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Healthcare Energy Efficiency Research And Development

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Jerry Brown
Governor

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PIER PROJECT REPORT

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-654-4878.

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Abstract

Hospitals are known to be among the most energy intensive commercial buildings in California. Estimates of energy end-uses (e.g. for heating, cooling, lighting, etc.) in hospitals are uncertain for lack of information about hospital-specific mechanical system operations and process loads. Lawrence Berkeley National Laboratory developed and demonstrated a benchmarking system designed specifically for hospitals. Version 1.0 featured metrics to assess energy performance for the broad variety of ventilation and thermal systems that are present in California hospitals. It required moderate to extensive sub-metering or supplemental monitoring. In this new project, we developed a companion handbook with detailed equations that can be used to convert data from energy and other sensors that may be added to or already part of hospital heating, ventilation and cooling systems into metrics described in the benchmarking document. This report additionally includes a case study and guidance on including metering into designs for new hospitals, renovations and retrofits.

Despite widespread concern that this end-use is large and growing, there is limited reliable information about energy use by distributed medical equipment and other miscellaneous electrical loads in hospitals. This report proposes a framework for quantifying aggregate energy use of medical equipment and miscellaneous loads. Novel approaches are suggested and tried in an attempt to obtain data to support this framework.

Key words: benchmarking, commercial buildings, end-use, energy utilization intensity, health care, hospitals, medical, miscellaneous electrical load, tertiary care

Executive Summary

Introduction

Hospitals are among the most energy intensive of all commercial buildings in the U.S. and the healthcare industry as a whole represents a substantial fraction of total U.S. commercial building energy use. While healthcare facilities have many special characteristics that lead to higher energy consumption, there is broad recognition among knowledgeable designers and operators that energy use can be reduced substantially with net economic benefit to the industry. Energy benchmarking has proven to be an effective tool to improve energy efficiency in other high-tech buildings. A preliminary hospital energy benchmarking system developed by LBNL advanced these goals but lacked the detailed guidance required for widespread adoption and use by facilities engineers and energy managers.

Among hospital energy engineers and energy managers, there is a belief that electronic medical equipment and other miscellaneous electric loads account for a large and growing fraction of total electricity use in hospitals. Top-down estimates of energy use by such equipment in individual hospitals vary widely and are highly uncertain. Bottom-up estimates can not only help to reduce that uncertainty, but also help in the identification of the devices that use the most energy in aggregate and illuminate opportunities for energy savings.

Objectives

The overall goal of this project was to conduct research to advance energy efficiency in the healthcare sector. Specific objectives included the development of tools to advance hospital energy benchmarking and the development and demonstration of methodologies to quantify energy use of medical equipment and other miscellaneous electrical loads in hospitals.

Approach

Guidance documents to advance hospital energy benchmarking were developed by LBNL and collaborators based on input from hospital design engineers, facilities engineers and others working in the field of healthcare energy efficiency.

Based on the general approach used for miscellaneous loads in other commercial buildings, we developed a framework for quantifying power and energy consumption rates of medical equipment and miscellaneous electrical loads in hospitals. We worked collaboratively with staff from Stanford University Hospitals and Clinics and the Lucille Packard Children's Hospital to identify, understand and overcome challenges in adapting techniques for equipment inventory, use and power consumption data collection to the hospital environment.

Results

A peer-reviewed companion document to the LBNL benchmarking guidance was developed by collaborators Mazzeti Nash Lipsey Burch (MNLB) through a case study of integrating energy end-use sub-metering into the design phase of a new hospital and also presents a cost estimate for installing energy end-use sub-metering in a hypothetical, typical existing hospital.

LBNL responded to MNLB companion document reviewer comments by creating a Hospital Energy Benchmarking Handbook that clearly and explicitly shows the equations for calculating

the major energy end-use benchmark metrics. For clarity all data point names are either completely or nearly completely spelled out, and the few acronyms that are used follow common building control system point naming conventions.

We advanced the state of knowledge about medical equipment energy use in several ways. First, we identified and demonstrated that facilities inventories maintained for property management purposes could be utilized to obtain information about electrically powered beds and other equipment used for medical purposes. Tracking systems used to ensure regular maintenance and calibration of diagnostic and treatment devices were used to quantify the prevalence of these devices. And records of the information technology department were used to quantify the number of computers and peripheral devices.

We identified barriers to direct equipment monitoring in hospitals. These include (1) concerns about placing any device (e.g. a logging power meter) inline with the power supply to any device used for patient care, (2) the fact that many medical devices are mobile and moved frequently for use in different areas of the hospital, creating logistics issues with recovering any metering device, and (3) patient privacy concerns that increase the logistical costs of researchers gaining access to verify equipment inventories and install even non-invasive activity monitors.

Several alternative approaches were developed in an effort to obtain data on medical equipment energy use. We developed a protocol for hospital biomedical technicians to acquire data on power consumption during standby, operating and peak power modes. Data were obtained for roughly 130 individual devices covering roughly 30 device categories. We installed power meters to log activity in a medical treatment simulation facility; the intent was to extrapolate equipment and energy use during the simulated procedure to estimate aggregate energy use for all such procedures conducted at a hospital. While this approach did not result in useful data in this study, it could potentially be revisited in future studies.

With the objective of overcoming barriers to in-line metering, we developed and constructed a prototype logging current sensor that can be attached non-invasively to the power cord of any electronic equipment and calibrated to differentiate between any two desired levels of current induced electrical field. With two of these sensors, it would be possible to distinguish lower power standby and higher operating power modes for many devices.

Benefits to California

The tools and methodologies developed in this project will advance efforts to understand and reduce energy use in California hospitals. Improving energy efficiency will enable California hospitals to devote more resources to patient care and less to paying energy bills.

1.0 Introduction

Hospitals are known to be among the most energy intensive commercial buildings in California and throughout the U.S. Results from the Commercial End Use Survey (CEUS) indicate a median energy intensity of 470 kBtu per square foot per year for California hospitals. Both the CEUS and the national Commercial Building Energy Consumption Survey (CBECS) provide estimates of hospital energy consumption resolved by end-use. The largest end-uses are reported to be space cooling, space heating, domestic hot water, and ventilation. Yet the specific estimates are uncertain since the simulation (CEUS) and statistical (CBECS) models used to derive these estimates lack information about hospital-specific mechanical system operations and process loads. There is a dearth of information about the amount of energy used by medical equipment including both the high-power imaging systems such as MRIs and the smaller equipment that is ubiquitously distributed throughout hospitals. Owing in part to uncertainty in attribution, efforts to reduce energy use in hospitals typically focus on discrete measures and technologies that may ignore the most energy intensive systems and the largest opportunities for savings.

With support from the California Energy Commission, Lawrence Berkeley National Lab developed a research, development and deployment (RD&D) roadmap for high performance, energy efficient health care facilities (Singer and Tschudi, 2009). The effort included a literature review (Singer, Coughlin and Mathew, 2009) and stakeholder input process. The roadmap considered the special challenges facing hospitals and identified a range of RD&D needs. Priority challenges identified in the road map included improved understanding of end-use energy based on measured data from existing hospitals, measurements of medical equipment energy use, guidance for energy monitoring, accessible compilations of best practices and case studies, strategies to reduce reheat energy use, and long-range research on advanced heating, cooling and ventilation systems.

This research project was intended to advance research tools and knowledge in several areas critical to improving energy efficiency in hospitals. These are described in the following sub-sections. The planned work scope was adjusted as challenges with the second major focus area – medical equipment energy use – necessitated substantially more resources than originally planned.

1.1. Hospital Energy Benchmarking

To advance understanding of hospital energy end use, Lawrence Berkeley National Laboratory (LBNL) and Mazzetti, Nash, Lipsey, Burch (MNLB) worked collaboratively to develop an energy benchmarking system for hospitals (Singer et al., 2009). The first stage of development focused on defining a suite of metrics that could be obtained and provide useful energy performance information for the broad variety of ventilation and thermal (cooling, heating, domestic hot water and steam) systems that are present in California and U.S. hospitals. The pilot benchmarking system required moderate to extensive sub-metering and/or supplemental monitoring. Pilot implementation of this approach was demonstrated at a single Northern California hospital. The system provided a solid conceptual foundation for energy assessment and for the design of hospital energy monitoring systems.

A key conclusion of the initial benchmarking development project was that installation of sensors linked to a building management system (BMS) during construction or major renovation projects is especially valuable given the high costs of installing equipment into an existing facility. Such monitoring equipment can provide an ongoing record of energy use and help quantify the benefits of energy saving measures. Installed systems can provide data streams for ongoing benchmarking system development. Industry advisors to the RD&D road map indicated that guidance and recommendations for a standard package would greatly facilitate such systems being included in new construction projects.

