Monitoring & Reporting Applications Guide

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Section 1: Benefits of Monitoring and Reporting

By monitoring and reporting whole-building, system-level or subsystem energy use, building owners and operators can better understand the energy performance of their building. Benefits of M&R include:

- Ability to identify abnormally high or low energy usage and potential causes
- Graphically displayed information (i.e. kWh vs. time) that can help operators target wasted energy
- Reduced energy costs through improved energy efficiency and energy management
- Engagement with building occupants to participate in energy conservation
- Ability to inform building designers on actual building performance

The purpose of the Applications Guide is to provide building owners, operators, and members of the design team with a basic understanding of the benefits of M&R, available M&R equipment and tools, and best practices in the industry.

Topics discussed in this guide include: development of a monitoring and reporting plan, designing for meterability, monitoring and metering technologies and best practices, performance tracking tools, corrective action, and commissioning.

Section 2: Developing a Monitoring and Reporting Plan

Project owners interested in monitoring their building's energy use should work with their design team to create an M&R plan. Development of the M&R plan will help the project team set specific, targeted monitoring goals. Setting these goals early in the process will help ensure that the equipment and tools are incorporated into the design early enough to minimize costs, reduce construction coordination and maximize monitoring system expansion capability. The plan should be started during the development of design and construction documents and updated as necessary to reflect any changes that occur.

The M&R plan should address how the results of the energy monitoring will be used. Depending on the target audience for the results (e.g. building operator, owner, engineer), the design team can adjust the monitoring system and performance tracking tool requirements. Building size and complexity will also influence the goals and objectives of energy monitoring as well as how the energy consumption data is collected.

A basic M&R plan should include:

- Clearly defined monitoring goals and objectives
- Level of monitoring selected for the project (i.e. whole-building, system, or end-use)
- The level of monitoring designed to for future metering system build-out or building modification or expansion.
- Methodology for monitoring building energy consumption over time and required equipment
- Training requirements for building operations staff
- Corrective action plan for addressing problems and operational issues
- Cost information for monitoring equipment and performance tracking tools

Levels of Monitoring

Energy use can be measured and quantified at a variety of levels:

- Whole-Building Monitoring— Project owners establish whole-building metering to monitor energy use for the entire site. These measurements are recorded by the main electric and gas utility meters, as well as renewable energy system meters, and provide a high-level picture of how the building is performing. Because smaller buildings typically have simpler HVAC and lighting systems, data collected on a whole-building level is often sufficient for troubleshooting operational or performance issues. Electrical panels should still be designed to allow for easy subsystem monitoring, so that building operators can temporarily monitor subsystems to identify operational issues in the event that whole-building monitoring demonstrates that the building is not performing as expected. Appendix D provides examples of segregation of electrical panels for easier subsystem monitoring. To understand building energy use and troubleshoot performance issues, whole-building monitoring of individual buildings is necessary at a minimum.

- System Monitoring— Project owners establish permanent monitoring on systems, such as HVAC or lighting loads. Incorporating system monitoring goals early in the design phase of the project allows time for wiring schemes and panel locations to be incorporated into the design. For example, the design team could wire tenant lighting and plug loads circuits separately from HVAC equipment so that subsystem level metering of individual tenant lighting and plug loads can be accomplished while minimizing design/construction costs.

  In larger, more complex buildings consideration during design should be given to further monitoring of specific subsystem equipment or spaces such as air handlers, chillers, domestic hot water heaters, plug loads, miscellaneous process loads, or tenant spaces.

- Area Monitoring— It is common for a single meter to be installed for an entire campus of buildings. This serves the purposes of the utility, but does not provide any information about the distribution of the owner's individual loads.

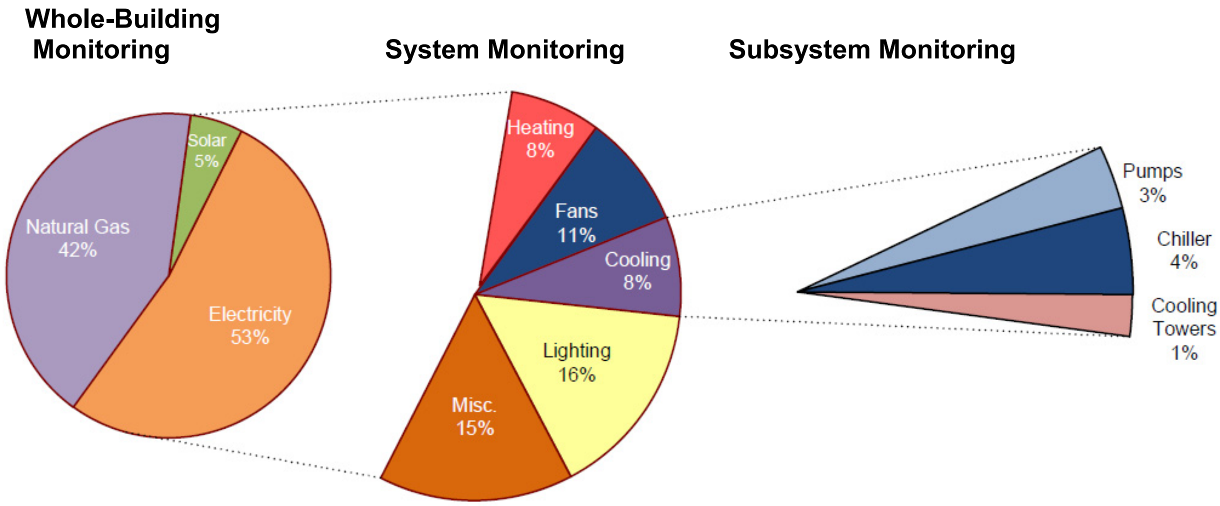
- Comprehensive building monitoring— Larger buildings may benefit from comprehensive building monitoring. This combination of whole-building, system and subsystem monitoring provides a comprehensive and accurate depiction of a building's energy performance.

Table 1: Example building monitoring levels

Whole-Building Level	System Level	Subsystem Level
Electricity consumption	HVAC	Air handlers, chillers, cooling towers, and chilled water and condenser water pumps
	Lighting	Lighting by tenant space
	Plug loads	Workstations, printers, misc. office or retail sales equipment
	Misc. Building Serves	Elevators, server rooms, UPS equipment, commercial kitchen, swimming pool, manufacturing equipment and other significant point source loads
Natural gas consumption	Space heating	Boilers and heating hot water use by tenant space
	Domestic hot water	Domestic hot water heater use by tenant space
On-site renewable generation	n/a	n/a

The chart below provides a visual example of the different levels of energy monitoring.

Chart 1: Energy use breakdown for an example building



Section 3: Design for Monitoring and Meterability

When developed early in the design process, the Monitoring and Reporting Plan can be used to inform the design of the building electrical, lighting, HVAC and plumbing systems. It is imperative that the designers of each of these systems be involved in the development of the M&R Plan and understand its intent, including the type of data to be collected and how the data will be used by the building owner to achieve long term operational goals.

The electrical power distribution system is the system most impacted by the introduction of requirements for monitoring and meterability. The discussion of these impacts requires a good understanding of electrical power systems and the many design criteria that shape them.

General Power Distribution System Design Criteria

In today's modern buildings, the design of the electrical power distribution system is influenced by many factors. The primary electrical design criteria that influences design decisions are listed below. A detailed discussion of these criteria and their impact on electrical system design can be found in Appendix C: The Electrical Power Distribution System. The metering goals impose a secondary level of electrical design criteria that the designer needs to incorporate. The level of complication associated with the primary design goals can significantly influence the design of the metering system. A well-designed electrical system should be simultaneously robust and as simple as possible, while meeting all applicable project requirements in the most cost effective manner.

Primary Electrical Design Criteria

- Available utility service (voltage/phase)
- Nature of the electrical loads (power/voltage/phase, quantity, location)
- Overall building size (total capacity, distances)
- Maintainability
- Flexibility for future changes within the building
- Capability to accommodate future expansion to the building
- Metering requirements

- Level of power quality required
- Emergency power provisions
- Degree of reliability
- Requirements for continuous, uninterrupted power
- Building architectural constraints
- Presence of on-site renewable energy systems
- System cost

Impact of Metering Requirements on the Power Distribution System

The requirement to meter various end-use categories of electrical energy introduces a new challenge to the electrical system designer, and may well change the fundamental architecture of the electrical system.

The M&R Plan provides essential direction to the electrical designer about electrical metering requirements and the necessary level of monitoring. The level of monitoring dictates the categories of electrical energy usage or building areas that will be measured by the metering system. Typical levels include whole-building monitoring, system monitoring, area monitoring, and comprehensive building monitoring. Regardless of the current level of monitoring in a design, the M&R Plan may require the electrical system to be designed to accommodate future temporary or permanent meters to measure certain planned or unplanned categories of electrical energy usage.

While it is possible to add meters to any electrical system to achieve virtually any monitoring goal, early integration of metering requirements results in a metering system that is simpler, easier to understand, and less expensive to install, maintain and operate. It also allows for greater flexibility to accommodate future changes and ultimately provides more reliable, useful data to the building owner.

A detailed discussion of power metering system design and its impact on the architecture of the power distribution system, including sample buildings, can be found in Appendix D: Power Metering Design Considerations.

Monitoring of Other Non-Electrical Energy Uses

The M&R Plan will typically call for monitoring of data other than electrical energy usage such as natural gas usage and energy sub-system data, including but not limited to various temperatures, air and water flow rates, light levels, setpoints, and schedules. The designers of these systems should familiarize themselves with the M&R Plan and add any additional sensors or data collection devices that are required to meet the goals of the plan.

Some of this data may be collected by a Building Automation System (BAS). Other data may be collected by separate standalone controllers dedicated to specific equipment of systems such as the lighting control system, motor drives, boiler system, chiller system or server room power management. It is critical that the interoperability of these various controllers is well understood and thought out for successful integration into the monitoring and metering system.

The designers of these systems should familiarize themselves with the M&R Plan and add any additional sensors or data collection devices that are required to meet the goals of the plan. Other design criteria for these systems may include data storage and/or data transmission to performance tracking software that may be located in other systems or on other data servers. These issues are discussed further in Section 5: Performance Tracking Tools and Uses.

Section 4: Monitoring and Metering Technology

Metering

Energy metering provides owners, operators and energy managers with the information needed to meet energy-efficiency goals and improve building operations. Installing energy meters is not an energy conservation measure itself, but it provides valuable data for supporting energy improvements. Common uses of metered data include:

- Energy billing
- Tracking historical energy use over time
- Calibration of building energy simulation model
- Energy use benchmarking: comparison of a building's energy use to the performance of other similar buildings
- Operations and troubleshooting diagnosis
- Performance optimization through trending, observation and analysis of metered data
- Measurement and verification of energy project savings and utility bill reduction

Electric Meters

Electric meters track energy use over time by measuring the electrical current and voltages for each phase or wire coming into the meter. An electric meter installation consists of a number of subcomponents as shown in Figure 1 below and explained here. Either a voltage tap or circuit breaker supplies power to operate the meter and serves to provide the voltage reference. If a voltage tap is used, fuse blocks are required to provide overcurrent protection to the meter. Current transformers mounted on each conductor provide the current reference to the meter. Current transformers are readily available in millivolt and 5 ampere varieties. Millivolt CTs are safer and do not require shorting blocks, but are more expensive.

<u>Meter Types:</u> There are many types of meters available from a wide variety of manufacturers. The most basic power meter is capable of measuring the quantity of power being used. Tables 2 and 3 summarize available meter types, features, and common applications.

Figure 1 – Typical Electrical Meter Subcomponents and Configuration

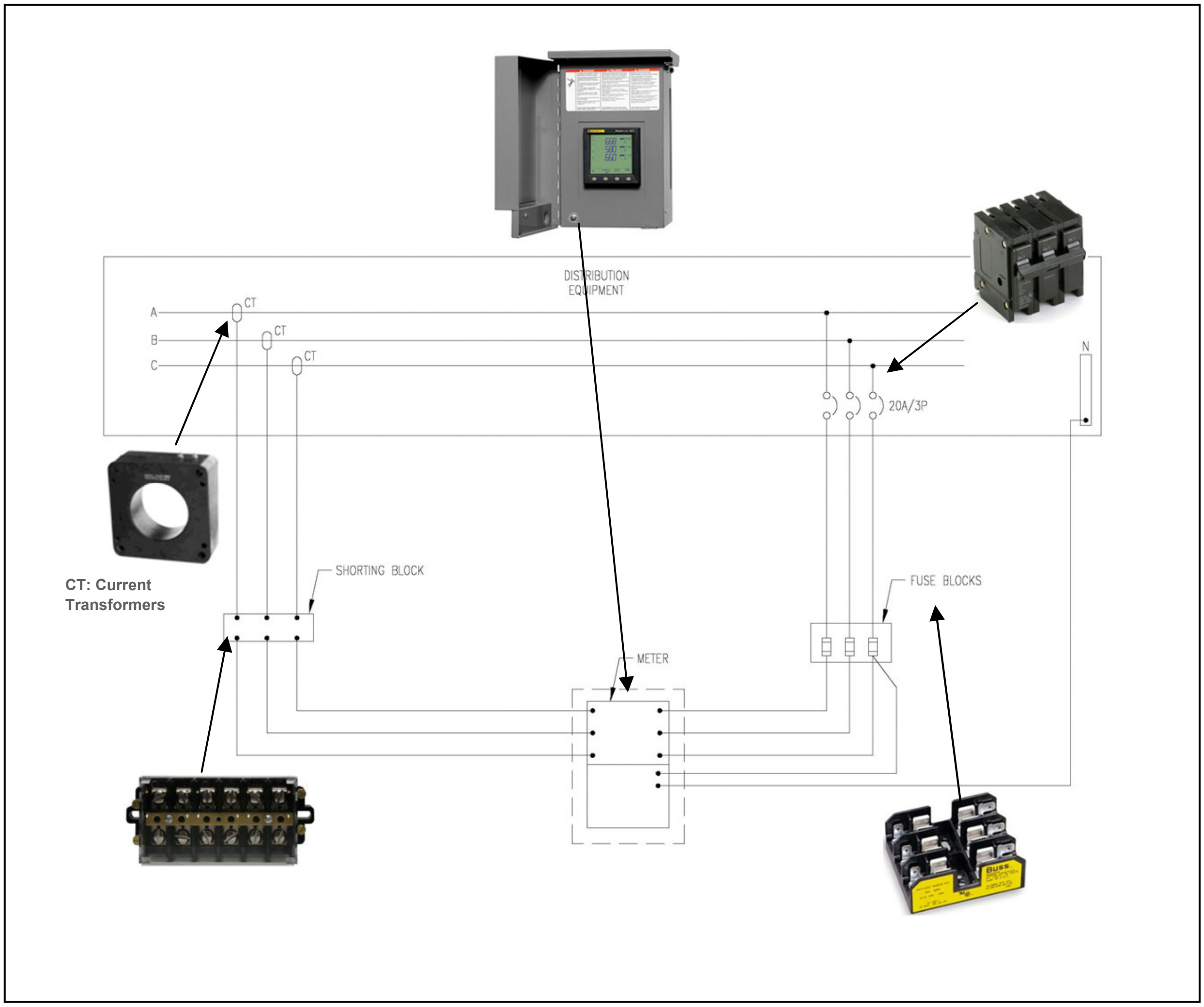


Table 2: Whole-building electric metering technologies

Meter Technology	Level	Description
Mechanical/electro-mechanical	Basic (whole-bldg)	Energy use is read manually using a mechanical dial on the meter and monthly energy consumption is calculated by comparing the dial position between previous and current readings.
Advanced (solid state/digital) meters	Advanced (whole-bldg)	Advanced meters require no moving parts, but rely instead on integrated circuits, built-in memory, and communication technology.

