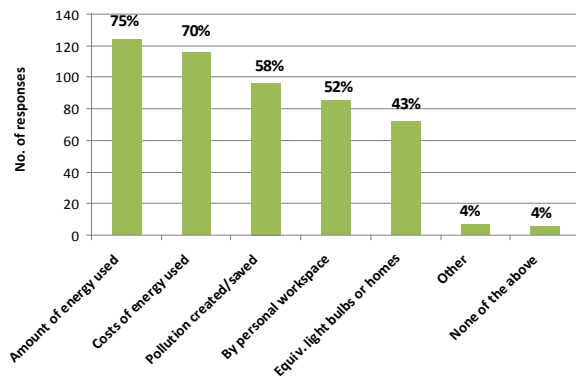
It is interesting to note that people indicate that their main motivations to conserve energy stem from environmental and ethical concerns, however they still seem to express preference for visualizations that highlight the *amount* and *costs* of energy use as opposed to pollution caused or homes powered, parameters that would seem to be more aligned with their underlying motivations to conserve.

Figure 37: Motivations to Save Energy (N=168)



Multiple checkboxes, responses do not add to 100%.

Figure 38: Useful Metrics for Showing Energy Consumption (N=166)



Multiple checkboxes, responses do not add to 100%.

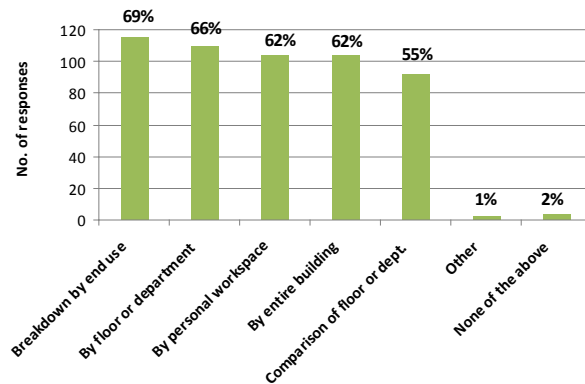
The survey also asked about the kinds of energy details that would be useful (Fig. 39). The results showed that people place a high value on visualizing energy use broken down by end-use (69%) similar to the earlier findings from the expert survey. Other types of information cited as useful include showing energy use by floor, area or department (66%), by personal workspace (62%), and by comparisons of energy use by floors, areas and departments (55%). Finally, there seems to be a strong preference in the method of information display – about three-fourths of the respondents cite the web as being the best medium for visualizing the building’s energy information (Fig. 40).¹⁸

To identify correlations (if any) between people’s energy behaviors at their workplace and home, respondents were asked about their actions to conserve energy at home. Even though one would expect a greater sense of care and precaution to minimize energy costs at home, surprisingly, the survey results show that people care about the amount and costs of energy consumption equally at their workplaces and homes. The relationship between self-reported energy conservation at home and at work is charted in Table 3.

Ninety-four percent of the respondents report that they are aware of their energy costs at home, almost all of them (98%) report (strongly agree or agree) that they take steps to reduce their energy use at home, and a only a slightly smaller number (91%) report taking similar steps at work.

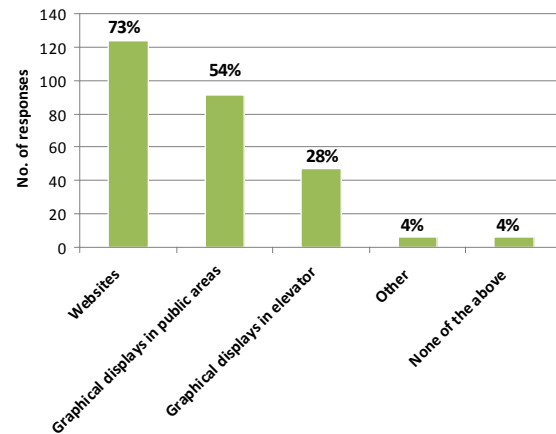
¹⁸ Hand-held devices such as smart phones now present an additional option for energy displays, unfortunately this was not included as one of the check box responses to this question.

