USING BUILDINGS TO TEACH ENVIRONMENTAL STEWARDSHIP: REALTIME DISPLAY OF ENVIRONMENTAL PERFORMANCE AS A MECHANISM FOR EDUCATING, MOTIVATING AND EMPOWERING THE STUDENT BODY

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ABSTRACT: At residential colleges and universities, activities that take place within the built environment are responsible for the bulk of greenhouse gas emissions and other environmental pollutants. A number of institutions are now taking aggressive steps to implement construction and management practices that increase energy and resource use efficiency, reduce toxicity, foster biodiversity, seek locally available materials and capture renewable energy. At the same time, colleges and universities are also developing programs designed to foster a culture and ethic of environmental stewardship among members of the campus community. These parallel efforts focused on facilities and on culture are linked by the fact that changes in the attitude and then in the behavior of members of the campus community are critical for both their education value and for their actual effect on campus resource use. In this paper we explore how real-time feedback on the environmental performance of campus buildings can and has been used as a mechanism for engaging, educating, motivating and empowering the student body. Our experience developing real-time feedback systems on a variety of campuses and in a variety of contexts suggests specific conditions that maximize the effectiveness of feedback as a tool for building community and motivating environmental stewardship.

Keywords: energy, feedback, display, education, behavior

Introduction

Residential and commercial buildings account for two-thirds of the electricity used in the U.S., 36% of U.S. greenhouse gasses, 9% of world greenhouse emissions, and 12% of U.S. fresh water consumption [1]. Buildings also dominate the environmental footprints of residential institutions of higher education. For example, greater than 90% of Oberlin College's greenhouse gas emissions are attributable to activities that take place in campus buildings [2]. Faculty, administrators and students are beginning to recognize that campus buildings are not just places in which learning occurs. David Orr has described a "pedagogy of architecture" that to date has played a negative rather than positive role in fostering environmental understanding and stewardship [3]; the story of profligate resource use that is embodied (but also generally hidden) within our campus buildings provides lessons that are fundamentally inconsistent with the ethic of environmental stewardship that many institutions are now striving to encourage. A central goal of campus sustainability efforts should be to transform students' daily experience on campus such that this experience conveys lessons of environmental stewardship. There is increasing recognition that campus buildings can and should function as integral components of the curriculum by serving as laboratories for teaching and learning lessons of environmental sustainability. One mechanism to achieve this goal is to provide students with clear, direct and actionable feedback on the environmental impact of activities and technologies associated with campus buildings.

How might attitude and behavior be affected if students and faculty could immediately see the environmental consequences of flows of matter and energy through campus buildings? In 2000 this question lead a group of students and faculty at Oberlin College to develop a novel real-time system for monitoring and displaying the ecological performance of the many green technologies incorporated into the Adam Joseph Lewis Center for Environmental Studies (www.oberlin.edu/ajlc). Widespread national interest in this system from green architects and from administrators, students and faculty at other institutions stimulated graduates of the Oberlin team to develop a commercial software product, “Building Dashboard™”, and to found Lucid Design Group, LLC to make data monitoring and display systems designed for education easily available. During the last three years, Lucid Design Group has been engaged to develop feedback systems for a broad range of educational clients including colleges (e.g. Oberlin College and Alma College), universities (e.g. University of North Carolina Chapel Hill and Harvard), primary schools (e.g. Sidwell Friends School and Williamstown Elementary School), and environmentally concerned non-profits (e.g. Southface Energy Institute and New Jersey Adventure Aquarium). As an example of one context in which the technology is being used, by early 2008 Lucid Design Group will be supplying nearly 5,000 students in colleges and universities with real-time feedback on energy consumption in their dormitories.

The use of real-time feedback on the environmental performance of the campus environment is still a novel approach to campus sustainability. Understanding the full range of opportunities as well as potential limitations of this technology in transforming attitudes and behaviors will require broad-scale and long-term studies that are only now being initiated. Nevertheless, early research and our own hands-on experience suggest that what are now invisible flows of energy and matter through buildings can be made visible, easily accessible, engaging and actionable to a non-technical audience in real-time. In the sections that follow, we begin by describing two distinct applications that we have been involved in developing at Oberlin. We then describe contexts and features that are likely to maximize the benefits of real-time feedback on the environmental performance of buildings. Finally, we conclude with some thoughts on how socio-technical feedback systems of the type we are involved in developing are distinct from many other environmental technologies in that they are explicitly designed to help foster the development of stewardship at both individual and community levels.