Table 3: Electric system or subsystem metering technologies

Meter Technology	Use	Description
Power Meter (PM)	Energy consumption from a single point of use.	Can be used to provide peak demand to identify when highest usage occurs. Applications include: tenant sub-metering, measuring output from solar panels, monitoring plug load power draw. Most power meters can provide the following information: power, energy, power factor, volts, amps, and kVAR.
Multi Circuit Power Meter (MCM)	Energy consumption of up to 8 circuits within one panelboard.	MCMs are typically used to monitor the energy consumption from a group of associated loads. A MCM typically provides limited information about a specific monitoring point: power, energy, and amps. A MCM can monitor multiple circuits fed by the same voltage source; typical installations include apartment complexes or office buildings
Branch Circuit Power Meter (BCPM)	Energy consumption of all the circuits within one panelboard.	A BCPM is a robust metering option that can provide data for all of the connected loads within one panelboard. BCPMs are typically used when the power consumption of unassociated loads within one panelboard (i.e., HVAC and Lighting) is wanted and are used where maximum metering flexibility is desired. The information provided by a BCPM typically mirrors a MCM (power, energy, amps).

Power Meters, Multi Circuit Power Meters and Branch Circuit Power Meters are discussed in further detail in Appendix D and E of this Application Guide.

Electrical Power Metering Systems

Power monitoring systems that combine multiple meters through a communication network to a central server or data acquisition system provide a comprehensive integrated solution to monitoring building electrical energy use. These systems are becoming more affordable as more commercial products become available from manufacturers that focus on energy monitoring versus more complicated power quality monitoring systems. A greater number of equipment manufacturers are standardizing to common communication protocols, allowing more equipment from multiple vendors to be networked together. A common communication network protocol saves metering system hardware and startup expenses when communication protocol conversion is not required. Software packages are becoming more powerful in gathering, storing, analyzing, normalizing, and presenting large data streams into simple straightforward reports and graphical displays.

A more in-depth discussion of power metering systems can be found in Appendix F: Power Monitoring as an Integrated System.

Natural Gas Meters

Metering natural gas presents a unique challenge compared to other fluid metering. The physical properties of natural gas (relationship between pressure and temperature) can cause a high level of inaccuracy unless the meter is properly calibrated. Tables 4 and 5 summarize available meter types, features, and common applications. There are a number of options for natural gas meters, so meters should be selected based on the application. Considerations include:

- Expected range of gas flows
- Accuracy requirements over the flow range (will help determine turndown ratio, or the range that a specific flow meter is able to measure with acceptable accuracy). For buildings that experience a wide range of flows, a higher turndown ratio will ensure accurate flow

measurements. Turndown ratio is of particular importance when selecting equipment for system or subsystem monitoring because accuracy diminishes when flow varies.
- Pressure losses
- Physical installation requirements for meter location
- Communication requirements

At the whole-building level, positive displacement diaphragm meters and rotary meters are common, with the typical data output (digital) recorded in calibrated pulses. Analog data output types also exist (four to 20 mA or zero to five volts).

Table 4: Whole building natural gas metering technologies

Meter Technology	Type	Description
Diaphragm	Positive displacement	The most common type of gas meter; commonly found on buildings with line sizes of 0.75 to 2 inches. Within the meter body there are two or more chambers formed by movable diaphragms. The diaphragm movement is converted into flow measurement.
Rotary	Positive displacement	Typically found on buildings with line sizes of 1.5 to 4 inches and located on buildings with higher gas flow rates. The fluid physically displaces the measuring mechanism to increment a recording dial.

Table 5: Natural gas system and subsystem metering technologies

Meter type	Type	Description
Orifice	Differential pressure	Relies on the velocity-pressure relationship of flowing fluids. Orifice element is held between two flanges in the fluid stream. As fluid flows through opening in the orifice plate, the restriction creates a pressure differential proportional to the flow rate.
Turbine	Velocity	As the fluid passes, an impeller rotates at a speed directly proportional to the velocity, and hence, flow rate. These typically have better turndown ratios than other meter types.
Ultrasonic	Ultrasonic	Measures the speed of gas movement by measuring the speed at which sound travels in the gaseous medium within the pipe. The meter creates a 'ping' with a transducer and measures the time elapsed before the sensor receives the sonic pulse.

Section 5: Performance Tracking Tools and Uses

What is an Energy Performance Tracking System?

At a minimum, an energy performance tracking system collects and reports whole-building energy consumption data on a continuous basis. This data is processed into a form that is informative and actionable and can be graphically displayed to accurately depict the energy performance of a building over time.

Common types of performance tracking tools available in the marketplace include energy information systems (EIS), energy management and control systems (EMCS), and automated fault detection and diagnostic software (FDD).

Benefits of a Performance Tracking System

A performance tracking system provides facility managers and operators with information about the building's current and historical energy performance with respect to energy consumption and demand. Benefits of installing a performance tracking system include:

- Building performance and operational issues can be identified by comparing measured energy use with expected energy use, benchmarks, or historical data.
- If FDD tools are incorporated into the performance tracking tool, abnormal energy use (high when compared to an energy baseline) can be detected and flagged.
- Use of a performance tracking system to aid building operations staff often results in savings on utility bills (electric, gas, water) and operations and maintenance costs.
- Peak demand spikes can be easily identified, which may lead the building owner and operations team to investigate the cause and identify opportunities to reduce this load.

Energy performance tracking systems often have additional performance tracking capabilities beyond whole-building, system or subsystem energy data. Some tracking systems may include summary metrics of HVAC and lighting system performance, such as equipment run-time, deviation of temperatures from set-points, and equipment efficiency. More advanced energy performance tracking systems employ automated diagnostic software to detect specific operational deficiencies and alert users.

Types of Performance Tracking Systems

As the size, type, and complexity of commercial buildings vary, so do the analysis capabilities and functionalities of performance tracking tools. Project teams and building owners need to select a performance tracking tool based on their monitoring and performance goals for the building.

Basic systems collect energy consumption data and perform simple calculations so that the data can be displayed in a manner that's useful to the user. These assessment tools are better suited for smaller buildings that have simple systems. As building size and complexity increase, more advanced tools may be used to obtain a better understanding of a building's energy use. Energy tracking tools can help identify inefficiencies at the whole-building level and for large energy end-uses, while diagnostics allow detection of specific problems and help target the causes of these problems.

A discussion on capabilities and functionalities of available performance tracking tools follows. Refer to Appendix A for a summary table of system types discussed in this section.

Basic Performance Tracking Systems

A basic performance tracking system is a web-based software package that provides a fundamental level of energy consumption analysis. Basic performance tracking systems or energy information systems (EIS) are considered systems in which meters, data storage, and software tools are employed to track energy performance and, at a minimum, can provide the functionalities listed below. Custom calculations, alarms or diagnostic features are not included in a basic performance tracking system.

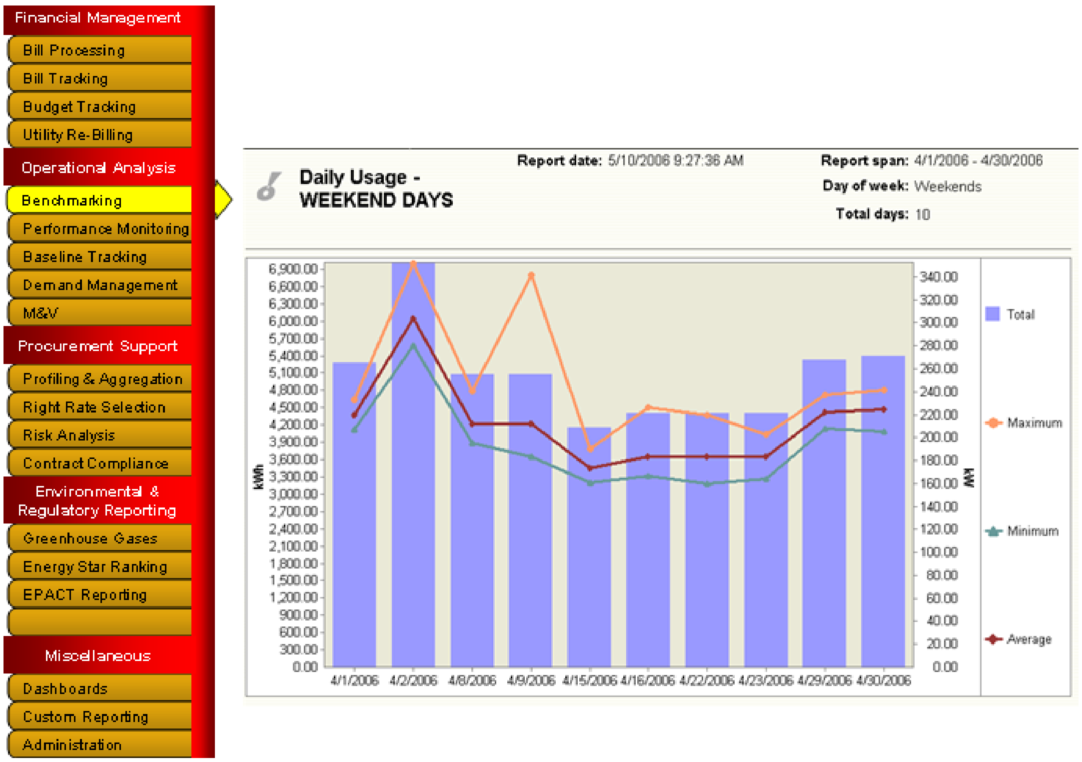
By comparison, the data displayed by an energy dashboard is generally on the whole-building level and communicates to the user what is happening during a particular snapshot in time. A dashboard alone does not have the ability to store historical data and analyze building energy consumption data over an extended period of time and therefore is not considered a true performance tracking system.

Standard functionalities provided by a basic performance tracking system include, but are not limited to, the following:

- Automated tracking of whole-building energy use
- Graphical displays of information that allow energy consumption to be viewed on a daily, weekly, monthly, or annual basis

- Ability to export data to a .csv file or other format for further analysis
- Ability to calculate and track the energy use index (EUI) and other performance or benchmarking parameters

Chart 2: Example graphic from a basic EIS



Some examples of basic performance tracking tools are Itron's Enterprise Energy Management Suite (EEM) and Powermand Dreamwatts.

Advanced Performance Tracking Systems

Whole-building monitoring may not provide enough useful information for buildings with complex, integrated systems. In order to draw useful conclusions from energy use data, these buildings are encouraged to install a more robust performance tracking tool to help identify causes of unnecessary energy use.

1. Whole-Building and System Monitoring

   A. Energy Management and Controls System (EMCS)

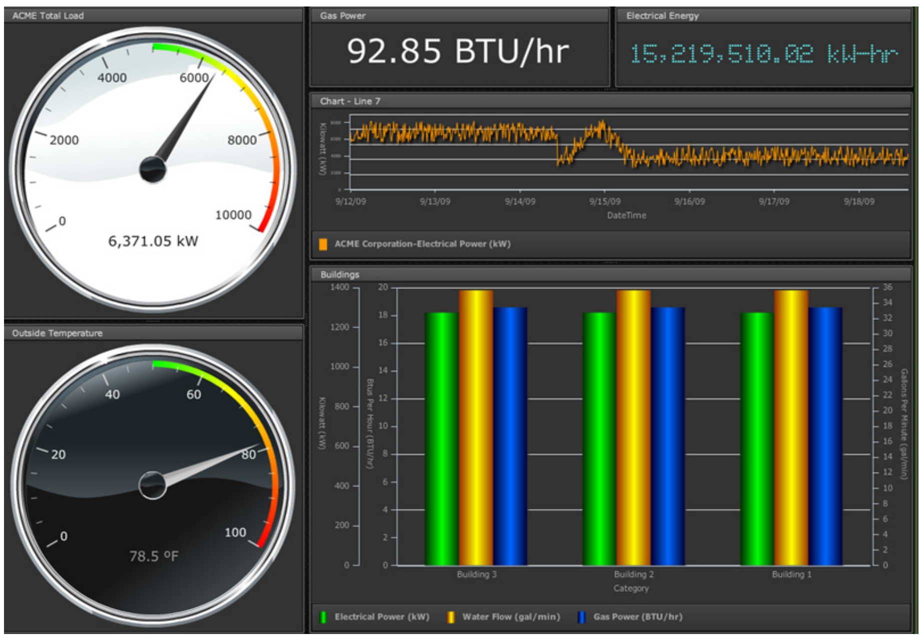
   Building owners and managers are installing EMCS—sometimes called building automation systems (BAS), building management systems (BMS), or energy management systems (EMS)—in an increasing number of commercial buildings. A typical EMCS uses sensors, transmitters, and data acquisition to gather operational and performance data in order to execute sequences of operation. The EMCS may also display the data using graphs, tables, or sometimes performance metrics. At a minimum an EMCS has the capability to measure control variables (e.g. temperatures, flow rates, fan speeds) and allows the building operator to evaluate building control system operation.

