Implementing Long-Term Measurement & Verification at a Building: A Socio-Technical Analysis

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ABSTRACT

This paper is a socio-technical study of the design and programming of a metering system. Metering systems and the reports they generate can provide useful feedback for building operators and occupants. They allow the operators to monitor energy consumption and improve building performance. Ultimately, the goal of these systems is to engage building operators and occupants to conserve energy. This paper studies the perspectives of four team members who were involved in the design, installation and programming of one such system: owner, electrical engineer, energy consultant, and manufacturer's field representative. The paper explores and compares the team members' understanding of (1) the intended use of the system, (2) the technical requirements of the system, and (3) their understanding of their role in the execution of the system. The paper identifies the barriers to installing such a system and provides suggestions for eliminating these barriers.

Introduction

Metering systems in commercial office buildings provide opportunities to monitor a building's energy performance by providing detailed data on lighting; heating, ventilation, and air conditioning (HVAC); and plug load consumption. This information is useful to building operators since it helps identify where energy is being used, compare the performance of these building systems year-to-year, and identify problems such as lighting left on after hours. By helping to identify problems better and set expectations of performance, metering systems can save energy, reduce operating costs, and improve occupant comfort.

Leadership in Energy and Environmental Design (LEED®) for New Construction version 2.2 awards one point for installing an energy submetering system and verifying the energy savings expected for the project according to the International Performance Measurement and Verification Protocol (IPMVP). Yet metering systems that measure the energy use at the whole building level and break them in to submetered energy uses are relatively new. Few engineers, consultants, contractors and commissioning agents are knowledgeable about designing and installing these systems. Consequently, it is challenging to get systems up and running. In a recent study of LEED buildings, Energy Performance of LEED for New Construction Buildings, only 44 of the 121 buildings in the sample pursued the credit for measurement and verification (M&V) (Turner and Frankel 2009). It is anybody's guess as to how many of these metering systems were installed successfully and are being used for their intended purpose by the building operator

This paper is a socio-technical study of the design and programming of a metering system at a newly constructed facility in Reno, Nevada. We study the perspectives of four team members who were involved in the design, installation and programming of the system: owner, electrical engineer, energy consultant, and manufacturer's field representative. The paper explores and compares the team members' understanding of (1) the intended use of the system,

(2) the technical requirements of the system, and (3) their understanding of their role in the execution of the system. We identify the barriers to installing such a system and provide suggestions on eliminating these barriers.

Project Summary

This facility is a new 40,000 square foot information-technology-intensive office building inhabited by researchers. Completed in early 2009, the facility consists of 4 building pods which are connected by a central circulation corridor. The building was awarded a LEED certification which included achieving the M&V credit.

The team that worked on the metering system consisted of the owner, electrical engineer, energy consultant, and meter manufacturer's field representative. The owner and electrical engineer were located in Reno; the energy consultants and the manufacturer's representative were out of state. This geographical separation was one of the project's implementation barriers and will be discussed later.

The requirements for the LEED M&V credit are rather vague. This LEED credit references the IPMVP documentation with the alternative to follow Option B for isolated energy conservation measures (ECM) or Option D for interacting ECMs. The IPMVP documents are written as best practices guides and do not have standards for minimum requirements for M&V. There are three IPMVP volumes: Volume I defines terminology and suggests good practices for documenting the effectiveness of energy or water efficiency projects that are implemented in buildings and industrial facilities. Volume II reviews indoor environmental quality issues which may influence energy efficiency. Volume III contains specific application guidance manuals for Volume I. (Efficiency Valuation Organization 2008). This lack of specificity leaves a lot to interpretation of the project teams in terms of what constitutes the required M&V process and equipment.

The energy consultant on the project interpreted the M&V requirements into an M&V Plan. This included (1) visual inspection of the installed ECMs to check their performance metrics and functional set-up, (2) short-term data-logging of selected ECMs, (3) installation of an energy metering system with the capability to do long-term monitoring and storage of energy end-use data, (4) calibration of the energy model to metered building energy use, and (5) recalculation of the energy savings achieved based on one year of building operation. The M&V Plan also laid out the requirements of the data that needed to be collected by the metering system and a schematic of the metering and data collection system. This M&V Plan and some documentation of the metering system were submitted for review during the application for LEED certification. While the LEED certification was awarded based on the M&V Plan and supporting documentation, the intended function of the metering system was not achieved at the time of certification. The team has continued to work on the system to ensure that the reporting from the system is useful.