Case Studies at Oberlin College

Oberlin College continues to serve as a showcase for data monitoring and display. The two major projects underway at Oberlin have been funded through grants and private donations. Working in partnership, Oberlin faculty and Lucid Design Group received Phase I and Phase II grant awards from U.S. EPA’s “People Prosperity and the Planet” (P3) program as well as additional grant funds from the Ohio Foundation of Independent Colleges. These funds have supported the development of the “Campus Resource Monitoring System” (CRMS). In contrast, the monitoring and display system for the Adam Joseph Lewis Center for Environmental Studies (AJLC) has been funded largely by private donations to the College. Both systems have received considerable national media attention, and the work has been recognized through awards including the Ohio Governor’s Award for Energy Excellence, (2002) and the National Wildlife Foundation’s “Chill Out” contest (2007).

Adam Joseph Lewis Center for Environmental Studies

Oberlin’s Adam Joseph Lewis Center for Environmental Studies was completed in January of 2000 at the start of what has become a green building boom on campuses. Given the scope and novelty of the project, the timing, and the prominent members of the design team, the AJLC has served as something of a national icon for the green building movement and for the emerging field of ecological design as a whole. The programmatic goals for the AJLC were succinctly stated by David Orr who spearheaded fundraising and creative efforts to bring the center to fruition. He described the center as, “a building that would cause no ugliness, human or ecological, somewhere else or at some later time” [4]. Key ecological design goals and features of the center include:

1) material recycling and material responsibility: high recycled content in building and furnishings, sustainably harvested woods, low toxicity materials, products of service, a “Living Machine™” that treats and internally recycles over 70% of the water used in the building;
2) integrated landscaping: high biodiversity restored wetland ecosystem that functions as a storm water retention basin, cistern water storage, organic fruit orchards and vegetable gardens;
3) energy efficiency: enhanced thermal envelope, ground source heat pumps, efficient lighting and appliances, “smart” building controls;
4) solar: exceptional natural lighting, passive heating and ventilation, largest photovoltaic array in Ohio (160 kW).

Oberlin students were perceived as a primary target audience for lessons embodied within the AJLC. For four years Oberlin’s Environmental Studies Program offered a practicum in ecological design that focused on technologies incorporated into the center. Other classes and class projects within and outside of the Environmental Studies Program have focused on individual technologies incorporated into the center. Students continue to gain understanding and expertise through employment as managers of the data monitoring system, research assistants, operators of the Living Machine and tour guides. In addition to Oberlin students, the broader educational audience that has been served by the facility includes students elsewhere (primary, secondary and college students), design professionals (architects, engineers, energy specialists, wastewater managers) and an interested general public (parents, homeowners, environmental enthusiasts). The real-time data monitoring and display system is a unique component of the overall educational program in that it ties together all of the individual environmental features and serves audiences both locally (through a lobby kiosk display) and remotely (through the web).

Two goals of the data monitoring and display system are to create a long-term dataset that can be used to study the ecological performance of the building and to render technical data on building performance easily accessible, engaging and interpretable to a non-technical audience. With respect to this second goal, data provide supportive and dynamic content for telling the story of environmental stewardship embodied within the building. Compared to other Lucid Design Group installations, the AJLC's data monitoring and display system probably stands our as an extreme in terms of complexity, but is nevertheless illustrative of the feedback design concept applied to green buildings.

Over 150 sensors installed throughout the building and landscape monitor flows of energy, cycles of matter and other environmental conditions. Data from these devices are collected by a datalogging computer, are translated by a server computer into derived variables that capture all aspects of building performance and are then made available for display to the public, all within 1 minute of being acquired.