Figure 39: Potentially Useful Kinds of Energy Information (N=167)



Multiple checkboxes, responses do not add to 100%.

Figure 40: Preferred Methods for Displaying Energy Information (N=169)



Multiple checkboxes, responses do not add to 100%.

Table 3: Relationship Between Self-Reported Energy Conservation at Home and at Work (N=170)

		Currently takes steps to conserve energy at <i>home</i>				
		Strongly agree	Agree	No opinion	Disagree	Strongly disagree
Currently takes steps to conserve energy at <i>work</i>	Strongly agree	34	11	0	0	0
	Agree	50	57	1	2	0
	No opinion	5	3	0	0	0
	Disagree	2	5	0	0	0
	Strongly disagree	0	0	0	0	0

4.4 Summary of Workplace Energy Survey of Workplace Occupants

The number of survey responses was smaller than desired and included a low response rates in a few of the selected sites. The sample of 170 yields an approximate margin of error of 7.5%; however, a few caveats should be noted. There may be a bias towards higher energy awareness in this sample. This is a self-selecting population, and more energy-aware individuals may be likely to take the time to respond to such a survey. In addition, the buildings included the offices of campus construction and engineering staff, who may be more interested in building energy than other types of office occupants. Accepting

these limitations, the study does provide insight into the energy attitudes of some workplace occupants, and their preferences for viewing energy information that are summarized below.

Slightly more than half of the survey respondents have access to some information about energy use in their workplaces: The most common sources of this information are word-of-mouth from co-workers or managers, followed by company and external communications. The small number of occupants that have access to a graphical energy display view it infrequently, most people indicate that they view it once a month or less.

A large majority of workplace occupants report that they already take actions to save energy: Turning off desk lights is the most commonly cited action, followed by turning off ceiling lights and equipment, using energy-saving settings for computers and monitors, and adjusting windows and/or blinds. Additional research would be valuable to see the degree to which this is true in practice, to what degree such actions are beneficial.

Many respondents indicated that they would take more energy conserving actions if they got feedback on either the amount or cost of energy used: Respondents did not show a strong preference between cost and energy used. People indicated that they would be interested in seeing energy use for the entire building, and also broken down by end use, by floor or department, and/or at the level of individual workspaces. They had a preference for seeing information via a website that they could view at will, or such an interface located in a kiosk in a lobby or public area.

The primary motivations for saving energy at work are environmental and ethical concerns (“doing the right thing”), followed by saving money for the company: Other motivations included an interest in seeing results in an information display, setting an example for co-workers, and for reasons of comfort or personal benefit.