With proper planning, an EMCS may also serve as a performance tracking tool if additional points and reporting functions are added to enhance monitoring capabilities. Additional points, such as whole-building level and optional subsystem or end-use meters need to be added to most EMCS tools in order for the system to be considered a true performance tracking system.

Standard functionalities provided by an EMCS with whole-building and optional system and subsystem monitoring points include, but are not limited to, the following:

- Automated tracking of whole-building energy use
- Smart alarms that alert staff when equipment, temperatures or general building operation is abnormal
- Trend data and displays that inform the building's facilities staff
- Trend data that can be downloaded to a spreadsheet for analysis
- Ability to control and change set points remotely

Chart 3: Example graphic from an EMCS with an energy dashboard



Most controls manufacturers or vendors can easily add the functionalities described above to a standard EMCS package.

B. Performance Tracking System with System-Level Monitoring

Another method for achieving advanced performance tracking is through enhancing a basic EIS to collect data from system-level meters, subsystem meters, and additional monitoring points, such as temperatures and pressures. In addition to providing the standard functionalities outlined for basic performance tracking systems (Section 5), many basic EIS systems can be upgraded to display equipment or system-specific monitoring points in combination with whole-building level data. For example, the whole-building gas meter will inform the owner of total gas consumption, but the ability to monitor domestic hot water and boiler gas usage will further break out gas consumption in the building which will assist in trouble shooting operational issues in the future.

2. Advanced Fault Detection (FD) Monitoring

A. Whole-Building Monitoring with Fault Detection

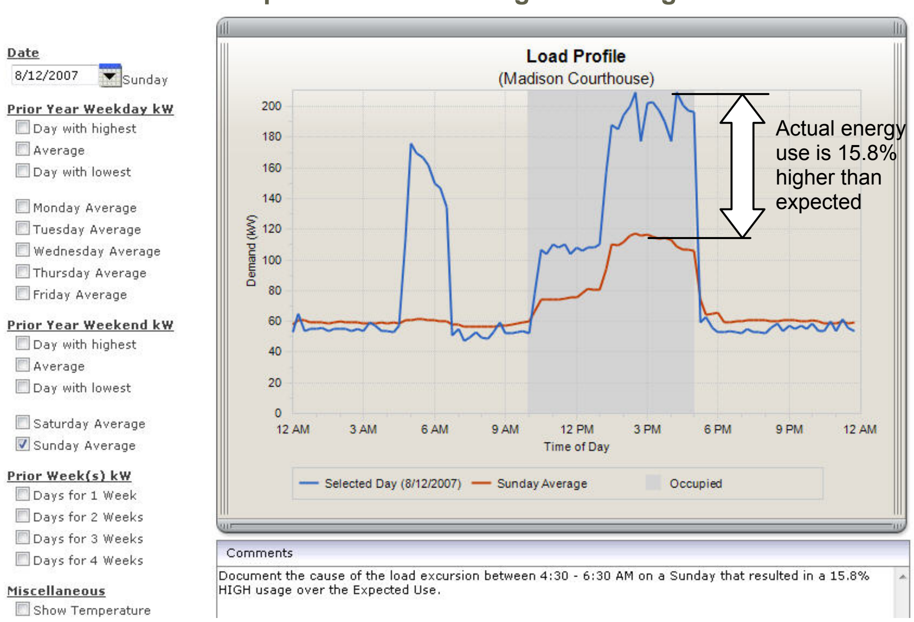
Owners of buildings concerned about the labor investment needed to manually analyze and track building energy use and operational data can consider installing a monitoring system with automated fault detection capabilities.

In addition to performing the functions of a basic performance tracking tool, whole-building monitoring systems with fault detection use historical energy consumption data to create a baseline model. This model is used to compare the expected performance of the building with the metered (actual) energy use. An operator can be notified if the energy use is not within the expected range. Many advanced EIS tools have the capability to create these baseline models and fall under this category. Some of these systems also have the ability to incorporate system or subsystem meters or additional monitoring points (e.g. space temperature) into the tool.

Typical functionalities include, but are not limited to, the following:

- Creating a baseline model of building or system energy use as a function of independent parameters such as weather, operating schedules, equipment schedules, or production characteristics (number of widgets produced/hour).
- Alerting or flagging the user when whole-building energy consumption is outside of the range predicted by the baseline model.
- Providing customized reports or graphical displays of energy consumption.

Chart 4: Example of whole-building monitoring with FD



Some examples of whole-building tracking systems with fault detection are Pulse Energy's Energy Management Software and Northwrite's Energy Expert. Portland General Electric (PGE) offers a monitoring service using Energy Expert. This service automatically gathers whole-building utility interval meter data from a building site and compiles the information into online reports for customer use.

B. System Monitoring with Fault Detection & Diagnostics

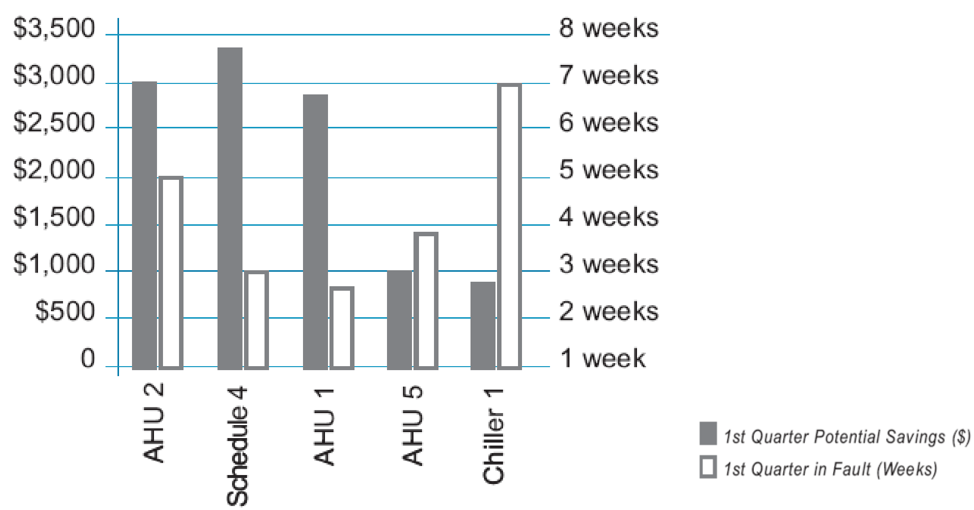
Performance tracking tools with fault detection and diagnostics are appropriate and useful in large buildings with complex HVAC systems, lighting strategies, etc. Diagnostics tools evaluate specific system and component operations, helping the user to identify the causes of energy anomalies.

The data needed for diagnostics is more extensive than for basic energy tracking; however, this jump in complexity can provide the information needed to aid in correcting problems. Automating the process of detection and diagnosis saves time in reviewing raw data. Whole-building level monitoring with fault detection also detects problems that would have otherwise gone unnoticed.

Typical functionalities provided by a system monitoring tool with fault detection and diagnostics include, but are not limited to, the following:

- Data acquisition from the EMCS to continuously identify faults in building operation
- Data management and pre-processing to prepare the data for use in the diagnostic algorithm (may include time stamp synchronization and data validation to filter erroneous data)
- Problem detection that incorporates a comparison of the "correct" operation of the building using either quantitative (modeling) or qualitative (expert knowledge) baselines
- Operator alerts for any perceived anomalies.
- Diagnosis of detected problems, including probable causes and potential remedies

Chart 5: Example output report from an FDD tool



Some examples of performance tracking systems with fault detection and diagnostics are: Facility Dynamics' PACRAT, Cimetrics Infometrics, Architectural Energy Corporation's ENFORMA, and ScientificConservation's SCIWatch

Section 6: Corrective Action

Monitoring and reporting requirements can give owners and operators insight into the energy use of their building. Owners are encouraged to use the information provided by the performance tracking tool to enhance building operating practices and to verify that the energy efficiency measures are installed and operating correctly. To make the most of the energy use data, building operators are encouraged to observe and understand the energy consumption data they are collecting. When data appears outside of the normal range, the operator should investigate and take actions to improve the building's energy performance.

The graphs below show a hypothetical spreadsheet output from a performance tracking system. Fifteen-minute interval electricity use data has been plotted for a typical commercial building by day (including the monthly average) for the second and third weeks in January 2008. The graph of the second week in January depicts typical energy consumption, while during the third week in January, the energy use on Saturday matches the expected energy use during the week.

Building operators can use information such as this to review equipment schedules and to make sure that equipment isn't operating unnecessarily.

Chart 6: Example performance tracking system output

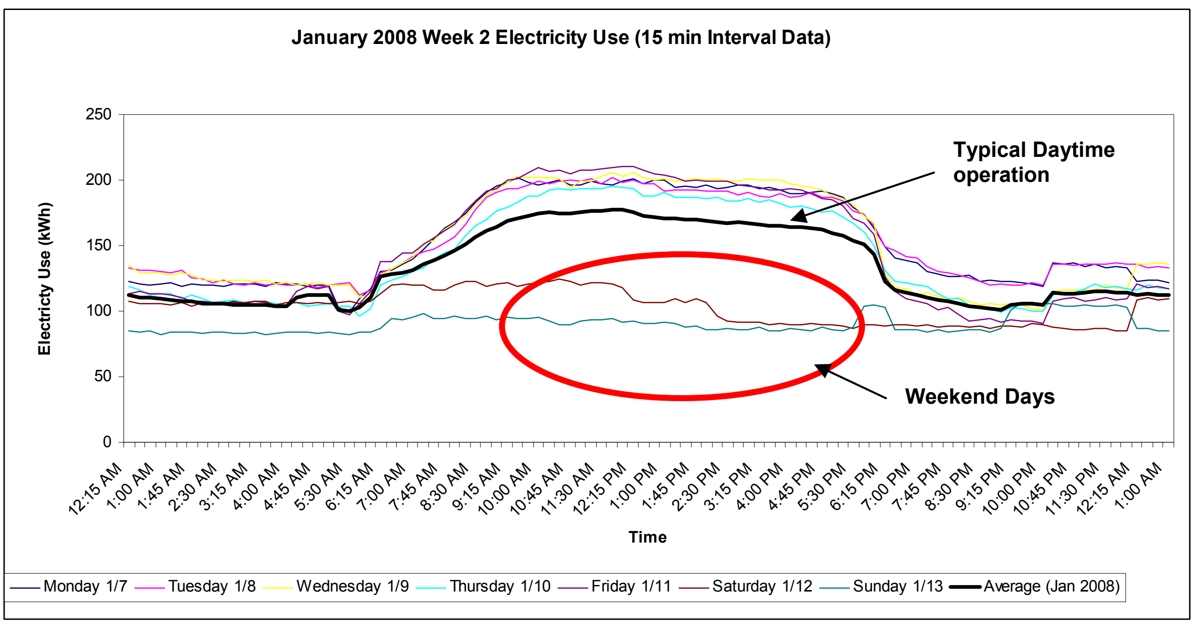
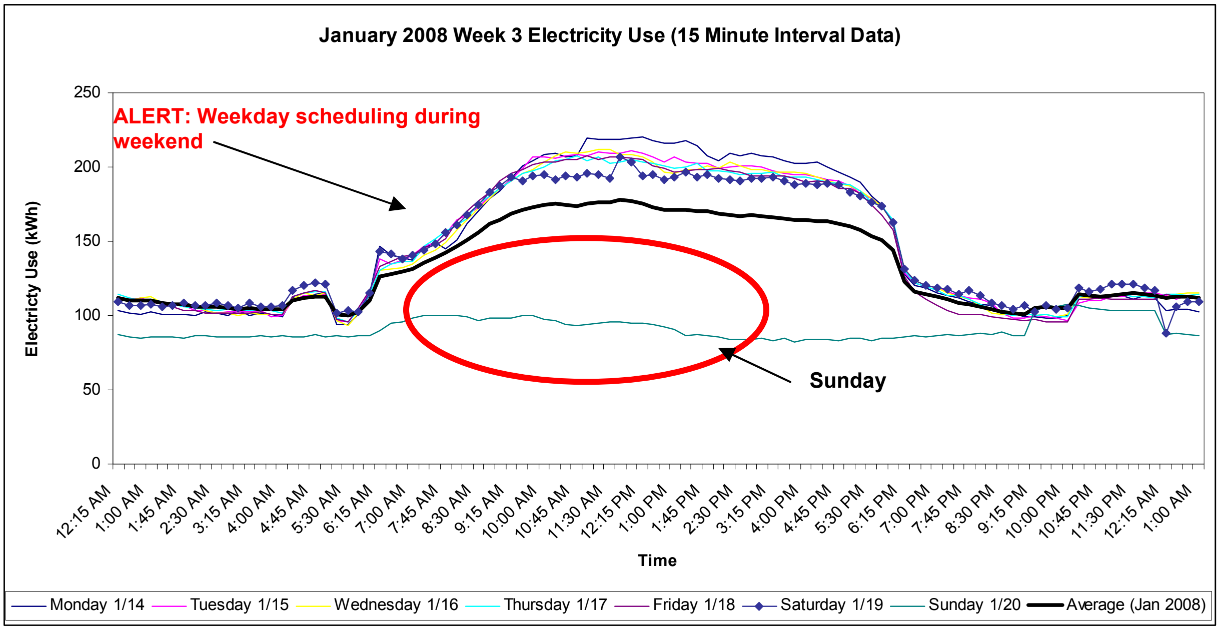


Chart 7: Example performance tracking system output



Section 7: Commissioning

Building commissioning is a quality assurance process that a new building undergoes to ensure that all of the systems and subsystems operate as intended. Given the increased level of complexity of new construction projects, commissioning is essential to ensuring a building is operating effectively, efficiently, and reliably. The benefits of this process include, but are not limited to:

- Cost savings
- Improved coordination between design, construction, and occupancy
- Fewer system deficiencies
- Energy savings
- Improved indoor environmental quality

Typically, building owners will hire a commissioning agent or commissioning authority (CxA) who is responsible for coordinating and implementing the commissioning process. The commissioning agent should work with the project team from early in the design and construction process to ensure that the building, once complete, meets the owners needs. Agents should follow the commissioning protocol outlined in *ASHRAE Guideline 0: The Commissioning Process*. Commissioning agent responsibilities include:

- Create a commissioning plan.
- Review design and construction documents.
- Review all change orders.
- Complete equipment testing
- Document the commissioning process and any findings in a commissioning report.