Real-time and historical data are presented both in the lobby of the building and on a website. A large (42") plasma display and smaller (15") touch screen controller are prominently located in the central atrium lobby of the AJLC (Figure 1 above). The lobby display proceeds through a sequence of topical presentations that start by providing an introduction to the AJLC and its data monitoring system. Real-time and long term data records are then used to explain energy production and consumption in the facility, water use and treatment in the Living Machine, and outside environmental conditions. A calendar of current events is also included in the sequence. Time series data are linked to time stamped photographs taken from a permanent web camera pointed at the facility. Animations of the data are constructed so that time lapse photographs of the building and landscape are displayed as time series graphs and gauges depicting environmental performance "play" on the screen. The touch screen allows lobby visitors or tour guides to easily toggle between different sections of the presentation.

The website display differs from the lobby display in providing a more comprehensive, open-ended and interactive pathway through information and data describing the environmental performance of the center (Figure 2). For example, website visitors can easily scroll back and forth through time series data and gauges. A password protected "Data Downloader" (discussed further below) allows web users to select and download data for the full range of monitored variables over any time interval.

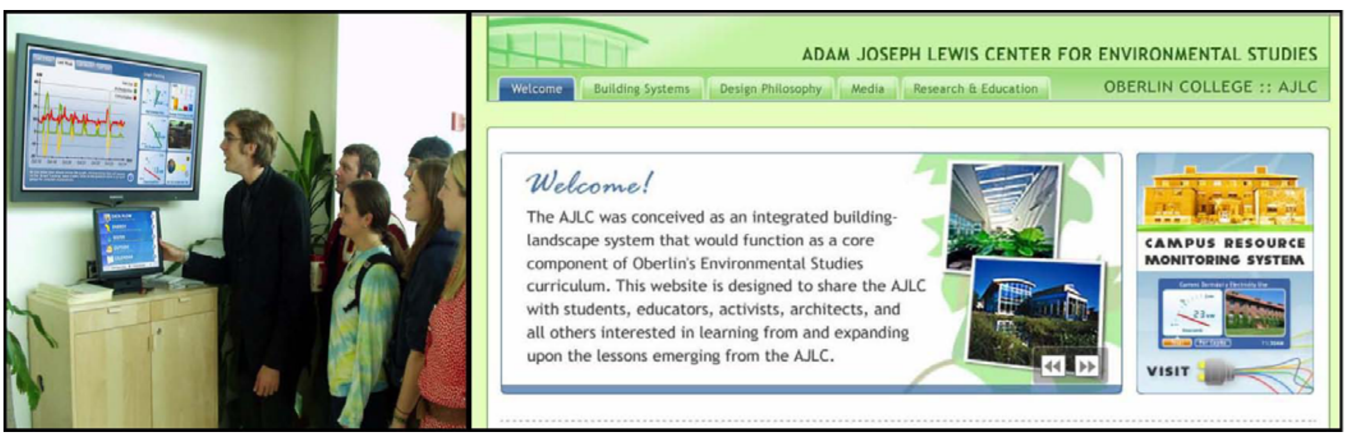

Figure 1. Touch-screen lobby display and homepage of AJLC website, both featuring real-time data.

Figure 2. Webpage featuring time series graph of photovoltaic production (green) energy consumption (red) and net consumption (yellow) at the AJLC over a two-day period. On the right, gauges and time lapse photography track performance at any given moment as the data "play" through the time series or as the visitor pulls a control bar back and forth through the time series data. The top right gauge depicts the percentage of electricity at any given moment being consumed through different end-uses (HVAC, Living Machine, lighting and plug loads). The gauge on the bottom right shows changes in the earth's position relative to the sun (the earth spins as days go by and the angle of the sun changes with the season). Tabs above the graph allow the visitor to display data over a range of time scales. Other portions of the website feature similar real-time data displays for other components of the building and landscape systems.

A comprehensive study to assess the impact of the data monitoring and display system on the attitudes and behaviors of those who experience it through the lobby display and the through the website has yet to be conducted. However, even in the absence of such a study, the considerable interest in and use of the system suggests that it is affecting users. For example, we track the number and origin of website hits and over the last several years we have averaged approximately 70,000 hits per year. Interestingly, almost a quarter of these hits come from computers located outside of the United States suggesting that the real-time website has enabled the AJLC to serve as an educational tool for an international audience. In the last few years Oberlin has provided approximately 250 tours of the AJLC per year. The lobby display has become a central feature of these tours. It was the strong interest expressed by both on-site and website visitors in reproducing the AJLC display technology elsewhere that initially stimulated the formation of Lucid Design Group.