Metering System

A Power Logic® Enercept® system manufactured by Square-D was installed. Each of the 4 building pods were metered separately for lighting, plug loads, and HVAC fan energy use. Data from the four pods were then aggregated so that these end uses for the entire building could be reported. The central plant that supplies heating and cooling to all 4 pods is separately metered. Despite being part of a campus of buildings, the building's total energy and water use is also metered separately by the utility.

The decision to install the system was made toward the end of construction; as an add-on, its drawings and specifications were completed later, after the coordination and scrutiny for the rest of the project documents had been completed. Imprecise drawings and specifications is one of the project's implementation barriers and will be discussed later. The electrical engineer selected the system, in part, based on its compact size and ability to be integrated into existing electrical design.

Method

Review of Literature

Research in the residential sector has evaluated the potential for energy conservation using meters or display systems to influence behavior. These systems provide real-time feedback to customers on their energy use. Energy savings from direct feedback can average 5% to 15% (Darby 2006). However, there is little research on building-level energy metering systems in commercial buildings. There is even less research on the socio-technical aspects of designing, installing, and using energy metering systems in commercial buildings. (Socio-technical refers to studying an "artifact through the eyes of the members of a relevant social group" (Bijker 1993, 119).) A socio-technical study on the installation of a multi-agent comfort management system was conducted at the Energy Research Center of the Netherlands in Petten, The Netherlands (Jelsma, Kamphuis, and Zeiler 2003). Jelsma et al. studied the *design logic* of the system's installation. *Design logic* is a concept defined as the "shared logic underlying design scenarios according to which the resulting object or system is supposed to work as intended by the designers. It is the outcome of a social process, of the negotiations between different actor logics brought to the design team by its members" (Jelsma, Kamphuis, and Zeiler 2003, 1172). The research revealed that it is not the design of systems that explain poor performance but the clash of logics (Ibid.). In particular there was a triadic clash between the logic of users, the *design logic* of the building, and the *design logic* of the comfort management system.

There is a similar paucity of research on how energy information should be presented to engage building occupants or operators in commercial buildings. Researchers at Lawrence Berkeley National Laboratory (LBNL) are evaluating Energy Information Systems (EIS), and their first effort included creating a characterization framework to organize the range of capabilities. These characteristics are: (1) data collection, transmission storage and security; (2) display and visualization; (3) energy analysis; (4) advance analysis; (5) financial analysis; and (6) demand response. Their current work is an evaluation using this framework of 30 EIS products, as well as detailed review of four EIS case studies (University of California-Merced, University of California- Berkeley, Wal-Mart and Sysco). These case studies provide answers to questions such as: Which features have proved most useful in attaining energy savings? What actions are taken based on the information provided via an EIS? How much of a building's low energy use or energy savings can be attributed to the use of an EIS? (Granderson 2009). In addition to LBNL's work, there are two significant research efforts underway to study effective visualization of building information. They are an ASHRAE sponsored study User Interface Design for Advanced System Operation and the Center for the Built Environment's Visualizing Information in Commercial Buildings (Lehrer 2009).

Research Questions and Approach

Building on the work of Jelsma, Kamphuis, and Zeiler, we conducted a socio-technical study of the process, team member roles, and challenges to design, install and program a metering system. We attempted to answer the following questions:

- What was the intent of the system? Was there agreement between team members on intent?
- What were the team's assumptions about the building operator's needs?
- Were the technical requirements of the system clearly understood by the team members and clearly communicated in the contract documents?
- Were team member roles clearly defined?
- What barriers did each team member perceive?
- How can those barriers be eliminated?

