Title

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ABSTRACT

Energy information systems (real-time acquisition, analysis, and presentation of information from energy end-uses) in commercial buildings have demonstrated value as tools for improving energy efficiency and thermal comfort. These improvements include characterization through benchmarking, identification of retrofit opportunities, anomaly detection to inform retro-commissioning, and feedback to occupants to encourage shifts in behavior. Energy information systems can play a vital role in achieving a variety of ambitious sustainability goals for the existing stock of commercial buildings, but their implementation is often fraught with pitfalls. In this paper, we present a case study of an EIS and sub-metering project executed in a representative commercial office building. We describe the building, highlight a few of its problems, and detail the hardware and software technologies we employed to address them. We summarize the difficulties encountered and lessons learned, and suggest general guidelines for future EIS projects to improve performance and save energy in the commercial building fleet. These guidelines include measurement criteria, monitoring strategies, and analysis methods. In particular, we propose processes for:

- Defining project goals
- Selecting end-use targets and depth of metering
- Selecting contractors and software vendors
- Installing and networking measurement devices
- Commissioning and using the energy information system

Introduction

Residential and commercial buildings are responsible for 40% of US primary energy consumption, 70% of electricity use and 45% of energy-related carbon emissions (EIA 2008). Studies have also shown that Americans spend as much as 90% of their time indoors (Adgate et al. 2004; Jenkins et al. 1992). Ambitious goals have been set for improving the efficiency of the US building stock (DOE 2010), and it is widely understood that improving indoor environment can lead to significant increases in health and productivity (Fisk 2000). Energy information systems (EISs) have demonstrated value as tools for improving energy efficiency and indoor environmental quality (Granderson et al. 2009), but their implementation is often fraught with pitfalls. In this paper, we discuss the lessons learned from implementing an EIS in Building 90 (B90), an office building at Lawrence Berkeley National Laboratory (LBNL).

The motivations for installing an EIS in B90 were several-fold. First, to help improve occupant comfort, we wanted to further characterize the temperature variations throughout the building. Related to this effort, we wanted to better understand the actual operating sequence and energy consumption of the HVAC system. Second, we wanted a full end-use breakdown of the building's energy use in order to inform potential retrofit projects. Third, we wanted to give the occupants, operations personnel, and management easy access to suitable real-time and trended energy use and thermal comfort data in order to boost occupant awareness, improve operations, and allow high-level tracking of the building's performance.

EISs have been commercially available for over a decade. Significant work has been done to analyze the capabilities and applications of EIS products, and to highlight opportunities for improving the technology. In 2001, several diagnostic tools for HVAC systems in large commercial buildings were studied (Friedman & Piette 2001); these diagnostic methods were reviewed earlier in another study (Haves 1999). In 2002, a multi-facility EIS was discussed, including the technology employed and the energy-saving actions it enabled (Piette et al. 2002). Several case studies were then presented, documenting the importance of in-depth energy information to ongoing commissioning efforts (Friedman et al. 2003). More recently, a framework for cross-product comparison of EIS functionality using Web-based infrastructure was developed (Motegi et al. 2003). A recent study built on this work by characterizing current EIS features, reviewing an extensive set of EIS products on the market as of 2009, and by analyzing the usage and benefits of several EISs deployed in large commercial buildings (Granderson et al. 2009).

This paper builds on the EIS literature by documenting a sub-metering and EIS project in a 50-year-old commercial office building. While most EISs present relatively few data points – typically only the building, lighting and HVAC mains – we installed over 100 measuring devices and integrated a legacy Energy Management and Control System (EMCS) to acquire floor-by-floor breakdowns of HVAC, lighting, and miscellaneous electrical loads. While the hardware and software costs of the B90 system far exceed those of more typical EIS projects, our system also provides a far more extensive data set. In the future, we hope to leverage these rich data both to save energy in B90, and to study the comfort, behavioral and economic benefits of EIS technologies in general. In this paper, however, we focus on the lessons we learned in the installation and commissioning of our EIS, in the hopes that future projects can avoid the difficulties we encountered.

This paper begins with an overview of the building we monitored and the technologies that we employed. We then discuss the challenges we encountered and summarize a few lessons learned. Finally, we generalize these lessons into a set of guidelines for future EIS planning, installation, and commissioning.