One broad goal of the research project described in this report was to advance development of tools for hospital energy benchmarking. Priorities included trial implementation at additional facilities and the development of a database of performance measurements to use in setting of benchmarks. A specific objective was development of a guidance document for design engineers to include energy monitoring equipment in designs for new hospitals and major renovation projects. The intent was to build upon existing guidance documents including the "Specifications Guide for Performance Monitoring Systems" developed by LBNL, PG&E and others (http://cbs.lbl.gov/performance-monitoring/specifications/). Other specific objectives included in the original work plan were scaled back or eliminated as unforeseen challenges and re-prioritization of goals necessitated that more resources be allocated to the development of techniques for quantifying medical equipment energy use.

1.2. Medical Equipment Energy Use

There is much concern that medical equipment comprises a substantial and sharply increasing fraction of energy use in hospitals. At the time that this project was initiated, there was scarcely any reliable, information about the energy use of such devices. Reliable information was lacking for the total magnitude of energy use within given facilities and for detailed breakdowns of use by equipment class. There were no meaningful bottom up estimates that aggregated measured or estimated energy consumption of individual devices, and top down estimates were derived from subtracting relatively uncertain estimates for other electrical loads (e.g. cooling, lighting, etc.) from uncertain total electrical use rates for hospital buildings. The collection and analysis of data related to medical equipment energy use was identified as a high priority in the roadmap for energy efficient hospitals (Singer and Tschudi, 2009).

While much attention is typically focused on high-powered medical imaging devices such as MRIs, other devices may be important based on their number (e.g. beds) and/or use patterns (e.g. laboratory analytical instrumentation). Also, while the concern is often characterized as relating to medical equipment, it must be recognized that such devices are just one category of miscellaneous electrical loads (MELs). In hospitals, MELs include three broad categories or types of devices: those with a uniquely medical function, devices which can have non-medical function but are used for in hospitals for purposes of medical care, and electrical devices without a direct medical function. Examples of devices with a uniquely medical function include those that contribute to patient care, e.g., through diagnosis or treatment. These include patient monitors, patient beds, and infant warmers, among others. Devices that have non-medical application but are used for medical purposes include refrigerators, microwaves, and computers, among others. Finally, devices such as vending machines, televisions, and water fountain chillers exemplify devices without a direct medical function.

A major goal of this study was to develop and demonstrate methodologies to quantify power and energy use both for uniquely medical devices and for devices with non-medical purposes that serve medical functions. Relevant to this goal, the following specific objectives were identified in the initial proposal:

a. Identify one or more medical institutions that will provide access for collection of data on equipment prevalence in agreed-upon areas of the hospital, and offer support by medical staff to understand equipment use patterns

b. Develop a data collection plan in consultation with hospital medical staff. The intent was for the plan to include cataloging of devices observed to be present in representative sub-areas of the hospital and logging of time-resolved power consumption for selected devices.

c. Implement the data collection plan to determine equipment prevalence and use patterns.

d. Estimate aggregate energy consumption for selected high-use equipment and as funds allow, investigate the potential to reduce energy consumption through improved design (e.g. to reduce stand-by losses.)

1.3. Technical Support to Advance Healthcare Energy Research

The objective of this task was for LBNL to engage in technical support activities to advance research and development for healthcare energy efficiency. The intent was to support work at a level of effort much smaller than the tasks noted above and depending in large part on the challenges and costs required to achieve them. As the effort required for developing methods to quantify medical equipment energy use required so much additional effort, few resources were available for this task. The one exception is noted below.

Energy efficiency standards for California hospitals. California hospitals are currently exempt from the energy-related requirements (Part 6) of California's Building Standards Code (Title 24 of the Code of Regulations). Hospital building codes and permits are issued by the Office of Statewide Health Planning and Development (OSHPD). An executive order by the Governor directed relevant state agencies to establish green building standards for all buildings in California (as Part 11 of Title 24). Standards for hospitals are recommended by OSHPD (to the CBSC) based in large part on recommendations of the Hospital Building Safety Board and a sub-committee tasked to examine the issue. While some provisions of the Part 6 energy requirements are incongruent with hospital health and safety constraints, there is growing recognition that it is technically feasible to apply many of the provisions to hospitals. LBNL organized a meeting of leading hospital designers to provide input to OSHPD for the 2010 code cycle.

2.0 Methods

2.1. Hospital Energy Benchmarking

As described above in the Introduction and subsequent report sections, the original work plan for this project had to be revised and effort reallocated in reaction to unforeseen challenges and resource requirements in the medical equipment task. We present here the original work plan for advancing hospital energy benchmarking – including unrealized elements of the plan – as a potential guide for future efforts.

The focus of this task was to advance the hospital benchmarking system. Priority issues identified during development, expert review and pilot implementation included the following: demonstration and validation of techniques to extrapolate from short-term monitoring of cooling and heating system performance metrics to annual values (accounting for seasonality); development of data collection tools and detailed protocols; development of methods to measure steam energy provided through district systems; monitoring of high voltage electrical distribution panels and medical equipment; and strategies for staged monitoring and estimation procedures when monitoring equipment is limited. Implementation guidance on monitoring system options for existing facilities, and mining of existing information sources to obtain data for metric comparisons were identified as key development priorities.

As a preliminary planning exercise, LBNL identified several sources of potentially useful system-level hospital energy use data that are based on direct monitoring and/or consideration of specific equipment and use patterns at acute care facilities. These sources include energy audits and assessments conducted for California utility energy savings incentive programs and research and development work supported by the Northwest Energy Efficiency Alliance (NEEA). LBNL has had discussions with Pacific Gas & Electric (PG&E) about applying the benchmarking system as part of the energy audit service that they provide to hospitals as part of their portfolio of energy efficiency programs. The intent was to attempt to obtain and if obtained, analyze these data sources for their potential to contribute to databases of energy use metrics. This task was ultimately not pursued in this research project but it should be considered in future efforts.

Work on this task focused on development of two tools to advance hospital energy benchmarking efforts. The first is a supplement to the existing benchmarking guidance document that provides detailed and specific equations for calculating energy metrics from measurements or other collected data. The second tool is a guidance document intended to aid hospital design engineers in specifying metering devices to be installed during construction or renovation. Permanent monitoring equipment can provide an ongoing record of energy use and help quantify the benefits of energy saving measures. Installed systems can provide data streams for ongoing benchmarking system development. A key conclusion of the initial benchmarking development project was that installation of sensors linked to a building management system (BMS) during construction or major renovation projects is especially valuable given the high costs of installing equipment into an existing facility. Industry advisors to the RD&D road map indicated that guidance and recommendations for a standard package would greatly facilitate such systems being included in new construction projects. This guidance document was developed by design engineers at MNLB and vetted through a peer review process.

2.2. Hospital Medical Equipment Energy Consumption

2.2.1. Planned methods

The original work plan was to adapt and apply to hospitals the techniques used to estimate miscellaneous electrical loads (MELs) in other high-tech commercial buildings. This basic approach involves collecting data on two key parameters: device prevalence, and energy consumption per device. Device prevalence is typically assessed through observation supported density estimates providing the number of devices per worker, per square foot of floor space or for some other metric of space and utility. The function of the space is a key parameter. Energy consumption per device can be measured directly by monitoring / metering or calculated based on measurements of power consumption by mode and estimates or measurements of use time for each operational mode. For example, energy consumption for a computer display is calculated as the product of in-use power consumption and time of use. The calculation is expanded to include energy consumption during standby operation when the power consumption during standby is high and/or when the majority of time is spent in standby.

For this project, the plan was to conduct visual inventory assessments and install metering devices on in-use medical equipment in hospitals. The plan was for LBNL to work collaboratively with MNLB and hospital partners who would provide access and guidance on distributed medical equipment use patterns. The plan was to obtain information about the distributed medical equipment present in hospitals and about the power and energy use of this equipment. The plan was to begin with a census of the medical equipment present in selected patient room and diagnostic and treatment areas. Census information was to be combined with information provided by MNLB equipment experts and medical staff about the operational levels for which power measurement should be made. The plan was to work with medical staff to understand how the equipment is used and to operate the equipment through simulated typical procedures and/or all standard modes that vary in power consumption. The intent was to develop a database to develop estimates of aggregated medical equipment energy use, and to provide data that will help drive the development of more energy efficient medical equipment. Specific objectives of the initial plan are described in the Introduction.

2.2.2. Revised plan: Method development as focus of project

The objectives and tasks outlined above were based around the assumption that information about medical equipment energy consumption could be obtained by adapting methodologies used to study MELs in other types of high-tech commercial buildings.

