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Visualizing information to improve building performance: a study of expert users

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Visualizing Information to Improve Building Performance: A Study of Expert Users

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ABSTRACT

The overarching goal of this research is to identify the optimal methods for visualizing building performance information in commercial buildings. In the most recent phase of this work, we conducted surveys and "contextual inquiries" of industry professionals who are experts in energy monitoring and analysis, in order to understand their information practices, needs and preferences.

We learned that the 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 serious analysis of visualizing building information for analysis, benchmarking and diagnostics, remains a time intensive, do-it-yourself undertaking. Many people we interviewed, including those with access to state-of-the-art building information systems, still rely on data exported from building management systems, and manipulated in spreadsheet programs. We also observed a preference for more end-use and historical energy data, and a nearly unanimous desire for better methods of communicating with building occupants.

Finally, we offer a few suggestions for methods to display building information which we will develop and test with human subjects in a future phase of this research. From our observations, industry 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."

Adoption of 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."[1]

In the building industry, a growing number of companies are providing products to enable the visualization of building performance data, primarily energy and water use, and renewable power generation. Many of these companies have been launched within the last few years, and we can expect additional companies now in stealth mode to come onto the scene in coming months and years.

The adoption of information displays in commercial buildings is led by several drivers. 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.

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[1] Ben Shneiderman lecture at CITRIS, UC Berkeley, 3/3/10.

Increased public scrutiny of green building results, combined with controversy in the research arena have also increased interest in measured energy performance (Brown 2009; Diamond et al. 2006; Turner & Frankel 2008).

In a previous phase of this research, we reviewed several commercial building information products (Lehrer 2009). These products are designed for monitoring energy and water use, performing diagnostics, and for educating occupants about building features. 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 cost, CO_2 produced, or 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. Lucid Design Group advertises a "Building Dashboard Starter" package for two buildings, including hardware and software for under $10,000.[2] On the other end of the scale, we learned of a proposal from a major control supplier to provide a user-friendly monitoring system for a larger mixed use building for a cost of over $170,000.[3] (The building already had a new EMCS.)

Development and implementation of a survey of expert users

The goal of user experience research is to provide insight into the users: who they are, what they can do, and what they want to do (Kuniavsky 2003). We used a combination of surveys and contextual inquiries to capture a mix of quantitative and qualitative data describing the users' attitudes, practices, and information needs, concerning viewing and analyzing energy and other performance information.

We first developed an "expert user" survey to gather information from user groups who are very familiar with energy monitoring and analysis, and who may be able to influence (to varying degrees) energy performance in commercial buildings. Such groups 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 survey used conditionally branching pages so that users of energy management systems (which we describe as having control capability) and/or energy visualization tools (no control capability) were asked additional questions on their use of these specific tools. The second section asked respondents to rate the usefulness of several types of energy information. The final section included background questions on the users' demographics and computer use patterns.

Respondent demographics and current sources of energy information

Via email invitations we invited a broad range of building industry professionals 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. We view these survey results as a convenience sample, not statistically representative of a larger population, however still

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[2] Retrieved 3/4/10 from http://www.luciddesigngroup.com/starter.php
[3] Personal correspondence with ZGF Architects, 2/24/10

useful for qualitatively assessing information practices and preferences. We received a total of 70 complete responses to this survey; the distribution of job titles is shown in Figure 1. 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: under 30, 30-40, 40-50, and 50-60.

Figure 1: Primary job function of respondents. (N=70)

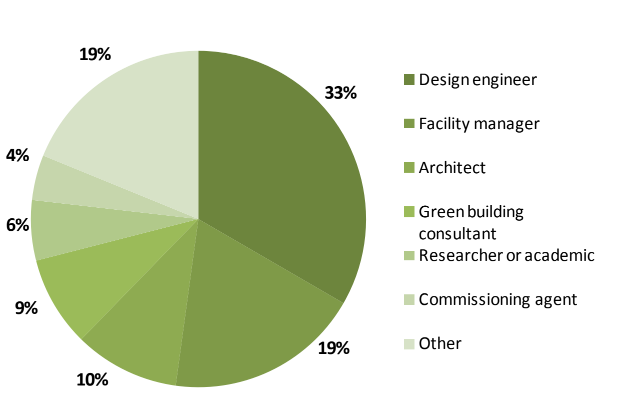
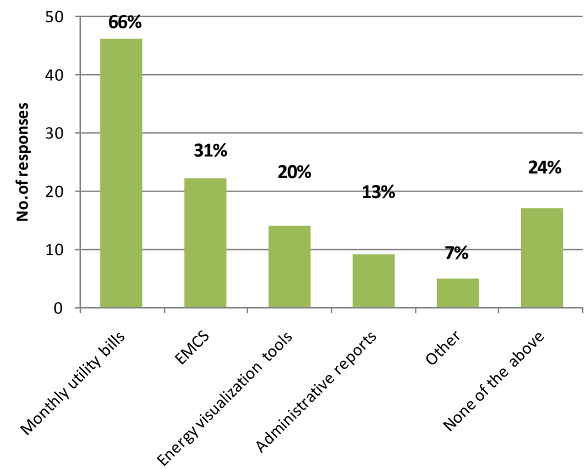