Building Overview

The building used as a case study is a 90,000 gross square feet [8,400 m^2] office building built in 1960 in Berkeley, California. The building has a steel frame, four floors and a partial basement. The envelope has single-glazed operable windows and minimal insulation; windows are partially shaded by an overhang on three sides. The heating system is predominantly hot water from gas-fired boilers, and cooling is provided by direct-expansion air conditioners, the largest of which use evaporative condensers. There are a total of 22 temperature control zones on the three floors served by the main HVAC system. The HVAC systems and controls have been subject to numerous modifications over the building's 50-year history.

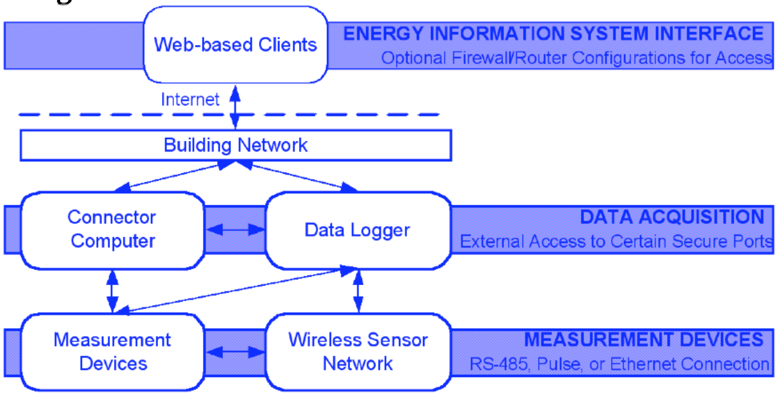
The building is fairly low-energy, achieving 71 of the 75 points required for Energy Star status. However, it ranks well below average in occupant satisfaction, according to a study of some 215 buildings surveyed by UC-Berkeley's Center for the Built Environment (CBE 2008). This survey ranks general occupant satisfaction on a scale of -3 to +3, with +3 indicating the highest degree of satisfaction. B90 scored -0.26, as compared to the 1.01 average score of all the buildings in the database. In particular, the thermal comfort is poor (B90 at -0.73 vs. -0.1; and with only 27% of B90 survey respondents being satisfied with thermal comfort vs. 69% of all the buildings' respondents), with some spaces too cold in winter and summer and others too hot in winter and summer (Huppert 2009). This is true in spite of recently-installed air conditioning in the main part of the building. From qualitative observations of building operations, we suspect that HVAC energy can be saved while also improving comfort, either through improvements to building controls or through HVAC retrofits. We hope the B90 EIS will provide data to support these observations, and highlight opportunities for improvements. While lighting in B90 has been replaced with a relatively modern, low-energy system (T-8 fluorescents and some daylighting and controls), there is room for improvement here as well. Increases in building occupancy and computerization are bringing additional plug loads, with questions about how to optimally control them. The building is thus a good candidate for an EIS to help characterize the end uses and identify retrofit opportunities.

Hardware and Software Technologies Employed

The typical EIS consists of building measurement equipment, on-site connector computers, off-site servers for data storage and analysis, and visualization by the clients (Granderson et al. 2009). These systems generally include both existing and additional measurement infrastructure. In B90, most of the measurement equipment was new, including electric sub-meters and wireless temperature sensors, although many of the existing EMCS points were mapped into the new EIS.