Campus Resource Monitoring System

Starting in 2004, Lucid Design Group began worked with Oberlin College to develop the "Campus Resource Monitoring System" (CRMS), a technology designed to provide Oberlin students with real-time, environmentally contextualized feedback on resource use in residential halls (www.oberlin.edu/dormenergy). The CRMS was conceived as a system that would allow students to teach themselves how to better conserve resources in the context of conventional residential buildings that do not feature green technologies.

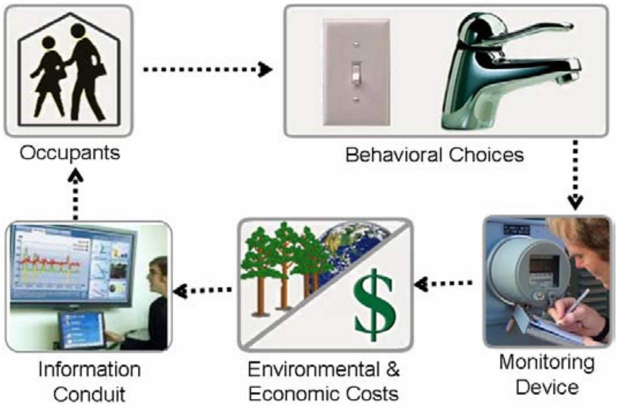

Figure 3. Feedback loop designed to positively alter attitudes and consumptive behaviors of dormitory residents.

Feedback in residence halls can be divided into five components (Figure 3): 1) as with green building technologies, residence halls are instrumented with sensors and datalogging equipment to monitor resource use; 2) information is processed and translated into environmental and economic currencies.; 3) contextualized information is presented to students on lobby and kiosk displays (Figures 5); 4) dormitory occupants process this information and 5) are able to make behavior choices that then change the feedback information that they receive.

We have previously reported on the results of a preliminary study conducted to examine the impact of the Campus Resource Monitoring System developed for Oberlin College [5, 6]. To briefly summarize, in the context of a two-week long, campus-wide "dorm energy competition", students in dormitories receiving real-time feedback reduced their electricity consumption by 56% over baseline consumption. During the two-week period approximately 70,000 kWh of electricity and 150,000 lbs of CO2 were conserved. The results of a post-competition survey affirmed that students did, indeed, use the feedback combined with educational materials provided during the competition to teach themselves how to better conserve resources. 52% of survey respondents indicated that they had learned electricity conservation strategies that they intended to continue beyond the competition. 45% of respondents indicated that they would be motivated to conserve electricity by real-time feedback alone, even in the absence of a competition. Since this initial study was completed, we have expanded the CRMS to provide real-time feedback to approximately 80% of dormitory residents on the Oberlin campus. Results have yet to be analyzed for a competition and survey held in the spring of '07. Psychology and Environmental Studies faculty and students at Oberlin are currently working together to quantify how experience with this technology alters students' feelings of connectedness with nature as well as their behavior.

Figure 4. Homepage of Oberlin's Campus Resource Monitoring System. Visitors can choose to view resource consumption in a variety of different currencies.

Figure 5. Bars depict electricity use in different residence halls. Tabs at top allow visitors to select different time scales over which data are averaged. The visitor can click on the icons at bottom of page to re-express electricity consumption in terms of a range of energetic, environmental and economic currencies (carbon dioxide units are selected above).