With the intention of understanding the *design logic* for the four team members involved, we created a questionnaire that attempts at providing data for analysis to answer the questions above. This questionnaire has been provided in the Appendix. The questionnaire was used to conduct in-person or phone interviews. The interviews were taped and transcripts were analyzed. The analysis consisted of comparing the answers provided by the four team members in the broad areas of (1) understanding of LEED requirements for M&V, (2) interpretation of the purpose of the metering system, (3) understanding of the building operator's needs and use of the system, (4) understanding of the individual's role in the overall process, and 5) the difficulties faced in the process. Project design reports, the M&V plan, along with 18-months worth of email communication between team members were also reviewed to understand the flow of information and provide a cross-check for the interview responses.

Analysis Results

Survey responses to most of the questions yielded rich information that led to meaningful analysis. Responses to questions #2, #5, #6, #9 and #10 provided contextual information but were not useful for meaningful analysis.

The analysis results are grouped in to the following sections: (1) purpose of the system; (2) the building operator's needs; (3) reports and; (4) team member roles.

Purpose of the System

Each of the four team members had their own *design logic* which included slightly different definitions of the system's intent, especially initially. Their difference in *logics* became obvious when the initial information reported by the system (post set-up and staff training by the manufacturer's representative) was different from that described in the M&V plan. As the programming process progressed, their *design logic* converged. Each person's perspective on the system's purpose is discussed below. This section also includes team member expectations of energy savings from system, if any.

To the energy consultant, the purpose of the system was to determine the savings achieved from the energy conservation measures that were installed based on the operation of the building. The data collected at the energy end-use level allows the energy consultant to calibrate the energy model and calculate savings based on actual building operation[1]. To him, the second purpose is to help the building operator see the ramifications of changes they might make in the way they operate the building. The energy consultant said it was "too soon to assume any energy savings from system. My expectation was that the savings would be there. And that is based on the fact that we've worked on a lot of different energy modeling projects and we've gone back over with some regularity, over a period of time and historically the savings have been there."

To the electrical engineer, the purpose of the system was to monitor the building loads and record the data every hour, which are used to populate various forms and graphs. He wanted the staff to have the ability to look at various systems on an individual level and be able to compare this data from month to month or year to year. He projected that they would use the data to implement preventative maintenance program (changing light bulbs or filters) and educate building occupants of energy used in the past, present and future projections. To the electrical engineer, "the M&V system by itself will not save energy. However, if the system is used as an operations and maintenance tool then the building owner will save operating and maintenance costs."

To the manufacturer's representative the purpose of the system was rather generic, because his different clients use it for different things and he tailors each system to the client's needs. To him the purpose of the system was to monitor electrical use per meter and to allow users to "log into a database where they can run and access reports". He had no expectations of the system's energy savings. "That's normally the end users. From my standpoint I try to give them all the tools they need. But their expectations are their expectations. I try to make [it] so they can meet their expectations. I can give them the best system I can make but that's it."

To the owner, the purpose of the system was to achieve a LEED point, validate the energy consultant's model, to examine in detail the electrical loads at any particular point. Validating the model would help the design community do a better job of modeling in the future. The owner had no expectation of energy savings from the system nor was it a priority. "The building's operations is predicated from researcher's [users] needs first and foremost. The primary consumer of energy, beyond the HVAC plant, is the computer room that is located within the building. So those are outside the control of building operator. They are what they are. The sorts of things we did to control energy consumption came in design of the lighting and HVAC system. The best we could hope for the M&V system is to validate we made appropriate selections".

Ideally, there would be a fifth person's design logic, the building operator's. This facility, however, doesn't have a building operator; instead they have maintenance staff with many different responsibilities. Therefore a building operator was not a part of the core team nor were their needs communicated by the owner.

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[1] New buildings, as opposed to existing building retrofits, do not have any previously metered energy data that can become the baseline case. During design, the energy calculations assume an installation quality and operational schedule of the building, and the baseline for the savings is a hypothetical case that references the minimum efficiency levels prescribed by the energy code. The IPMPV calibrated model approach requires that the design level calculations be modified so that the energy models for the building reflect the actual installation and the building operation. The model is calibrated so that the energy use matches wit the actual energy use of the building. The calibration also requires the changes to the model are kept consistent between the baseline and proposed building versions.