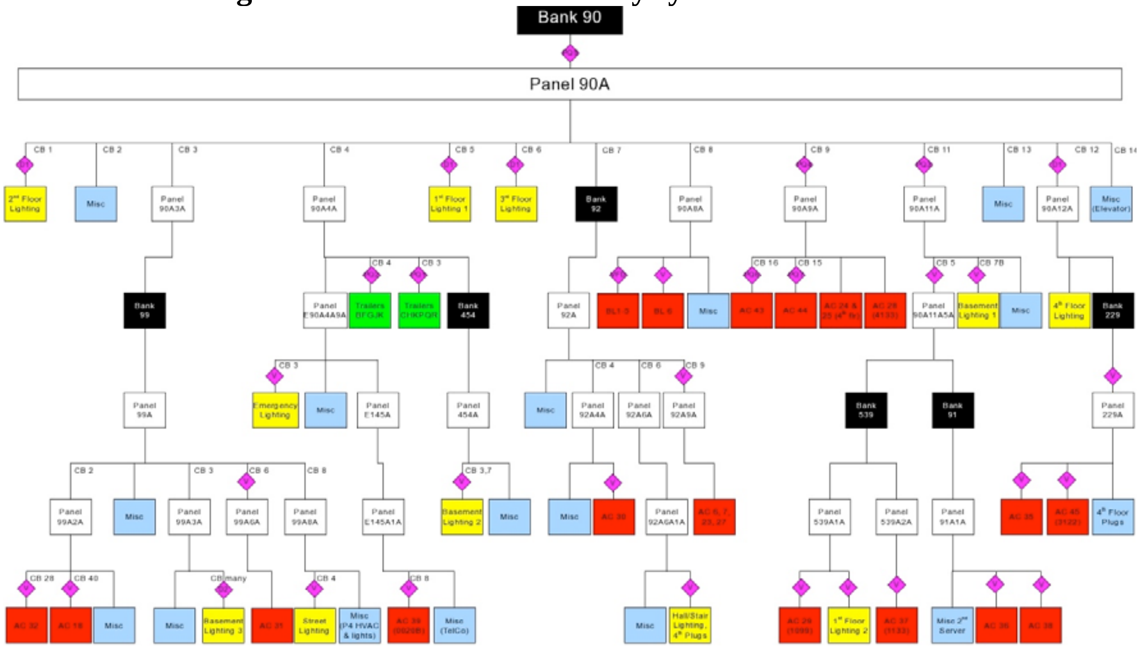
Figure 1 shows the B90 EIS architecture. To retrieve data from measurement devices (meters and sensors), the data acquisition devices (data loggers and connectors) used serial connections (RS-485), pulse outputs, or Ethernet. The EIS used a variety of protocols to retrieve the data and convey it to a centralized repository for analysis. This required port configuration within facility's firewall, a sensitive procedure that had to be conducted by LBNL IT security staff. The visualized data was made accessible to Web-based clients by the EIS.

Figure 1. Overview of EIS hardware and software.



We deployed four types of power meters from three vendors, as well as two gas meters (a legacy bellows-style meter and a new turbine-style meter with temperature and pressure compensation), measuring a total of 42 gas and electrical loads. The power meter locations are highly varied, both spatially and, as shown in Figure 2, in terms of the electrical system architecture.

Figure 2. B90 end-use electricity system architecture.



From lightest to darkest, the boxes represent: electrical panels (white), lighting end loads, miscellaneous electrical loads, HVAC loads, and transformers (black). Bank 90 is the main transformer feeding the building.

While most of the gas and power meters communicate through wired pulse, serial, or Ethernet connections, some power meters communicate via a mesh network of wireless sensors, which connects to the building local area network through a central gateway. The wireless sensor network (WSN) consists of 55 devices (motes), each with on-board sensing, processing and communication capabilities, configured in a dynamic and self-organizing topology. Some motes in the B90 WSN transmit power data, others act as communicating thermometers, and others act solely as relays to strengthen connectivity to isolated motes.

We chose to use a WSN as part of the EIS for two reasons. First, the decreased wiring and labor requirements of WSN led to lower up-front costs (and, in some cases, allowed access to panels where hard-wired connections would have been impractical or impossible). Second, we were interested in exploring the applications of this emerging technology in commercial buildings. Recent reviews of WSN cover the technology's history, hardware and software details, and potential applications in further depth (Akyildiz et al. 2002; Chong & Kumar 2003). We expand on our experience with installing and configuring a WSN, as well as various other challenges we encountered, in the following section.

Challenges and Lessons Learned

As in any complex engineering project, we overcame many technical and organizational challenges while installing and commissioning our EIS. Many of these project management challenges, such as coordinating stakeholders and scheduling labor, are fairly common and have well-known solutions. We don’t discuss those challenges here. Rather, we focus on the problems specific to sub-metering and EIS projects in commercial buildings. We recognize that each building is different and will therefore present a different set of obstacles and opportunities; however, the points discussed below were chosen for their wide applicability.

