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UC Berkeley�s Cory Hall: Evaluation of Challenges and Potential Applications of Building-to-Grid Implementation

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UC Berkeley's Cory Hall:
Evaluation of Challenges and Potential Applications of Building-to-Grid Implementation

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Task #8 of the Building-to-Grid (B2G) Technology Evaluation and Roadmap

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Project Summary

From September 2009 through June 2010, a team of researchers developed, installed, and tested instrumentation on the energy flows in Cory Hall on the UC Berkeley campus to create a Building-to-Grid testbed. The UC Berkeley team was headed by Professor David Culler, and assisted by members from EnerNex, Lawrence Berkeley National Laboratory, California State University Sacramento, and the California Institute for Energy & Environment. While the Berkeley team mapped the load tree of the building, EnerNex researched types of meters, submeters, monitors, and sensors to be used (Task 1). Next the UC Berkeley team analyzed building needs and designed the network of metering components and data storage/visualization software (Task 2). After meeting with vendors in January, the UCB team procured and installed the components starting in late March (Task 3). Next, the UCB team tested and demonstrated the system (Task 4). Meanwhile, the CSUS team documented the methodology and steps necessary to implement a testbed (Task 5) and Harold Galicer developed a roadmap for the CSUS Smart Grid Center with results from the testbed (Task 5a) and evaluated the Cory Hall implementation process (Task 5b). The CSUS team also worked with local utilities to develop an approach to the energy information communication link between buildings and the utility (Task 6). The UC Berkeley team then prepared a roadmap to outline necessary technology development for Building-to-Grid, and presented the results of the project in early July (Task 7). Finally, CIEE evaluated the implementation, noting challenges and potential applications of Building-to-Grid (Task 8). These deliverables are available at the i4Energy site: http://i4energy.org/.

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Introduction

Traditionally, communication between energy utilities and buildings has been one-way (e.g., a bill or request to curtail load from the utility to the building). Likewise, sensors and actuators within the building typically remain autonomous within the building, perhaps internally used for energy efficiency or conservation measures. Building-to-Grid describes the instrumentation and communication infrastructure to allow a dynamic near real-time two-way communication between commercial buildings and the utility in order to optimize energy use.

Building-to-Grid is one of five major areas of focus by the National Institute of Standards and Technology (NIST) to build interoperability into the Smart Grid.[1] The Smart Grid in turn describes the sensors, two-way communication, and computing power directly connecting building automation features as well as distributed generation and storage to the electrical grid. According to the U.S. Department of Energy (DOE), "the Smart Grid is an automated electric power system that monitors and controls grid activities, ensuring the two-way flow of electricity and information between power plants and consumers—and all points in between….what makes this grid "smart" is the ability to sense, monitor, and, in some cases, control (automatically or remotely) how the system operates or behaves under a given set of conditions…. to optimize our use of electricity" (U.S. Department of Energy (DOE)). The U.S. DOE lists five technologies fundamental to the development of the Smart Grid:

- "Integrated communications, connecting components to open architecture for real-time information and control,
- Sensing and measurement technologies, to support faster and more accurate response such as remote monitoring, time-of-use pricing and demand-side management,
- Advanced components, to apply the latest research in superconductivity, storage, power electronics and diagnostics,
- Advanced control methods, to monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event,
- Improved interfaces and decision support, to amplify human decision-making" (Litos Strategic Communication for U.S. Department of Energy (DOE) 2008; U.S. Department of Energy (DOE)).

According to the U.S. DOE, "a smarter grid will enable many benefits, including improved response to power demand, more intelligent management of outages, better integration of renewable forms of energy, and the storage of electricity" (U.S. Department of Energy (DOE)).

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[1] "Under the Energy Independence and Security Act (EISA) of 2007, the National Institute of Standards and Technology (NIST) has 'primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems…'" (National Institute for Standards and Technology (NIST) 2010).

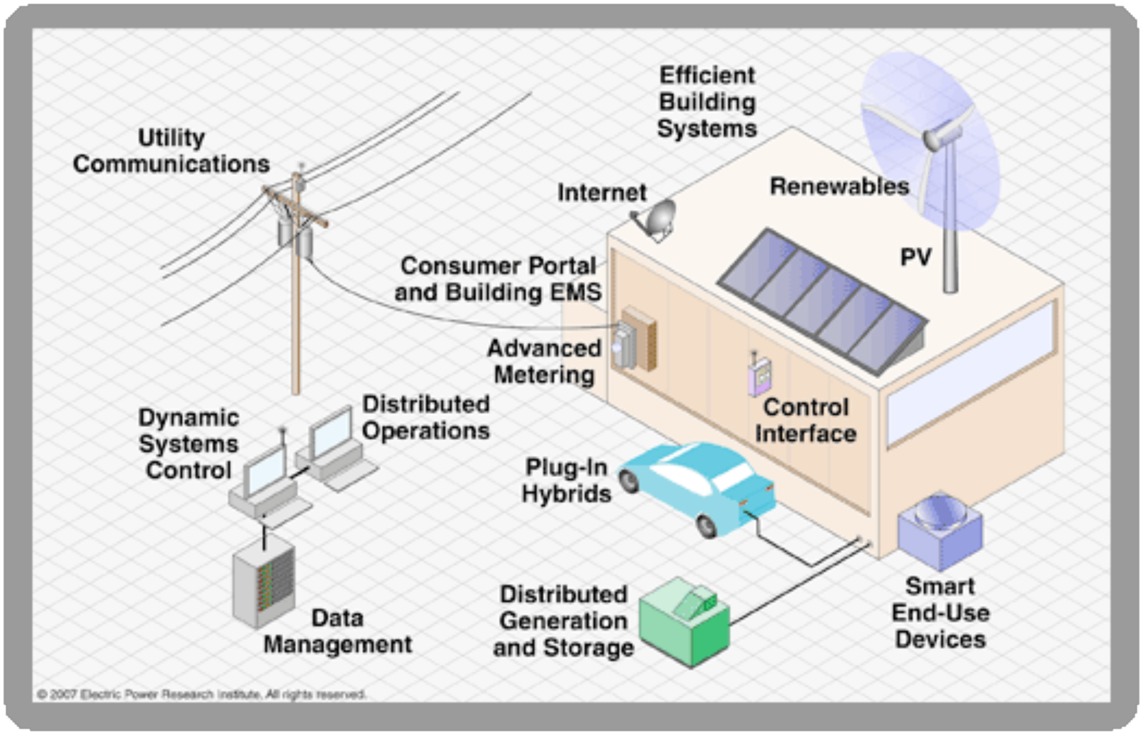

Figure 1: Vision of the Smart Grid interconnecting buildings, vehicles, distributed energy generation and storage (EPRI website).

Building-to-Grid (B2G) describes the interaction of the Smart Grid with *commercial* buildings as distinct from industrial or residential buildings.[2] Commercial buildings include small and large offices, restaurants, retail, food stores, refrigerated and unrefrigerated warehouses, schools, colleges, health, lodging, and a miscellaneous category (Itron 2006). These buildings require electricity and fuels such as natural gas to function. Electricity is primarily used for lighting and cooling while gas or other fuels are primarily used for space and water heating; some mixed-use buildings with industrial-like processes such as clean rooms and laboratories populate the “college” sector (e.g., Cory Hall at UC Berkeley). Appendix A contains more detail on energy end-uses. Building-to-Grid activities include participation in demand response, distributed energy generation (e.g., through renewables such as photovoltaics), or storage (e.g., thermal storage such as making ice for air conditioning or hot water storage), as well as diagnostics and energy efficiency analysis within the building itself.

The next section outlines the technical and social components of B2G and the process of implementing a B2G system, followed by a brief description of the implementation at Cory Hall. Then the opportunities of B2G and the challenges are described. The final section concludes with the next steps and questions that introduce further areas of research.

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[2] The five areas of focus are Transmission and Distribution, Building-to-Grid, Industry to Grid, Home to Grid, and Business and Policy (National Institute for Standards and Technology (NIST) 2010).

Background

This section introduces the what, who, and how of implementing a B2G system, in order to frame the discussion of opportunities and challenges. First, the technical components of B2G are discussed, followed by the social components. Finally the process or methodology of developing a system is outlined.

Technical components

The technology required to enable B2G includes sensing and measurement devices, communication within these components as well as communication to the utility or service provider, advanced components (such as photovoltaics and storage devices), advanced control methods, and user interfaces.

Sensing and measurement technologies. These can meter purchased energy from the utility—including electricity, natural gas, steam, or hot/chilled water. Site electricity can also be measured within the building from the individual plugload or receptacle level to the major branch circuits, as well as on the utility side of the revenue meter at transformers or substations. The Advanced Metering Infrastructure (AMI) meters that measure and record electrical energy consumption in 15-minute or other time intervals is an example of a common component to enable B2G.

Measuring the internal energy flows for heating, ventilation, and air conditioning (HVAC) within buildings is more difficult. Complexities include measuring fluid flow and multizone air handling systems that implement control through simultaneous heating and cooling. Appendix B describes some of the metering specific to Cory Hall.

Communication among the components. Current commercial buildings in the U.S. vary in the sophistication of their Building Automation Systems (BAS) and Energy Management Control Systems (EMCS) that typically control space heating, cooling and ventilation systems. The more advanced systems use direct digital control (DDC); "DDC contains networked microprocessor-based controllers, which are connected to sensors and actuators" (Kiliccote, Piette, and Hansen 2006). DDC to the zone level can facilitate demand response through temperature setpoint adjustment, as changes can be globally or centrally implemented. Older systems use pneumatic or electrical controls, with more limited EMCS and DR capability. Thus communication can take place via wires such as RS-485 using ModBUS protocol (or LonTalk or BACNet), or wireless, or a hybrid system using both.

Communication between the building and grid. The typical building-grid communication consists of telephone, email or pager dispatches to request the initiation of an interruptible load, or radio-activated direct load control. These systems may be replaced with Internet communication via XML such as grid data following the IntelliGrid architecture, carbon offset data from a GreenXML source, pricing or reliability signals from an OpenADR link, or wireless communication to a smart thermostat via the ZigBee Smart Energy public application profile. The format could be a dedicated gateway with software (expensive) vs. Internet-activated relay remotely activated via LAN, WAN or the Internet (Kiliccote, Piette, and Hansen 2006). Appendix C lists different types of information that can be exchanged.

Advanced components and control methods. Integrating advanced controls is easier with buildings with DDC controls; "EMCS built upon DDCs establish the potential for real-time monitoring of all sensor, control, and data points from a central location. The data can be logged, trended, used for fault detection and as feedback to refine system operation and energy usage" (Kiliccote, Piette, and Hansen 2006). These advanced controls can switch into several different operational modes depending on schedule—"occupied, unoccupied, maintenance, cleaning, night purge, warm up and cool down" (Ibid.). Advanced controls influenced by price or reliability signals, weather, renewables etc. will need to be integrated into the existing EMCS system. Older controls/legacy systems using pneumatic controls are harder to integrate with sophisticated controls. Sophisticated controls are more dynamic and change with a unique building's loads and needs. Peak load management includes demand limiting or demand shifting (e.g. precooling or preheating before peak demand periods). Controls that respond to price or reliability signals, or demand response, may be fully manual (requires labor-intensive human intervention), semi-automatic (requires human to initiate control strategy), or fully automatic (controls initiated through external communications signal) (Ibid.). Demand Response can reduce loads by demand shedding, such as dimming lights and increasing temperature setpoint during cooling periods (global temperature reset), or reducing fan velocity.