Figure 2: Information sources currently available to users. (N=70)



Note: Multiple checkboxes, do not add to 100%.

Approximately three fourths of the respondents currently have access to some building energy information (Fig. 2). 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. We also asked about the types of information available, for example historical, normative, end use, real time, or time of day (Fig. 3). Close to half of the respondents have access to historical energy use, and 33% have real-time energy data. We also asked respondents 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, 6 people (12%) view it a few times a month, and only 6 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. We 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, and also included Alerton, Invensys, Adura, Tridium, and Barrington. The useful features that respondents listed most frequently include trending, real-time information, information on individual units or devices, and graphical displays such as charting and views of zones and floor layouts.

Figure 3: Information types currently available to users. (N=70)

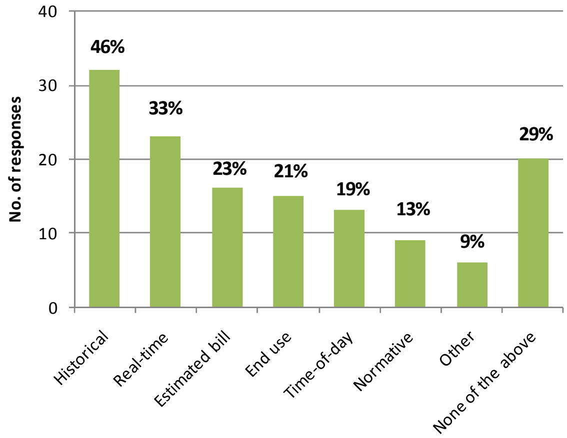
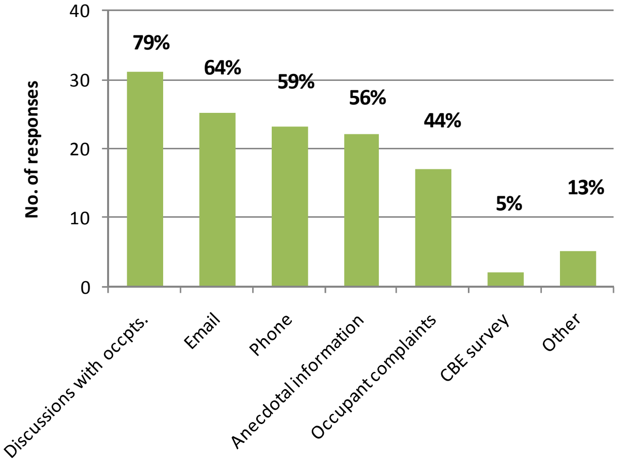


Figure 4: Occupant feedback sources. (N=38)



Note: 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 (defined in the questionnaire as having no control capability), seven (39%) indicated that they use Excel or a spreadsheet program to manually manage data for visualization, something that we also observed during our 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 are similar to those noted for EMCS products, 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 of less, and only one user who uses the system daily.

The fact that we see a significant overlap between the sets of comments, 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.