The first hurdle we encountered was a lack of clear documentation on the details of the building’s electrical and mechanical systems. Many existing buildings will have sparse documentation or no documentation at all. Missing electrical panel schedules, incomplete single-line drawings, and outdated floor plans can make it difficult to formulate a clear list of loads to be metered. It is therefore important to procure whatever information is required during the earliest stages of the EIS project, confirm its accuracy, and fill in missing information.

The second major obstacle was interoperability of the various systems we employed. As discussed above, we integrated four varieties of electric power meters, two types of gas meter, a network of wireless sensors, and a legacy energy management and control system (EMCS). Additionally, we plan to install and network several hundred distributed plug load meters and a second network of wireless temperature sensors. These systems sample data at different intervals, communicate via different protocols, and transmit data in a variety of formats. The EIS development team faced a formidable task in integrating these disparate data streams into one consistent format. In future projects, we encourage anyone who installs an EIS to consider hardware/software combination such that device and data interoperability could be achieved with relative ease. These issues could be mitigated by the hardware/software industry working together to adopt a common set of data and communication standards.

Another information technology (IT) related issue was security. In B90, all the data collected from the various measurement systems was stored in a centralized data center hosted by the EIS software vendor. This off-site server therefore needs access, at regular intervals and for varying durations, to an array of devices within a local network. While the energy data gathered in B90 was not particularly sensitive, it may have greater strategic importance in some other firms. We suggest that engineers pursuing future EIS projects involve their IT staff as early in the project as possible.

Finally, we encountered significant challenges while installing and configuring our wireless sensors. This was due in part to our somewhat limited understanding of the underlying technology, a fault we sought to remedy. However, to our knowledge, the WSN literature lacks a practical field guide for WSN deployment. Such a guide is beyond the scope of this paper, but we document a few of our problems and solutions as a step in that direction.

The first WSN problem to become immediately evident was the difficulty of communicating through floors. As shown in Figure 3, most inter-floor links have weak signal strength. One cause of this difficulty is signal attenuation through dense flooring materials, but a less obvious contributor is the propagation direction of radio waves broadcast from motes, which have linear antennae oriented vertically. Waves thus propagate primarily horizontally, confounding vertical communication. One solution to this problem is to mount motes at angles conducive to communication with their neighbors above and below. Another solution, and the one we ultimately employed, is to place a relay mote outside the building envelope, at a height and orientation that facilitated communication with motes on floors both above and below the relay. A final problem we encountered was suspected interference with other wireless office equipment (printers, scanners, headsets, etc.).

We employed two basic strategies to overcome these and other WSN connectivity problems: moving motes, and increasing the fraction of time motes spend transmitting and receiving. Both strategies involve trade-offs and opportunity costs. The former requires significant labor and shifting motes to non-optimal locations; the latter involves decreasing mote battery life (and therefore increasing the ongoing costs of maintaining the network). Our experiences suggest that, while the integration and troubleshooting of many different measuring systems are indeed challenges, they can be accomplished surprisingly easily. The next section outlines some of the strategies we employed to successfully install our EIS.

Guidelines and Best Practices for EIS Projects

In the following sections, we generalize the lessons learned from our experiences into a set of guidelines and best practices for future EIS projects. We begin by discussing two key aspects of the planning phase: defining a clear set of project goals, and selecting the end-use targets and meter locations these goals necessitate. We then suggest methods for selecting hardware and software vendors, provide a guide for simplifying the installation and networking of hardware, and discuss methods for commissioning and using the completed EIS.

Defining Project Goals

An EIS project should begin with a clear definition of the overarching goals, as these will guide many future decisions. The EIS projects documented in the literature have been undertaken with one of three broad goals: (1) decreasing the energy and carbon footprint of a building or enterprise; (2) saving money on energy bills; or (3) improving occupant satisfaction (Granderson et al. 2009). Each of these goals can lead to somewhat different project structures: for instance, an enterprise focused on saving money will be interested in the system with the highest projected return on investment. In this case, the enterprise should focus on installing relatively few meters, accessibly and strategically located to enable the easiest energy savings. In contrast, an organization interested in achieving more aggressive goals, such as carbon neutrality or net-zero energy, will be willing to accept higher up-front costs and longer payback times in order to acquire information that will enable deeper energy savings.