Interface with user. The Smart Grid can create smart customers by encouraging participation to enable customer choice; this requires user interfaces, such as dashboards or other data visualization tools that provide feedback and advice/suggestions. The type of data will vary depending on the user—whether the building occupant (wanting to know why the temperature is warmer), facilities manager, financial manager and so on. Typical types of data include real time and historic energy use, cost and rate schedule, trends and projected forecast of usage and costs, amount and costs of renewable energy sources, carbon content of power sources, weather forecast, and power quality and reliability (Sinopoli 2009). Energy information systems (EIS) provide more data archiving, trending, and user interface capability than typical BAS or EMCS (Granderson et al. 2009). Many companies are currently involved in developing related tools, including advanced user interfaces (e.g., dashboards). These companies include Google, GE, Greenbox, Lucid Design Group, Agilewaves, GRIDiant, PowerMand, and so on.

Social Component

Implementing B2G involves many players. The more obvious participants include the occupants of the building, building manager, in a campus setting the campus manager/facilities manager, the owner, local utility company, and vendors/manufacturers of technology. However, in addition to facilities managers, participants may include financial managers, information and communication managers, and maintenance and engineering departments. Other outside participants include local fire and building code enforcement. Appendix D outlines some of the people and organizations involved in energy usage information transfer.

Process[3]

The steps to implement a building improvement project such as enabling Building-to-Grid activities in a building may be broken down into seven main phases: the initial Commitment or

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[3] This section draws upon the California State University Sacramento's methodology report, including the 14 step flowchart of implementing a Building-to-Grid system.

buy-in, Predesign (setting goals, gathering information), Design Development (estimating loads, deciding metering points and protocols), Specification, Bidding, Installation, and Commissioning. Similar to other design methodologies, these steps overlap and many activities are iterative, and progressively evolve throughout the process. These steps are outlined in Figure 2 below and described in detail in Appendix E.

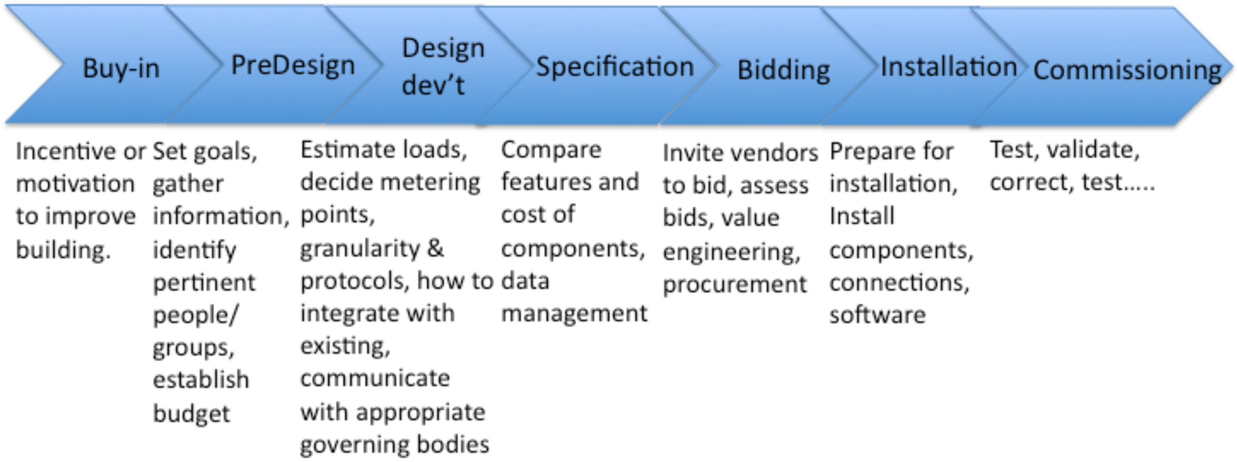

Figure 2: Process of implementing a Building-to-Grid system.

UC Berkeley's Cory Hall as a Building-to-Grid Testbed

Cory Hall represents a large complex energy load within the UC Berkeley campus. It is an older (1950) building that has undergone multiple renovations, so comprises a complex set of buildings within a building, with classrooms, offices, and energy-intensive laboratories of various vintages. At the beginning of the project, the electrical load of Cory Hall averaged approximately 1000 kilowatts, representing the 5th largest load on campus, with an annual energy cost of approximately $1 million.

Beginning in September 2009, a system of sensors, meters, submeters, and monitors, along with data management software was designed, procured, installed, and tested in Cory Hall in order to develop a Building-to-Grid testbed. Appendix F describes the process in more detail.

The goals for applying the instrumentation system were four-fold: first, to "do nothing well", or eliminate energy waste; second, develop a power proportional design, or design instrumentation granularity in proportion to electrical load; third, "sculpt" the load, by shedding or shifting; and finally, forecast, plan, negotiate, and manage (Culler 2010). The design of the data communication infrastructure was also four layered in nature, with each layer independent of each other, as shown in the figure below.

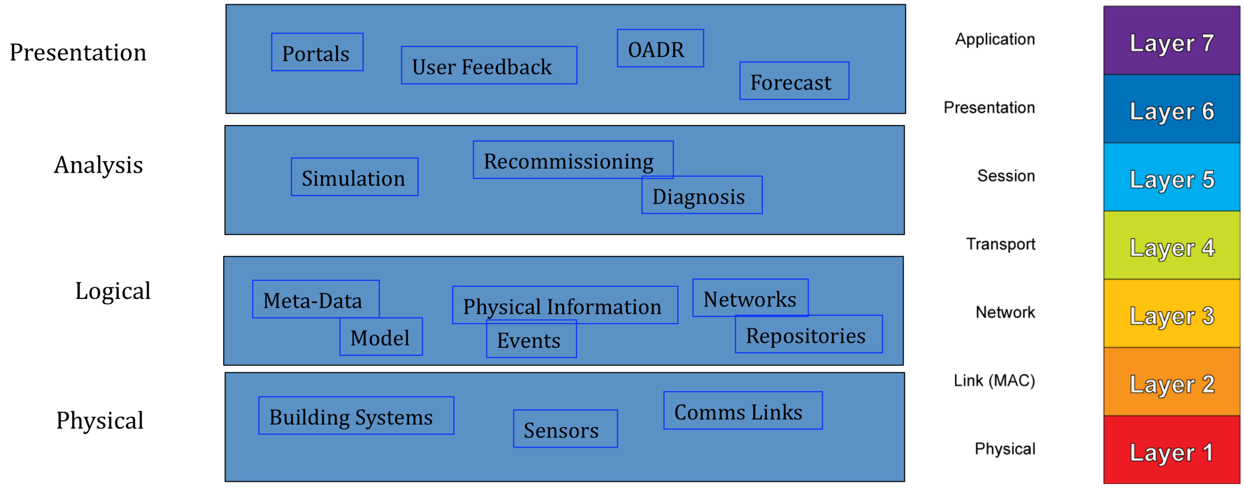

Figure 3: Left: Independent four layered design in Cory Hall. Right: For comparison, OSI 7-layer model for data communication.

Whole building electricity use was metered with a PSL power quality meter; Dent meters monitored the 13 branch feeds and subpanels (approximately 40 sense points) (Dawson-Haggerty, Jiang et al. 2010). The environmental control systems and lighting were submetered, as well as major lab tools. The installation included mostly commercially off the shelf equipment; however, the receptacle loads, most notably the lab machines, were monitored with a wireless network of ACme monitors and controllers developed by UC Berkeley. The steam provided from a campus district system and supplemental chilled water supplied from an adjacent building were also metered. A small sensor network of TelosB motes contributed temperature information from the lab, which a Hydrowatch Environmental monitoring system on the roof and connection to Berkeley weather through the internet provided external environmental conditions (Ibid.).

In addition, parallel data management systems were installed: a commercial software system by OSIsoft and a new open architecture internet-based system using sMAP[4], developed by UC Berkeley. The data involved many sources from different manufacturers of equipment, both new and existing—around 2000 distinct measurements—many with their own proprietary interface. sMAP was developed to provide an open means of data integration and communication using a RESTful[5] web service (Dawson-Haggerty, Jiang et al. 2010). The novel solution UC Berkeley developed requires assigning an IP address for each device to allow seamless data management via HTTP for data access and JSON[6] for object representation (rather than XML, although JSON can be translated to XML) (Ibid.). As a data interchange layer, sMAP provides an easy means to get data out; sMAP uses a data model to represent and organize data and an architecture to implement the metrology in a physical system, instead of unique registers and translation for each device (Ibid.). Thus the emphasis is on distributed architectures to allow nimble and independent addition of applications and devices.

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[4] Simple Measuring and Actuation Profile

[5] REpresentation State Transfer, convention-based web services built on top of HTTP.

[6] Javascript Object Notation is a simple data interchange format that is language independent.

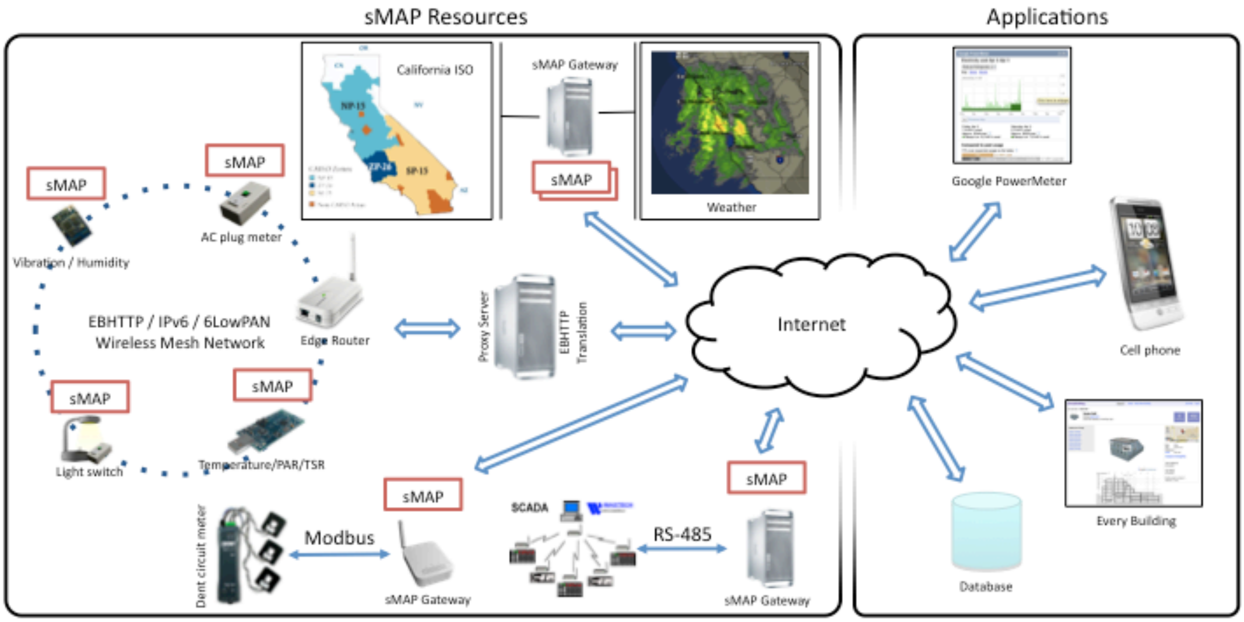

Figure 4: sMAP as communication interface solution for the many sources of data—whether Modbus/RS-485 (wired), 6lowpan/IEEE802.15.4 wireless, or proxied data from weather or grid (Culler 2010).