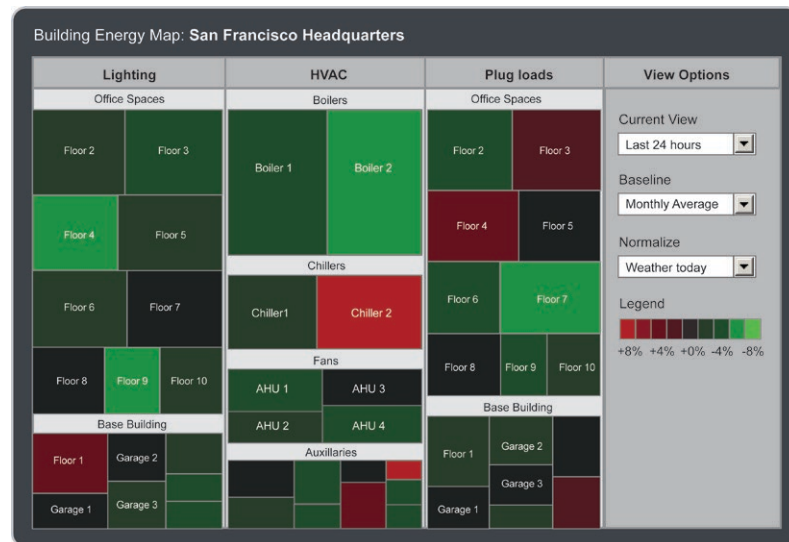
5. DISCUSSION AND DIRECTIONS FOR FUTURE WORK

This report summarizes the first phase of this research project. Results from the expert user study (section 3) were presented at ACEEE 2010 Summer Study on Energy Efficiency in Buildings and is included in the conference proceedings (Lehrer & Vasudev 2010). The study identified a number of information needs that are not being met by current visualization tools, although a growing number of companies are working on innovative new concepts to address these needs.

One type of visualization that appears promising for viewing trends in buildings, but that has not been generally adopted by building software providers, is the “treemap” visualization. Treemaps can display multivariate data and allow users to quickly understand trends, along with their relative importance. Clicking on squares on the treemap allow users to drill down into deeper levels of information without navigating multiple menus. A highly successful application of this method is the Map of the Market, a powerful data visualization of stock market trends.¹⁹ The research team hypothesizes that applied to building operations, a treemap could allow a building manager to quickly identify trends or anomalies and drill down for more information.

¹⁹ Map of the Market is viewable at <http://www.smartmoney.com/map-of-the-market/>

Figure 41: Prototype Building Treemap Visualization



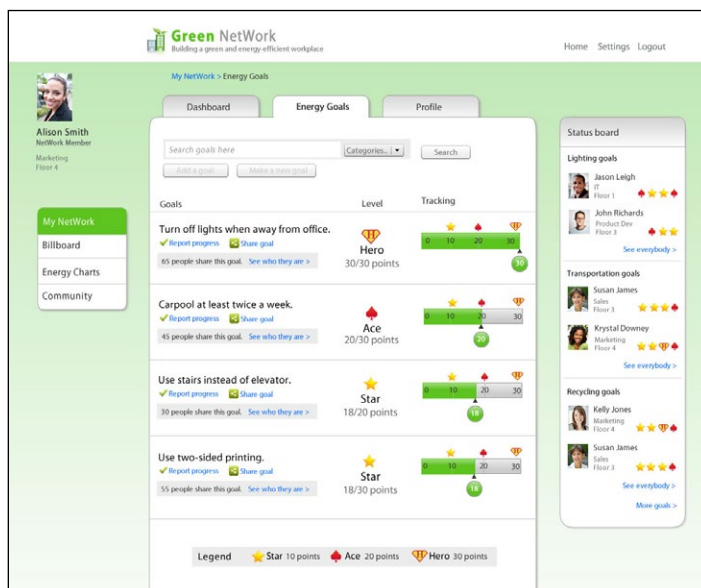
Source: Center for the Built Environment (CBE)

A prototype treemap visualization that might be applied to a commercial building is shown in Fig. 41. The rectangles represent both the relative energy use of various end uses (shown by the areas of the rectangles) and the trends of each relative to a benchmark (shown by the colors of the rectangles). In Fig. 41, the large red square in the HVAC section makes it immediately apparent that a chiller is operating at a level well above the norm. Another bright red rectangle below shows that an auxiliary load is operating above the norm, but its small size helps the building operator know that this problem is less urgent than the errant chiller. Although these anomalies might not show up on a trend line of overall building energy use, it is immediately obvious in this treemap visualization. A view options panel (at right in Fig. 41) would allow the user to select the timeframe for the data visualization, select the benchmark data, and control normalization of the data. For more detailed information, a user clicks on a rectangle of interest to view other screens with details such as trend lines or component status.

Results from both the expert user study and the workplace occupant study (section 4) lend weight to the belief that commercial building energy use and operations could be improved through the availability of tools that enable operator-occupant communication, and that show occupants detailed information about building energy use, especially if that information could be made relevant to their individual workspaces or offices.