Our experiences indicate that seemingly simple goals, such as breaking down energy used by lighting, HVAC and plug loads (computers, copiers etc.), can quickly expand into extensive metering equipment requirements. Measuring these parameters for each tenant or floor could multiply the equipment and labor requirements accordingly. This tendency toward expansion should not be underestimated.

Selecting End-Use Targets and Depth of Metering

It is important for the scope of the monitoring project to be appropriate for the building, the issues to be addressed, and the budget. Once the project goals have been established, one must ask how they can be achieved. For example, is an end-use breakdown of the total building usage required, or is some subset adequate? What are the accuracy requirements of the measured data? Is the EIS temporary or permanent? Who will be using the data and for what purpose? The scope and sophistication of the system to be justified by anticipated energy savings should scale with the building energy cost, unless other goals are driving the project's justification.

Selecting Contractors and Software Vendors

Due to the emerging nature of the EIS market, EISs are rarely specified in new commercial building projects. EIS awareness is low among the consulting and specifying engineering community. In addition, there are few firms that specialize in providing turnkey provision and installation of EIS. While there are many vendors who offer various components of EIS, it is often necessary to find a prime contractor with a unique set of skills if a turnkey solution is desired. Metering and sub-metering equipment expertise is required along with requisite electrical installation skills. As previously described, wireless sensors can be very cost effective when applied properly. Networking and telecommunication skills are required to leverage the existing IT network and to make additions as required. Finally, software commissioning and integration of the database(s) into EIS visualization and reporting tools is required. Striking a balance between cost and value is key to successful EIS implementation.

Following are some suggestions for a facility manager or other decision maker considering an EIS. In many facilities, major equipment loads have discrete breakers, while smaller loads may share breakers. Disambiguation of loads is achieved by measurement of loads of interest. In some cases it may be useful to add measured values from multiple sources (e.g., all 3rd floor lighting circuits). In other cases, unmeasured loads can be determined by subtracting known loads from a measured value upstream. The EIS software visualization and reporting tools should support arithmetic functions for these types of calculations. Through review of the electrical panel schedules, single line diagrams and other as-built documents, the quantity of sub-metering points will become apparent. Because it is rarely practical or cost effective in retrofit projects to meter every breaker in every panel, priorities should be given to measure the loads of greatest value. In the B90 project, electrical metering locations were each given a priority of 1 through 4, (where 1 = "must have", 2 = "should have", etc.). Multiple project teams were given the opportunity to bid on the project by proposing what they could do for a stated fixed price (same price for all). A contract was awarded to the team that provided the "best value" based on our broadly written scope of work and prioritized metering schedule. This acknowledges that each vendor may have strengths and weaknesses that can be optimized in their proposal. The winning bidder supplied several meter types that collectively covered priorities 1, 2 and 3. Other selection criteria included the specifications of the equipment supplied such as meters, wireless sensors, and EIS software and installation services.

Installing and Networking Measurement Devices

This section provides a generalized guide for integrating the many devices used for measurement. The data from these devices form the underlying framework of the EIS. Data mining and analysis enable EIS users with capabilities for interactive visualization tools (e.g., dashboards) and customizable user-controlled interfaces. These measurement points originate from the selection of end-use targets and sub-metering needs.

Prior to the selection and installation of EIS and measurement devices, it is essential that selection criteria are established for network and data communication and its security. For the