The implementation of applications is under development. Current data visualization and re-aggregation of the data takes place with another UC Berkeley developed product, IS4 (Integrated Sensor-Stream Storage System). IS4 effectively develops associations between the data, and manages the meta-data by sensing type (e.g., cooling) (Ortiz and Culler 2010).

The next steps include further applications, such as fault detection, other data visualization, advice development, and implementing control algorithms. Other possibilities include the addition of renewables such as photovoltaics and potential storage applications.

At the end of this project, the electrical load of Cory Hall averaged approximately 750 kilowatts—a reduction of 250 kW. Approximately one fifth of this load reduction, 40 kW, stems from equipment removed from the semiconductor microfabrication laboratory during this project. This load was partially reduced by unnecessary equipment shutdown due to a fire and findings from a parallel Monitoring Based Commissioning project. However, the newly installed instrumentation has also identified other load savings, including the discovery of a chiller accidentally left in manual mode, and opportunities for scheduling, so that unused spaces do not consume thermal conditioning energy. Estimated savings is approximately 1.3 million kilowatt-hours, or $130,000 per year.

As a testbed, more instrumentation was installed than may be typical for a Building-to-Grid system. In addition, as a building within a campus, Cory Hall has some different opportunities and challenges than a stand-alone building.

Potential applications

Cory Hall was instrumented as a testbed for research on Building-to-Grid applications. After the system has been fully commissioned, researchers from various organizations can test different scenarios. The instrumentation can supply a great deal of data, both for within building use and for communicating with the utility. There are several potential applications of the sensing and measurement technology as well as the communication and data visualization to the user; several of these are listed below (Brown 2010). In addition, the EIS Alliance has identified 19 use cases for sharing of energy usage information, as shown in Table 1; their recent report outlines a narrative for each scenario with the actors and types of information transmitted (EIS Alliance 2010).

Table 1: Types of use cases for sharing energy usage information (EIS Alliance 2010).

Use Case Name
Manage power demand to minimize cost.
Manage production needs with power and energy management
Customer Forecasts Power Usage
Balance power purchases between utility and on-site generation
Balance power purchases between multiple utilities
Buy or Sell Electric Power
Customer includes social, environmental and regulatory aspects of energy consumed into the business model.
Measure Plug Load to calculate Cost and Consumption
Measure Equipment Power to calculate Cost and Consumption
Measure Energy to Allocate Energy Cost
Measure Energy Cost, Emissions and Consumption for Display
Measure energy cost, emissions, and consumption to compare against building portfolio for benchmarking purposes.
Measure energy cost, emissions and consumption to compare against similar buildings for benchmarking purposes.
Measure Energy to validate Energy Consumption
Communicate Generation Status for Grid Maintenance and Planning
Receive Grid Maintenance Planning Information
Receive Instantaneous Power Quality to Validate Power Service Level Agreement
Load(s) Controlled by External Source
Make Choices Regarding Price Signal from Utility

Both energy management and demand response are general applications for a B2G system, whether on at a thin or deep (extensive) level. Goldman et al discuss the coordination of energy efficiency and demand response in (Goldman et al. 2010). The figure below expresses the continuum between the two along a progressive time scale. Energy management includes both energy efficiency and energy conservation as goals for reducing environmental impact or operational costs. Demand response refers to load management that supports grid and market health as well as integrates renewable energy sources (Brown 2010). Demand response can mean reducing demand during peak times or potentially increasing demand during periods of low energy use in order to balance the system. Reduced demand may be different for every building, but can include dimming lights, changing thermostat setpoints, or decreasing fan speed. On a campus or in a large building, demand response may involve switching fuels. Though steam capacity at UC Berkeley may not be an issue, in theory a reduction in steam use for reheat can make more steam available for use by heat-driven chillers, such as those in the recently constructed Sutardja Dai Hall next door to Cory Hall. Sutardja Dai Hall has a fuel flexible system that can use either an electrical or steam-driven chiller according to SDH Facilities Manager, Domenico Caramagno (Personal communication, Caramagno 2010).

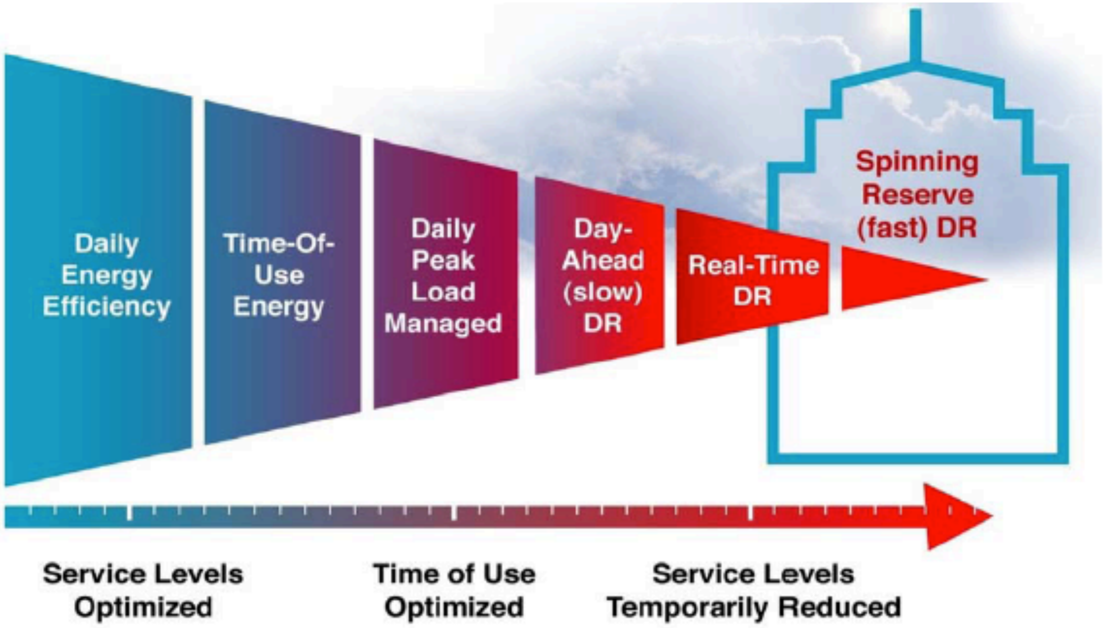

Figure 5: The energy efficiency-demand response continuum (Demand Response Research Center (DRRC) 2008).

Energy management within the building includes monitoring-based commissioning (MBCx, a form of retrocommissioning emphasizing enery use measurement) and benchmarking. **Monitoring-based commissioning** including verification and enabling of persistence of energy use reduction can be implemented for both heating/cooling (steam/chilled water) as well as electrical energy consumption. Retro-commissioning at Cory Hall found many issues: heating and cooling systems “fighting” each other and a chiller set to manual instead of auto mode. **Benchmarking** the building with respect to energy consumption can involve comparing the same building’s historic energy trends or comparing energy consumption with similar buildings. The latter entails comparing the Energy Use Intensity (EUI) (kBTU/sf) with other buildings of similar use and in a similar region. Both are useful to understand the potential for energy savings, set performance goals, create and implement action plans, assess performance and progress, and recognize the achievement of these plans.

Applications of the instrumentation that supports demand response include checking load diversity, sharpness of peaks, creating accurate load predictions, and creating an aggregated load shed profile. **Checking load diversity** describes measuring the maximum load at each branch and the main feed, using the same sampling and averaging periods. With meters on all branches, one can compare the sum of the peaks to the main feed peak and determine the diversity of the branch loads. This may lead to refinement of estimates for available demand response, as well as provide design engineers with better information for building renovations or even design of new buildings (Brown 2010). **Checking the "sharpness" of peaks** entails examining the shape of the loads (Brown 2010)**.** Utilities have historically used a relatively long averaging time interval for datalogging and billing (typically 15 minutes, which is the case for the local utility for UC Berkeley and Cory Hall). It is critical to observe, trend and archive building and sub-system data with a replication of the utility billing protocol, for comparison with the huge body of knowledge collected with similar measurements of buildings in the same service territory. However the value observed as "maximum demand" varies significantly with the averaging interval. Observations using shorter averaging intervals may yield important information about the nature of building and subsystem peaks that will impact the ability for demand response (Brown 2010).

Creating an accurate load prediction involves using the instrumentation with various load prediction algorithms to create a 15 minute, hourly, or next day load profile prediction to be communicated to the utility for any season or time of year. **Creating an aggregated load shed profile** may require using the instrumentation to understand load shed capability over the day, and throughout the year. This dynamic load shed profile can be communicated to the utility (Kiliccote 2010).

Other potential applications include **building energy modeling**. This is facilitated by including additional sensors that record exterior weather conditions (e.g., air temperature, humidity, and solar radiation). Modeling can be used to identify ways to improve building performance, as well as quantify the magnitude of energy use reduction from measures identified by other means (Brown 2010).

Additional applications involve the integration with other programs and applications pursued by building management, such as qualifying for LEED Existing Building or EnergyStar rating, or involvement with cap and trade for carbon emissions.

The potential for Smart Grid extends to Smart Buildings, Smart Appliances, and Smart People. If people are provided timely information and controls, they can make decisions that best suit their needs as well as cooperating to create a more stable electricity grid. This information flow to consumer might include energy use, choice of power sources (i.e., renewables, plug-in hybrid vehicles), weather forecast, quality/reliability of power, and specific requests, such as "utility needs var support, please shut down unnecessary motors".

Challenges/Barriers

Implementing a Building-to-Grid system is complex and provides many challenges. Some challenges are physical or structural in nature, others based on policy/regulation, some economic, still others are socially related, and many are an intricate combination of these. These challenges occur at different phases of the project.

One challenge is just getting the initial buy-in or commitment to develop a B2G system. Adopting Building-to-Grid instrumentation will most likely follow the Rogers' Innovation/Adoption curve with a few brave souls adopting initially, followed by the early adopters composed of opinion leaders, then early majority, the skeptical late majority and finally the traditionalist laggards (Piette et al. 2002). The goals or aspirations of the organization (e.g., wanting to set an example, show good citizenship) affect the buy-in, as do external incentives such as financial benefits. The degree to which the building already engages in energy management and/or demand response also may affect the buy-in, as does the general capability of the existing building EMCS (Brown 2010). As in other examples of technology adoption, policy can play a role in speeding up the adoption rate.