Commissioning the Energy Monitoring System

Just as it is important to commission a building or equipment, so is it crucial to complete commissioning and functional testing of the performance tracking system. This process is intended to verify that the performance tracking system is performing in accordance with the owner's final design intent, contract documents, and manufacturer specifications. The testing sequences that involve the energy monitoring systems are conducted in conjunction with the functional performance testing of equipment, subsystems, and systems being commissioned.

The commissioning effort should include testing of the following components (if applicable to the system): central processing, monitoring hardware, user interface, and individual monitoring points. Operational and performance parameters will vary widely depending on the size and complexity of the facility being monitored and the level of control delegated to the performance tracking system.

Section 8: Resources & References

As designing for energy efficiency and energy monitoring has become increasingly prevalent in the new construction industry, more and more research and literature has become available to help guide owners and energy managers toward best practices. Below are several published resources that provide further information about energy monitoring and reporting and commissioning that may be useful.

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Appendix A: Performance Tracking System Summary

	Basic	Advanced		Advanced Fault Detection Monitoring	
System Feature	**Whole-building level (e.g. EIS or custom)**	**Whole-building and system-level monitoring (e.g. EIS or custom)**	**EMCS with whole building level monitoring**	**Whole-building monitoring with fault detection (FD) (e.g. Advanced EIS)**	**System-level fault detection and diagnositcs (FDD)**
Automated tracking of whole-building energy use with graphical display	●	●	●	●	◖
Graphical displays of system-level or equipment energy consumption		●	◖	◖	●
Ability to calculate and track whole building metrics, such as Energy Use Intensity (EUI)	●	●	●	●	◖
Ability to control or change set-points remotely			●		
Trend data is available for a range of variables (e.g. temperatures, equipment run-times, fan speeds)		◖	●		●
Creates a baseline model of building or system-level energy use based on historical data				●	
Alerts the user when whole-building energy consumption is out of a typical range				●	◖
Alarms or alerts can be set-up to alert staff when system level equipment operation is abnormal		◖	●	◖	●
Identifies faults in building operation down to the system level and provides recommended checks or remedies for these faults.					●
Ability to export to a .csv file or other format for further analysis	●	●	●	●	●

●	Common feature for this system type
◖	May be an added feature for this system type

Appendix B: The Electrical Power Distribution System

Power Uses in Buildings

Power is distributed throughout a building to serve a variety of electrically operated equipment, devices and functions. In general, electrical loads fall into the following end use categories:

- Lighting
- Receptacles
- HVAC Equipment
- Domestic Water Heating
- Miscellaneous Building Services (elevators, doors, security and fire alarm, servers, UPS equipment, etc.)
- Process (commercial kitchens, swimming pools, manufacturing equipment, etc.)

Power Distribution System Architecture

The architecture of a typical power distribution system is depicted in Figure C-1. A service from the utility is brought to the main distribution switchboard; from there it is further distributed to major electrically powered equipment, sub-distribution panelboards, and branch panels. Branch circuits serving smaller electrical devices are connected to branch panels. A brief definition of the function of each component is given here:

Utility Service Entrance: The conductors and equipment for delivering electric energy from the serving utility to the wiring system of the building, buildings, or campus served.

Main Distribution Switchboard (MDS): A large panelboard that is the point of utility service termination and includes disconnecting means, overcurrent protection, buses, and instrumentation. Typically, an MDS is the primary distribution point of the wiring system.

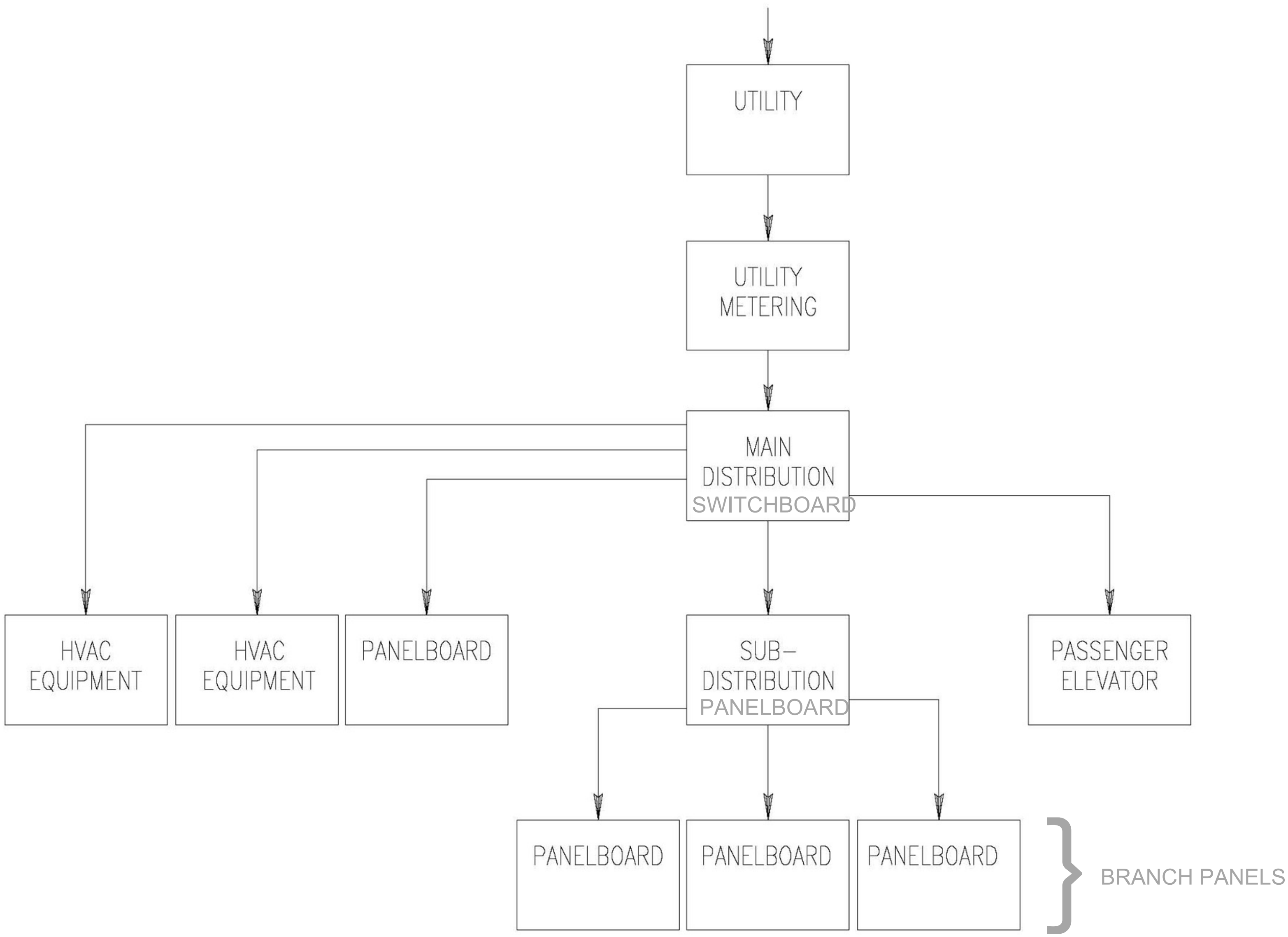
Transformer: Electromagnetic equipment on AC power systems used to change system voltage or provide electrical separation.

Sub-Distribution Panelboard (SDP): A large panelboard which includes disconnecting means, overcurrent protection, buses, and instrumentation. SDPs are used to distribute larger amounts of power to large electrical equipment or branch panels within a portion of the building, buildings, or campus. More robust and flexible than a branch panel.

Branch Panel: A panelboard which includes disconnecting means, overcurrent protection, and buses. Branch panels are typically fed by MDPs or SDPs and used to distribute power to smaller electrical equipment via branch circuits. A branch panelboard is limited to 600 amps.

Conductor: Wires or buses design to electrically connect all the elements of a wiring system.

Figure C-1: Typical Power Distribution System



Power Distribution System Design Criteria

The design of the electrical power distribution system is influenced by many factors, including:

- Available utility service (voltage/phase)
- Nature of the electrical loads (power/voltage/phase, quantity, location)
- Overall building size (total capacity, distances)
- Maintainability
- Flexibility for future changes within the building
- Capability to accommodate future expansion to the building
- Need for redundant capacity
- Level of power quality required
- Emergency power provisions
- Degree of reliability
- Requirements for continuous, uninterrupted power
- Building architectural constraints
- Presence of on-site renewable energy systems
- System cost

A brief discussion of the impact of each criteria follows:

Available Utility Service (Voltage/Phase): If an option for a utility service provider exists at the building site, the choice of provider may impact the design of the power distribution system. For example, developed, urban sites will typically have more options available than rural or residentially zoned sites.

Nature of Electrical Loads (power/voltage/phase, quantity, location): The economics of power distribution are most profoundly affected by the building loads served. Conductors are sized based on the potential current flow, which depends on the maximum connected load and the drop in voltage from one end of the conductor to the other. A higher equipment voltage allows a reduced conductor size or more equipment to be connected to the same conductor. Therefore cost considerations drive large loads to be served by higher voltage.

Additional load factors that influence system design include: equipment load/type, equipment voltage (available voltages are typically different for large and small pieces of equipment), location and quantity of the loads, and power requirements of the connected loads.

Overall Building Size: Large buildings may require multiple utility services and electrical distribution systems. Electrical loads may be divided between services based on load types or by location within the building.

Maintainability: Designing a low-maintenance electrical distribution system requires that electrical distribution equipment be grouped in common locations, that electrical gear is designed to reduce arc flash hazards, and that the system is designed to minimize the use of specialty components.

Flexibility for Future Changes within the Building: Adding large equipment or new panelboards is common during remodels and should be considered in the initial design. The cost to provide extra physical space and electrical capacity in the original installation is minimal compared to the cost of connecting new equipment to an electrical distribution system in which no provisions were made for future changes.

Need for Redundant Capacity: Large electrical systems in which the availability of power is critical are often designed with redundant sources of power such as multiple utility feeds, backup generators, and UPS equipment. A redundant power source may also be provided to keep equipment running when the main power source requires servicing.

Level of Power Quality Required: Modern electrical device power supplies and variable frequency drives generate harmonic distortions that can result in transient power events such as high voltages that can damage electrical systems and electronic devices. Devices that frequently cause harmonic distortions are often separated within the power distribution system from the equipment that is sensitive to such events. For example, branch circuits that feed laser printers could be placed in a different panel than branch circuits that feed telecommunications racks. These separate panels are often referred to as clean or dirty power.

Emergency Power Provisions: Three types of emergency power distribution systems and allowable connected loads for each are defined in the Oregon building code. These power distribution systems are emergency, legally required standby, and optional standby. Equipment is connected to emergency power distribution systems in order to protect life or property. Owners may elect to connect additional equipment which does not require emergency power by Code to the optional standby emergency power distribution system.

Degree of Reliability: The degree of reliability needed in the power distribution system may be driven by the intended use of the building and the sensitivity of the systems and operations. Common methods of increasing electrical distribution system reliability include connection to a utility network, providing power conditioning devices such as surge protection devices, electrically isolating sensitive electronics, physically separating equipment, providing redundant equipment, and selectively coordinating overcurrent protection to limit the effected equipment during an electrical fault. Often tradeoffs exist between reliability, maintainability and cost.

Requirements for Continuous, Uninterrupted Power: Some equipment requires continuous power at all times and must be shut down via a process rather than switched off. This equipment is often provided with an uninterrupted power supply (UPS) which provides a near instantaneous transfer of power to batteries upon loss of building power. For example, servers and other data center components are often provided with a UPS.

Building Architectural Constraints: Available electrical room size, location, conduit concealment requirements, available space above ceilings, and other similar architectural constraints impact electrical gear size, placement, and quantities.

Presence of On-Site Renewable Energy Systems: The presence of on-site renewable energy systems can complicate power flows within a building depending on where the renewable energy systems are connected within the electrical distribution system. For this reason, building codes typically limit the locations of connection and requires special provisions, such as increased electrical capacity.

System Cost: Project budgets will ultimately determine the degree to which the electrical system design is modified to accommodate other design influences. There are often tradeoffs between power distribution system cost and other design requirements.

Appendix D: Power Metering Design Considerations

Designing the Power Distribution System to Accommodate Metering

Building owners seeking to manage their building's energy use by integrating system-level metering into their building design should consider this requirement during the design of the power distribution system. The requirement to meter various categories of electrical energy introduces a new challenge to the electrical system designer and may significantly alter the fundamental architecture of the electrical system.

While it is always possible to add meters to an electrical system after construction to achieve virtually any monitoring goal, early integration of metering requirements will result in a metering system that is easier to understand, less expensive to install, simpler to maintain and operate, more flexible to accommodate future changes, and ultimately provides more reliable data to the building owner.

Monitoring Level

The Monitoring & Reporting (M&R) Plan provides essential direction to the electrical designer about electrical metering requirements, particularly the required level of monitoring in the building. The level of monitoring dictates the basic categories of electrical energy usage and building area or system that should be measured by the metering system. Regardless of the monitoring level requirements, the M&R Plan may require the electrical system be designed to accommodate installation of future temporary or permanent meters

As described previously in Section 2 of the guide, monitoring levels can be characterized into four categories: Whole-building monitoring, system monitoring, area monitoring and comprehensive building monitoring.

Integration of Equipment Controllers into Metering Design

Metering of individual equipment does not always require a stand-alone meter. Sometimes it is possible to capture meter data directly from lighting, HVAC, UPS, and other equipment that have a control system with integral metering. Original Equipment Manufacturers (OEMs) are increasingly adding metering capabilities to their products; however, a note of caution is in order before selecting an OEM for metering.