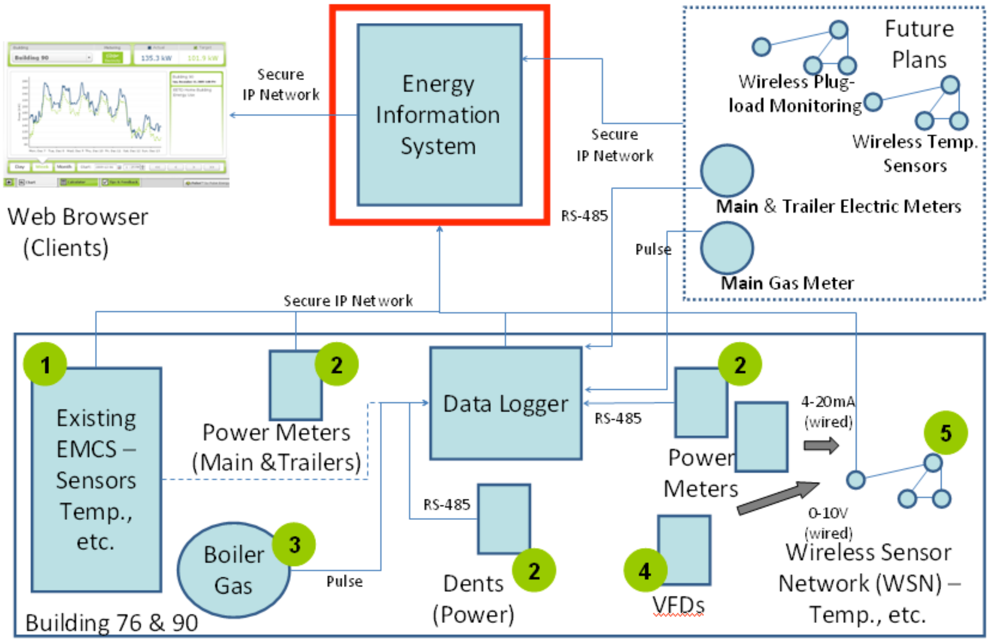
B90 monitoring, these criteria were low priority because the main purpose of the EIS was for research and public education. However, depending on principal activity of occupants, many commercial and industrial facilities have corporate networks and stringent policies such as network communication, security, etc, which may require enforcement of such guidelines. The selection criteria used for B90 monitoring that could be relevant elsewhere are as follows:

- **Data Collection, Access, Cleaning, Storage, & Analysis:** Criteria to assure interoperability of the EIS with measurement devices and allow for consolidation of data from disparate sources. The stored data in the EIS must be in a consistent format and be accurate, which will lead to analysis that can be trusted and makes sure that a facility has access to data at all times.
- **Network Communication Protocols:** This defines the protocols to be used for systems interoperability and how data is communicated within the network. The EIS communication technologies should allow for third-party integrators and future expansion.
- **Network and Data Security:** The network and data security are crucial for certain businesses and buildings. This also makes sure that the privacy and data integrity is maintained using a secure access (e.g., 128-bit encryption).

Figure 4 below shows the network and communication architecture used for the EIS. The end-use devices and architecture used here could also apply to other generalized EIS implementations. They are mainly categorized as follows and further explained later:

1. **Energy Management and Control System (EMCS):** The EMCS generally uses building network protocols (e.g., BACnet, Modbus, etc) and IT/networking protocols such as Internet Protocol (IP) using a Ethernet network. EMCS within buildings are used to record the whole-building or partial data sets, depending on the specific implementation.
2. **Power Meters:** The meters support both proprietary and open protocols. For B90, meters by multiple vendors were used to measure the whole building and trailer electricity and power data. The Ethernet, RS-485, 4-20 mA (all wired), and wireless sensor-based communication protocols were used to collect the data.
3. **Pulse Devices:** Pulse devices were used to measure boiler gas using pulse data outputs.
4. **Variable Frequency Drives (VFDs):** The devices used 0-10 V wired connection to measure energy usage via WSN. A gateway device was used to transmit data to the EIS.
5. **Wireless Sensor Network (WSN):** The motes using WSN were deployed within the building to measure temperature data and report measurements from other devices such as VFDs and other power meters.

Figure 4. B90 network and data communications architecture.



In the bottom half of Figure 4, we have end-use measurement devices that can either be connected to the EIS directly or through data loggers. The top half of Figure 4 shows the EIS back-end and client tools, which integrate, analyze and visualize data. Energy information can then be viewed by clients via web-based dashboards. These dashboards could be used in many ways, determined by clients and limited only by the granularity of data. With office- or cubicle-level data, for instance, building occupants could track their personal carbon footprint and compare it to that of their neighbors. With zone-level data, facilities engineers could establish charts to track the temperature in problem zones at different times of day and in different seasons, which might lead to improved HVAC controls and thermal comfort. Energy management staff in large enterprises could compare the energy consumption of each of their buildings, identifying the poor performers and enabling inter-facility competition. Since the economic and environmental benefits of EIS depend strongly on how people use these systems, we suggest further study both of how existing EIS tools are used, and of how these tools could be made more intuitive and useful.