Another challenge that occurs in the Predesign phase is setting appropriate goals that reflect the context of each particular building (Ibid.). Types of goals include demand response load/peak load management such as shifting/shedding load, renewable energy integration, energy efficiency targets, carbon emission reduction, benchmarking, and/or energy storage. The goals of the project set the stage for what types of equipment will be needed; many buildings currently achieve rudimentary energy management and/or demand response goals with minimal technology. The first step may be assessing where the building is currently (e.g., capability of current EMCS (e.g., to zone level), current extent of energy management, participation in demand response programs), and then determining goals for improvement. A building's existing equipment may be used to achieve the most basic goals. But more sophisticated technology such as that installed in Cory Hall can provide greater energy management and/or demand response, for example, to extend and/or quicken a building's response during peak periods.

One of several challenges during the Design Development state is selecting components. One aspect is deciding what to meter and submeter with respect to balancing cost with granularity of data. Another difficulty is in sizing sensors. For example, for the best accuracy in measurement, the current transducer (CT) should be sized appropriately to the expected dynamic range of current flow. But in order to choose the appropriate CT, one has to assess the rough magnitude of existing current flow. Design information is generally not accurate enough. Measuring a live circuit can violate safety standards; however, a shutdown of the building to conduct these tests can be expensive and difficult.

Integrating existing equipment is another challenge, especially for older buildings. Integrating new sensors and control scenarios with legacy EMCS systems can be problematic. With the Cory Hall project, the researchers "cracked the code" of the legacy Barrington system in order to integrate it into the new sensor network using the newly developed IP-based sMAP virtual network. The company (Barrington) was out of business, so there was no infringement on proprietary protocols; however, this is not a replicable process in typical applications.

Developing B2G infrastructure for monitoring versus control poses another issue. Using a sensor network for control spawns many potential liability issues for equipment manufacturers. However, merely using data for monitoring purposes is relatively benign with respect to equipment and human safety issues.

Yet another concern is determining the metering protocol. Building engineers may prefer a one minute time interval, but most utility companies use a 15 minute interval (the UCB campus is billed on a 15 minute average demand cycle). Yet for diagnostic purposes, a one second or shorter interval may be necessary to observe certain modes of dysfunctional equipment or control cycling, or to observe motor start up peaks, which interact with var support for the grid. Good and useful data is desired, but so is matching the data up with utility data. This also represents an economic concern of balancing cost with data management.

A challenge of the Bidding phase is that currently there are only 1 or 2 companies that offer a turn-key B2G service of designing, installing, and commissioning metering and automation systems. These service providers can reduce the need for coordinating multiple vendors, but may not offer the flexibility needed by the B2G implementer.

One example of a structural issue that occurs during the Installation phase is the challenge of physically getting the sensors and communication system in place. In Cory Hall, some circuit breaker panels had older wiring with brittle insulation that required the use of light flexible current transducers (with tradeoffs in functionality). In addition, the location of several panels were such that long wire feeds made more sense than installing junction boxes. These were custom ordered, which typically takes extra time.

Safety issues may present a challenge to the installation process. While some metering systems can be installed in live panels, the nature of the existing infrastructure in Cory Hall required the shutdown of the electrical system for installation. The installation at Cory Hall was greatly facilitated by a convenient building shutdown conveniently scheduled during project implementation.

An issue during the Commissioning phase is how to validate measurements once the system is up and running. This is interrelated to the choice of metering protocol (e.g., are branch circuits all metered, which makes checksums feasible?).

Another challenge is the lack of standards and lack of coordination of existing standards. The National Institute of Science and Technology has identified both existing standards and gaps for applicable standards; approximately 77 standards or specifications are applicable to the Smart Grid (Sinopoli 2009); Appendix G lists the standards that affect Building-to-Grid. While these standards are currently being developed, the UC Berkeley team chose to develop communication schemes with open architecture so that future components, such as sensors or data visualization devices could easily "talk to" the system via unique IP addresses, with JSON (rather than XML) used for communication. Sinopoli suggests open communication standards (like JSON or XML), and the need for standards such as pricing formats and time of day schedules.

In general, one problem is components/system software where the companies go out of business and is no longer supported. This scenario is a concern both when dealing with legacy systems and selecting vendors for new equipment.

An economic barrier is represented by the sheer cost to implement B2G: not only the cost of hardware and software, but also labor to plan, install and maintain. Just planning for a system requires a tremendous time investment in categorizing all the circuit breakers, panels, figuring out what to meter, at what granularity, and how. The design of the system is complex with respect to balancing the cost of the system with useful granularity/precision of data sensing. For example, high-cost sensors may provide higher granularity, yet in some cases a low-cost sensor may provide enough information. What is needed is systematic, internally consistent information about meter accuracy, sample rate, features, and labor cost.

Another set of challenges is social in nature. Implementing a B2G system requires a champion or team with vision and with the authority and organizational skills to pull it all together; a great deal of coordination in involved to achieve good communication among the utility, facilities/building manager, financial manager, and IT personnel. Another issue is whether to hire a manager for the project[7] or to handle management in-house, as it was for UC Berkeley's Cory Hall. In either case, it is vital to have the facilities people onboard at the very beginning of the project. Many decisions in developing the Cory Hall testbed were social in nature; hiring electricians outside the University would have been less expensive, but for a campus project, there was value in having the University electricians involved and in essence, training them for future installations elsewhere on campus. In addition, codes and regulations play a role in component installation; the campus fire codes dictated who and how the installation could proceed.

The goals of the utilities are different from the goals of facilities people, and in turn are different from the goals of the users of the building. When we spoke to Dan Pearson of PG&E, he said the most important questions were: how much can a building reduce load, how quickly can this be done (i.e. how much notice is needed), how long can this load be reduced, and how often can this curtailment be called upon? Goals of the facilities people differ by organization. For example, in speaking with the CSUS facilities, I found that their goals were focused on reliably providing the campus with power, not testing new equipment or control algorithms. In contrast, the Berkeley team had that freedom for exploratory research, and drove the creation of an open data communication architecture among the various devices. The issues and questions the CSUS facilities team had were for the most part procedural (i.e., how to bid out, how to document the process, how to procure equipment, how to manage the installation, and how to budget hours for staff time). Finally, the customer may be more concerned with increased or decreased electricity costs, loss of control over building, loss of privacy, and the impact of new technology. In addition, there is the effect on users of the building, from the planning and installation (which may involve a shutdown of the building's energy systems) as well as the effect of implementation of sophisticated control (i.e., dimming lights, change in temperature or ventilation rates).

In general, it is common for any change or difference from what is known and understood to be resisted. It may take a great deal of marketing or financial incentive to motivate people to buy into a new system. Building managers will need retraining to use the system (i.e., may need stationary engineers in the building). Previous research suggests that the more the occupants know what is happening with the building, the more tolerant they are with changes to their indoor environment. It will take time to understand and analyze the data in order to design improvements to the building and potential control strategies.

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[7] The metering project at Building 90 of Lawrence Berkeley National Lab was managed by a general contractor.

Conclusion

The installation of a Building-to-Grid testbed at Cory Hall provided a framework for understanding the barriers and opportunities in developing Building-to-Grid systems. Cory Hall is not the typical B2G installation since it is a campus building in a campus master-metered scenario, as well as an extensively instrumented academic research testbed. However, the process for design and development of the system illuminated some challenges and applications general to all buildings, especially older larger buildings that are quite prevalent in the U.S. The challenges occur at every phase of development and range in nature from technological in structure or design, social (including policy and standards), economic, and a complex interaction among many factors. Just getting buildings to sign on or buy in to a B2G is a challenge. A design challenge is setting goals and then how to choose what to meter, at what granularity, and whether to use wired vs. wireless sensors. Physical or structural barriers include installing sensors in panels and integrating legacy systems. Policy and regulation that play a role are electrical/fire codes and the lack of standards for component communication. An economic concern, in addition to the simple cost of the components and installation, is the initial time investment to develop a load tree. At the present time, there are few companies that can provide turn-key systems. Examples of social challenges include the sheer coordination of all players involved and whether the project should be managed in-house or by an external contractor. Examples of complex challenges include how to measure loads and planning a building shutdown.

A Building-to-Grid system also provides many opportunities not only to the utility grid, but also within the building. The instrumentation can enable monitor-based commissioning or retro-commissioning. A building might be benchmarked to compare with other like buildings. The load diversity and load shape may be understood and analyzed to better prepare demand response scenarios and better load management. The instrumentation can be used to predict loads as well as develop load shed profiles. Additional sensors might be added to help model whole building energy flux to suggest energy efficiency improvements. A Building-to-Grid system can potentially integrate with LEED or EnergyStar certifications and perhaps cap and trade carbon emissions endeavors.

Next Steps

What can we learn from the process at Cory Hall that will inform other B2G installations, or as Mike Gravely of the CEC put it: “consolidate [the information] and get it out there in an understandable form”? How would we share this information with other research centers? We would need to understand better the audience or players involved, whether facilities managers, financial managers, or IT folks. What would they find useful about a B2G system? What would they need to implement the system (i.e., procedural issues, such as how to choose what to meter and how well, or marketing issues, such as obtaining buy-in from other groups)? What is the best format to guide others in developing a B2G system? Does the current documentation on implementing the testbed in Cory Hall provide enough detail to be useful to others? However, the documentation from this project may not suffice either in its present form or with additional detail. Perhaps a more interactive approach, such as a workshop would be more productive. What about the implementation at Cory Hall is idiosynchatic to Cory Hall and what is generalizable to other buildings? What went well in Cory Hall that might be more difficult elsewhere (i.e., fire leading to shutting down of equipment, facilities-driven shutdown, no tenant-subtenant billing issues)? What were innovations that bear replicating in other buildings (i.e., sMAP)? What were barriers in Cory Hall? Would these be barriers in other buildings?

Are there areas that lend to developing policy, such as standards or codes such as Title 24 building energy codes?

What were lessons learned? For example, what tools are available to document load trees? (Scott used Excel to chart this, what do electrical engineers use to design electrical systems in buildings?) Another example is the potential need to develop a methodology to design a B2G system: i.e., how to balance cost/granularity of measurement with value (i.e., data to make better decisions, save energy, return on investment), how to prioritize what to measure, how to size current transducers.

Another question is about coordination—how to get all players to talk to each other? Are there marketing tools and/or training programs needed to implement B2G?

Another set of questions addresses the next steps for Cory Hall: testing/commissioning, adding more capability, exploring storage potential, what to do with information (i.e., apply to controls, document different strategies for different goals (e.g., EE, DR)), what are the potential applications, what visualization/advice tools need developing? Finally, how can the testbed be marketed to potential researchers?

We look forward to continued dialogue about this building to address some of the research questions posed here.