Based on these findings, the authors hypothesized that a social media application, integrated into the workplace, can enable such communication and also take advantage of social influence to engage and positively affect energy-related behavior of occupants. For the second phase of this research, a prototype of such an application was developed through iterative design, and will be tested with a number of subjects to evaluate the ability of such an application to provide a platform for commercial building operators to better communicate with occupants, and to influence attitudes and behaviors of office workers (Fig. 42). The conceptual approach to this work was presented at the CHI 2011 Conference on Human Factors in Computing Systems as an extended abstract. (Lehrer & Vasudev, 2011). The results of this work are reported in appendix 2.3.2 of PIER .

Figure 42: Prototype Social Media Application for Energy and Building Operations



Source: Center for the Built Environment (CBE)

6. ACKNOWLEDGEMENTS

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<http://www.cbe.berkeley.edu/aboutus/industrypartners.htm>.

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APPENDIX A: BUILDING INFORMATION QUESTIONNAIRE FOR EXPERT USERS: ARCHITECTS, ENGINEERS, BUILDING OWNERS AND OPERATORS

Page 1: Please tell us about your current sources of building performance information.

1. What is your current source of energy information in your building(s)? Check all that apply.
 - ☐ Monthly utility bills
 - ☐ Administrative reports
 - ☐ Energy management and control system (EMCS) or building management system (BMS)
 - ☐ Energy visualization tools (energy information only, no control capability)
 - ☐ Other _____
 - ☐ I have no energy information
2. How frequently do you review energy and/or other performance information about your building(s)?
 - ☐ Once a month or less
 - ☐ A few times a month
 - ☐ One or more times a week
 - ☐ Once a day or more
 - ☐ I have no such energy information
3. Which of the following kinds of energy information do you have currently? Check all that apply.
 - ☐ Real-time energy consumption (Current use)
 - ☐ Normative energy consumption (Compared to other buildings)
 - ☐ Historical energy consumption (Compared to previous time periods)
 - ☐ Time-of-day consumption (Energy use at different hours of the day)
 - ☐ End use energy consumption (Separate energy use of heating, cooling, lighting, etc.)
 - ☐ Estimated bill based on energy consumption (Energy cost for current period and beyond)
 - ☐ Other _____
 - ☐ None of the above
4. Do you receive information from occupants in the building, regarding occupants' satisfaction, problems, or general building performance?
 - ☐ Yes
 - ☐ No
5. If you responded yes to question 4 above, how do you receive this information? Check all that apply.
 - ☐ From complaints submitted by occupants (via a CMMS or other logging method)
 - ☐ From discussions with occupants or tenant representatives
 - ☐ Email
 - ☐ Phone
 - ☐ Heard anecdotally from others
 - ☐ Other _____
 - ☐

Page 1A: Branching page if respondent selects EMCS/BMS or energy visualization tool in question 1.

You responded that you use an EMCS/BMS, or an energy visualization tool. Please tell us more about this:

- ☐ What energy management and control system(s) (EMCS) or building management system(s) (BMS) do you use? _____

- How often do you use it/them?
- Once a month or less
- A few times a month
- One or more times a week
- Once a day or more
- What features of the EMCS or BMS are most useful? _____
- Are there features the EMCS or BMS are lacking? _____
- What energy visualization tools (excluding EMCS or BMS) do you use? _____
- How often do you use it?
 - Once a month or less
 - A few times a month
 - One or more times a week
 - Once a day or more
- What features of the energy visualization tools are most useful? _____
- Are there features the energy visualization tool is lacking? _____
-

Page 2: Please tell us what types of information would be useful to you.