Relatively early in the implementation phase, it became clear that typical MELs approaches could not be applied to hospitals for several reasons. The approach of conducting visual inspections to inventory devices was deemed both unworkable owing to privacy-related access limitations, and unsuitable owing to the extraordinary diversity of functional areas in hospital buildings. The diversity and specificity of functional areas presented an additional challenge in defining common areas in which typical equipment prevalence could be established and inter-compared among hospitals. Owing to these and other hospital-specific challenges, the medical equipment energy task became the major focus of work on the overall project, and the task focus was shifted to the development and demonstration of methodologies for quantifying power consumption and energy use of these devices. Since method development was the focus, the actual methods explored, developed and implemented are results of the project. This material will therefore be presented in the Results section.

Preliminary planning and work on this task was conducted through collaboration with MNLB. The Stanford University Medical Center's Stanford Hospital and Clinics (SHC) and the Lucille Salter Packard Children's Hospital (LPCH) generously agreed to assist in the project and staff at those institutions provided information, access as allowed, technical support, suggestions, and various other forms of assistance throughout the project. Critically, the staff at SHC and LPCH helped guide us through the many regulatory and other barriers to collecting data on device prevalence and energy use in hospitals. These institutions provided equipment inventories and conducted measurements of power consumption levels for medical devices in connection with calibration and maintenance activities. Details about the methods used are provided in the Results section.

3.0 Results and Discussion

3.1. Hospital Energy Benchmarking Tools

3.1.1. Implementing the LBNL hospital energy benchmarking protocol

Collaborators at Mazzeti Nash Lipsey Burch (MNLB) created a companion to the Version 1.0 LBNL Benchmarking Guidance entitled "Implementing the LBNL Hospital Energy Benchmarking Protocol"; this document is provided as Appendix A to this report. The companion document was developed through a case study of integrating energy end-use sub-metering into the design phase of a new hospital. The guide covers the many decisions faced by designers in cost-effectively including sub-metering during the design phase. In the end, the hospital owner chose not to install sub-meters due to the cost and uncertainty of the benefits. The MNLB document also presents a cost estimate for installing energy end-use sub-metering in a hypothetical, typical existing hospital. A draft version of the document was distributed to peer reviewers including hospital facilities operators and building energy researchers. Reviewer comments were considered in preparing the final version provided as Appendix A.

3.1.2. Hospital energy benchmarking handbook

Feedback provided in the peer review of the implementation evaluation prepared by MNLB indicated that the Hospital Energy Benchmarking Guidance created by LBNL would be improved by making it more straight-forward and user friendly for facilities operators to implement. LBNL responded to this by creating a Hospital Energy Benchmarking Handbook (see Appendix B) that clearly and explicitly shows the equations for calculating each benchmark metric. For clarity all data point names are either completely or nearly completely spelled out, and the few acronyms that are used follow common building control system point naming conventions.

A method for apportioning central plant loads to the separate medical buildings being served by the central plant is also shown. This is done by using the median value of energy intensity of a particular thermal load for each of three healthcare building types—hospital, clinic, and medical office building. The median values of energy intensity are provided by the CBECS database and can be used as weighting factors for apportioning central plant loads by floor area and building type to the various healthcare buildings being served. This method needs to be evaluated on an actual medical campus with sub-meters on central plant loads and the loads at each building before being extensively applied.

3.2. Framework for Quantifying Medical Equipment Energy Use

3.2.1. Proposed framework

In developing a framework for quantifying energy consumption of medical equipment, we started with generic methodologies developed for miscellaneous electrical loads in other commercial buildings (Kawamoto et al., 2002). Figure 1 shows the basic framework for quantifying the energy consumed by MELs using a bottom-up approach. The approach is to calculate aggregate energy use from three component data sources: (1) power consumption in each operating mode for each device, (2) amount of time spent in each operating mode, and (3) total prevalence or device density, based on a spatially resolved inventory. To begin, data is collected about the device's power consumption in each of its operational modes. Sources can include existing data (e.g., from manufacturers) or data collected expressly for the research study (e.g., with logging power meters). The calculation of energy consumption by MELs also has a time element, and requires data about the amount of time spent in each operational mode throughout some given time period. This time period needs to be long enough to reflect "typical" use and long enough to capture variability over relevant time scales, e.g. diurnal and weekday vs. weekend variations. For medical equipment used in hospitals, a one-week period should be considered as a minimum and multiple weeks is preferred. The product of the power use in each mode and the time spent in each mode yields the energy consumed by a single device over a given time period. Multiplying that energy consumption by the total number of devices allows calculation of cumulative energy consumption for a given device at the hospital. Alternatively, we can multiply the energy consumed by a single device over a given time period by the spatial density of devices, to yield an End Use Intensity (EUI) [kWh/ft^2] for each device. The summation of each of the devices' EUI yields a MELs EUI for the hospital.

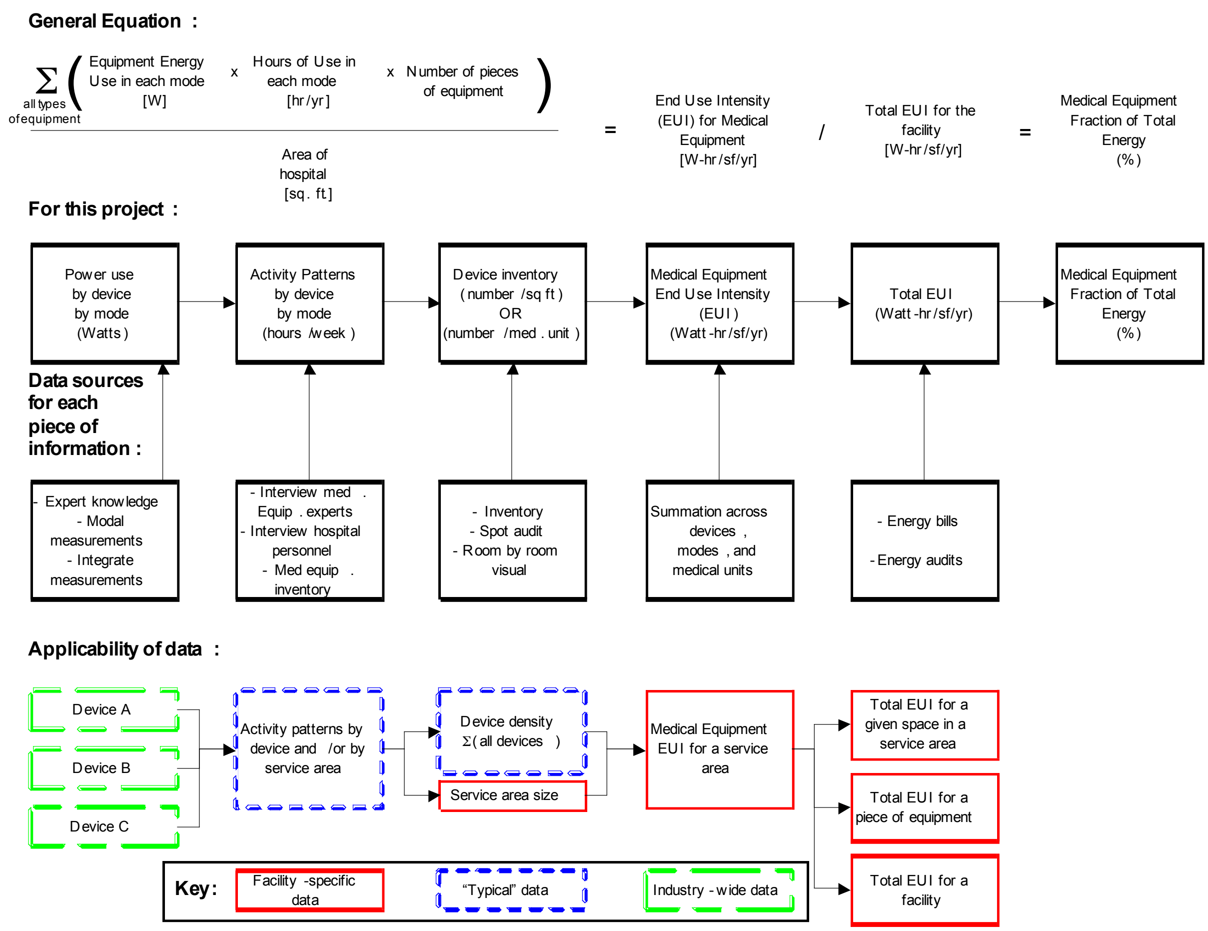

Figure 1. Framework for medical equipment measurements in hospitals

In principle, the data necessary to quantify medical equipment energy consumption can be collected with one of two basic approaches: (1) separately obtain information on power use in each operational mode and time spent in each mode for a sample population of devices, or (2) take accurate time-resolved measurements of power use for a sample population of devices. The former has the advantage of being obtainable with less accurate time-resolved metering. The latter is more direct. In either case, the variability among different makes and models (e.g., different generations) of devices that perform a given function (e.g., patient bed, infant warmer, IV pump, etc.) can be measured. Moreover, the variability in use patterns can also be measured. The variability in use patterns is assumed, in many cases, to be correlated with medical service (e.g., the different activity pattern of a ventilator in an ICU as compared to a ventilator in radiology).