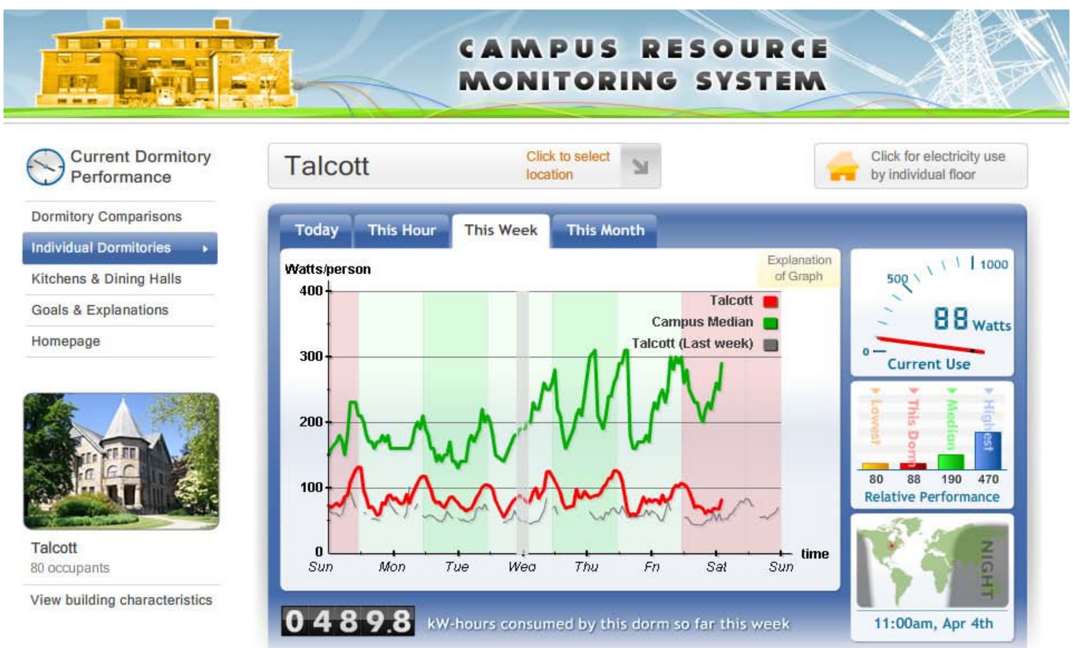

Figure 6. Visitors can choose to view the time series graphs of individual residence halls at a variety of time scales. The dark red line is this dormitory's consumption so far this week. The light gray line is consumption last week. The green line is the median consumption this week for all dormitories at Oberlin. The middle gauge on the right provides an animated view of residence halls with the highest and lowest consumption rates at any given time.

Maximizing Benefits in Different Contexts

Goals of Data Monitoring and Public Display

The four linked goals of a real-time data monitoring and public display are to engage, educate, motivate and empower people to make desirable changes in environmental attitudes and behaviors. The display must first capture and hold attention and then create an experiential learning environment in which the observer easily sees and then understands the environmental consequences of design decisions and personal behavior on the dynamic flows of energy and cycles of matter through the built environment. The premise is that this new knowledge and understanding will then motivate the observer to want to engage with the community and the world differently. Ideally, the viewer should feel empowered by the experience to act as a participant rather than a spectator in resource use management decisions.

More specific goals of data monitoring and display vary with context. In some situations, particularly in the case of non-residential applications, the goal may be to inspire general changes in consciousness and behavior that the participant exhibits outside of the monitored facility. In other cases the goal may be to inspire site-specific changes that act as feedback to affect the performance of the monitored facility and are directly observable on the display. Similarly, in some contexts the goal may focus on a one-time or occasional experience with a display in a particular facility, while in other cases the display may be explicitly designed as a resource that the viewer experiences and returns to on a regular basis. Our experiences suggest that for some participants, real-time display may have a profound and transformative affect on their thinking and action while for others the effect may be far more subtle.

In addition to changing attitude and behavior, an important secondary goal of public display is to facilitate "continuous commissioning" of buildings. Maintaining and improving building performance requires that facilities managers regularly track data to detect and correct operating deficiencies and continuously exploit new opportunities for increasing efficiency. At many institutions the work load of facilities managers forces them to function primarily as crisis managers, leaving them few resources for continuous commissioning. When real-time and historical data are publicly displayed in a form that is easily understandable and accessible to a non-technical (and sometimes highly technical) audience, the entire community of viewers can participate in and assist managers in identifying problems and proposing solutions. Web-based display enhances this possibility. On a number of occasions web visitors with no direct institutional affiliation have noticed and notified building managers of system malfunctions or opportunities for enhancing efficiency within buildings monitored by Building Dashboard™.

Engaging the audience

The educational literature indicates that we acquire, retain and understand information most effectively through active rather than passive modes of learning. A well-designed display should go well beyond simple navigation options; active learning means that the visitor is encouraged to become a participant in evaluating the environmental implications of the flows of energy and cycles of matter taking place around them and in improving the environmental performance of the facility and campus. Several distinct types of interactivity can be incorporated into a data monitoring and display system. One mode of interactivity occurs when the viewer is encouraged to engage in a consideration of how his or her own actions affect building performance. For instance, the viewer turns on a light switch, changes a thermostat setting or takes a drink from a water fountain and then directly and immediately experiences the consequence of these decisions on a display.