In some cases, due to differences in communication protocols, the OEM software and labor necessary to integrate with the metering system will exceed the cost of a stand-alone meter that would monitor the same load. For example, power metering systems traditionally utilize MODBUS protocols. Metering that is integral to other systems such as mechanical controls or lighting controls often utilize BACNET protocol. Metering in datacenters or telecom equipment often utilizes SNMP protocol. Increasing the number of protocols a metering system must support can increase cost, complexity, and commissioning requirements. It is not uncommon to have a single piece of equipment that uses a different protocol than the rest of the system. In such cases, the benefits of the including this piece of equipment must be weighed against the integration costs.

Segregation of Electrical Loads

Grouping loads that serve similar types of equipment within the electrical distribution system is an excellent method of reducing the cost and complexity of a metering system. Of course, the metering system goals and benefits must be weighed against increased electrical system costs, with consideration given to overall value added. For example, in some cases grouping loads may require adding additional panelboards which also increase the electrical system flexibility by providing additional capacity and space to connect future loads. Adding panelboards and equipment in the future may be more expensive and may not be possible due to equipment capacity or electrical space constraints. Adding panelboards to the system design will serve the dual purposes of improving metering capability and increasing flexibility for future expansions. Ultimately, design decisions regarding grouping of loads are often complex and must be made while considering all other project criteria.

To illustrate a straightforward example, Figure D-1 (below) depicts two panelboards where branch circuit electrical loads of multiple categories are mixed. In this example, 6 meter points would be required to monitor loads separately.

Figure D-2 is an example of good practice, where electrical circuits are grouped into categories based on the types of loads they serve. In this example, the required number of meter points necessary to separately monitor Lighting, Receptacles, and HVAC equipment was reduced by 50% to 3 meter points.

Figure D-1: Non-Grouped Panelboard Loads

Panelboard A Schedule

(3 meter points)

#	Description	Phase	Description	#
1	Receptacle	A	Lighting	2
3	Receptacle	B	HVAC	4
5	Receptacle	C	HVAC	6
7	Receptacle	A	HVAC	8
9	Receptacle	B	Receptacle	10
11	Receptacle	C	HVAC	12

Panelboard B Schedule

(3 meter points)

#	Description	Phase	Description	#
1	Lighting	A	Lighting	2
3	Receptacle	B	HVAC	4
5	Receptacle	C	HVAC	6
7	Receptacle	A	HVAC	8
9	Lighting	B	Receptacle	10
11	Receptacle	C	HVAC	12

Figure D-2: Grouped Panelboard Loads

Panelboard A Schedule

(1 meter point)

#	Description	Phase	Description	#
1	Receptacle	A	Receptacle	2
3	Receptacle	B	Receptacle	4
5	Receptacle	C	Receptacle	6
7	Receptacle	A	Receptacle	8
9	Receptacle	B	Receptacle	10
11	Receptacle	C	Receptacle	12

Panelboard B Schedule

(2 meter points)

#	Description	Phase	Description	#
1	Lighting	A	HVAC	2
3	Lighting	B	HVAC	4
5	Lighting	C	HVAC	6
7	Lighting	A	HVAC	8
9	HVAC	B	HVAC	10
11	HVAC	C	HVAC	12

Legend	
Lighting	(yellow)
Receptacle	(green)
HVAC	(blue)

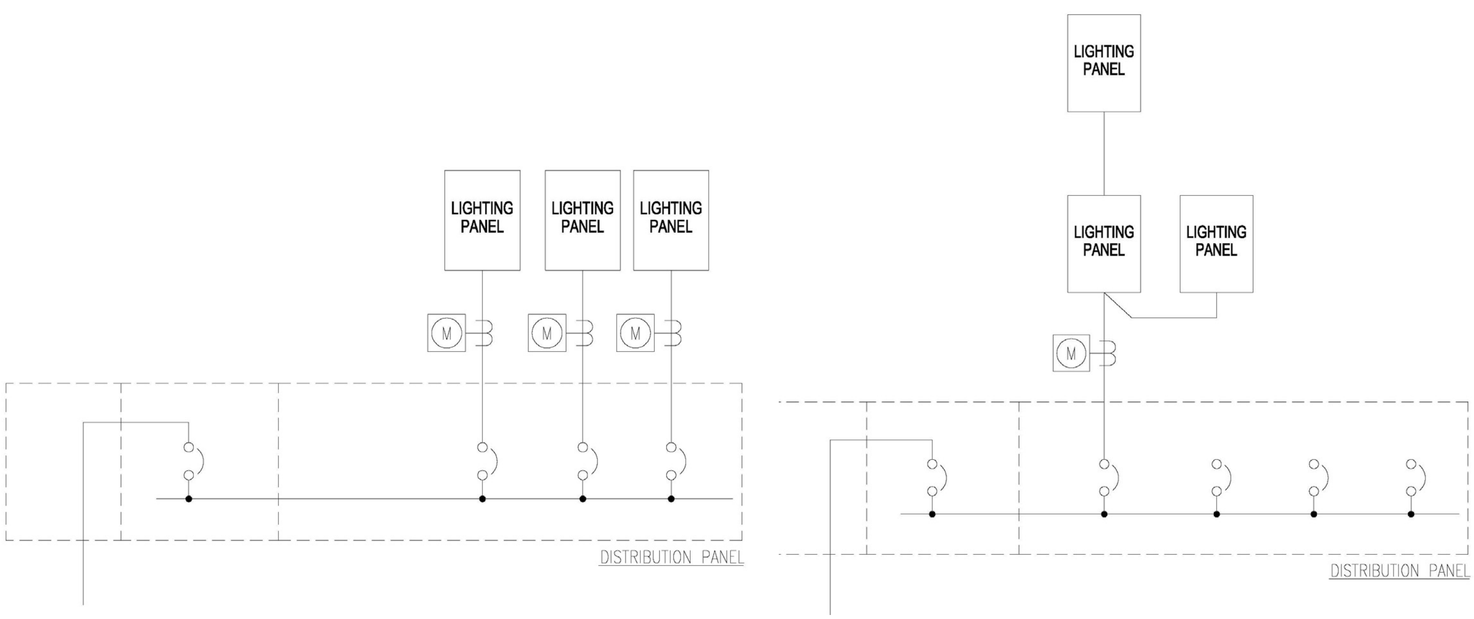
When loads are grouped at the feeder or panelboard level, they can be monitored by a single meter point reducing the cost and complexity of the metering system. Figure D-3 shows how the number of meter points is reduced when lighting circuits are grouped together within panelboards and these lighting panelboards are grouped in the electrical distribution system.

In some cases, loads cannot be grouped. For example, the Oregon building code requires that emergency loads be served by a separate power distribution system. This prevents the grouping of emergency and non-emergency lighting loads. If a building has multiple emergency distribution systems, the number of meter points will increase significantly if all the load types being monitored are connected to each emergency system. Typically, each emergency distribution system will predominately serve one or two load types.

While grouping common loads is generally good practice, it is not always practical to fully segregate electrical load types. For example, it may not be necessary to add a meter point to a receptacle load panel to capture the energy consumed by a fractional horsepower fan in a cabinet unit heater. Decisions on whether it makes sense to neglect segregation of certain small loads should be made in conjunction with other members of the design team, such as the energy modeler and mechanical system designer. These decisions should be noted in the M&R Plan and other Operation and Maintenance documentation so that required adjustments, to account for un-metered or un-separated loads, are made when analyzing performance data.

After the loads have been grouped in response to the M&R Plan, the electrical designer should evaluate the costs and benefits of further segregating the electrical distribution system to support additional meter points. The electrical designer should consider the number of meter points required by the base electrical system design relative to the number of meter points required if the electrical distribution was segregated further. The cost of added electrical equipment and feeders should then be compared to the reduction in equipment size and feeder size as well as metering system cost. This is an iterative process that will continue until all the electrical load categories have been fully segregated within the electrical system or a point of economic equilibrium is reached. The sample buildings that follow in Appendix E provide an example evaluation of the costs and benefits of metering a building designed with segregated loads versus one designed without metering in mind.

Figure D-3: Non-Grouped (left) and Grouped (right) Electrical Distribution



Commissioning, Long Term Operating Costs and Reliability of Data

The initial cost tradeoffs that occur between the electrical distribution system and metering system are just one part of the picture when analyzing the total cost of owning and operating the metering system. A metering system that is excessively complex and not clearly defined will require additional labor for initial setup and commissioning. Similar additional costs may be incurred over time when changes are made to the electrical system to accommodate renovations, tenant changes, or other programmatic functional changes within the building. The probability that the system will be misunderstood or that mistakes will be made during software configuration, data manipulation and analysis is much greater with complex metering systems. Building operations staff often do not have adequate time or resources to manage a complex metering system. A thorough evaluation of operations staff role in data acquisition, data processing and interpreting monitoring reports is needed to guard against designing an overly complex metering system. Designing the electrical system to accommodate a simple, straight-forward metering system is an investment in the long term success of the metering plan and operating efficiency of the building.

Appendix E: Example Metering Designs and Costs

Designing for Meterability Examples

To illustrate the benefits of designing for meterability and the associated cost considerations, analysis of two example buildings are presented below. The first example looks at a small building with a relatively simple electrical distribution system. The second example describes a more complex, multi-story office building. In both examples, a basic description of the building is provided followed by two electrical design scenarios which are referenced as:

- Base Case - in which metering has not been considered in electrical system design
- Designed For Meterability Case - in which metering and metering flexibility has been considered in electrical system design.

A cost comparison of the two scenarios is then presented, followed by the conclusions.

The purpose of the following examples is to demonstrate that consideration to metering and monitoring during the design process allows for a flexible metering system and for future expansion of the monitoring system. Planning for metering and monitoring has cost advantages which are more beneficial when expansion to the system is anticipated. For each example, a single line diagram and cost estimate is shown for a base case building and a building that has been designed for meterability.

Additional information on meters and scientific principles used to record measurements is provided in the Monitoring and Report Applications Guide, Section 4: Monitoring and Metering Technology. Information regarding metering equipment descriptions, terminology, and costs used in the two examples is illustrated in Table E-1 below.

Table E-1: Common Metering Equipment Descriptions

Equipment Name	Description	Avg. Cost ($)
Branch Circuit	Smaller circuits that distribute power from the service panel to point of use. In other words, a feeder supplies power to the panel or main breaker and branch circuits leave the panel to power devices	n/a
Branch Circuit Power Meters (BCPM)	A recent product that can monitor all of the circuits within one panelboard. A BCPM provides data for all connected loads within that panelboard. BCPMs are typically used when the power consumption of unassociated loads is wanted and are used where maximum metering flexibility is desired (i.e. lighting loads, plug loads and HVAC loads can be isolated within a single panelboard). The CTs used in a BCPM are smaller (1/2 dollar in size) and have greater accuracy at low amperage readings. The information provided by a BCPM mirrors a MCM (power, energy, amps), however most BCPMs can provide alarms. These meters include more CT hardware which is better integrated into the panelboard than a MCM.	$6,000
Circuit	The closed path conductor or wire through which electric current flows. There are two types of circuits: feeder and branch.	n/a
Current Transformer (CT)	Used in the measurement of electric currents. When current in a circuit is too high to directly apply to a monitoring device, a CT produces a reduced current proportional to the current in the circuit	n/a
Feeder Circuit	A circuit that carries a large block of power from service equipment to a point where the power is broken down (i.e. a panelboard).	$600
Feeder Meter	Used to measure the electrical consumption at the whole building/campus level.	n/a
Multiple Circuit Meters (MCM)	Monitors up to 24 positions from the same voltage source with one device. For example, instead of installing 8 power meters to monitor 8 three phase circuits, 1 MCM can be used instead. Alternatively, twelve 2-phase circuits or twenty four 1-phase circuits can theoretically be monitored within the 24 position architecture. However, installing a MCM on a panelboard typically will not capture the power consumption of all connected loads because of limited CT space needed to incorporate onto the monitoring positions. MCMs can be used to meter multiple feeder circuits or a limited number of branch circuits within a panelboard. MCMs are typically used to monitor the energy consumption from a group of associated loads. For example, if it was desirable to isolate the lighting energy from a panelboard that servers multiple loads (e.g. HVAC and receptacles), the lighting branch circuits could be isolated and metered. A MCM is similar to a PM in that the designer has to deliberately select the circuits he/she wishes to monitor. MCM typically provide energy and not power quality information about a specific monitoring point: power, energy, and amps.	$5,000
Panelboard	A component of an electrical distribution system which divides the current and provides a fuse or breaker for protection	$2,000
Power Meter (PM)	Measures the energy consumption from a single point of use which can vary from a single feeder circuit or a single branch circuit within a panel board. Generally used on larger feeder circuits, but multiple power meters can be used in a single panelboard. However, space constraints can prevent fitting many CTs in the panelboard because they run 3-4 "square in size. Power meters can be most effectively utilized when the electrical distribution wiring system has been consolidated into a limited number of feeder circuits. Most power meters can provide the following information: power, energy, power factor, volts, amps and kVAR.	$1,000

Sample Building “A” - Description

Sample Building “A” represents a relatively simple, 2 story, building layout (10,000 sf) with 2 main space uses. The owner’s monitoring goal is to monitor lighting, mechanical equipment and plug loads separately for the office tenant and retail tenant. The elevator load for the building will be captured as part of the office tenant load. Domestic hot water heating is fueled by natural gas and is not metered.

Sample building “A” is a small office building with the following characteristics:

- First floor – Retail Space
- Second floor - Office Space
- One centralized packaged HVAC system for the office tenant space
- Several decentralized packaged HVAC systems for the retail tenant space
- Single 230Y/115V utility electrical service to main electrical room on the main floor
- Electrical distribution equipment is located in the building electrical room and in tenants’ electrical spaces.
    - Building / Office Electrical Room: Houses multiple panelboards dedicated to HVAC units, plug loads and auxiliary equipment;
    - Retail Tenant Electrical Space: Houses one panelboard for HVAC units, lighting, and plug loads.