As part of either approach, the first step in data collection is to conduct a range finding analysis to prioritize data collection efforts; this should be based on preliminary estimates of device prevalence, preliminary measurements or estimates of power consumption for any device with substantial prevalence and preliminary measurements or estimates of the time spent in each operating mode for any device with substantial prevalence. Those devices that show the potential for substantial contributions to aggregate energy use should be the focus of monitoring efforts.

3.2.2. Organization of hospitals

The initial vision was that the approach outlined in Figure 1 could be applied to defined functional areas within hospitals. The intent was to relate MELs to activities, and in turn, to spaces in support of calculating equipment energy use intensity, e.g. as kWh per square foot of facility space per week. There were several reasons for this approach. One objective was to designate areas that could be surveyed and sampled in tractable manner. Second was the hypothesis that equipment prevalence and use should vary with medical functionality. The third rationale was the recognition that since hospitals vary in the suite of medical services they provide, comparisons between hospitals are most suitable if they could be at the level of common medical services.

To explore the feasibility of analysis by function area, we consulted medical professionals to understand the activities that occur in hospitals, the devices these activities require, and where these activities occur. Activities in hospitals can be classified first as medical or non-medical. A medical activity can be sub-categorized as diagnostic, treatment, or recovery. Non-medical activities include administrative services, food service, non-patient service (e.g., services for visitors), and others. Similar to other commercial buildings, these activities can be related to specific spaces; that is, food service typically occurs in a kitchen or cafeteria setting, administrative services often occur in office spaces, etc. While hospitals certainly include more activities and space types than other commercial buildings, researchers can nonetheless relate this broader portfolio of activities to the variety of spaces in a hospital. An approach that links equipment energy consumption to defined functional areas may be particularly beneficial in a hospital, as device activity patterns may vary with medical services provided. Devices may perform the same activity, but have a distinct *activity pattern (*i.e., different patterns of use), in different places in the hospital. For instance, a ventilator will likely have a different activity pattern in the Intensive Care Unit (ICU) than it would in a radiology space.

Hospitals are physically organized into service areas that perform a specific medical purpose and administratively organized into departments that perform support activities.

Service areas

Patients "flow" through service areas in a hospital (shown on a hospital map), each of which serves a medical purpose. While nomenclature and specific boundaries may vary, typical service areas found in many hospitals include medical surgery, labor and delivery, radiology, pediatrics, emergency, orthopedics, etc. Hospitals have on the order of tens of service areas, and these are often listed on the hospital's website. A service area may incorporate special services as well. For instance, "medical surgery" is a service area that has multiple specialties (e.g., pediatric surgery and orthopedic surgery). Moreover, each service area may have distinct spaces associated with it. Service areas may contain: (1) a pharmacy, (2) a medicine room, (3) patient rooms, (4) nurses stations, (5) procedural rooms, (6) laboratories, and (7) a supply room. Some services may require specialized devices that are specific to the service being provided, or may use a device differently in their area than in other areas. On the one hand, the medical imaging service area may be the only service that requires a magnetic resonance imaging machine. On the other hand, the medical imaging and the labor and delivery service areas may both require ultrasound machines, though these may have different activity patterns in each service area.

Departments

Departments are the administrative units of a hospital. These may be the administrative arms of a service area or sub-service area or they may be non-medical departments, e.g., Accounts Receivable (a financial department). Thus, hospitals may have on the order hundreds of departments, compared to tens of service areas. Whereas service areas have the responsibility of operating medical equipment for patient care, the purchasing of medical equipment happens at the department level. Thus, departments own medical equipment while service areas operate it. In consideration of these organizational structures, medical equipment and MEL tracking in hospitals is more directly relatable to service area. In comparing hospitals, similar service areas generally should include a similar suite and density of devices even if the number exact densities and activity patters vary. Density in this case is most meaningfully related to the number of patient beds. Activity patterns also are likely to be more similar for the same service area in different hospitals than they are across different service areas within the same hospital.

3.3. Special Challenges and Opportunities in Hospitals

Working with the team at SHC and LPCH, we learned that the standard MEL methodologies described above could not be applied directly or even adapted to hospitals; fundamentally different methods were needed. The special characteristics of hospitals make some elements of this approach prohibitively difficult and/or limiting; other elements are completely infeasible. The first limiting element is access to catalog equipment. In most buildings, device prevalence can be cataloged in a smaller area that is considered as representative of some larger area; this typically occurs during off-hours, but can be accomplished during occupied periods when necessary. In hospitals, most functional areas (e.g. service areas) are comprised of specialized sub-areas with no single sub-area being representative of the larger area. In addition, many areas are not accessible to researchers without a dedicated escort and some areas are essentially inaccessible due to privacy or safety concerns. To further complicate matters, equipment is constantly in flux and typically moved into the place of use only when needed by a patient. The most restricted access is in any area in which patient care is ongoing. Thus, access is expressly forbidden precisely at the times and locations most relevant to equipment cataloging.

The second and perhaps even more problematic restriction is that energy meters cannot be connected inline to any device that is being used for patient care or patient services. This restriction on connecting to in-use equipment limits the potential for either direct metering of energy use or even metering to determine activity data. In consideration of these critically limiting conditions, we devoted some resources to the development of a clamp on current meter that could be attached to medical equipment without being inline and thus would be allowable in hospitals. The development of this device is described in a subsequent section.

The many medical devices that can be powered both from a wall outlet and internal rechargeable batteries poses another challenge. These devices have levels of power consumption that vary depending on if they are charging while operating or not and the state of the battery charge. Even with thorough in-use power metering, it may difficult to determine the power consumption levels of the various modes.

The one opportunity that hospitals present is in quantifying medical devices and miscellaneous load equipment. Hospitals keep good inventories for property management purposes, which are described in detail in section 3.4.4.

3.4. Inventory Approaches and Tools

3.4.1. Application-based taxonomy of medical devices and MELs

A taxonomy was initially developed for this study that defined medical equipment into four broad categories: (a) diagnostic, (b) treatment, (c) infrastructure, or (d) integrated devices. There were no sub-categorizations of product types in keeping with the taxonomy format that was developed for the commercial buildings MELs project [please refer to appendix?]. However, after preliminary analyses of the hospital equipment inventory, it was determined that this type of taxonomy-based approach for hospital MELs could not realistically be implemented due to the high number of unique medical product types. As a comparison, the electronics taxonomy that was developed for the commercial buildings MELs study contained roughly 150 product types, whereas the medical devices inventory was a factor of four larger and contained close to 650 unique product types. So while the taxonomy appeared promising in the beginning, an alternative method for categorizing equipment had to be developed that could better account for the intractability of the inventory.

3.4.2. Inventory approaches and available information

Most hospitals have several electronic databases of equipment for inventory tracking purposes. These electronic databases are not generally set up for categorizing equipment and are not generally very easy to navigate and manipulate. Hospital equipment inventories are designed for very specific purposes with the primary one being property management. Hospitals often manage a separate inventory of medical devices that require regular maintenance or calibration. Typically, hospitals maintain separate inventories for medical devices, information technology (IT) equipment and facilities equipment. Inventory device designations are often not uniform and can sometimes be cryptic to even those who work closely with them. Inventories may sometimes not be up to date or contain multiple entries for the same device. A particular challenge in hospitals settings is that so many pieces of equipment, especially medical devices, are portable and move within very large hospital floor areas. Medical device locations are not tracked making the search for a particular device rather difficult. Medical devices often return to one or more of several maintenance shops for service and/or calibration, but this happens more on a between patient use basis than a fixed schedule and many devices are not tied to one particular shop. So, even with regular frequent servicing, the success of finding a particular medical device can be unpredictable.

3.4.3. Inventories obtained and analyzed

SHC and LPCH staff provided several equipment inventories. For each hospital, we obtained inventories for medical devices, hospital beds, IT equipment, and facilities equipment. Room report inventories were also provided detailing the space allocation within the 903,000 sq.ft. of SHC and within the 257,000 sq.ft of LPCH. Hospital staff provided much needed guidance in interpreting the inventories, which was especially helpful in the case of the medical device inventories.