A second type of interactivity concerns the opportunities a viewer has to select and immediately manipulate data that are presented on the display. For example, when a visitor moves a cursor through a time series graph, gauges can be animated to display values of other variables at the specified moment in time. Linking graphical data presentation with time-lapse photographic imagery together with gauges provides a powerful mechanism for making technical data accessible, fun and intuitively understandable to a non-technical audience.

In educational facilities, interactivity provides important curricular opportunities. The easy availability of real-time and historical data on building performance enable the development of exciting hands-on curricular materials in environmental studies, biology, physics, architecture, engineering and other disciplines. For example, Lucid Design Group is currently working with a middle school that is building a LEED certified classroom building and seeks to integrate real-time environmental data across their curriculum. The monitoring system will allow the building itself to serve as a core component of the curriculum. Lucid Design Group has developed a "Data downloader" component that allows data collected on a building's performance to be easily selected and downloaded in spreadsheet format for use inside and outside of the classroom.

In some circumstances it may be desirable to allow building occupants and visitors to upload data that they have personally collected. For example, the weight or volume of trash and recyclable materials might be measured by hand and then entered through an interface. Lucid Design Group is working on an interface that allows hand-collected data to be uploaded via the web and integrated for display with automated data. In this way, the data monitoring system itself becomes an interactive device that allows users to develop a greater degree of direct engagement and participation in the content of the display.

Green Academic Buildings versus Residential Housing

Campuses across the country are experiencing a green building boom that includes both dormitories and academic buildings. Buildings that are explicitly constructed to feature environmental technologies pose a particular set of educational opportunities. The presence of solar panels, geothermal heating, gray water systems and other energy efficient, water conserving and green technologies does not in itself ensure that students, faculty and visitors tangibly sense or gain insight into the environmental benefits of these features. Real-time feedback systems provide a mechanism for engaging target audiences so that they directly experience, learn from and respond to the positive environmental implications of environmental design and management choices. A well designed monitoring and display system can be crafted to reflect the technologies, people and sense of place that define the particular facility and can be tailored to serve multiple organizational objectives as well as to effectively communicate desired information to carefully defined target audiences (Figures 7 and 8).

Figure 7. Lobby display and touch screen (inset) displaying geothermal heating system in Wright Hall, a residence hall at Alma College. Color of water in loop and rate of pulsing in loop change in response to monitored conditions to foster a more intuitive understanding of heat flow.

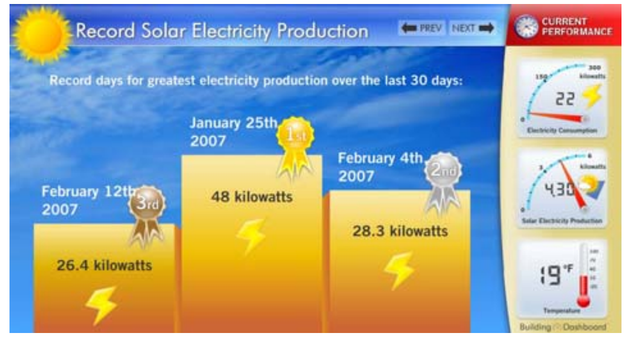

Figure 8. Performance of photovoltaic array at Williamstown elementary school is contextualized as a competition.

Experience with non-residential green academic buildings suggests that real-time data monitoring and display provides a powerful tool for integrating building performance into a curriculum that emphasizes environmental stewardship. These benefits notwithstanding, it is important to recognize that this setting provides only limited capacity for true feedback; the visitor to a green academic facility, particularly one that incorporates so-called "smart building" control technology, generally has little capacity to directly affect the performance of that facility. Indeed, it was recognition of this pedagogical limitation that motivated the authors of this paper to expand from an original emphasis on green non-residential buildings to also focus on "brown" residential halls that may incorporate little or nothing in the way of green features and green facilities management. Because students exert substantial control over resource consumption in residence halls, feedback introduced in the form of a data monitoring and display system provides a tool that allows them to essentially teach themselves how to be better stewards of the environment (Figure 3).