Commissioning and Using the Energy Information System

An Energy Information System (EIS) requires commissioning and verification before the data can inform building operations. The commissioning of the EIS includes the following steps:

- Validation and calibration of measured values from the devices (e.g., kW, kWh, etc.)
- Incorporation of calculations within the EIS
- Configuring of meaningful dashboards to ease management (e.g., end-uses, floors, etc.)

Once the data measurement and acquisition devices are installed, there is a need to validate and calibrate the values measured from these devices. This process is necessary even if the devices are calibrated prior to the deployment. This is a crucial step for analysis of measured representations of values that will help in assuring the building users that the received data are valid and consistent without any data gaps. Such system commissioning issues are not unique to B90 monitoring and are commonly known within the industry.

Figure 5. B90 data gaps from zone air temperature sensors.

☑ 90_0014 - ZAT_3
☑ 90_0020 - ZAT
☐ 90_0026 - SS_CMP
☐ 90_AC28 - SS_SF

Start: 2009-10-18 3 :12 AM

Data gaps can happen for various reasons within a building (e.g., missing data folder, broken sensors, etc.) and can potentially be visualized by the EIS. An example on the EIS dashboard is shown in Figure 5 above. The data from the Zone Area Temperature (ZAT) sensors are missing as the folder containing the information was moved. Mitigating these issues include maintaining a log of different data storage systems and setting alerts in the EIS (which most of the EIS allow) whenever problems arise. Other advanced data validation and data integrity methodologies can be applied for mission critical data.

Once the data is calibrated and verified for accuracy, these data and those from any external sources (e.g., weather) can be mapped against some math calculations within EIS to factor different value representations reported from each of the sources. It is not necessary that the data from different sources has to be recorded at the same time interval and use consistent units. The EIS can easily map inputs that use different units (e.g., you can add kWh and Btu and represent it as joules) and at different time intervals. This EIS process also includes conversion of energy use and related data with consistent units (e.g., kW, time, etc.). This one-time set-up of custom math calculations and certain built-in EIS algorithms will allow the configuration of dashboards for consistent interpretation of data for analysis by the users. These visualization techniques ease subsequent management of the repetitive aspects of an EIS. The final step in the use of the EIS is the energy analysis to meet energy goals. This requires understanding and availability of historic data to make sure the energy measurements are accurate and match actual consumption. Some utilities offer access to whole building energy data, however, at the end-use level, it requires validation. Certain EISs have the ability to forecast energy use based on variables such as temperature, occupants, etc.

Conclusions

In this paper, we have detailed a sub-metering and EIS project in a representative commercial office building, and proposed a set of best practices for planning and executing similar projects. For most buildings additional sub-metering is needed to provide data for analysis by the EIS. The extent of sub-metering depends on the goals of the project. The sub-metering infrastructure should consider both wired and wireless communications. Wireless sensors provide ease of installation. However, implementations of wireless sensors should consider reliability issues that vary with building types and communication protocols. There are issues related to interoperability of different measurement devices and communication systems that an EIS can integrate effectively. A thorough commissioning of the sub-metering and the EIS is necessary to ensure data validity and reliability. The EIS can then be used to inform efforts to reduce energy use and improve occupant comfort.

Future Research

This paper does not comprehensively address all issues that are relevant to EIS implementation. Future research should include focus on the following areas:

- How EIS tools are used by building occupants, facility managers, and energy management personnel.
- Economic analysis of the costs and benefits (both in thermal comfort and energy savings) of EIS, including the optimal depth of metering.
- Development of a field guide for installing and commissioning wireless sensor networks in office buildings.
- Linking EIS and real-time simulation for model calibration and fault detection.
- Demonstration of EIS integration for building controls, energy efficiency and demand response.

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