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I would like to thank the many persons with whom I spoke about this project in the writing of this paper, especially Scott McNally, Karl Brown, Harold Galicer, Sila Kiloccote, and many others of the testbed team.

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Appendix A: Commercial building energy end use

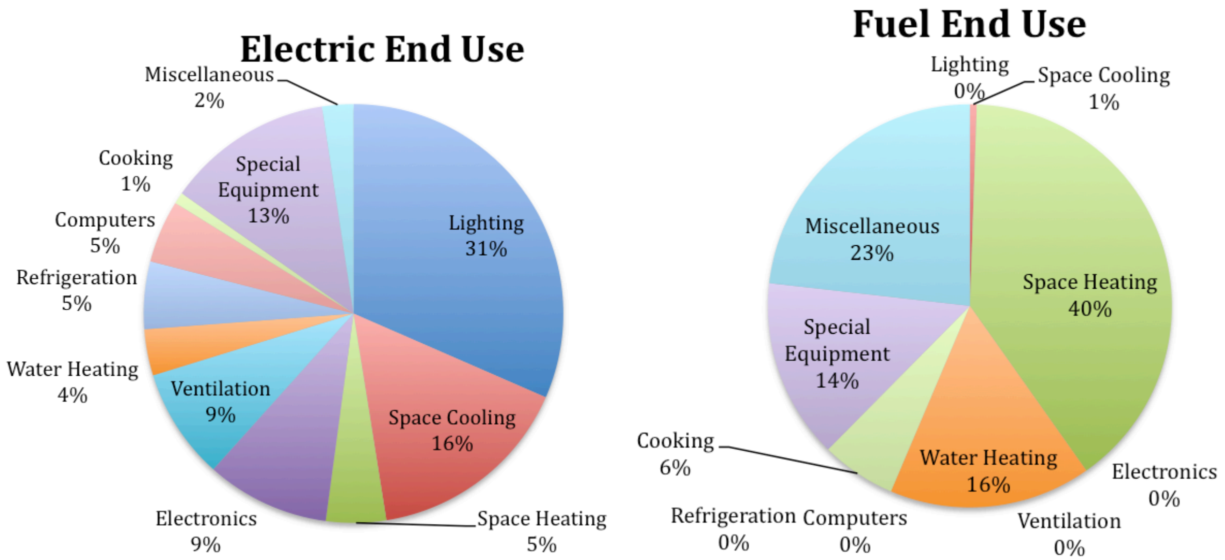

Figure 6: Site energy per end-use for commercial buildings (from Table 3.1.4 from (U.S. Department of Energy (DOE) 2009)).

Appendix B: Cory Hall Metering notes

Purchased natural gas is often metered with a positive displacement meter e.g., a diaphragm meter (domestic scale) or rotary displacement meter (commercial scale).

Building steam usage is often measured with either a steam supply meter or a condensate meter, which measures the condensate discharged from the building after the steam is used. The use of both is desirable for more accurate measurement in all flow regimes; in addition, leaks into and out of the system might be detected if both are employed (Brown 2010). Chilled or hot water supply can be measured with a "BTU" meter, which combines measurement of water flow and temperature differential (Ibid).

A campus environment is often a special case that lacks the whole-building metering usually provided by the utility for billing purposes. Campus environments are also the most likely to have the district steam, chilled water, and hot water systems that increase building-level metering complexity and expense (Brown 2010).

Appendix C: Types of information

ID	Name	Description
1	Weather	Forecast weather, and related conditions, including: temperature, relative humidity, hours of sunshine, sunrise, sunset, precipitation, wind speed and direction, ozone, smog, particulates, allergens, etc.
2	Power Quality	Various attributes of Power Quality on both an instantaneous as well as historical or scheduled (future) perspective. Attributes would include appropriate elements of the following: · Communication time stamp · Power availability · Power quality (voltage, frequency, harmonics) · Scheduled Maintenance start time · Scheduled Maintenance completion time · Scheduled Maintenance quantified or qualified projected impact on power quality during the Maintenance window
3	Pricing Information	Customer-specific real-time pricing (RTP) data tables and demand interval data (e.g. demand rules, tariffs, previous highest demand etc)
4	Energy-Related Emissions	Present and/or historical information used to quantify the environmental burden created during the generation of the power. This could be power received from an energy supplier or, it could pertain to energy generated onsite (e.g. Carbon, CO_2, SOx, NOx, and other by-products of fossil-fuel combustion).
5	Present Demand, Aggregated	Instantaneous energy usage[8] of the facility or production site, as an aggregate.
6	Present Demand, Sub Loads	Instantaneous energy usage of the sub loads being monitored (conditional on sub-metering installed).
7	Sheddable Load	Individual loads and their aggregate value that may be shed or controlled to reduce power demand
8	Critical Load	Individual loads deemed to be critical, and their aggregate value, which may not be shed
9	State Change Interval	How quickly sub loads can respond to a shed command to reduce power demand
10	Existing Demand Thresholds	Existing peak demand in current billing period; existing maximum demand during ratchet demand period
11	Onsite generation capabilities	The on-site generation capabilities, current and future status are summarized. This also includes availability: spinning, and non-spinning reserves. Onsite generation includes spinning reserves (generation that can be called upon

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[8] "Instantaneous" implies a single sample power measurement as opposed to power averaged over a nominal time (e.g., 15 minutes).

		quickly, typically less than 5 minutes) and non-spinning reserves (generation that may take 15 minutes or more to become available).
12	Onsite energy storage	The on-site energy storage capacity as well as current and future status is summarized. To the outside, on-site energy storage is stored energy that will appear as generation capacity. This also includes availability.
13	Onsite thermal storage	The capacity and availability of on-site thermal energy storage.
14	Loads to Shed	Specific loads the EMS commands to shed.
15	Demand Forecast	Forecasted demand (based on production schedule and historical data).
16	Historical interval usage	Historical information about the energy consumed per block of time (e.g. 15 minute sliding window), as well as the power quality data for that block of time.
17	Energy Cost	Energy cost per unit of time (e.g. minute, hour).
18	Energy Emissions per kW	“Energy Emissions” (ID 4, above) per kilowatt of power used.
19	Building Report – Common Data	Information related to building energy usage information, including information about consumption, cost, and emissions.

Table 2: Energy information to be exchanged (Table B.1 from (EIS Alliance 2010)).

Appendix D: People or organizations involved with energy usage information transactions

Facility Manager	Person responsible for the maintenance and operation of the facility.
End Use Customer	Person in a commercial/industrial building that is consuming energy. This customer may also be an entity (e.g. department)
ESCO	Business providing energy savings, efficiency, and generation solutions.
Energy Information Provider	Business providing energy supply or demand information.
Energy Supplier	A company that delivers electricity to end use customers.
Financial Manager	Person that is responsible for cost accounting and developing financial strategies for an industrial or commercial business.
Operations Manager	Person that is responsible for the operational activities within an industrial or commercial building.
Installer (service technician)	Installer of intelligent end-point loads, DR loads, or EMS system and components

Table 3: People or organizations involved in energy usage information exchange (EIS Alliance 2010).

Appendix E: Process of Implementation

Of the seven steps discussed below to implement a B2G system, perhaps the most difficult is the first step. The initial **Commitment**, or the decision to adopt the technology, also known as buy-in, may depend on the goals of the organization, incentives provided, or other extrinsic or intrinsic motivation.

In the **Predesign** phase, one sets goals (i.e., demand response load/peak load management such as shifting/shedding load, renewable energy integration, energy efficiency targets, carbon emission reduction, benchmarking, and/or energy storage), gathers information (i.e., building drawings, applicable codes, utility bills), identifies pertinent groups or persons that will be involved in the project, and establishes a budget. The goals of the project set the stage for what types of equipment will be needed.

During **Design Development**, one would estimate or measure the building thermal and electrical loads and map the load tree. During this phase, one would identify various methods of characterizing the building's energy loads into sectors (i.e., organized around HVAC system (air handler or cooling source), electrical distribution (power feeder), or building configuration (i.e., floor, company, space use functions (i.e., office, meeting, lab etc))) (Brown 2009).

Once various building sectors are defined, the next step is to decide the extensivity (i.e., how many) and intensivity (i.e, to what level of detail) to meter, balancing cost of sensors and meters with value of data and potential savings from mitigation scenarios. Prioritizing what to instrument is a difficult but important step. In this phase, one revisits the goals, which may dictate the choice of and features of the components. Selection may be based on uncertainty of load, enabling of accounting of savings for monitor-based commissioning, enabling analysis of potential energy efficiency endeavors, enabling demand response, or other goals, such as carbon emission reduction or qualifying for LEED, EnergyStar, or other performance-based category (Ibid). Sensing might include not only electrical and HVAC systems, but outdoor environmental conditions and occupancy.

The metering protocol should also be evaluated: the metered energy from the building may be used to compare with bills from the utility company, which will dictate the time interval and accuracy of the electrical meters. If metering of a set of branch circuits is comprehensive, then checksums of the parts (switchblock branches) compared to the main circuit (e.g.,whole building) metering may also be performed.

Another important element is integrating a new metering system with existing energy management control systems. During this phase, one should communicate with any governing bodies that affect the project: the local utility company or service provider to determine communication protocols and other issues, local building, electrical, fire, safety, and/or facilities departments to determine applicable codes and standards to follow during installation.

In the **Specification** phase, one compares the features and cost of the commercially available facility meters, zone submeters, machine monitors, state-variable sensors, and other components.

The electrical meters measure, accumulate values for, record, and/or report voltage, current, and calculate watts, vars, VA, power factor etc. Meters for thermal equipment would also be evaluated. At this phase, one might evaluate the pros and cons of using wired versus wireless sensor networks.

Another vital component is the data management system to receive, store, manipulate, and visualize the information available via the sensor network, and then aid in the decision making and analysis for controlling, monitoring, maintaining, and managing the loads. Each sensor from the various manufacturers must be able to communicate to the same data management system. At the end of this phase is the specification of all components and connectivity.

The **Bidding** phase includes inviting vendors to bid on the hardware and software and other components of the system. Based on the bids, the design of the system may be modified as part of value engineering. Once the selection is made, procurement can begin.

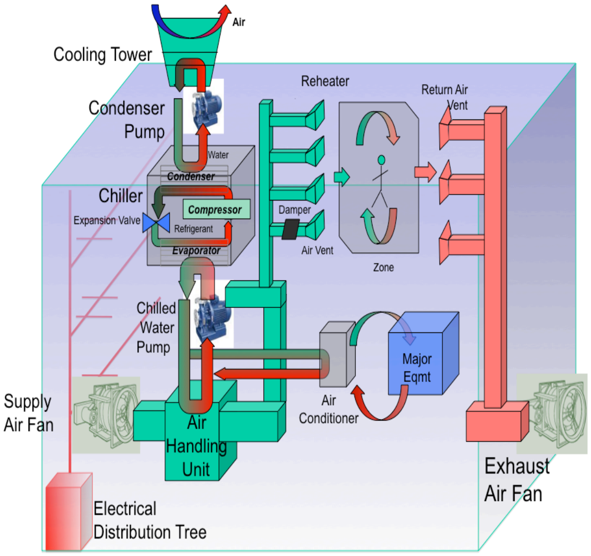
During the **Installation** phase, the system components are installed and labeled. The networks are connected and software installed to deliver data to the database and manage it. The Installation phase requires a great deal of preplanning and preparatory work (i.e., installation of conduit). The building may require shutdown to install components, which is costly and affects building occupants as well. In addition, installation of components may require approval from various building/electrical/mechanical/fire/safety officials.