Sample Building “A” Base Case – Monitoring Points

Because this is the base case and no consideration was given to monitoring during the design of panel boards and distribution wiring layout, it will be assumed that using several PMs inside a panelboard is not practical. Multiple points within a shared panelboard are best served by a MCM or BCPM. Therefore, six metering devices are required to meet the owner’s needs, as outlined below:

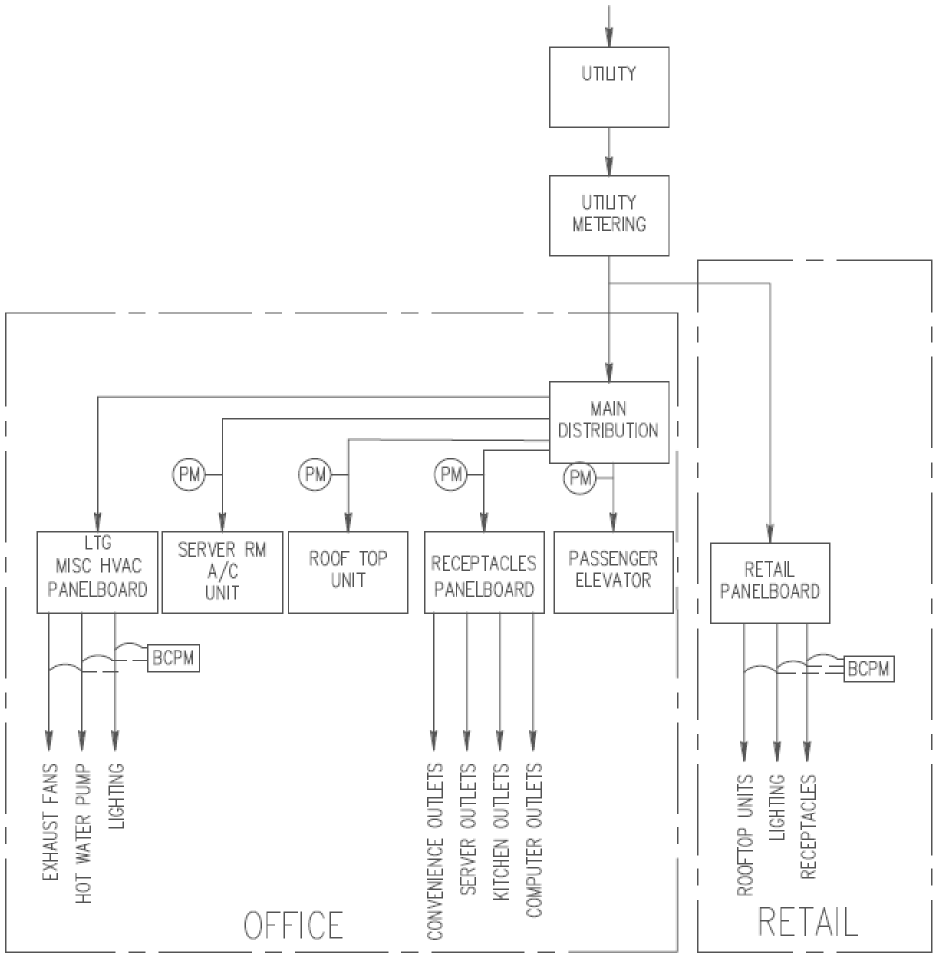
Retail Panel

- 1 BCPM in Retail Panel Board to record: HVAC, receptacles and lighting.

Main Building/Office Panel

- 1 BPCM in the Lighting/Misc HVAC panelboard
- 4 PMs in the building main distribution panelboard to record: A/C Unit for the Server Room, rooftop unit, receptacles, and passenger elevator.

Figure E-1: Sample Building "A" - Base Case



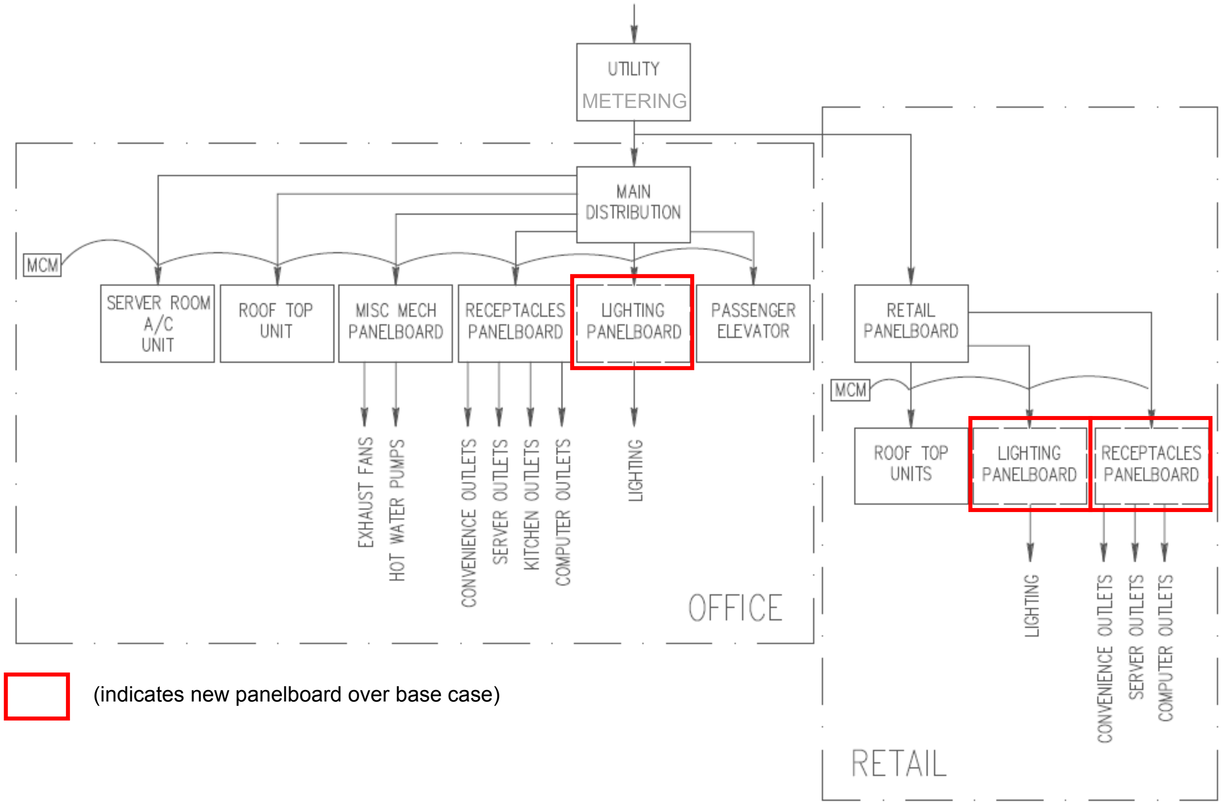
Sample Building "A" Designed for Meterability – Monitoring Points

When metering and monitoring goals are incorporated during the design process the electrical designer can layout the distribution equipment in a way that isolates the loads and allows for the efficient use of metering. In this example, the electrical designer added three panelboards in an effort to segregate the loads that the owner wishes to monitor. Therefore, only two meters are required to monitor the required categories in the designed for meterability case, see below:

- 1 MCM in Retail Panelboard (3 points): Roof top units, lighting panelboard, receptacles panelboard
- 1 MCM in Building Main Distribution Panel (6 points): Server Room A/C unit, rooftop unit, Miscellaneous Mechanical Equipment panelboard, receptacles panelboard, lighting panelboard, and passenger elevator.

As with any monitoring system, there are several options available to the electrical designer. Figure E-2, below, demonstrates just one possible monitoring scenario.

Figure E-2: Sample Building "A"-Design for Meterability Case



The designer has several metering options available, especially in the retail space. In Figure E-2, a MCM has been installed to monitor the loads associated with the retail area. Another designer may choose to install a power meter for each of the loads (1 each for roof top units, lighting, and receptacles). The three PMs will be cheaper than one MCM ($3,000 vs $5,000), however this monitoring scenario is more complex, is less flexible and does not allow for future expansion. If the owner wishes to monitor additional loads in the future, he/she may do so with the MCM without installing any additional metering equipment. The PM scenario is not as flexible: in order to monitor additional points, the purchase of additional PMs would we required. Beyond hardware, labor will typically be less with the installation of a MCM over multiple PMs because the installer has to open one panelboard as opposed to selecting multiple locations for the PM installation. Table E-2 (below) provides a summary of costs for each design case.

Table E-2: Total Electrical and Metering Installed Cost Comparison – Sample Building "A"

	Design Cost Difference	**Cost (Base Cost)**	**Cost (Designed for Meterability)**	**Cost Difference**
1	**Electrical Designers**			
	Design Fee Increase	$0	$800	$800
	Net Design Fee Cost Increase			*$800*
2	**Electrical Distribution**			
	Additional Panelboards (3 @ $2000/each)	$0	$6,000	$6,000
	Additional Feeder (1 @ $600/each)	$0	$600	$600
	Net Electrical Distribution Cost Increase			*$6,600*
3	**Metering System**			
	Base Option	-	-	
	4 Power Meters	$4,000	-	
	2 Branch Circuit Power Meters	$12,000	-	
	Total Base Option	**$16,000**	-	
	Designed for Meterability Option	-	-	
	2 Multi Circuit Meters	-	$10,000	
	Total Designed for Meterability Option	-	**$10,000**	
	Net Metering System Cost Increase			*($6,000)*
	Total Project Cost Impact			**$1,400**

Sample Building "A" - Design for Meterability Conclusions

If the electrical distribution equipment of Sample Building "A" is modified to increase segregation of electrical load types (addition of panelboards), it becomes possible to reduce metering system complexity. The metering system becomes easier to setup and commission and increases the likelihood that the owner will benefit from the monitoring capabilities. Also, additional capacity in the metering system and electrical distribution system saves the owner money when adding future loads.

Although the electrical distribution system costs more, the metering costs are lower in the designed for meterability scenario. The overall cost addition for this design for meterability case is modest at only $1,400. This example demonstrates that adding metering into a building is not free, but when done as part of the original project design intent, the owner benefits from increased monitoring capacity into the future at basically the same cost of implementing metering after the electrical system has been installed.

Sample Building “B” - Description

Sample Building “B” represents a larger six story building that is more complex than Sample Building “A”. Similar to Sample Building “A”, the owner’s monitoring goal is to capture lighting, mechanical, and plug loads for each floor of the building.

Sample Building “B” is a large office building with the following characteristics:

- 6 stories
- 25,000 SF per floor
- A centralized variable air volume (VAV) roof top unit (RTU) with DX cooling compressors
- Electric 277V service to multiple VAV terminal units distributed on each floor
- A central gas boiler and heating water pump located on the main floor serving a preheat coil in the RTU
- Single 480Y/277V utility electrical service to main electrical room on the main floor
- 480Y/277V distribution via a bus duct riser to each floor with208Y/120V distribution via sub-distribution panels on each floor.

Sample Building “B” Base Case

As with Sample Building “A”, there are many ways to meter this more complex building. Assuming that there was no thought given to meterability during design, nine (9) metering devices are required to meet the owner’s needs.

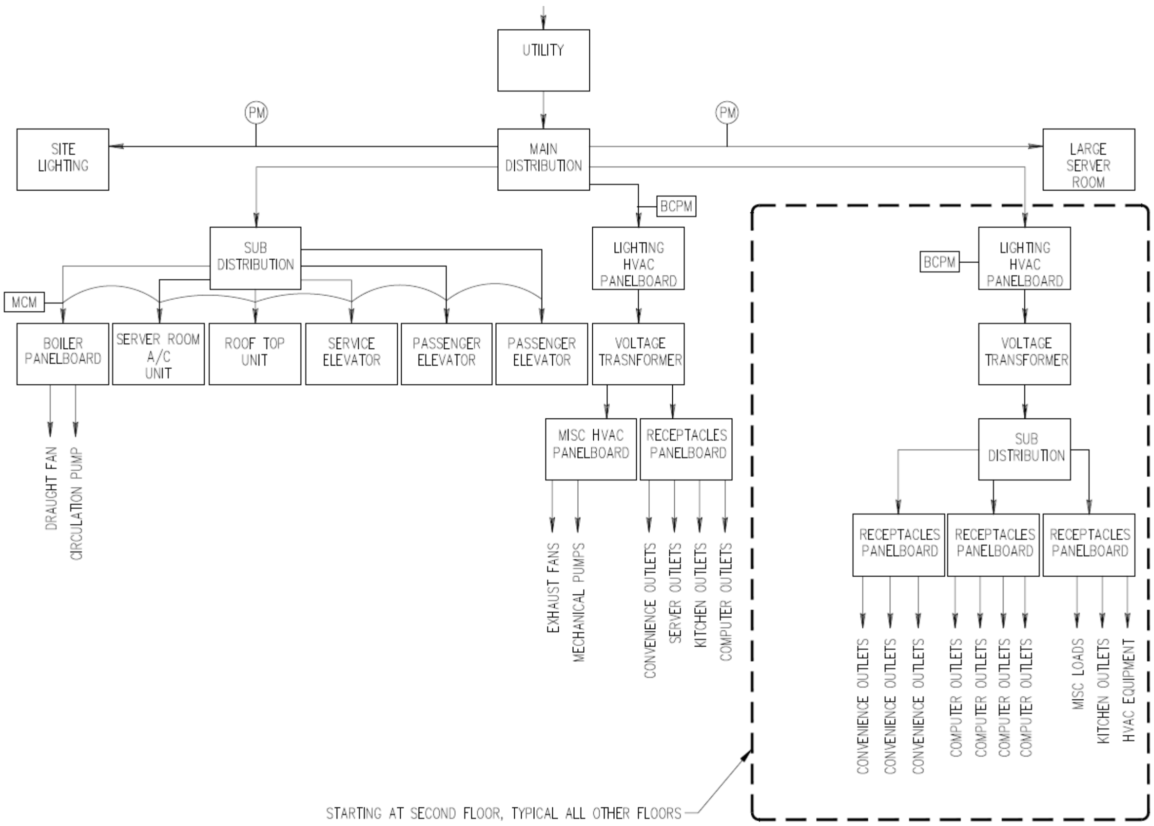
Main Floor Electrical Room

- 2 PMs in the Main Electrical room for the site lighting and large server room
- 1 MCM in the Main Electrical room for larger HVAC and Elevator branch circuits, and the boiler panelboard.
- 1 BCPM in the Main Electrical room for 1st floor Lighting, HVAC panelboard which also feeds power to lower voltage Plug loads.