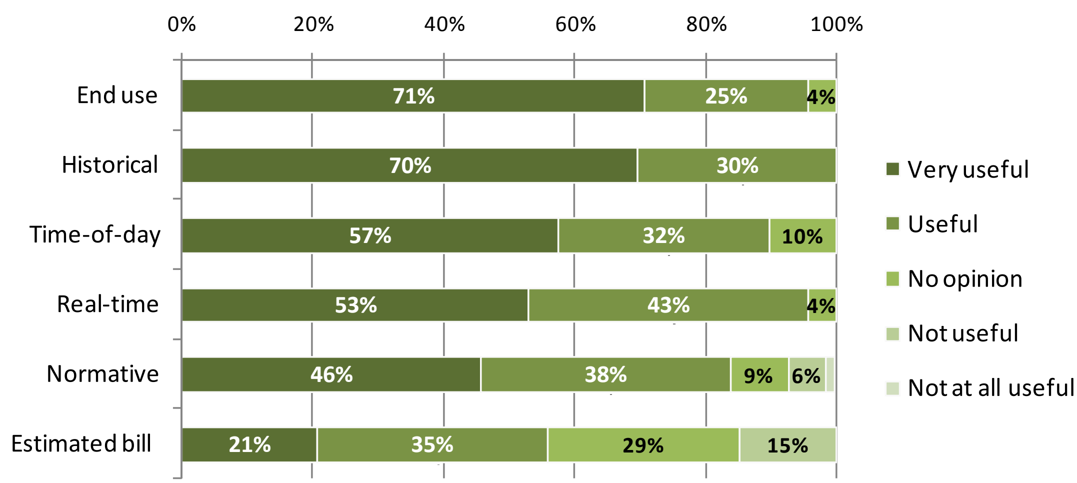
User preferences for energy and performance information

To understand the gaps between the desired and currently available energy information, we asked respondents 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. 5). 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.

Prior to this survey, we had conducted a pilot survey and learned of the high level of interest in end-use energy information, and included a detailed question regarding the types of end-use data that would be useful (Fig. 6). 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.

We also asked about the usefulness of other types of information that are included in some newer energy visualization products (Fig. 7). 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 5: Comparative usefulness of types of information. (N=70)



Information feedback from occupants

As building occupants provide a valuable source of information about building performance (Zagreus et al. 2004), we asked our respondents whether they get information about the building from occupants regarding "occupants' satisfaction, problems, or general building performance." We found the results to be 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 (79%) is from discussions with occupants or tenant representatives, followed by email, phone, anecdotal information, and via complaints logged in a building management system (Fig 4.) 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.

Figure 6: Usefulness of types of end-use data. (N=70)

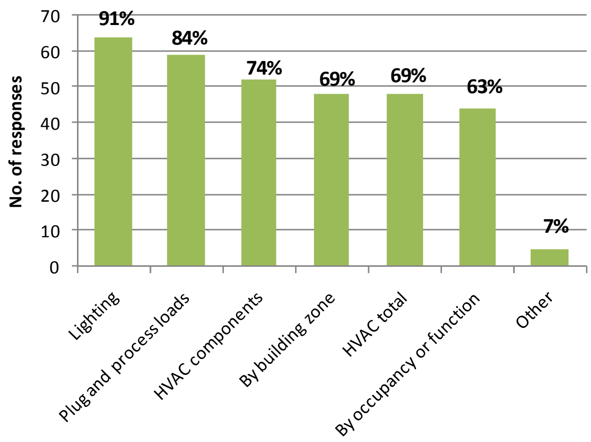
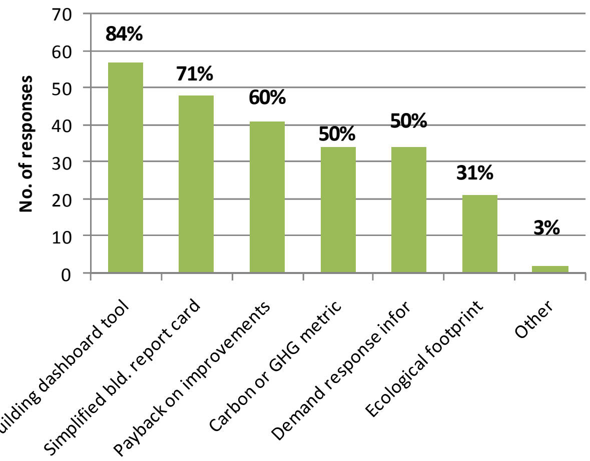


Figure 7: Usefulness of other information. (N=70)



Note: Multiple checkboxes, responses do not add to 100%

Contextual inquiry studies of expert users

Contextual inquiry is a method for understanding users by interviewing them in their workplaces and observing how they use interactive products. We conducted six interviews with subjects having a variety of information needs and practices. Previous research has used case study methods to document how facility managers use energy information systems to manage energy use in commercial buildings (Motegi et al. 2003, Granderson et al. 2009). As there are many diverse users of building performance information, our case studies included design team members and other 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. We also asked subjects to demonstrate the tools they used to view building information, with attention to the commonly used features. During the interviews we also asked the users about shortcomings with the current sources of information, and additional building information that might be useful.