3.4.4. Inventory processing tool development and demonstration

An Excel spreadsheet tool that can roughly "read" a medical equipment inventory list was developed. For the tool to work, a text-based medical device list in columnar form first has to be pasted into the proper location in the spreadsheet. This prompts the calculation of the pre-existing formulas, which automatically check for keywords in the inventory descriptions, groups devices into approximately 50 different categories based on their function, and shows the results in a summary column.

While this method was able to semi-automate a fairly tedious process, human intervention was still needed afterwards to clean up and catch any incorrect categorizations.

3.4.5. Medical device inventories

Central to the MELs analyses were the medical inventories of SHC and LPCH. The original lists contained 18,540 and 10,500 devices, respectively. Several clean up steps had to be taken prior to applying spreadsheet tool to the medical device inventories.

A first pass was needed to remove items which did not consume electricity, i.e., were attachments or extensions and would never be plugged into the wall directly.

Next, all laboratory equipment were manually removed from the list as they were out of the scope of this study. Generally speaking, laboratory equipment never came directly into contact with patients, for example, centrifuges, mixers, etc.

Finally, it was necessary to remove items that ran exclusively on non-rechargeable batteries; items that use rechargeable batteries are left in the inventory. This last step required significant effort due to the fact that the power supply requirements of any given device type often varied by manufacturer and also differ from model to model. A fetal heart detector, depending on manufacturer and model number, for example, can run on AC or battery, and/or can run on rechargeable or non-rechargeable batteries.

The revised SHC and LPCH medical device inventories number 14,648 and 7,372 items each. Table 1 shows the total number of medical devices in each category in both SHC and LPCH.

Table 1. Total number of medical devices in each category.

LBNL Category	SHC	LPCH	Total
Airway Clearance	9	11	20
Analyzer-patient	49	81	130
Anesthesia Unit	56	29	85
Aspirator	276	78	354
Autotransfusion	50	5	55
Camera-video	262	85	347
Charger	75	61	136
Circulatory Assist	552	5	557
Compressor	25	0	25
Computer-infosys	194	529	723
Contrast Media Injector	24	0	24
Data interface unit	320	0	320
Defibrillator	201	59	260
Display	285	237	522
Electrocardiograph	56	15	71
Electroencephalograph	15	9	24
Electrosurgical Unit	291	29	320
Exam chair or table	595	179	774
Exerciser	68	7	75
Hemodialysis Unit	19	16	35
Humidifier	76	210	286
Incubator-infant	0	68	68
Insufflator-exsufflator	31	13	44
Irrigation-Distention System	44	0	44
Laser	59	9	68
Lightsource	426	123	549
Meter	2143	376	2519
Microscope	59	17	76
Monitor-patient	2462	2157	4619
Nebulizer	5	62	67
Nitric Oxide Delivery	13	42	55
Others	1005	341	1346
Patient Transfer Aid	80	0	80
Phototherapy	5	59	64
Positive Airway Pressure Unit	36	17	53
Pump-IV	2629	465	3094
Pump-other	492	1193	1685
Recorder	147	62	209
Scale-patient	180	124	304
Scanning Systems	156	56	212
Scope	487	148	635
Smoke Evacuation System	64	7	71
Surgical tool	88	18	106
Tester	69	21	90
UPS	49	91	140
Ventilator	69	105	174
Warmer-blood	164	34	198

Warmer-patient	188	119	307
TOTAL	**14648**	**7372**	**22020**

3.4.6. Facilities equipment inventory

A summary of the breakdown of facilities equipment is shown below in Figure 2. SHC has 3140 items in its facilities inventory while LPCH has 891 items. Categories were made for items that numbered roughly 15 or above; below 15, items are left in the "others" category and not shown. Roughly 10% and 20% of the inventory for SHC and LPCH remained uncategorized ("other"). Note that without information on power consumption or usage patterns, the *number* of items is a weak indicator of energy use.

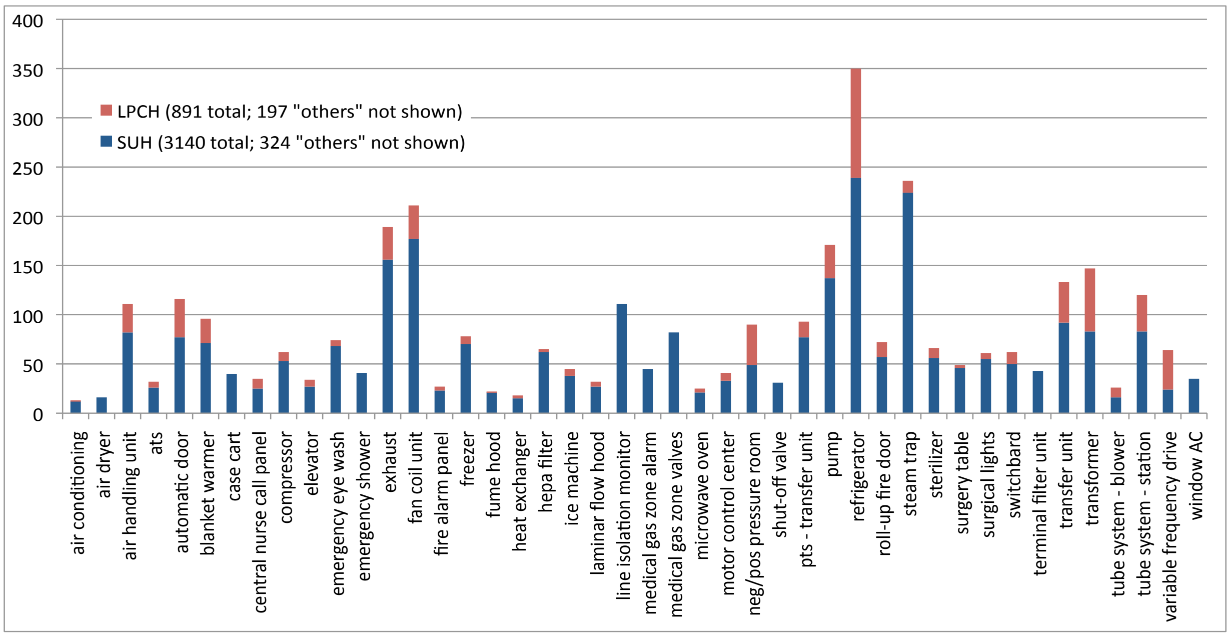

Figure 2. Inventory of hospital facilities equipment.

3.4.7. Beds

The electronic (rechargeable battery) hospital beds were counted separately from the medical equipment. SHC and LPCH had 548 and 137 beds, respectively.

3.4.8. Information technology (IT) inventory

The IT inventory provided for both SHC and LPCH included computers (both desktop and laptop) and printers/imaging devices. The SHC and LPCH IT devices were in a single inventory file and not disaggregated. The inventories for both hospitals, therefore, have been treated as one.

Computers in the inventory are categorized into five device types: (1) space-saving, (2) low-profile desktop, (3) notebook, (4) all-in-one computers, and (5) mini tower. In total, 2518 computers were inventoried in SHC and LPCH.

The printers and imaging devices are categorized into six device types: (1) laserjet, (2) multi-function device (MFD), (3) color laserjet, (4) barcode/label maker, (5) deskjet, and (6) other, which includes equipment that are in the inventory but without sufficient descriptions. In total, 482 printers and imaging devices were inventoried in SHC and LPCH.

3.5. Power Consumption Measurements

Our main objective was to quantify the aggregate power consumption of hospital medical devices. In addition to knowing what devices and how many of each device is present in the hospital, we also needed to measure the power consumption of a representative sample of devices. Ideally the power consumption measurements would be made during actual use of the devices, but this was not possible because Stanford University Medical Center (SUMC) officials were concerned that power meters placed in line with medical device power cords could possibly fail in a way that would compromise the performance of the medical device and, in turn, pose a risk to patient safety. While the power meters we intended to use meet electrical safety standards and we believe posed no risk to causing medical devices to fail, the concern of hospital officials with regard to patient safety is quite understandable and one that we could not overcome.

As a next best option, we collaborated with the biomedical engineering and clinical technologies (BME/CT) staff at SHC and LPCH to devise a methodology to measure the power consumption of medical devices during maintenance, calibration, and safety check procedures performed in various BME/CT shops in both SHC and LPCH. Each shop was provided with at least one WattsUp power meter and a logbook for each meter. Technicians were asked to plug medical devices being serviced into a WattsUp meter and record the date, time, specific information about the device (manufacturer, model, and description), and to check boxes indicating which power modes (charge, standby, and operation) the device was in during the metering period. WattsUp meters were configured to log power measurements in units of Watts and power factor values every ten seconds. Technicians were asked to make power measurements of devices for at least two minutes, which was often exceeded. The memory capacity of the WattsUp meters as configured in this study was ten days and LBNL staff made weekly visits to download and clear data from power meters and collect logsheets. Downloaded data were processed by averaging power measurements in each power mode for each device and noting the peak power measurement of each.