Building Operator's Needs

The building operator's needs were not articulated by any team member at any point during the process. Yet all team members, except for the manufacturer's representative, expressed some general assumptions on what the building operator would need.

In reference to discussing the building operator's needs energy consultant said "ideally it would have been early on… we talked to the building owner about what they wanted and helped them. That's how we arrived at it [building operator needs]. I would say we had assumptions about what we wanted the reports to look like and what data the building owner was looking for." The assumption from his side is that the energy data at a system level needed to be viewed to enable the building operator to understand the system operation and judge system performance.

The electrical engineer was familiar with the campus from previous projects and was aware of maintenance staff and how they work. While, "the building owner did not articulate the needs of operations, installation or future use" maintenance staff, based on his previous work on campus, is actively engaged in methods to save energy. "Therefore, we want the [maintenance] staff to have the ability to look at these various systems on an individual level and be able to compare this data from month to month or year to year. We projected that they would use the data to implement preventative maintenance programs, changing light bulbs or filters, and educate building occupants of energy used in the past , present and future projections."

The manufacturer's representative had no assumptions about the building operator's needs and was uncomfortable projecting what they may be.

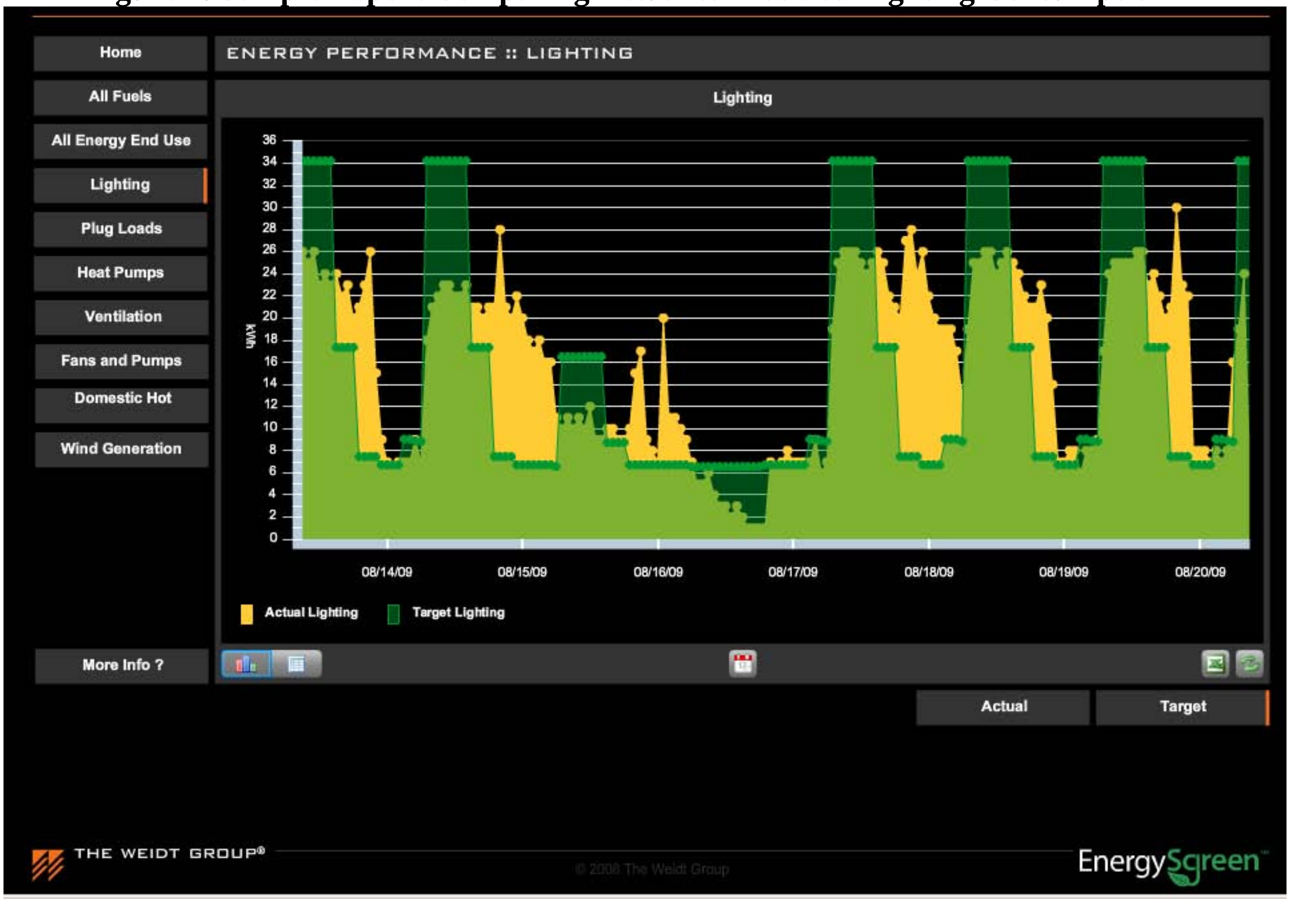
The owner did not provide a vision on the building operator's needs because, as previously mentioned, there isn't a dedicated building operator at this facility. Instead the campus has a facilities group that move furniture, makes repairs, etc. "In a large facilities shop there's typically an energy manager; it's generally someone charged with calculating energy consumption for the various buildings and physical plant and being sure that you're using energy optimally. [Our institute] is not big enough to have such a person. Using energy efficiently is a matter of optimizing control strategies for your mechanical systems, being sure that you don't have things like inefficient motors…" "And on the housekeeping side, you don't have a bunch of people using electric space heaters. So it runs the gamut. It's a responsibility that is diffused throughout the department. It's also something that on larger campus is centralized in that you usually have one or several people on the team/that monitor and manage energy consumption."