During the **Commissioning** phase, every component of the system as well as the system as a whole is tested and evaluated, troubleshooting problems.

Appendix F: Implementation process at UC Berkeley's Cory Hall

Cory Hall houses UC Berkeley's Electrical Engineering Department, and thus contains offices, classrooms, laboratories, a machine shop, and several elevators in 132,000 assigned square feet of floor area. During the eight months of this project, part of the 10,000 sf semiconductor micro fabrication lab was moved out of the building (representing about 40 kW). At the initiation of the project, Cory Hall was the 5th largest consumer of electricity on campus with an average load of 1000 kW, and annual energy consumption of 45 kWh/sf. This is supplied through two three-phase 12 kV/480V transformers. The building was constructed in 1950, with numerous additions, including the addition of a fifth floor. The Energy Management Control System is an old Barrington[9] SCADA system, with access via the University's Broadwin web access site. The main electric power meter (480 Volt) and steam meters are monitored via the University's Obvius network and web site.

Cory Hall, like many commercial buildings, has a variable air volume with reheat for space conditioning. There are 13 air handling systems within the building, four of which are chilled water systems. Heat, reheat, and steam are derived from steam supplied by a third-party owned cogeneration plant on campus. Chilled water is supplied internally as well as from a neighboring building, the Hearst Memorial Mining Building. The ventilation system is known to be inefficient. The building has recently been retro-commissioned, a monitoring-based commissioning (MBCx) process conducted by QuEST that occurred in parallel with the development of the testbed.



Building Environmental Manufacturing Infrastructure

Figure 7: Schematic of the energy systems in Cory Hall (Culler 2010).

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[9] Barrington went out of business several years ago; one driver for their system is WebAccess (Broadwin Systems), which is a web-enabled front end SCADA (Supervisory Control and Data Acquisition) that supports open protocols.

The energy consumption at Cory Hall is complex, equivalent to multiple buildings inside a building.[10] Cory Hall has five floors, a basement, and two mezzanines that contain laboratories, offices, and classrooms. Some areas are newly constructed and are quite modern; others represent antiquated equipment and functionality. Figure 5 below is a section diagram of Cory Hall, showing the space use (i.e., laboratory, office, classrooms). Also noted are the Obvius meters for whole building power and steam condensate. The existing environmental sensors for the Barrington system are shown as well as the new power meters.

Figure 6 below shows the power flow diagram developed by the director of space planning and facilities for EECS department, Scott McNally. The campus substation provides 12kV service, which is delivered to the building via two transformers, one of which is used at a time.

The decision was made to analyze purchased energy from the utility (electricity, steam and chilled water) as well as building envelope energy flux (driven by solar, outside air). In general, because Cory Hall was designed as a research testbed for Building-to-Grid activities, it is "overinstrumented" compared to what is needed for a typical Building-to-Grid system.

The system was designed to meter the whole building electricity and the main branches of electrical distribution to enable checksums of the parts to the whole. The design development phase started with a careful examination of the archives of single-line power drawings for the building, and then physical verification; Scott McNally's 10 years of experience with the building (albeit mostly focused on the mechanical side) aided this process. However, the documentation of what loads are carried by which circuit is a challenging and time-consuming task.

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[10] A senior engineer from the concurrent monitor-based commissioning project considered Cory Hall one of the most difficult projects he had ever experienced.

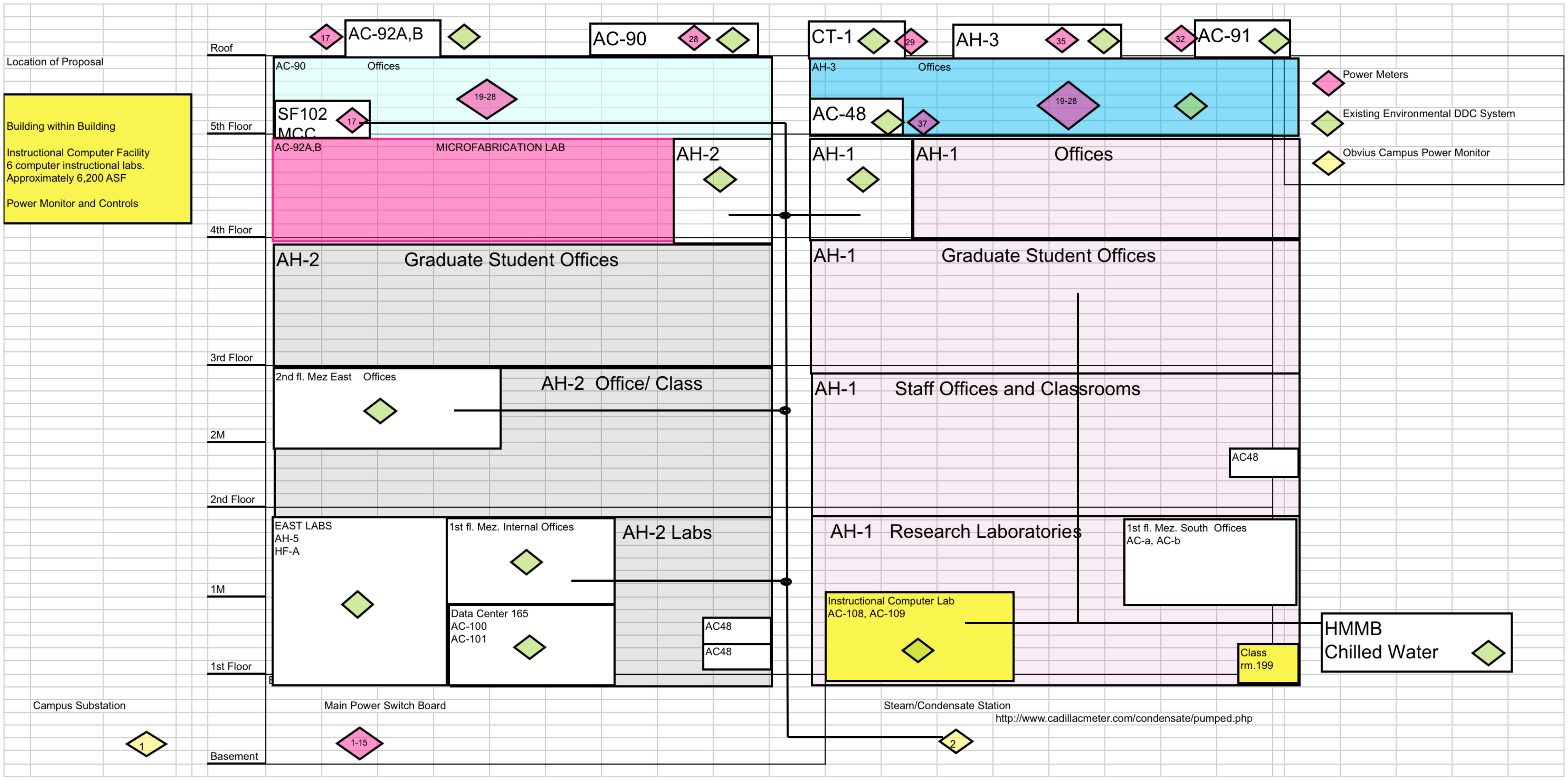


Figure 8: Schematic of Cory Hall, showing locations of installed power meters (by Scott McNally).

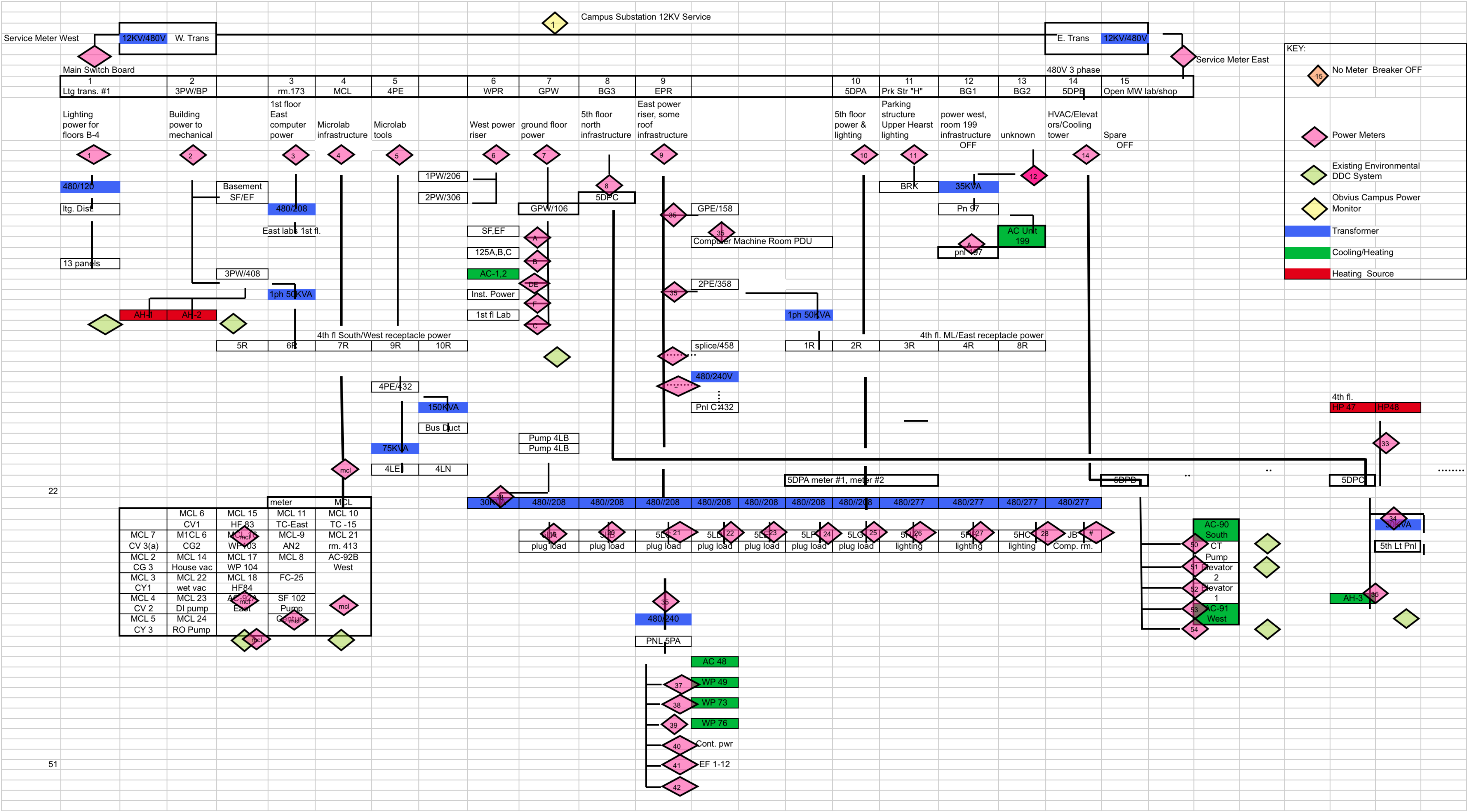


Figure 9: Power flow diagram of Cory Hall (by Scott McNally).