In all, power measurements of 130 individual medical devices were recorded representing 30 medical device categories (see Table 2). For the most part, technicians metered devices that just happened to come in for maintenance. Toward the end of the metering campaign, we identified categories for which no measurements had been made and requested that BME/CT staff seek out and meter specific devices in these categories, which they did. While each medical device was clearly in an operating mode during the servicing/metering period, it was not clear if or when the device was in a standby mode. Time did not allow the technicians to go outside of their normal service and calibration procedures and intentionally put devices in standby mode. Operating room technicians were provided with WattsUp meters, but participation was very low in these areas.

An initial concern about making power measurements during service procedures was that the devices would not be under the same load that they would be during actual use. Devices that operate with loads are put under simulated loads as part of their servicing and calibration procedures. For example the output of a ventilator is fitted with different size flexible tubes to mimic the resistance of adult- and child-sized lungs.

The measurements provided valuable insight into the range of power consumed by devices in the same category and even among the same make and model of devices (see Figure 3).

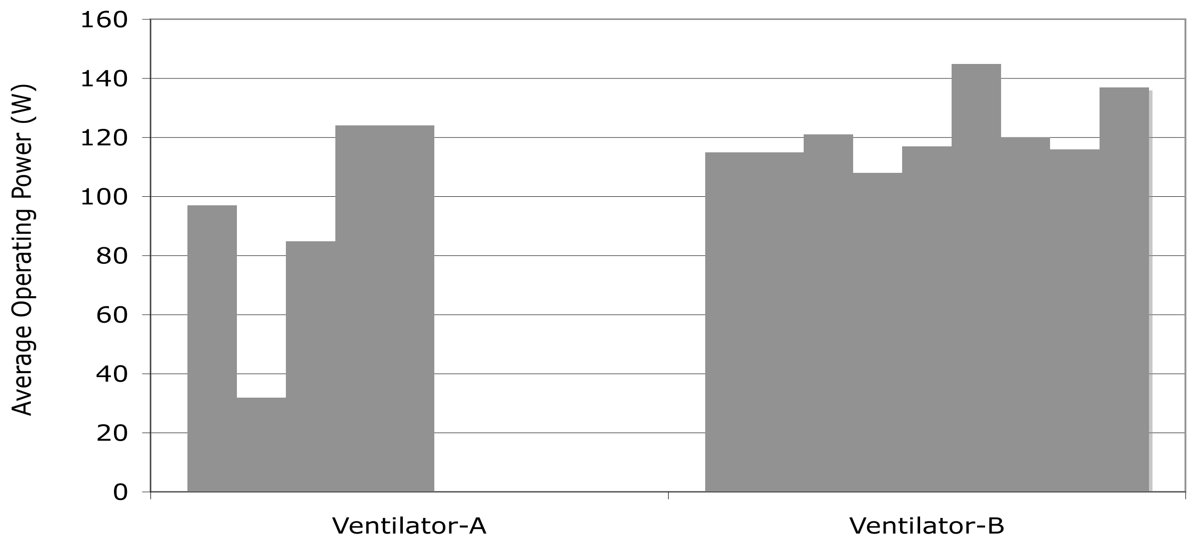

Figure 3. Average power measurements of two makes and models of ventilators (A and B) showing the variation in A and the relative consistency in B.

3.5.1. Comparisons of spot measurements to rated power

Comparisons of actual device measurements with their rated powers were performed as part of the analysis. When possible, measurements for standby, normal operation, and peak power consumption were recorded. Table 2 below shows the device categories, the measurements, and their rated powers. In fairly broad terms, the rated power is in almost all cases higher than operating and peak power draw, but the magnitude of this difference depends on the category of equipment, and often varies from brand to brand.

Table 2. Measured and rated power by device category and specific brand/models in each.

Category	Spot measurements: standby, average, peak (W)*	Rated power (W)
Airway clearance		
brand/model 1	12, 233, 235	500
Analyzer-patient		
brand/model 1	NA, NA, NA	35
brand/model 2	NA, NA, NA	90
Anesthesia Unit		
brand/model 1	153, 302, 342	200
Aspirators		
brand/model 1	12, 20, 40	60
brand/model 2	NA, 115, 119	240
Autotransfusion		
brand/model 1	63,153, 75	NA
Bed		
brand/model 1	20, 447, NA	NA
brand/model 2	30, 94, NA	NA
Circulatory Assist		
brand/model 1	NA, 4, 10	50
Compressor		
brand/model 1	NA, NA, NA	345
Computer-Infosys		
brand/model 1	NA, 24, 47	50
Contrast media injector		
brand/model 1	NA, NA, NA	960
brand/model 2	NA, NA, NA	250
Data interface		
brand/model 1	NA, NA, NA	
Defibrillator		5
brand/model 1	NA, 29, 31	130
Display		
brand/model 1	NA, NA, NA	30
brand/model 2	NA, NA, NA	115
brand/model 3	NA, NA, NA	90
brand/model 4	NA, NA, NA	43
brand/model 5	NA, NA, NA	120
EEG		
brand/model 1	NA, 142, 143	NA
Electrosurgical unit		
brand/model 1	NA, NA, NA	10
brand/model 2	NA, NA, NA	924
EEG		
brand/model 1	NA, 142, 143	NA

Category	**Spot measurements: standby, average, peak (W)***	**Rated power (W)**
Electrosurgical unit		
brand/model 1	NA, NA, NA	10
brand/model 2	NA, NA, NA	924
Exam chair or table		
brand/model 1	25, 150, 271	600
brand/model 2	NA, NA, NA	300
Exerciser		
brand/model 1	NA, 3, 6	NA
Hemodialysis unit		
brand/model 1	67, 87, 131	600
brand/model 2	NA, 48, 51	NA
brand/model 3	83, 504, 1574	1840
Humidifier		
brand/model 1	12, 16, 147	185
brand/model 2	NA, 8, 10	NA
brand/model 3	NA, 40, 45	NA
Incubator-infant		
brand/model 1	30, 308, 619	450
Insufflator/Exsufflator		
brand/model 1	NA, NA, NA	150
brand/model 2	NA, NA, NA	300
Irrigation-distention system		
brand/model 1	NA, NA, NA	40
brand/model 2	NA, NA, NA	48
Lightsource		
brand/model 1	NA, NA, NA	300
brand/model 2	NA, NA, NA	1
brand/model 3	NA, NA, NA	300
brand/model 4	NA, NA, NA	300
brand/model 5	NA, NA, NA	300
brand/model 6	NA, NA, NA	300
brand/model 7	NA, NA, NA	36
brand/model 8	NA, NA, NA	60
brand/model 9	NA, 155, NA	50
Meters		
brand/model 1	6, 16, 16	55
brand/model 2	NA, 7, 10	NA
Microscope		
brand/model 1	185, 602, 648	NA

Category	Spot measurements: standby, average, peak (W)*	Rated power (W)
Monitor-patient		
brand/model 1	8, 52, 53	145
brand/model 2	2, 18, 19	NA
brand/model 3	8, 38, 39	156
brand/model 4	2, 5, 8	6
brand/model 5	NA, 17, 17	161
brand/model 6	NA, 49, 52	47
brand/model 7	4, 37, 42	NA
Nebulizer		
brand/model 1	NA, NA, NA	90
brand/model 2	NA, NA, NA	7
brand/model 3	NA, NA, NA	8
Nitric oxide delivery		
brand/model 1	NA, NA, NA	110
Patient transfer aid		
brand/model 1	NA, NA, NA	1100
Phototherapy		
brand/model 1	2, 42, 44	180
Positive airway pressure unit		
brand/model 1	2, 126, 183	150
Pumps		
brand/model 1	NA, 8, 8	60
brand/model 2	NA, 193, 195	372
brand/model 3	7, 16, 18	14
brand/model 4	3, 41, 22	150
brand/model 5	NA, 15, 30	120
brand/model 6	NA, 57, 96	120
Scanning system		
brand/model 1	13, 945, 996	NA
Scopes		
brand/model 1	NA, NA, NA	60
brand/model 2	80, 250, 276	NA
Smoke evacuation		
brand/model 1	56, 876, 882	NA
Surgical tool		
brand/model 1	NA, NA, NA	600
Tester		
brand/model 1	NA, 7, 7	NA
brand/model 2	568, 1026, 1920	1920

Category	Spot measurements: standby, average, peak (W)*	Rated power (W)
Ventilator		
brand/model 1	NA, 119, 207	125
brand/model 2	NA, 58, 66	135
brand/model 3	NA, 35, 80	140
brand/model 4	71, 92, 194	140
brand/model 5	NA, 100, NA	800
brand/model 6	34, 164, 220	863
UPS		
brand/model 1	NA, NA, NA	980
brand/model 2	NA, 95, 109	660
Warmer-lab		
brand/model 1	1, 22, 94	NA
brand/model 2	1, 19, 92	450
Warmer-patient		
brand/model 1	NA, 650, NA	792
brand/model 2	46, 688, 826	1000
Water purification		
brand/model 1	4, 127, 272	570
brand/model 2	41, 132, 258	NA

3.5.2. *Impact of use of rated power in hospital design*

The power measurements of medical devices show that rated power often exceeds measured operating power and in some cases measured peak power. This may impact two major aspects of hospital facilities design. First the use of rated power for estimating cooling loads creating medical equipment plug loads may result in improperly sized and less than optimally efficient cooling system equipment. Also, receptacle electric service is required to be sized to satisfy a load representing all expected plug loads operating at rated power. With rated power often being significantly greater than typical operating mode power consumption, electric services may be wastefully oversized, although the safety aspect of this requirement does justify a conservative approach.