Multiple Scales of Feedback May be Necessary to Maximize Benefits

Our experience suggests that campus-wide application of data monitoring and display technology to residence halls can, indeed, be used to engage, educate, motivate and empower stewardship within the student body. Although the authors of this paper have experience with monitoring multiple dormitories and green academic buildings on the same campus, we are still in the initial stages of planning a comprehensive display system that would allow near real-time quantification of the environmental consequences of resource flows across an entire campus. This macro-level of resolution will be achieved by sensing and processing available data from heating and cooling plants, main water meters and central electrical distribution systems. Where real-time data are not available, rates of consumption can be estimated from utility bills and other sources and then combined to generate real-time displays. As with smaller scales of resolution, expressing data in multiple environmental and economic currencies will allow the display to resonate with the broadest possible audience. Given the increasing emphasis on climate change, we view carbon dioxide as a particularly important and universal currency for understanding the overall environmental impact of campus activities. Ultimately, total carbon release per student represents a metric that can be used to compare real-time resource use among as well as within campuses.

What we are describing here can be though of as a hierarchical approach that maximizes impact by allowing viewers to simultaneously observe environmental performance at multiple scales of resolution representing consequences of both individual and highly collective community behavior. For example, at the smallest scale of resolution, resource use can be monitored and displayed at the level of individual dormitory halls or, where feasible, individual rooms or apartments. This very localized scale provides participants with a resolution of feedback that is particularly suited to building understanding of the consequences of personal choices. At the next higher level of resolution, we have already demonstrated that dormitory-scale feedback is useful at raising consciousness, building community and fostering a culture that conserves resources. The performance of nonresidential green buildings plays a distinct role at a parallel scale of resolution in educating the community about specific environmental technologies. At the largest scale, a campus display featuring facility-wide feedback, perhaps broken down by core end use or resource (e.g. electricity, coal, natural gas, vehicle fuel and water) would be designed to foster consciousness of the environmental performance of the institution as a whole. This hierarchy of feedback would create a context in which the campus community is genuinely empowered with multiple scales of real-time data to "think globally and act locally" in taking action to bring about greater environmental sustainability.

Socio-Technical Feedback as a Community Building Phenomenon

Technologies aimed at increasing resource use efficiency are not going to solve environmental problems by themselves. Ultimately, changes in attitude and lifestyle are essential to reducing resource use and fostering a culture of environmental stewardship. Unsustainable relationships between people and the environment are at least partially attributable to ignorance and alienation between humans and the resource flows on which our societies depend. "Socio-technical" feedback occurs in causal loops that include both technology and people (e.g. Figure 3). Socio-technical feedback of the type described in this paper is distinct from many other "green" building technologies in that it is specifically designed to break down the alienation described above by making people more aware of the resource flows that support their daily activities. Following on the hierarchical approach discussed in the paragraph above, real-time display of resource use can be applied at an isolated individual level, by providing resource users with direct feedback on their personal consumption in a non-public setting. Although we see this as one valuable mode of feedback, we believe that the value of feedback is greatly enhanced when it occurs in a community context in which participants can compare their individual consumption and/or group consumption with that of other individuals and groups.

The emerging green building industry has placed a great deal of emphasis on developing and deploying so-called "smart building" control technology. This technology is designed to maximize resource conservation by shifting control decisions from sometimes unpredictable and poorly informed building occupants to sophisticated building automation systems. On one hand, resource savings from this strictly technological approach have been demonstrable. On the other hand, smart buildings remove management decisions and the thinking and learning that go with these decisions such that building occupants are at best only passively engaged and uninformed about the importance of resource conservation. For this reason, it could be argued that "smarter" buildings may lead to environmentally dumber people. Furthermore, the vast majority of building stock in the U.S. is comprised of older structures which are not easily upgraded with smart building control technology. In marked contrast to smart building technology, the type of socio-technical feedback systems described and envisioned in this paper are specifically designed to encourage building occupants to teach themselves how to conserve resources by engaging them in resource conservation decision making. Indeed, the technology incorporates humans as a critical component of an overall feedback system that is designed to minimize resource use. In contrast to the smart building philosophy, here the objective is to construct environmentally smarter individuals and communities in what are often environmentally and technologically dumb buildings.

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