Reports

Reports are the results of the system and the interface that allow the user to make judgments about the building performance. They communicate key information, such as energy consumption per pod, HVAC, lighting and plug loads and by monthly, weekly, daily or consumption. Real-time reports also provide live trend information. Reports are built on the time intervals on which performance is collected, and can illustrate the problem solving capabilities of the system. The expected reports and their formats were not included as a part of this project's system requirements – either during the system selection or in the contract documents.

Below is an example of a report from a different project. This graph shows hourly data for a one-week duration. The interface can be customized to show different periods (daily, weekly, monthly, etc.). The yellow graph shows the actual energy use for lighting. The green graph shows the target lighting energy use. This allows the building operator an easy comparison of actual energy use to target energy use. A report such as this sets an expectation of performance, allows the operator to see the difference, and either draw conclusions about the problems or identify areas for further investigation.

Figure 1: Sample Report Comparing Actual to Modeled Lighting Consumption



Source: The Weidt Group

Both the energy consultant and the electrical engineer indicate that the report should allow a comparison between the energy use of the building and the energy model. They both mentioned the reports should also identify day-to-day operation problems for the building operator. The energy consultant said the purpose of the reports is to show the total energy use, as well as by pod, broken down by various components and how those components add up to the total. The reports can illustrate operation problems, for example, if lighting in one of the pods is being used when the building is expected to be unoccupied.

The purpose of the reports to the electrical engineer, initially, is to compare the building energy usage to the building energy baseline model. "Then after the first year of operation future reports are used to compare to the first year. The owner uses the comparison data to fine tune the building's operating system in order to run efficiently and give building occupants the best working environment."

The owner said the purpose of the reports is to validate that the building uses 30% less energy than a typical building. To the owner the purpose of the reports is to answer the question, "did we really achieve an efficient building based on all the energy conservation measures the building's design included such as daylighting and energy efficient systems and lighting?"

The manufacturer's representative had a generic understanding of the purpose of the reports. "The purpose of the reports is to provide the end user or customer the tool to be able to go back to see the history of the usage over a period of time. So right now [the institute] wants monthly readings. So the software gives them the ability to go back over and month and get monthly reports."

Roles: Whose Job Is It?