The decision on what to meter was based on where the most uncertainty was and what loads would not change over time (since the micro fabrication lab was going to move). The MBCx process was an unexpected resource; for example, Scott was able to request them to measure unknown loads.

The installation required a great deal of planning and negotiation. While typical installations may not require a building shutdown, the installation in Cory Hall was scheduled to coordinate with a fortuitous facilities-driven shutdown of the building to recondition the old transformers. This also saved shutdown costs. Since the installation required drilling into old high voltage transformer switchgear, working under a shutdown was an extra safety precaution.

Scott engaged various groups early on in the process. The campus facilities department and high voltage crew were involved; the campus engineer reviewed the design. The campus electricians were brought in to do a lot of the preparation work. While the cost of hiring campus electricians was higher than subcontracting this work, Scott felt it worthwhile to build the relationship with the campus, especially since more systems on campus are expected.

Coordinating with the 700 occupants of the building was no easy task, since for many groups in the building the shutdown meant loss of money (and for the microlab, potential loss of tools). Scott coordinated with faculty, staff and the information technology department. Some groups had to bring in air conditioners and generators to maintain their work over the shutdown. In general, all the preplanning paid off: the installation of electrical metering at Cory Hall occurred without mishap in a matter of hours (and concluded with time to spare).

Metering of the electricity consumption occurred at the level of the whole building and at each power feeder branch (this would allow checksums of the 13 branch submetering with the whole building meter), and then submetered to the receptacle level on just a few of the branches.

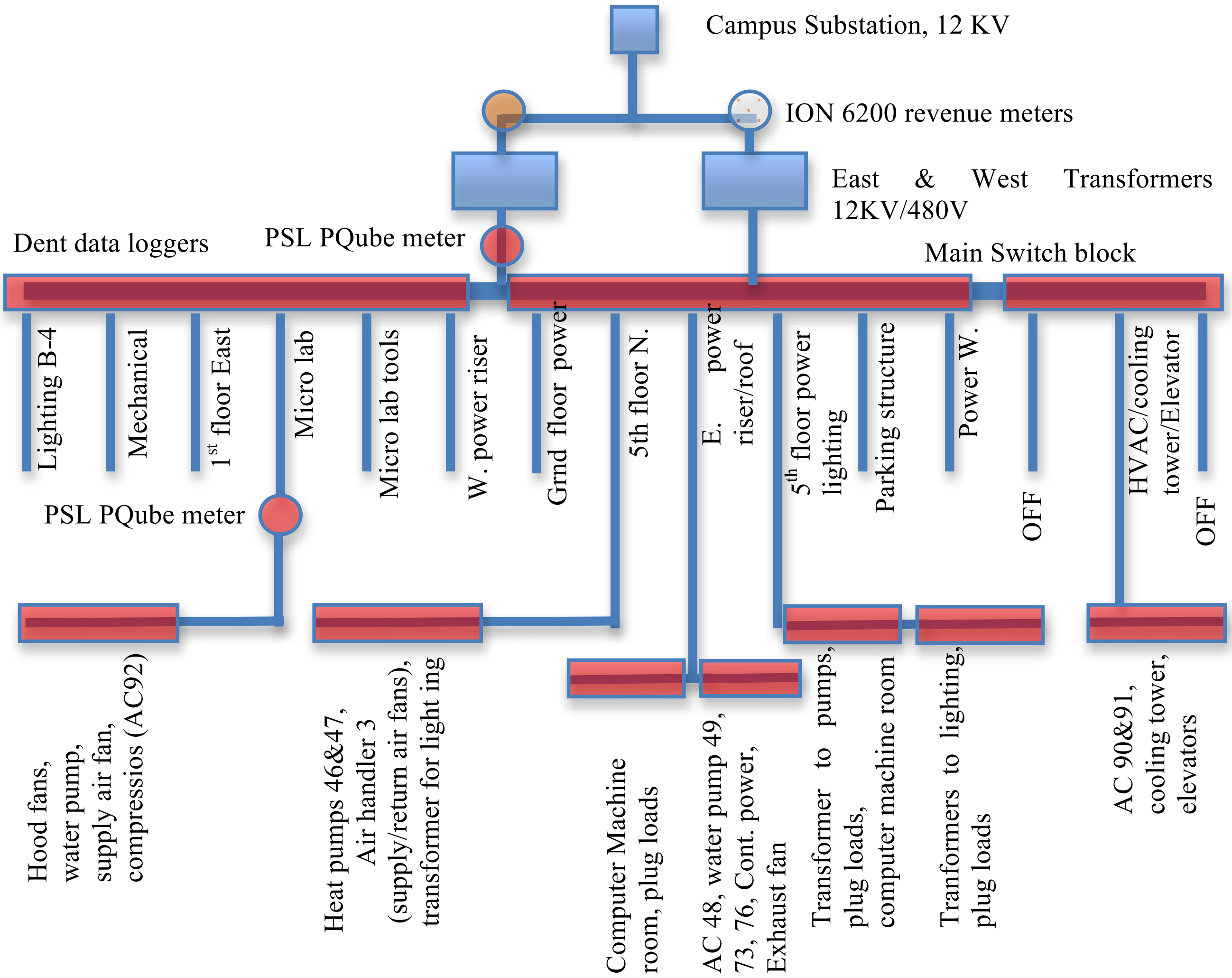


Figure 10: Load tree of the metered loads.

There are two Power Standards Labs (PSL) PQube Power Quality Meters (one on the Cory Hall side of the transformer and one for the micro fabrication lab); these can measure voltage, current, active power, reactive power, apparent power, power factor, integrated value, frequency, harmonics, temperature, and humidity. These communicate via Ethernet with an HTML table to a website. There are 15 branch switchblocks, 13 of which are active and thus metered. Ten Dent PowerScout 18 channel (6x3) data loggers were used, which communicate via a RS-485 Modbus (wired) interface to Ethernet. Two existing meters brought into the system are the ION 6200 revenue meters (that use a 30 second interval compared to the PSLs which use 10 second intervals); these are on the campus side of the transformer. Some of the panels have a single submeter (such as #1, which supplies lighting for floors 1-4); others are further submetered (such as #14, which has two elevators and water pumps submetered).

Figure 11: Left: Typical Dent installation. Right: One of two PSL PQube power meters.

Both Rogowski coil and split core current transducers (CTs) were used on individual circuit breakers to measure current. The Rogowski coil CTs were used because they are lighter and more flexible to install, which was a concern in some of the old panels with many solid cables with brittle insulation. This was a compromise as these current transducers have a more limited turn-down range (the range of current that can be accurately measured). Some of the CTs had to have specially ordered 60 foot leads because of the distance from the submeter to the circuit breaker in the panel itself; this was easier compared to installing additional terminal blocks.

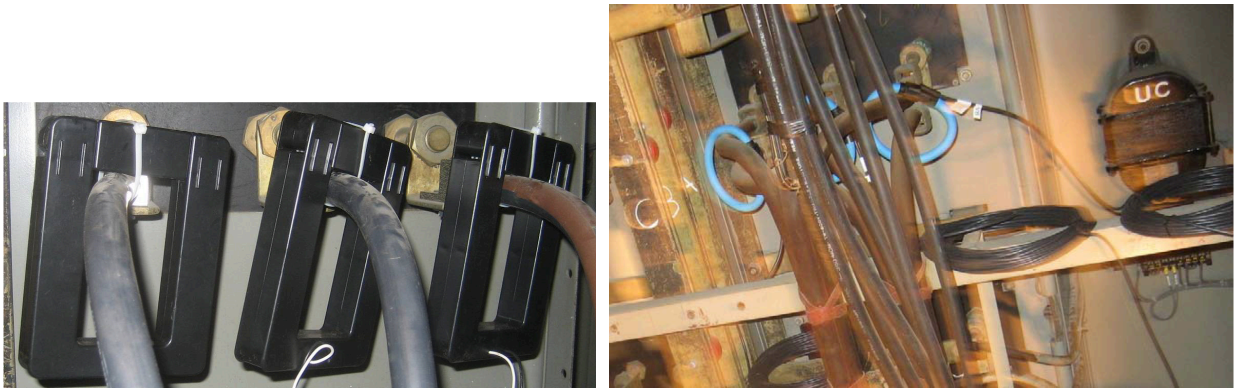


Figure 12: Typical installation of the split core current transducers on the left, the Rogowski coil CTs on the right.

In addition, many receptacles were measured with UCB-developed ACme wireless plugload energy monitor and controllers; about 70 of these sensors were used.

Figure 13: ACme outlet energy monitor and controller.

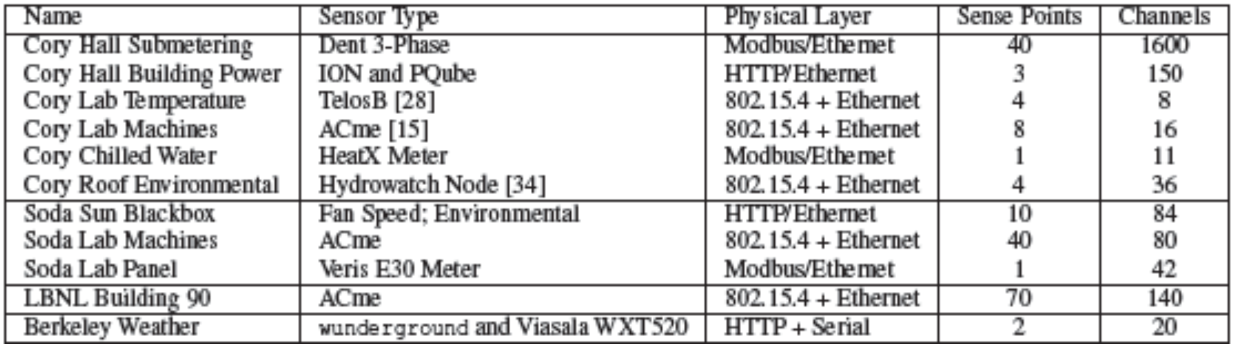
In addition to the electrical metering, a condensate meter was added, which measures the condensate discharged from the building after the steam is used. A chilled water meter was also added to measure the flow from the Hearst Memorial Mining Building.

Type	***Name***	***Connectivity***
Electric revenue meter	ION6200	XML/proprietary
Electric branch meter	Dent Powerscout 3/18	Modbus/RS-485
Electric meter	PSL PQube	HTML table
Electric panel meter	Veris E30	Modbus/RS-485
Electric home meter	GE	ANSI C12.19/IR
Chilled water		4-20mA current loop
Steam condensate		Modbus/TCP
Environmental	Sun Blackbox	XML/proprietary
PCT (programmable thermostat)	Basys QW Series	Zigbee
Climate	Hydrowatch node	6lowpan/IPv6

Figure 14: Data connectivity from various meters interfaced by sMAP (Culler, 2010).