3.5.3. Aggregate power consumption of hospital MELs

3.5.4. Medical Equipment

An estimate of the aggregate power consumption of medical equipment can only be made with knowledge of how much time each device spends in each of its power modes (e.g. off, standby, charging, and operation). We were not able to collect this data in the present study and are unable to calculate the aggregate power consumption of medical equipment. We devised two methods for acquiring time activity measurements of medical equipment that are presented in sections 3.5.5 and 3.5.6 below. We were not able to implement these methods in the present study, but they represent two promising approaches for further study.

3.5.5. IT equipment

The average operating and low-power mode wattages of the computers have been estimated by comparison with the values from the commercial MELs study. The time in mode percentages, 70% on, 25% low-power, and 5% off, are extrapolated estimates based on LBNL's commercial MELs research and the extended working hours of the hospital. The annual energy consumption of each device type has been estimated and the values presented in Table 3 and Figure 4 below. Space-saving and low-profile desktop computers together account for 77% of devices and 84% of total consumption, and notebooks make up 23% of devices and 16% of total computer consumption. The contributions from all-in-one and mini towers are negligible, less than one percent each.

Table 3. Computer inventory quantities and power consumption estimates for SHC and LPCH.

Device Type	Count	Average Operating (W)	Average Low-power (W)	On Mode (%)	Low-power Mode (%)	Off (%)	Total Consumption (kWh/yr)
Space-saving	1277	65	3	0.7	0.25	0.05	517,377
Low-profile Desktop	650	65	3	0.7	0.25	0.05	263,348
Notebook	579	40	2	0.7	0.25	0.05	144,553
All-in-one Computers	6	100	3	0.7	0.25	0.05	3,719
Mini Tower	4	100	3	0.7	0.25	0.05	2,479
Total	2516						**931,475**

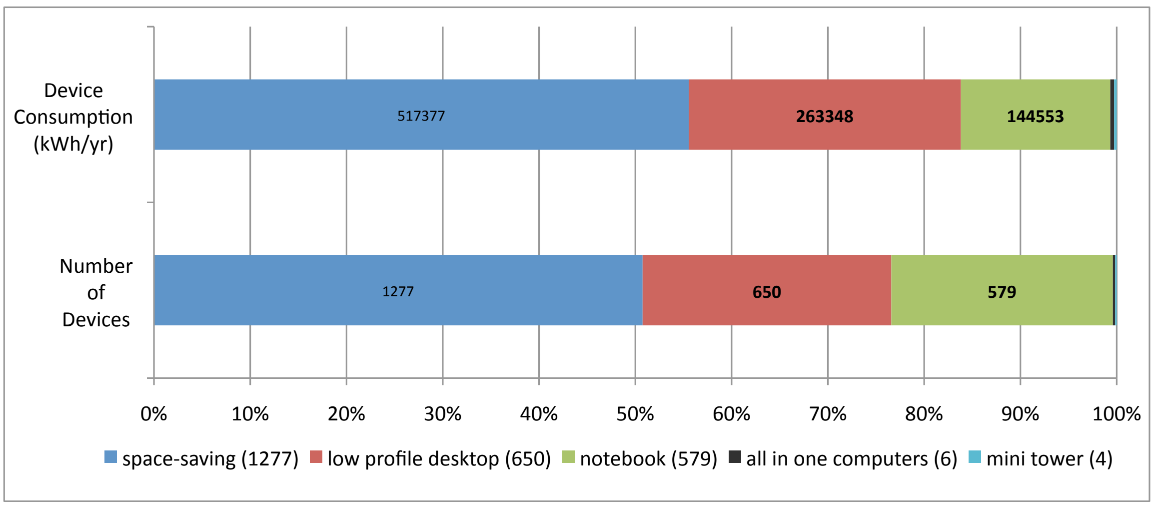

Figure 4. Aggregate power consumption of SHC and LPCH computers.

The average operating and low-power mode wattages of the printing/imaging devices have been estimated by comparison with the values from the commercial MELs study. The time in mode percentages, 30% on, 80% low-power, and 0% off, are extrapolated estimates based on LBNL's commercial MELs research and the extended working hours of the hospital. The annual energy consumption of each device type has been estimated and the values presented in Table 4 and Figure 5 below. Laserjets account for 70% of devices and 71% of total consumption, and MFDs and color laserjets make up 21% of devices and 24% of total consumption. The contributions from barcode/label makers, deskjets, others account for approximately 9% of the device total 5% of the printer/imaging electricity consumption.

Table 4. Printing/imaging device inventory quantities and power consumption estimates for SHC and LPCH.

Device Type	Count	Average Operating (W)	Average Low-power (W)	On Mode (%)	Low-power Mode (%)	Off (%)	Total Consumption (kWh/yr)
Laserjet	300	150	30	0.2	0.8	0	141,912
MFD	56	200	30	0.2	0.8	0	31,396
Color Laserjet	35	150	30	0.2	0.8	0	16,556
Barcode/Label Maker	19	5	0.5	0.2	0.8	0	233
Deskjet	3	100	30	0.2	0.8	0	1,156
Other	13	200	30	0.2	0.8	0	7,288
Total	**426**						**198,542**

MFD = Multi-function device (typically copier, scanner, printer, and/or fax combo)

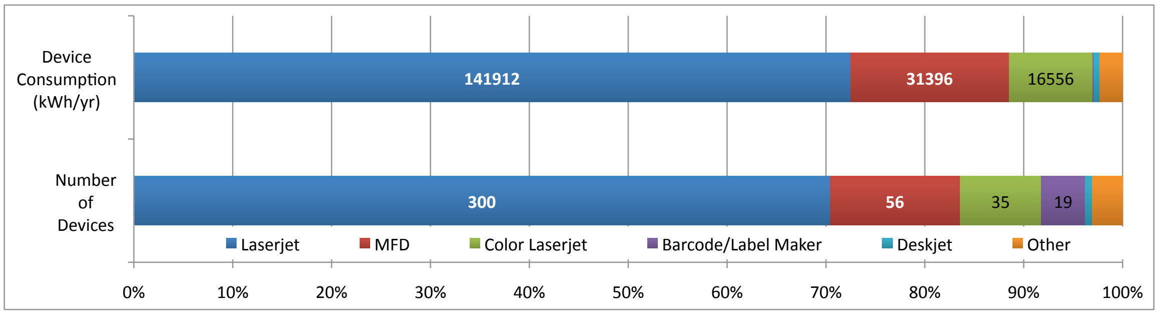

Figure 5. Aggregate power consumption of SHC and LPCH printing/imaging devices.

3.5.6. Measuring activity using a non-invasive current-based data-logging monitor that was created for this project.

A major obstacle we encountered was not being able to meter medical device power consumption during actual use. The measurements of actual medical device power consumption that we made are informative, but the pattern of use of each type of device is key to understanding how to improve the energy performance of those devices. Being unable to install power meters in-line with the power cords of medical devices in the hospital, prevented acquisition of critical activity data.

To address the significant need to measure the usage pattern of medical devices, we created a non-invasive current-based activity data logger. The monitor uses a hall-effect sensor that produces a voltage output in the presence of a magnetic field. Magnetic fields are created around power cords when current is flowing through them. The sensor only responds when it is touching a power cord that has a current flowing through it. The sensor's voltage output is not proportional to the amount of current flowing. The sensor's voltage output steps up when the current exceeds a certain threshold. A sensitivity control was coupled with the sensor to set the sensor's response threshold. With this sensitivity control, one monitor can be configured to respond when a device's current draw exceeds a level corresponding to the device's standby mode and another can be configured to respond only to currents exceeding those corresponding to the device's operation mode.