Electrical Rooms (Floors 2-6)

- 1 BCPM (1 per floor, 5 total) for Lighting/HVAC/Plug loads

Figure E-3: Sample Building B BASE CASE



Sample Building "B" – DESIGN FOR METERABILITY

When metering and monitoring goals are incorporated during the design process, the electrical designer can lay out the distribution equipment in a way that isolates the loads and allows for the efficient use of metering. In this example, the electrical designer added two (2) panelboards in an effort to segregate the loads that the owner wishes to monitor.

Main Floor Electrical Room

- 5 PMs in the Main Electrical room for the site lighting, large server room, HVAC panelboard, lighting panelboard, plug loads, and miscellaneous loads.
- 1 MCMs in the Main Electrical room for larger HVAC, Elevator and boiler panelboard

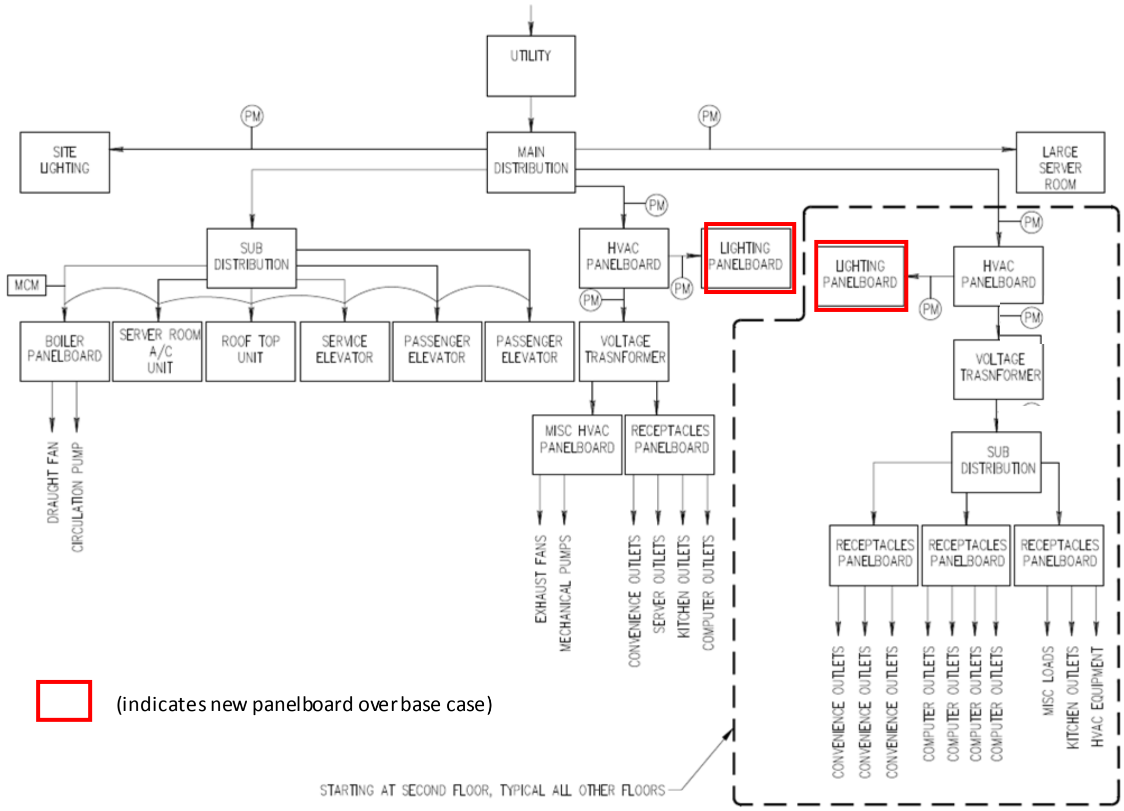
Electrical Rooms (Floors 2-6)

- 1 PM (1 per floor, 5 total) to capture total electrical load
- 1 PM (1 per floor, 5 total) to capture the lighting loads
- 1 PM (1 per floor, 5 total) to capture receptacle loads

(HVAC loads can be determined by subtracting lighting and plug loads from the total floor load)

As with any monitoring system, there are several options available to the electrical designer. Figure E-4, below, shows the monitoring scenario described above.

Figure E-4: Sample Building "B" Design for Meterability Case



The separation of the lighting and HVAC panels on each tenant floor adds the cost of one feeder and panelboard, but allows the designer to use individual power meters to monitor receptacle loads, lighting loads, and HVAC loads within the electrical room, which reduces the overall cost of the metering system.

Alternative metering system designs exist that will achieve the owner's metering goal for Floors 2 through 6. Figure E-5 outlines several alternative options that could be explored.

Figure E-5: Sample Building "B", Metering Alternatives for Floors 2-6

Alternative 1 **Alternative 2** **Alternative 3**

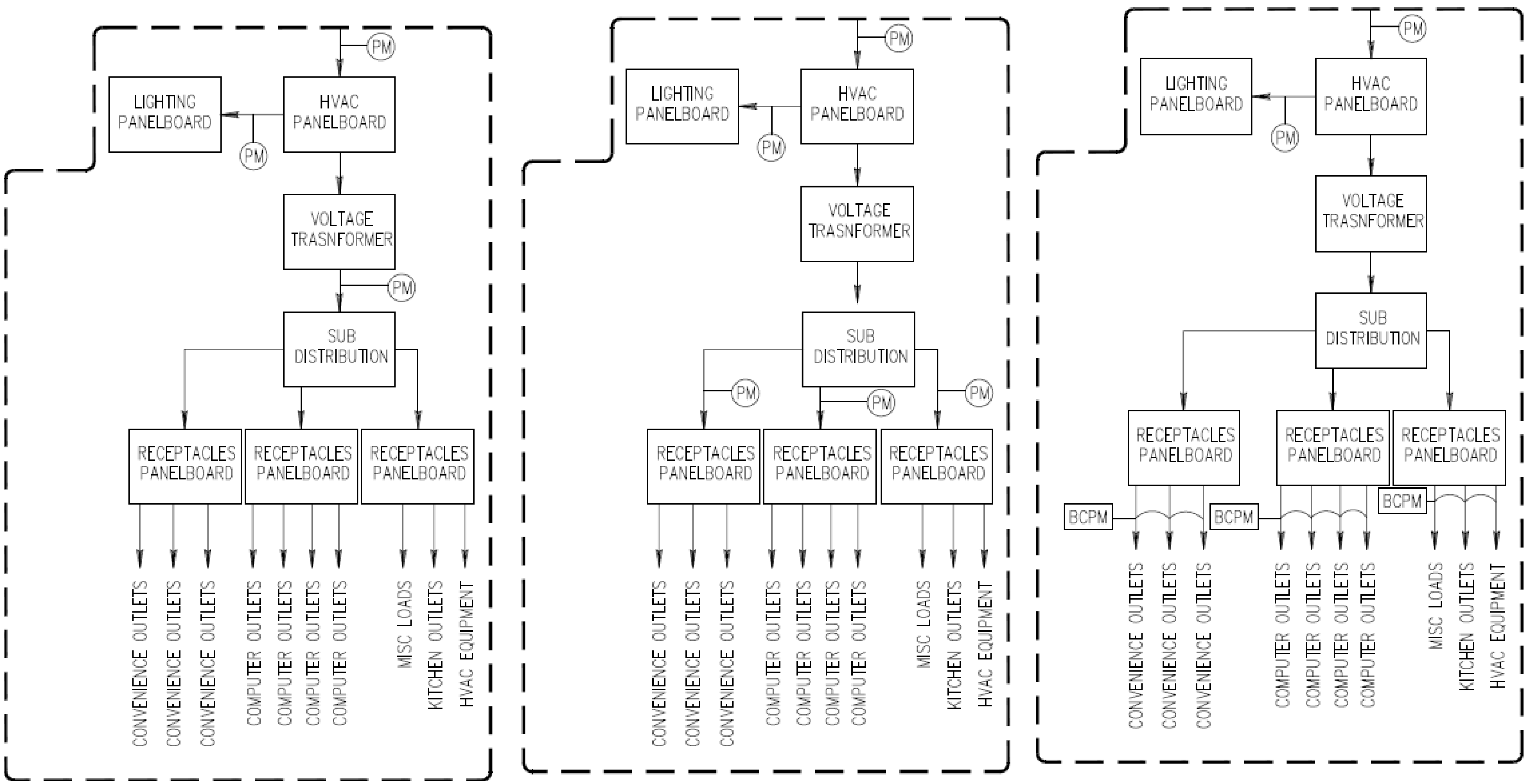


Table E-3: Total Electrical and Metering Installed Cost Comparison

	Design Cost Difference	Cost (Base Cost)	Cost (Designed for Meterability)	Cost Difference
1	**Electrical Designers**			
	Design Fee Increase	$0	$1,600	$1,600
	Net Design Fee Cost Increase			*$1,600*
2	**Electrical Distribution**			
	Additional Panelboards (7 @ $3500/each) (2 for Floor 1 and 1 for Floors 2-6)	$0	$24,500	$24,500
	Additional Feeder (1 @ $1000/each)	$0	$1,000	$1,000
	Net Electrical Distribution Cost Increase			*$25,500*
3	**Metering System**			
	Base Option	-	-	
	2 Power Meters	$2,000	-	
	1 Multi Circuit Meter	$5,000	-	
	6 Branch Circuit Power Meters	$36,000	-	
	Total Base Option	**$43,000**	-	
	Designed for Meterability Option	-	$25,000	
	20 Power Meters	-	$20,000	
	1 Multi Circuit Meter	-	$5,000	
	Total Designed for Meterability Option	-	**$25,000**	
	Net Metering System Cost Increase			*($18,000)*
	Total Project Cost Impact			**$9,100**

Table E-4: Metering Alternatives and Associated Costs for Floors 2-6

Alt #	Alternative Monitoring Plans for Floors 2-6	Disadvantage	Cost for Metering Floors 2-6
1	3 Power Meters for each floor (What is shown in selected Meterability Case)	Relatively low cost to achieve metering goal of knowing how HVAC, lighting and receptacle loads contribute to total power consumption.	3 PM/floor * $1,000/PM * 5 floors = $15,000
2	5 Power Meters for each floor	Moderate refinement in data collected. Does not allow for vast expansion of metering system.	5 PM/floor * $1,000/PM * 5 floors = $25,000
3	2 Power Meters for each floor (Total Floor Load and Lighting Panelboard) 3 Branch Circuit Power Meters for each floor (1 for each Plug Load Panelboard)	Very high cost for high level of data refinement that is probably not useful to the owner (i.e. may not be necessary to know power consumption of kitchen outlets). (Recall that a BCPM is restricted to the loads located in one panelboard)	2 PM/floor * $1,000/PM + 3 BCPM/floor * $6,000/MCM * 5 floors = $100,000

Conclusions – Sample Building "B"

The larger electrical distribution and segregation of load types based on influences other than metering goals, minimizes the need for further segregation. The initial cost of modifying the electrical distribution system (additional panelboards and feeder) is offset by the installation of a metering system that is less expensive. The additional electrical distribution equipment also provides additional capacity and flexibility, thus reducing the cost of future remodels.

Regarding the alternative designs explored, for a $10,000 increase in the price of the metering system (see Table E-4), five power meters per floor (as opposed to three) can be installed to achieve greater insight as to how the specific receptacle load types contribute to the total power consumption of each floor. There are many permutations of metering scenarios available to the designer. For $100,000, BCPMs can be installed to monitor the energy use of each outlet/circuit. Whether this level of information is useful to the owner will determine if paying the significant cost premium is beneficial.

Appendix F: Power Monitoring as an Integrated System

Electrical Design and Metering Definitions

V = Voltage
A = Current in amperes
kW = Real power in kilowatts
kWh = Energy in kilowatt hours
kVA = Apparent Power in kilovolt-amperes
kVAR = Reactive Power in kilovolt-amperes reactive

Meter: Measurement device that typical includes the following components: Calculation (meter), communication, and power supply.

Metering system: Network of meters and other networked devices that transmit to and store discreet meter data at a central location.

Circuit – the closed path conductor or wire through which electric current flows. There are two types of circuits: feeder and branch.

Feeder Circuit – a circuit that carries a large block of power from service equipment to a point where the power is broken down (i.e. a panelboard).

Branch Circuit – smaller circuits that distribute power from the service panel to point of use. In other words, a feeder supplies power to the panel or main breaker and branch circuits leave the panel to power devices.

Panelboard – component of an electrical distribution system which divides the current and provides a fuse or breaker for protection.

Feeder Meters - used to measure the electrical consumption at the whole building/campus level.

Shorting block: Switch that shorts 5 amp CT conductors to ground to reduce shock hazards to electricians. Refer to Figure 2 for graphic.

Voltage Tap: Connection from meter to electrical distribution system that allows the meter to measure voltage and may power the meter depending on the manufacturer's design. Refer to Figure 2 for graphic.

Fuse block: Equipment designed to house fuse overcurrent protection between the voltage tap and the meter. Refer to Figure 2 for graphic.

Server: A computer which houses EIS system software and is connected to the metering system network.

Real Power: the amount of power that is used by an electrical device or system.

Apparent Power: the amount of power that the utility must commit to a building or site. It includes both the real power and the reactive power.

Reactive Power: Power that is required by inductive loads such as motors.

Power Metering System Architecture

In a power metering system, data is collected at individual meters and then transmitted over a communications network to a server, where it becomes accessible to applications software. Power metering systems are comprised of three types of components: metering hardware, a communications network, and software.

Meters and Metering Hardware: Hardware includes meters, current transformers, voltage taps, and shorting blocks.

Communications Network: The communications network includes data loggers, servers, gateways, cabling between meters, Ethernet cards, switches, routers, and other similar components that communicate via standard protocols. Common protocols include EIA/TIA RS-485, EIA/TIA RS-232, and TCP/IP.

Sub Network: A smaller collection of computers and devices within a network.

Software: Software includes software modules that gather, store, analyze, normalize, and present data collected by meters within the metering system.