With respect to communication among the components, various means of connectivity were employed. Figure 14 above shows the different means of connectivity used by the various meters. The UCB team developed and used sMAP (Simple Monitoring and Actuation Profile) as well as using an off-the-shelf software package from OSIsoft to provide parallel systems to allow access to the data.

SMAP is a data schema and API for resource monitors, which provides an open resource of data in a web-based architecture. SMAP is a means "of creating a building information bus to let any application talk to any sensor or actuator (Dawson-Haggerty, Ortiz et al. 2010); sMAP "defines a data representation and a method of accessing the data over HTTP" (Dawson-Haggerty and Jiang 2010). The architecture is based on RESTful API over HTTP, and uses JSON instead of XML for the object interchange format. The data from the Dent meters goes direct via Ethernet to a harddrive, which can then be accessed with sMAP; the PQube was initially assigned an IP address, but is now accessed through sMAP as well.



Name	Sensor Type	Physical Layer	Sense Points	Channels
Cory Hall Submetering	Dent 3-Phase	Modbus/Ethernet	40	1600
Cory Hall Building Power	ION and PQube	HTTP/Ethernet	3	150
Cory Lab Temperature	TelosB [28]	802.15.4 + Ethernet	4	8
Cory Lab Machines	ACme [15]	802.15.4 + Ethernet	8	16
Cory Chilled Water	HeatX Meter	Modbus/Ethernet	1	11
Cory Roof Environmental	Hydrowatch Node [34]	802.15.4 + Ethernet	4	36
Soda Sun Blackbox	Fan Speed; Environmental	HTTP/Ethernet	10	84
Soda Lab Machines	ACme	802.15.4 + Ethernet	40	80
Soda Lab Panel	Veris E30 Meter	Modbus/Ethernet	1	42
LBNL Building 90	ACme	802.15.4 + Ethernet	70	140
Berkeley Weather	`wunderground` and Viasala WXT520	HTTP + Serial	2	20

Figure 15: Data monitored using sMAP (Table 5 from (Dawson-Haggerty, Jiang et al. 2010).

The purchased off-the shelf data management OSIsoft software was installed as well. As of mid July 2010, OSIsoft was not running yet, but is expected to allow parallel access to data.

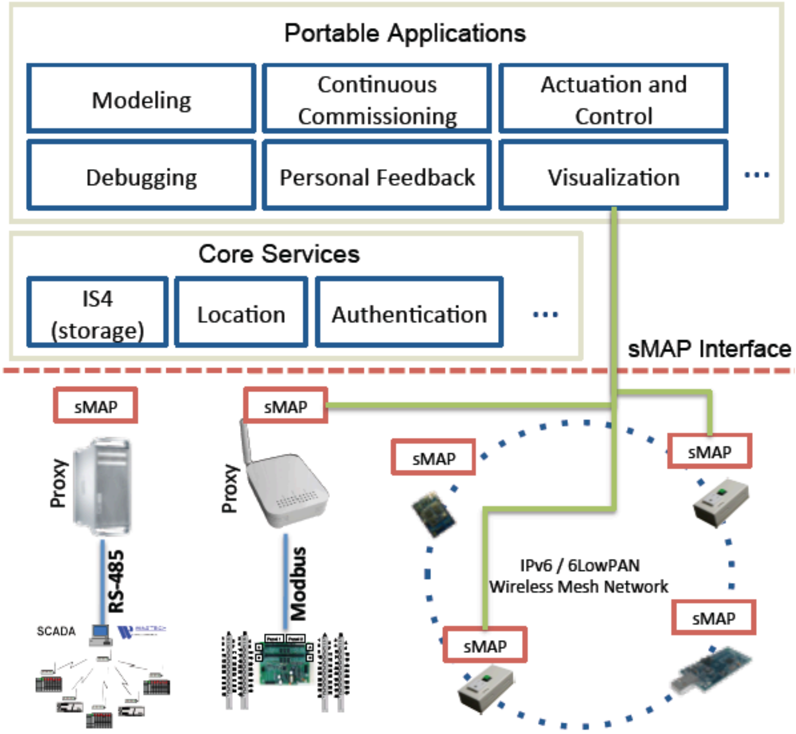
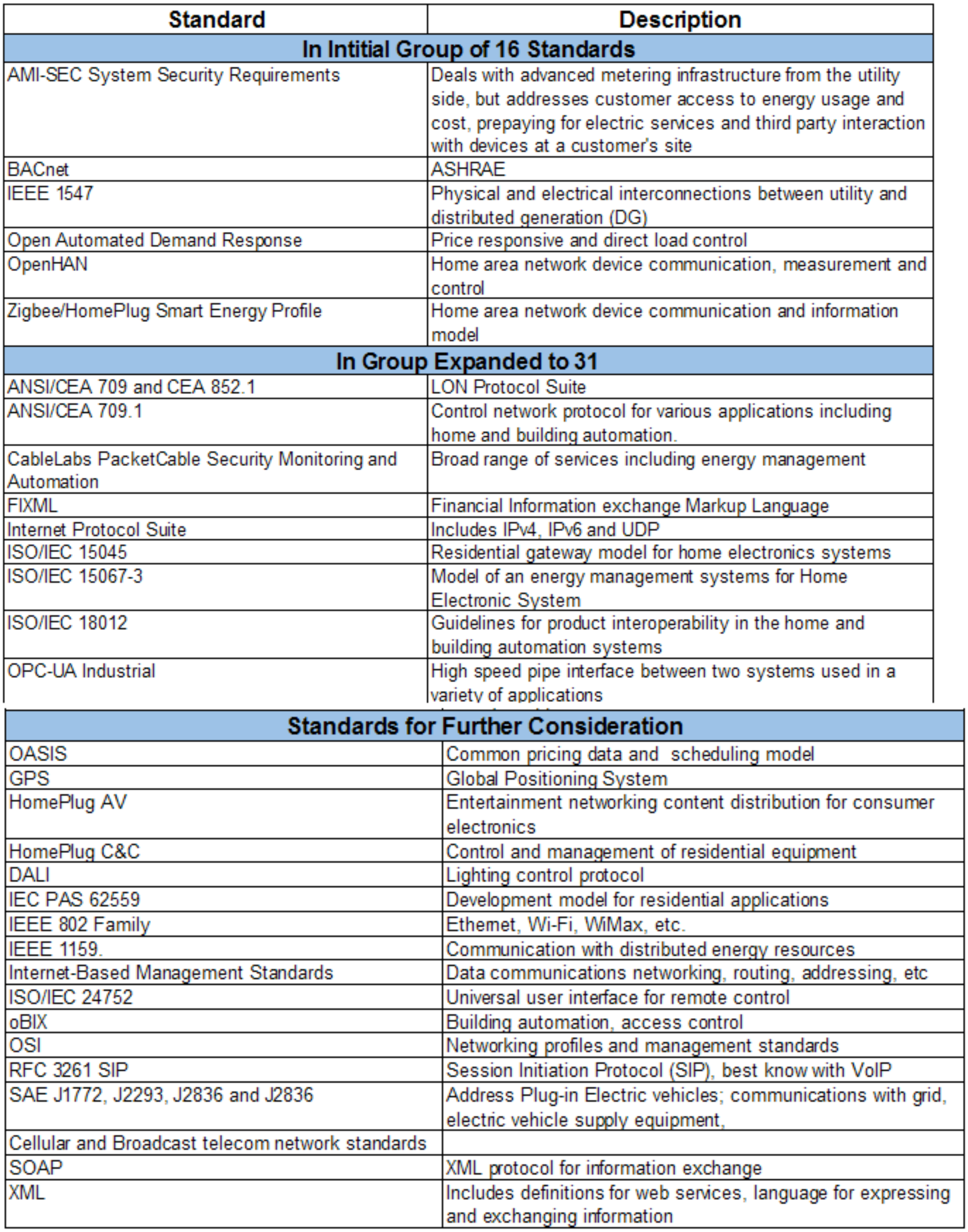


Figure 16: Creating a VLAN with sMAP (Dawson-Haggerty, Ortiz et al. 2010).

While the Barrington SCADA system was proprietary, since the company went out of business, the software was reverse-engineered to figure out the data schema in order to integrate with the sMAP interface.

The instrumentation at Cory Hall continues to be tested and evaluated. Early commissioning detected CTs on the wrong phase and mislabeled cables. In addition, data analysis led to the discovery of one chiller left inadvertently in manual mode.

Appendix G: Applicable Standards for Building-to-Grid



Standard	Description
In Intitial Group of 16 Standards	
AMI-SEC System Security Requirements	Deals with advanced metering infrastructure from the utility side, but addresses customer access to energy usage and cost, prepaying for electric services and third party interaction with devices at a customer's site
BACnet	ASHRAE
IEEE 1547	Physical and electrical interconnections between utility and distributed generation (DG)
Open Automated Demand Response	Price responsive and direct load control
OpenHAN	Home area network device communication, measurement and control
Zigbee/HomePlug Smart Energy Profile	Home area network device communication and information model
In Group Expanded to 31	
ANSI/CEA 709 and CEA 852.1	LON Protocol Suite
ANSI/CEA 709.1	Control network protocol for various applications including home and building automation.
CableLabs PacketCable Security Monitoring and Automation	Broad range of services including energy management
FIXML	Financial Information exchange Markup Language
Internet Protocol Suite	Includes IPv4, IPv6 and UDP
ISO/IEC 15045	Residential gateway model for home electronics systems
ISO/IEC 15067-3	Model of an energy management systems for Home Electronic System
ISO/IEC 18012	Guidelines for product interoperability in the home and building automation systems
OPC-UA Industrial	High speed pipe interface between two systems used in a variety of applications
Standards for Further Consideration	
OASIS	Common pricing data and scheduling model
GPS	Global Positioning System
HomePlug AV	Entertainment networking content distribution for consumer electronics
HomePlug C&C	Control and management of residential equipment
DALI	Lighting control protocol
IEC PAS 62559	Development model for residential applications
IEEE 802 Family	Ethernet, Wi-Fi, WiMax, etc.
IEEE 1159.	Communication with distributed energy resources
Internet-Based Management Standards	Data communications networking, routing, addressing, etc
ISO/IEC 24752	Universal user interface for remote control
oBIX	Building automation, access control
OSI	Networking profiles and management standards
RFC 3261 SIP	Session Initiation Protocol (SIP), best know with VoIP
SAE J1772, J2293, J2836 and J2836	Address Plug-in Electric vehicles; communications with grid, electric vehicle supply equipment,
Cellular and Broadcast telecom network standards	
SOAP	XML protocol for information exchange
XML	Includes definitions for web services, language for expressing and exchanging information

Table 4: Standards applicable to Building-to-Grid (Sinopoli 2009).