We selected a group of subjects that would provide a broad range of perspectives on visualizing building performance data. The interview subjects 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

Below we 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.

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 our survey findings indicate that many people have access to monthly utility bills, none of our interview subjects mentioned using monthly bills. The interviews confirmed our survey findings which show that many people use multiple BMS and/or energy visualization products.

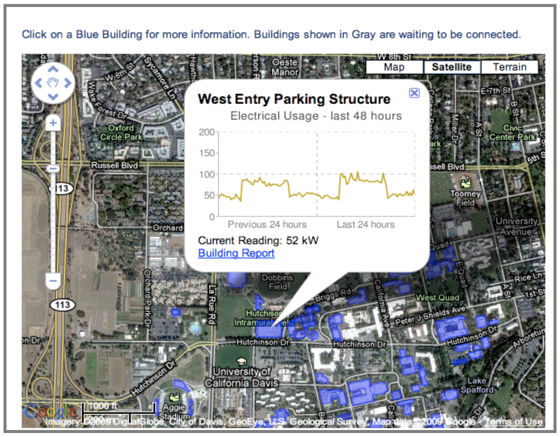
One example of the multiplicity of energy tool use is seen in the practices of the engineering team for a small commercial zero-energy building (ZEB). This team has monitored the building's performance to reach its net-zero goal since the initial occupancy. The project uses control and data systems that the design team describes as state-of-the-art, including a BMS product for HVAC control and monitoring, a web-based product 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 our 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 we 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. 8). Users can also view more detailed information, including the current demand compared to the previous day, averages, maximums, monthly utilization, and cost data. Our interview 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 we 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. 9). 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.[4]

[4] Information on this survey resource is available at http://www.cbe.berkeley.edu/research/survey.htm

Figure 8: Campus utilities consumption dashboard



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

Figure 9: Sample interface from EnergyIQ

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

Limitations of current tools

Our 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 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 ft^2) 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,[5] to create visually appealing visualizations and presentations (Fig. 10). 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 of their projects, they feel that the energy data from these tools are typically too simple to be useful for building designers. Additionally, they find that these dashboards are rarely available online and do little to benchmark performance against comparable buildings. The university project manager we 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 changes in occupancy. Such occurrences have raised concerns among users about the credibility of the tool.

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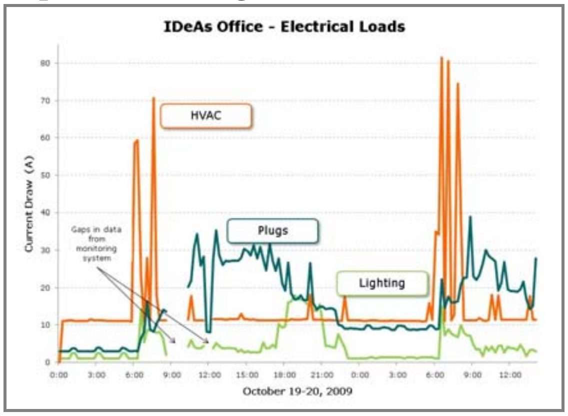
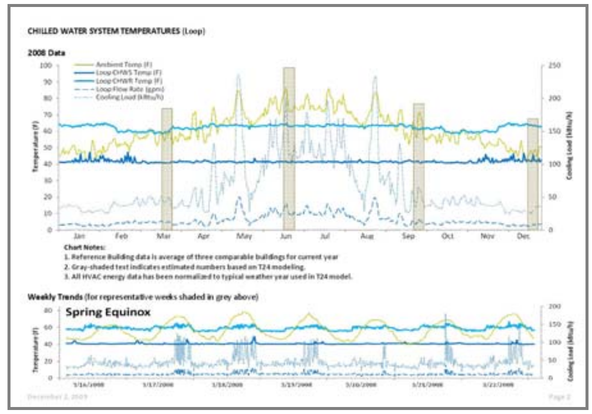
[5] A free software tool designed for the management and analysis of data from building management systems available at http://utonline.org/cms/

Figure 10: Elec. load visualization produced using Universal Translator



Source: IDeAs

Figure 11: Custom data visualization proposed for campus buildings



Source: Bill Starr, UC Davis

Summary of key information needs noted in contextual inquiries

Although our interview subjects varied in terms of information needs and access to energy information, they reported a common number of unmet information needs, which we summarize below. As part of our interview process, we asked the subjects 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 use energy information tools infrequently, which supports our survey findings. They require a visualization that provides a quick overview, with an ability to get 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. 11).