6. How useful to you is the following energy-related information for saving energy?
(Scale response: Very Useful, Useful, No opinion, Not Useful, Not at all useful)
 - Real-time energy consumption (Current energy use now)
 - Normative energy consumption (Energy use compared to other buildings)
 - Historical energy consumption (Energy use compared to previous time periods)
 - Time-of-day consumption (Energy use at different hours of the day)
 - End use energy consumption (Separate energy use of heating, cooling, lighting, etc.)
 - Estimated bill based on energy consumption (Energy cost for current period and beyond)
7. Which of the following end use load information might be useful to you? Check all that apply.
 - ☐ Lighting
 - ☐ HVAC total
 - ☐ HVAC components (heating, cooling, fans)
 - ☐ Plug and process loads
 - ☐ By building zone (floor or workspace levels)
 - ☐ By occupancy or function (classrooms, offices, conference rooms)
 - ☐ Other _____
8. Would it be valuable to have better methods of communicating with the occupants in the building in a systematic manner?
 - Yes
 - No
9. What other types of information would be useful to you? Check all that apply.
 - ☐ Simplified building report card
 - ☐ Building dashboard tool (single screen that gives an overview of multiple building metrics)
 - ☐ Carbon emissions or greenhouse gas metric
 - ☐ Ecological footprint metric
 - ☐ Payback period calculator for improvements
 - ☐ Demand response information
 - ☐ Other _____

Page 3: We have some general questions about you and your interest in future research of this type.

10. Which title best describes the work you do?
- ☐ Facility manager
 - ☐ Building operator
 - ☐ Building owner, developer, or real-estate professional
 - ☐ Architect
 - ☐ Design engineer
 - ☐ Commissioning agent
 - ☐ Researcher or academic
 - ☐ Green building or energy consultant
 - ☐ Other _____
11. What is the average time that you spend on the computer in a day?
- ☐ Less than 1 hour
 - ☐ 1-4 hours
 - ☐ 4-8 hours
 - ☐ More than 8 hours
 - ☐ I don't use a computer at all
12. What are the most convenient ways to receive information about your building(s)? Check all that apply
- ☐ Desktop computer in my workplace
 - ☐ Laptop computer that I can take with me
 - ☐ Handheld device
 - ☐ Standalone display or kiosk
 - ☐ Email notifications
13. What is your age?
- ☐ Less than 30
 - ☐ 30-40
 - ☐ 40-50
 - ☐ 50-60
 - ☐ Over 60
14. Would you be willing to participate in phone interviews, site visits or paid usability tests?
- ☐ I would be willing to participate in phone interviews.
 - ☐ I would be willing to have to someone visit and interview me.
 - ☐ I would like to participate in paid usability tests.
 - ☐ No thanks, I don't want to participate.
15. Please provide contact information to register for the prize drawing, and if you told us you would like to participate in future phases of this study.
- Name _____
- Email address _____

APPENDIX B: BUILDING INFORMATION QUESTIONNAIRE FOR WORKPLACE OCCUPANTS

Page 1: Tell us about your energy use in your workplace:

1. What information do you have about energy use in your workplace, if any? (Check all that apply.)

- ☐ Company communications (newsletter, articles, posters, email, etc.)
- ☐ External communications (articles, websites, email, etc.)
- ☐ A graphical energy display available online [branch to questions 13-16]
- ☐ A graphical energy display in the lobby [branch to questions 13-16]
- ☐ Things learned from a co-worker or manager
- ☐ Other source of information _____
- ☐ I have no energy information

Please indicate whether you agree or disagree with the following statements:

2. I currently make an effort to conserve energy in my workplace.
[Strongly Agree, Agree, No Opinion, Disagree, Strongly Disagree]
3. If I knew more about the **amount** of energy consumed in my workplace, I would make more of an effort to conserve energy. [Strongly Agree, Agree, No Opinion, Disagree, Strongly Disagree]
4. If I knew more about the **cost** of energy consumed in my workplace, I would make more of an effort to conserve energy. [Strongly Agree, Agree, No Opinion, Disagree, Strongly Disagree]
- 5.

Page 1A: Branching page if respondent selects graphical energy displays online or in lobby in question 1.