Meters and Metering Hardware

Meter Installation

A meter installation consists of a number of subcomponents. To determine the amount of power that is passing through a circuit, the meter must measure both the voltage and the amperage. Typically either a voltage tap or circuit breaker branch circuit supplies power to operate the meter and serves to provide the voltage reference. If a voltage tap is used, fuse blocks are required to provide overcurrent protection to the meter. Current transformers or current sensors mounted on each conductor provide the current reference to the meter. Current transformers are readily available in millivolt and 5 ampere varieties. Millivolt CTs are safer and do not require shorting blocks, but are more expensive. Not all meters have options to accept millivolt CTs or 5 amp CTs.

It is important to note that CTs are directional and typically have an arrow printed on them. The CT should be installed with the arrow pointing in the direction that current is flowing in the conductor for positive or additive metering. The CT can be turned over so the arrow points in the opposite direction for negative or subtractive metering. A common installation error is incorrect orientation of one or multiple CTs connected to a meter. Many manufacturers provide LED lights on the meters that change color based on the orientation of the CTs or use control logic which automatically determines what the correction CT orientation should be and reverses the readings of any incorrectly wired CTs.

Meter Types

The electrical designer has many types of meters available to them from a wide variety of manufacturers. The most basic power meter is capable of measuring the quantity of power being used. Other useful information may include peak consumption, interval use data, and power quality. Table F-1 summarizes the types of meter currently available.

Table F-1: Typical Meter Types and Capabilities

	Equipment	Description
	Solid State Circuit Breaker Power Meter	Power meter add-on for power circuit breakers with instantaneous voltage and current measurement.
	Advanced Power Quality Meter (APQM)	Power meter with capability to measure V, A, kW, kWH, kVA, kVAR, power factor, and provides waveform analysis.

	Power Quality Meter (PQM)	Power meter with capability to measure V,A, kW, kWH, kVA, kVAR, power factor of one single or three phase load
	Power Meter (PM)	Power meter with capability to measure V, A, kW and kWH of one single of three phase load
	Multi-Circuit Power Meter (MCPM)	Power meter with capability to measure V, A, kW and kWH of multiple single or three phase loads. Typically 3-24 loads
	Branch Circuit Power Meter (BCPM)	Power meter with capability to measure V, A, kW and kWH of multiple single or three phase loads within a single branch panelboard. Typically 42 to 84 loads

Metering Costs

Meters within an industry classification may vary significantly in features and cost from manufacturer to manufacturer. For this reason, the minimum meter requirements should be determined and matched carefully to the purpose of the metering system. In the past, metering systems were primarily intended to not only monitor power and energy but also power quality. More recently, most manufacturers have developed meters designed for energy performance metering that are significantly less expensive than traditional power quality meters.

Often manufacturers will reduce costs by removing Ethernet communications boards, reducing meter data types (power factor, V, kVA,etc), eliminating or reducing on-board memory, or providing a multi-channel meter that allows one meter to monitor multiple sets of current transformers (multi-circuit meters).

In most metering system applications intended to monitor energy consumption, measurement of peak power demand (kW) and cumulative energy consumption (kWh) is all that is necessary. In other applications, the owner may desire power quality metering as a tool to reduce risk and costs associated with power quality problems. Table F-2 indicates the relative costs for each of the meter types.

Table F-2: Relative Costs of Typical Metering Types

	Voltage	Current	Power, real	Power, apparent	Energy	Power factor	Waveform capture	First Cost	Cost per Point
Solid State Circuit Breaker Power Meter	X	X	X		X			$	0.8x $
Advanced Power Quality Meter	X	X	X	X	X	X	X	6x $	6x $
Power Quality Meter	X	X	X	X	X	X		2x $	$
Power Meter	/	/	X		X	/		$	$
Multi-circuit Power Meter	X	X	X		X			5x $	0.2x $
Branch Circuit Power Meter	X	X	X		X	X		6x $	0.1x $

(Note: / indicates that not all meters of this type are provided with this metering functionality)

Metering Accuracy

Metering system costs are impacted by system accuracy requirements. Overall meter accuracy is determined by summing the meter's calculation accuracy and the current transformer's accuracy. Meters with matched CTs (from the same manufacturer) often have better accuracy than units where CTs are purchased independent of the meter.

It is important when selecting CTs to evaluate the accuracy of the CT as well as the range of that accuracy measurement. A Typical CTs rating maybe 1% accuracy from 10-100% of rated current. Often CTs are sized based on the maximum connected code calculated circuit load. This is done to prevent overloading and damaging the CTs. In reality, many of the loads will not draw their full rated power and will be turned off at various times throughout the day. Therefore, a CT may need to provide accurate readings at relatively low current levels. CT selection is important, as accuracy can diminish as the load drops.

Mounting Considerations

Meters can be mounted on DIN rails within enclosures, located in a separate enclosure, or mounted in switchboards or panelboards. Panel or switchboard mounting is generally desired for new construction due to its durability and space efficiency. However, this limits networking options to those that can provide 600V switchboard rated communications cabling (RS-485). In retrofit applications, meters can be purchased that include fusing and shorting blocks saving labor and minimizing common installation errors.

Power Quality Issues

An in-depth discussion of power quality design and monitoring is beyond the scope of this document but it should be noted that power quality can impact the metering system design. Power quality metering systems have the capability to measure and record transient voltage events, harmonics, power factor as well as other power quality information.

Utilities must commit generation resources to meet both the real power and reactive power that a building consumes. Since utilities traditionally only bill for real power and energy consumed, they may levy additional charges to a building with a low power factor. This is done to recover the cost of generating power to meet reactive power loads which the utility doesn't bill for. Measuring power factor would allow owners to determine if their power factor was low and take corrective action.

Harmonics and transients are electrical events that can damage electrical devices and equipment. Transients are momentary electrical surges caused by harmonics, faults, lightning strikes or other electrical anomalies. Harmonics result from modern electronics' power supplies and can cause sustained and damaging overvoltage events.

Often power meters can be upgraded to power quality meters for an additional few hundred dollars. An Owner may desire to upgrade meters near sensitive electronics or at the main switchboard to power quality type if given the choice.

Communications Network

Each meter transmits the data it collects via the communications network. The communications network consists of hardware devices, cabling and communications protocols.

Communications Hardware

Table F-3 lists some examples of communications hardware that is available, and the functions they perform.

Table F-3: Typical Communications Hardware

	Equipment	Description
	Data Loggers	Sums instantaneous measurements and/or stores data from multiple meters. Can be permanent or temporarily installed.
	Gateways	Interface between separate networks and sub networks (ie: RS-485 to TCP/IP). Gateways can include protocol conversion (ie: Modbus to Bacnet).
	Servers	Downloads meter data from individual meters. Servers can either host metering system software or push metering system data to a software vendor over the Internet.

It is possible that telecommunications network outages or a server failure may result in loss of meter data if metering hardware does not have on-board memory. Designers can specify dataloggers or meters with onboard memory to mitigate this risk. Once normal operation of the network is restored the data stored in the dataloggers or meters can be gathered by the metering system.

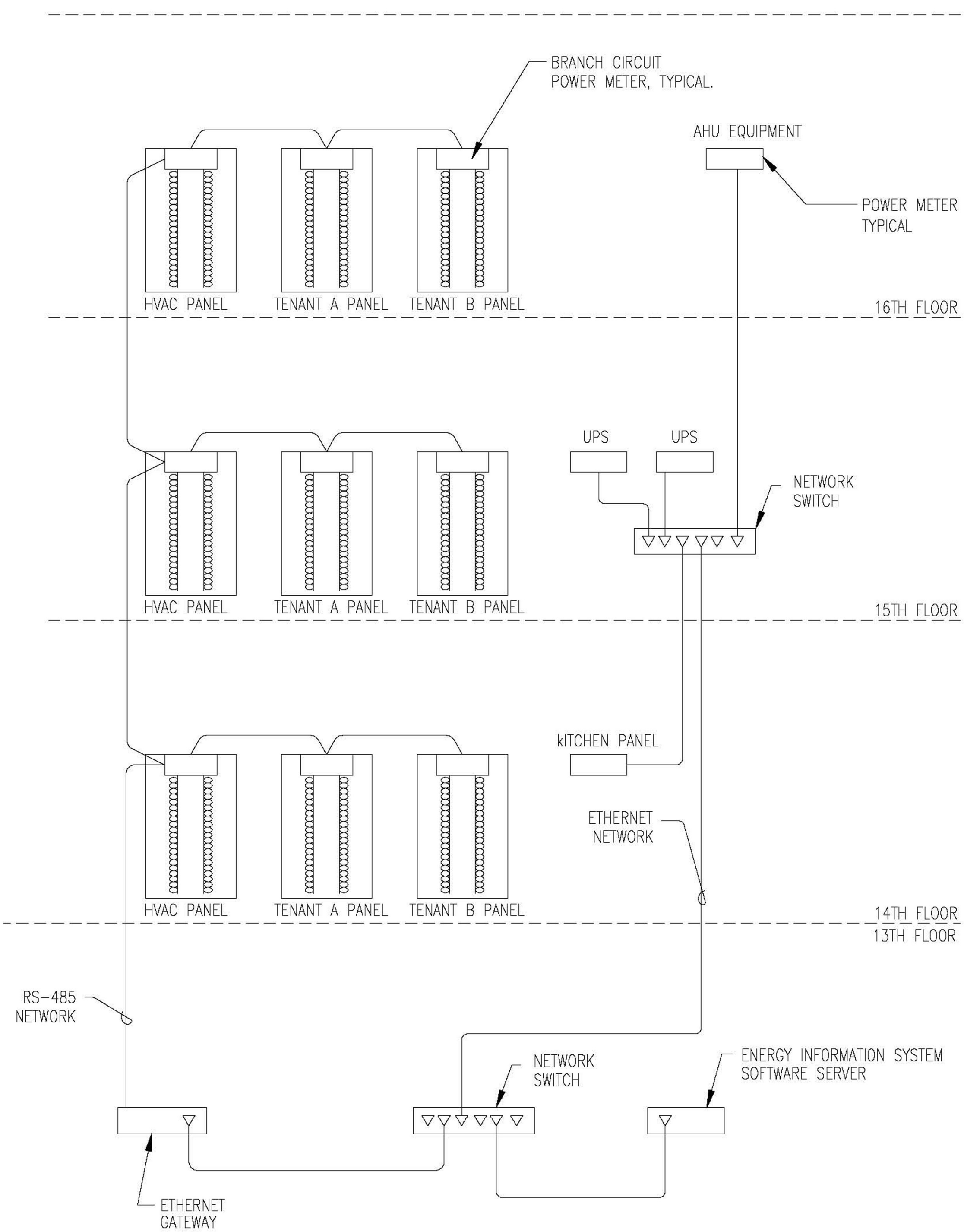
Meters typically support either Bacnet, Lonworks, or Modbus protocols. If the metering system also uses meters within OEM equipment, it is likely that the metering system will have to support multiple protocols. Multiple protocols increase metering system hardware and startup expense.

Network Characteristics

Metering system networks may be RS-232, RS-485, Ethernet, wireless (RF) or some combination of all of these. Large metering systems may have multiple sub-networks. RS-485 networks are limited to maximum of 32 devices in theory, but limiting networks to 26 devices is generally a good rule of thumb.

Figure F-1 illustrates an example of how meters can be networked together. In this example, both an RS-485 network and Ethernet network are shown.

Figure F-1: Example of a Metering Communications Network



Wireless Networks
The cost difference between wireless and wired metering system network options is less significant in new construction. In existing buildings, the cost differences between these network options should be evaluated carefully when specifying a system. Wireless systems come in two varieties: wireless meters and wireless pulse transceivers.

- Wireless meters communicate directly with the metering system via wireless signals.

- Wireless pulse transceivers transmit data to the metering system server from meters connected to a common RS-485 sub-network.

Wireless systems can be very flexible and eliminate the need to pull new cabling in existing buildings; however, wireless meters cannot be installed in panelboards or switchboards. Wireless metering systems in general share the same transmission design challenges typical of all wireless networking. These may include issues such as poor signal strength in some locations and protection of data.

Use of the Building Network
Metering systems that are designed to use the building telecom network may find that the telecommunications network is not operational early enough in a project to allow adequate time for metering system startup and commissioning prior to occupancy. For this reason, metering system manufacturers and integrators typically prefer to install a separate network for metering systems rather than use the project's telecommunications network. This represents an additional project cost that can be eliminated if installation of the building telecom network can be expedited.

Software

Metering system software products are available from meter manufacturers as well as independent software companies. These systems are often known as Energy Information Systems (EIS) or Dashboard systems. Software packages range in cost from free-of-charge to over $50,000. Similar to meters, it is important to determine the minimum requirements of the software. Metering system software typically includes alarming, data storage, data analysis tools, graphing tools, system reports, and meter configuration tools. Additionally, some software packages include financial analysis, data normalization tools, and billing capability.

Pricing Software Systems
Metering system software capability varies widely; however they are typically available in two pricing models: Traditional and Software-as-a-service. Traditional software models typically have a higher first cost, but lower operational costs.

- Traditional Software Models: a software license is purchased based on the number of meters and installed on a local server. This server can be owner furnished or manufacturer furnished. The owner is responsible for maintaining the server as well as paying for any software upgrades desired in the future.

- Software-as-a-service model: the owner pays an annual or monthly fee, typically based on the number of meter points. The owner is supplied with a server which pushes the meter data to the software vendor's off-site servers via the Internet. In this model hardware and software are maintained and upgraded by the software vendor.

Presentation of Data

A critical design concern for metering system software is data presentation. There is a danger as more meters are added that the owner will be inundated with data. One strategy to minimize the amount of data that the owner views is to aggregate multiple hardware meters into one virtual meter within the software. For example, all the lighting meters in a building could be aggregated into one meter called "lighting" in the software. This allows the owner to monitor one point to determine if their lighting system is performing. If problems are detected, they can still review the individual hardware meters' data associated with the "lighting" virtual meter.

Virtual meters created within software also allow designers to automatically add and subtract hardware meter data. In Figure F-2, the lighting branch panel loads can be subtracted from the serving branch panelboard in order to separate the HVAC loads from the lighting loads. This minimizes the impact of metering on the electrical distribution design by eliminating the requirement that branch panelboards be fed individually from distribution panels.

Figure F-2: Additive and Subtractive Virtual Metering