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 our 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 by Federspiel & Villafana 2003.)

Conclusions and directions for future research

Although our research deals with a relatively small sample, we can begin to generalize about information preferences of expert users of building information. From our survey research we learned 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 (and we assume they will not be ambivalent about the value of control capability.) We also observed a preference for historical energy data, and a desire for end-use data of many types, with lighting and plug/process loads ranking highest. The survey revealed a nearly unanimous desire for better methods of communicating with building occupants, and this finding was supported by our interview research.

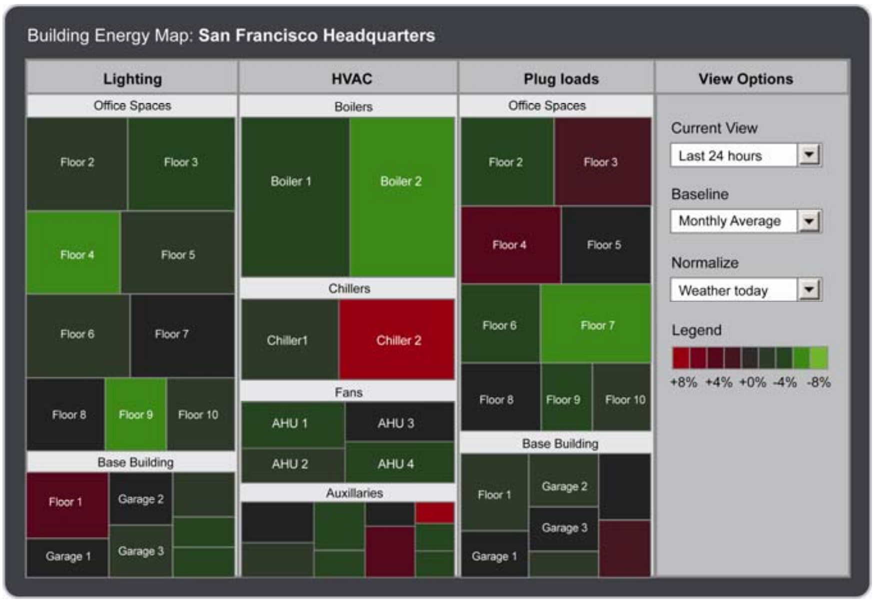
We also learned that the access to reliable energy and performance data varies considerably between firms and individuals, and that current tools have numerous shortcomings. Many people cited the lack of integration of energy sources and control systems, and the inability to modify and save views. From both the surveys and interviews, we learned 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.

We also found that many users would 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, in our contextual inquiry research we observed that there are 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 we 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.

For the next phase of this research, we plan to develop and test various methods for visualizing building information with human subjects. (Our expert survey allowed respondents to volunteer for such testing.) We expect to create specific interfaces for distinct users; for example, a single screen "dashboard" view of information may be appropriate for office tenants, however facility managers will likely want the ability to drill down to find actionable information for diagnostic purposes.

Figure 12: Prototype building treemap visualization



Source: Center for the Built Environment (CBE)

One type of visualization that appears highly promising for viewing trends in buildings, but that has not been adopted by software providers that we know of, 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. One of the most successful applications of this method is the Map of the Market, a powerful data visualization of stock market trends.[6]

Applied to building operations, we hypothesize that a treemap could allow a building manager to quickly identify trends or anomalies, and drill down for more information. We have developed a prototype treemap visualization that might be applied to a commercial building (Fig. 12). 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 the example above, 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 the prototype above) 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 would click on the rectangle of interest, and have the ability to view other screens with details such as trend lines or component status. (For a good example of the interactive possibilities of treemaps, see Map of the Market, cited in the footnote below.)

By exploring and testing the opportunities offered by treemaps and other visualization methods, we hope to contribute to our collective understanding of energy monitoring and

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[6] Map of the Market is viewable at http://www.smartmoney.com/map-of-the-market/

feedback systems, and ultimately to assist developers of energy information systems to provide tools that meet the needs of the building industry.

Acknowledgements

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