There seemed to be a general understanding of each team member's technical expertise but not on whose role it was to lead the effort. Team members operated independently during the design phase. A brief iterative process took place when the LEED documentation was being prepared and the electrical engineer revised the M&V plan (drafted by the energy consultant) to include his drawings and cutsheets, as well as his understanding of the M&V Data Specifications table, M&V Data Logging Locations, and schematic of M&V data logging locations. Problems surfaced during set up, and resolving these problems required the M&V team to collaborate. A consensus about the purpose of the system was formed after the manufacturer's field representative completed his initial scope and discovered the systems did not report data required by the M&V plan. Team member roles changed in response to the set up problems.

The energy consultant's perceived role was to inform the team of the "LEED requirements, help them understand the goals of the system, what they could get out of the system, verify the system was in place and functional, and to calibrate the model." Initially his firm's vision was "here's the information we need from the system you guys design it to meet those needs". His role changed when his firm realized the team needed more information. As a result his firm performed more work to create more software based measurement points. Some of these points (called virtual points) were not directly measured but calculated with arithmetic operations on others that were directly measured.

The electrical engineer perceived his role initially as the person responsible for designing and specifying equipment and software to meet the requirements of LEED. His role changed by "providing much more detail to the contractor for wiring schematics and software setup as well as ongoing troubleshooting" during the programming stage.

To the owner, his role was to "ensure the system would be useful for future use, was within project budget, and did not unnecessarily complicate building operation or maintenance."

Initially the manufacturer's field representative viewed his job as installing and programming the system, verifying communications, verifying data was being logged, setting up database for third party integration, and setting up custom device to communicate with generator control board and train staff. Initially he provided a direct measurement from each meter installed but after learning of LEED requirements he modified the programming by creating virtual points for HVAC, plug loads, and lighting and by all four pods. The manufacturer's field representative was a subcontractor to the electrical contractor. He received direction from the electrical contractor and not design team members such as the electrical engineer or energy consultants. The electrical contractor had no knowledge of the LEED requirements or the energy consultant's M&V plan in part because the system was an add-on, as previously mentioned. Consequently the manufacturer's representative did not receive the energy consultant's M&V plan and other critical information nor was he knowledgeable about other team members or their roles. The manufacturer's representative had completed his contracted scope before occupancy and went out of his way to return to the project to redo the programming.

As the system programming progressed each team member became more vested in a successful outcome. As the system presented challenges for set up they all collaborated to resolve missing or incomplete information, calculations, and report format.

Discussion

As previously mentioned, the system studied here was an add-on and not incorporated into the design process from the beginning. This had critical implications at every step and created a domino effect. The energy consultant provided an M&V plan. However, a direct involvement of a building operator and better examples of systems in the market would have equipped the electrical engineer with better information to provide precise drawings and specifications. Consequently the information presented in drawings to the manufacturer's representative was too general.

Problems Identified Post-Set up

Many of the problems were identified only at the time of system verification instead of being resolved during the design process. These problems became obvious when the manufacturer's field representative completed set up and it did not match the energy consultant's *design logic* for the system. The commissioning authority refused to deem the building as commissioned until the energy consultant had verified that the metering system was providing the correct data. Since commissioning is a prerequisite for LEED Certification, this became an effective gate-check to have the metering system working right and to allow the problems to be recognized.

Post set-up also revealed that not enough metered points were provided due to their cost. The add-on nature of system necessitated a limited amount of metering with convenience of circuiting rather than clean data. For example, VAV boxes are included on plug load circuits and could not be separated later. Outdoor and indoor lighting were not separated.

Reporting

Initially, reports were not set up correctly because the system's intent and energy consultant's M&V plan was not communicated to the manufacturer's field representative. Reports did not show submetering energy uses by pod, trend graphs were not provided, and there were incompatibility issues for exporting the data.

Creating accurate reports was also a challenge. Accuracy of the submetering is verified by summing up the meter reports and comparing with the utility bills. Initially they were off by 20%. Based on the way the meters were located, data from some meters needed to be subtracted to avoid double counting. A related issue was the Power Logic Web feature was not programmed for appropriate use. This feature allows the user to create and view custom reports for the data and in general has a better visual breakdown of the actual points. The Power Logic feature is helpful with setting up virtual points. For example, if a + b = c, b can be calculated if a and c are metered. Another problem was interfacing the system with other equipment manufacturer's protocol (Caterpillar generators).