Tell us more about your use of graphical energy displays:

- ☐ You have said that you have gotten information from a graphical energy display. How often do you look at this display?
 - ☐ Once a month or less
 - ☐ A few times a month
 - ☐ One or more times a week
 - ☐ Once a day or more
- ☐ How has this information been useful to you?
 - ☐ It is of general interest
 - ☐ It makes me more aware of the building
 - ☐ It makes me aware of my own energy using actions
 - ☐ Other _____
 - ☐ It's not very valuable to me.
- ☐ What are the most interesting or useful features of this energy display?
 - ☐ Electrical use
 - ☐ Renewable generation (for example, solar or wind power)
 - ☐ Water use
 - ☐ Carbon footprint
 - ☐ Description of green features
 - ☐ Other _____
- ☐ What additional features would be interesting or useful to you?

Page 2: Tell us about your energy use in your workplace:

6. What actions **do you currently** take to save energy in your workplace? (Check all that apply.)

- ☐ Turning off desk light(s) when not in the room
- ☐ Turning off ceiling light(s) when not in the room
- ☐ Turning off equipment when not in use (printers, fans, heaters, etc.)

- ☐ Using energy-saving settings for computer and monitor
 - ☐ Purchasing energy efficient equipment
 - ☐ Adjusting thermostat
 - ☐ Adjusting blinds and/or windows
 - ☐ Other _____
 - ☐ None of the above
7. What motivation would make you most likely to save energy in your workplace? (Check all that apply.)
- ☐ Saving money for my company or department
 - ☐ Benefiting the environment
 - ☐ Seeing the results in an information display
 - ☐ Setting an example among co-workers
 - ☐ Because it is the right thing to do
 - ☐ For my comfort of other personal benefit
 - ☐ Other _____
 - ☐ I am not interested in saving energy in my workplace
8. What would be a useful way to display how much energy is being used in your workplace? (Check all that apply.)
- ☐ A website showing the **amount** of energy used
 - ☐ A website showing the **costs** of energy used
 - ☐ A website that shows the energy used in my personal workspace
 - ☐ Energy displayed in terms of pollution created or prevented
 - ☐ Energy displayed in terms of the number of light bulbs or homes that could be powered
 - ☐ Other _____
 - ☐ I am not interested in seeing energy use
9. What kind of details about the energy used in your workplace would be most useful to you? (Check all that apply.)
- ☐ Energy used by my personal workspace
 - ☐ Energy used by my floor, area, or department
 - ☐ Energy used by the entire building
 - ☐ A comparison of energy used by different floors, areas, or department
 - ☐ Energy use broken down by use (lighting, equipment, heating, etc.)
 - ☐ Other _____
 - ☐ I am not interested in seeing energy use
10. What method of displaying energy information in the building would be most useful to you? (Check all that apply.)
- ☐ A website I can view when I am interested
 - ☐ Graphical energy displays in the building lobby or other public areas
 - ☐ Graphical energy displays in the elevator
 - ☐ Other _____
 - ☐ I am not interested in seeing an energy display
11. Which of the following best describes your personal workspace?
- ☐ Enclosed office, private
 - ☐ Enclosed office, shared with other people
 - ☐ Cubicles with partitions
 - ☐ Workspace in open office with no partitions (just desks)
 - ☐ Other

Page 3: We have a few additional questions about you and your energy use at home:

12. Are you aware of the utility costs in your home?
 - ☐ Yes
 - ☐ No
13. Please indicate whether you agree or disagree with the following question:
I currently take steps to conserve energy in my home.
[Strongly Agree, Agree, Not Sure, Disagree, Strongly Disagree]
14. What is your age?
 - ☐ Less than 30
 - ☐ 30-40
 - ☐ 40-50
 - ☐ 50-60
 - ☐ Over 60
15. What is your gender?
 - ☐ Male
 - ☐ Female
16. Would you be willing to participate in a paid usability test that will take place at the UC Berkeley campus?
 - ☐ Yes
 - ☐ No
17. Please provide contact information to be entered in the drawing for the prize and/or if you indicated above that you would be willing to participate in future phases of this study.
 - Name
 - Email address