Difficulty Verifying System

Verifying the system refers to checking what it's monitoring, how information is organized and presented, and whether data matches utility bills. Login issues (user error on site) reset the system and 45 days worth of recorded data, needed to compare with utility bills, was lost. On-site login is necessary to configure the system, but manufacturer's representative and energy consultant were located out of state. Remote login only provided the ability to view the data; the ability to program the system is only available onsite.

Barriers

The team experienced barriers due to the novelty of these systems to the design community. They are also new to owners and building operators who are not accustomed to monitoring real time energy regularly (hourly or weekly). As the LBNL characterization framework and review of 30 EIS illustrates, there are many systems with many options available. Owners and design teams are not familiar with the various options available. The lack of engagement on the part of owners and operators to monitor energy consumption on a daily (or even yearly basis) is also a barrier.

Metering systems are not off-the-shelf. A building can have a unique configuration based on the energy systems in the building and its architectural configuration. For example, a building with two large tenants will need to be submetered for each tenant. A school with multiple houses will need a different metering configuration than one that is a contiguous mass. And if a building has a series of heat pumps, they need a different configuration of metering.

A key barrier is the definition of the M&V credit in LEED® New Construction and Major Renovation Reference Guide v2.2 (September 2006); it does not provide clear guidance or specific minimum requirements for the credit. There is a lack of case studies or good descriptions to guide designers. Consequently there are different interpretations on the intent of the system. The design community flounders on how to meet this credit.

These issues impact the design process and in particular, the creation of detailed construction documents and specifications. Specifications do not clearly define roles in terms of expertise, responsibilities, and leadership for the design construction team. Without a clear set of construction documents and specifications to guide the construction team, it is almost impossible to get a building built right.

Overcoming Barriers

The LEED M&V Credit description and requirements need to be better defined. This will help facilitate the creation of more detailed drawings and specifications. Providing case studies, examples of metering schematics, and sample reports in the Reference Guides will help educate the design and construction community.

A standard set of specifications, made available from ACEEE, LBNL or another public entity, would provide designers a starting point and guide for their work.

The following matrix was created after the project was completed but it is informed by the issues discussed above on roles. Such a matrix filled out to assign roles and responsibilities can be included in the specifications.

Figure 2 Matrix of Roles and Responsibilities

Tasks	People Responsible TWG	EE	ME	AR	Cost Estimator	Owner's Energy manager	Owner's IT manager	Electrical/ Controls Sub	GC	CxA
Plan										
M&V Plan Draft										
Review of M&V Plan										
Design										
Meter Locations and Design										
System selection										
Technical coordination with selected system										
Construction Documents										
Construction										
Review contractor submittals										
Installation and programming										
Remote access setup										
Testing and calibration										
Training of Owners Staff										
Approval of system and programming										
Operation										
Periodic data checks and reports										
Calibrated Energy Model										
Ongoing checks after one year										

Source: The Weidt Group

Conclusion

We surveyed four team members on their perspectives designing and setting up a metering system and reviewed team emails. This data revealed the barriers during design and installation and set up based on the current state of the project. Those barriers are; lack of clear definition on the LEED requirements, lack of definition on the purpose of the system, lack of clearly defined team roles and responsibilities, lack of detailed construction drawings and specifications and lack of a of building operator in the process. Another barrier is that these systems cannot be off-the-shelf and need to be custom designed based on building configuration.

The implications of this paper for owners and building operators are to create a culture of interest and knowledge in real time energy information and to use this information in robust ways.

Another implication is for energy efficiency researchers. The effort and challenge of translating research to designers is not a new one. LBNL researchers' paper "Building Energy Information Systems: State of the Technology and User Case Studies" is rich, but they could reach out to the design community by summarizing and orienting information to meet designer as well as building operator information needs. Their characterization framework and case studies are a good start.

In the future, we intend to conduct more research on documenting a building operator's change in behavior as a result of a metering system. This part will include additional interviews to understand the barriers experienced by a building operator in successfully using the metering system.

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