The key feature of this activity sensing method is that it only has to be touching the outside of the power cord and can not possibly interfere with the function of the device it is monitoring. This sensing method appears to be the best method of acquiring usage pattern activity data of electrical devices in sensitive locations such as patient areas in hospitals.

It is important to note that this is not a current transformer (CT) that clamps around a conducting wire to measure current. A CT can only measure current in a single conductor and cannot be used to measure current flowing through a power cord. The opposite flow of current in each "hot" conductor of a power cord cancel each other out with respect to the CT. The only way a CT can measure current in a power cord is to split the two hot conductors and wrap the CT around only one of the conductors. Splicing open power cords would certainly be too invasive and pose too great a safety risk with regard to hospital medical devices.

A prototype monitor using the current sensor described above was built. A circuit board with the sensitivity threshold control knob was placed in a small enclosure with a battery pack and data logger. The current sensor was connect to the enclosed circuit board via an 18" flexible shielded cable, which facilitates the proper placement of the sensor onto the outside of power cords of devices to be monitored.

The prototype monitor has performed very well in lab tests. The prototype has been tested with a tabletop fan (~30 W), a nightlight (~4 W) and with a netbook computer (~5-15 W). In the nightlight test, the nightlight was plugged into a programmable timer that was plugged into a WattsUp power meter. The programmable timer was set to turn on and off periodically to test if the prototype monitor could repeatedly detect on and off activity. Figure 6 shows a portion of a test that ran over several days with the voltage output of the current sensor in red on the left axis and the WattsUp power measurement in blue on the right axis. The prototype monitor output is ~0.6 V when the fan is off and ~2.3 V when the nightlight is on. The monitor clearly indicates when the nightlight was on and when it was off.

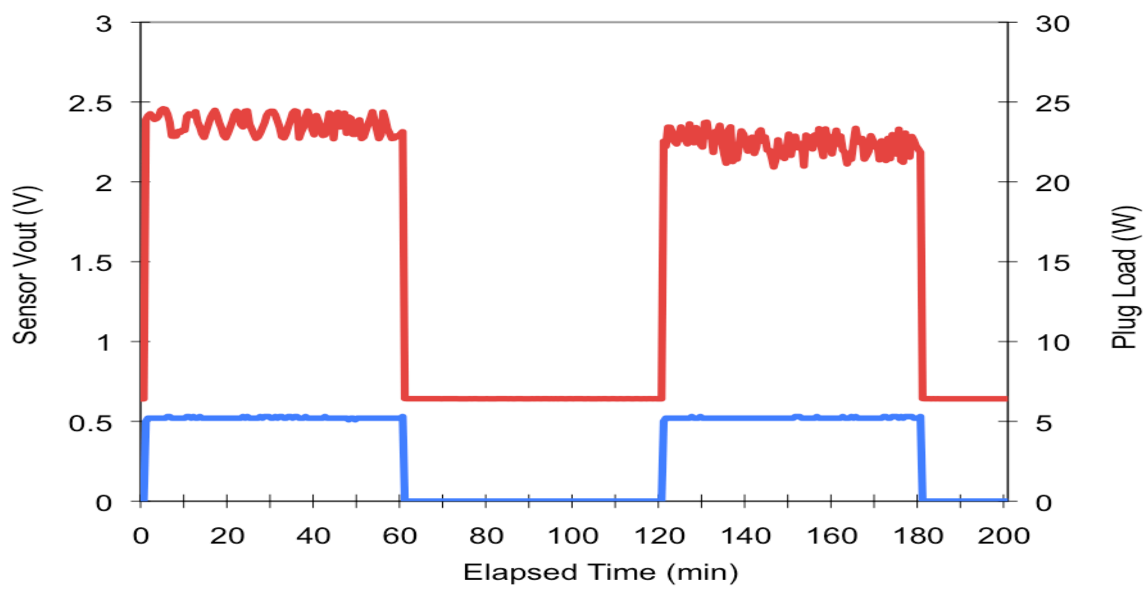

Figure 6. Prototype current sensing monitor output (red line, left axis) and WattsUp power meter measurements (blue line, right axis) of a nightlight.

In the netbook test, the power cord to the AC adapter of the netbook was plugged into a WattsUp power meter and the netbook was manually switched between sleep, and operating modes. Figure 7 shows the output of the prototype monitor (red line, left axis), the WattsUp power meter (blue line, right axis), and labels indicating the power mode of the netbook. The prototype monitor detects operation of the netbook in sleep mode and the WattsUp power meter did not. A more sensitive power meter measured the power of the netbook in sleep mode at ~0.5 W with peak current at ~0.1 A. These preliminary tests indicate that the current-based activity monitor will be effective at non-invasively recording activity of electronic devices even those with very low power consumption.

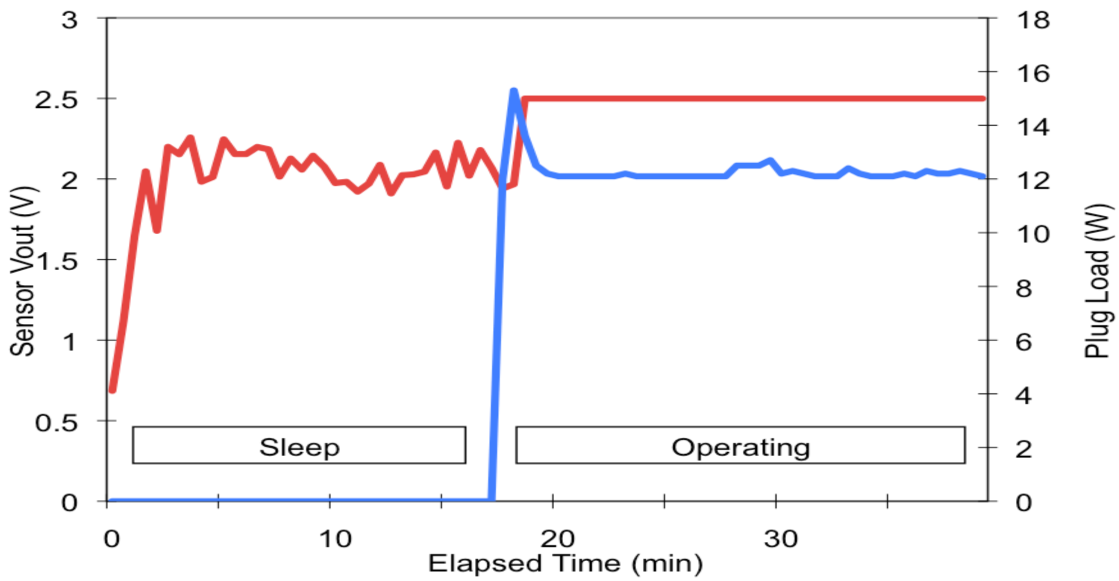

Figure 7. Prototype current sensing monitor output (red line, left axis) and WattsUp power meter measurements (blue line, right axis) of a netbook computer. The boxed labels indicate power mode of the netbook.

3.6. Metering of Device Activity by Procedure

SHC staff proposed a creative and innovative approach to obtaining both power consumption and activity mode data by medical procedure. The procedure-based data could then by multiplied by the number of times each procedure occurs in the hospital over a given period of time to calculate aggregate energy use. Staff further recommended that such data could be obtained expeditiously and without the complexities of placing monitoring devices on equipment being used with patients by monitoring device use during procedure-based training simulations.

A pilot implementation of this approach was conducted at the Center for Advanced Pediatric & Perinatal Education (CAPE) at LPCH. In this facility medical staff are trained and re-qualified for a variety of patient care interactions ranging from collection of basic vital signs and medical history to more intensive procedures like external defibrillation, intubation, and labor and delivery techniques. The medical equipment used in the rest of the hospital is brought to CAPE, plugged in, and used by the trainees under the supervision of an evaluation team. By measuring the load profile of the equipment under use, one can determine device activity profiles and how much total energy is used under particular care conditions. These data can then be combined with procedure activity data collected in accordance with the Office of Statewide Health Planning and Development (OSHPD) requirements. This combination of energy per procedure with number of procedures performed annually allows for the extrapolation of energy use from these single metering sessions to annual estimates.

In order to collect time series power data in CAPE, we deployed wireless power meters in the facility. Developed with UC Berkeley for LBNL plug-in device studies, the ACme wireless meters collect time series and report these data wirelessly using a wireless mesh network back to a base station node. The time-series data are reported back to a database at LBNL for later analysis. We installed 16 meters in the CAPE facility (one for each outlet in the training room), and CAPE staff recorded the time and date equipment was plugged into each meter. We later matched the recorded load profiles with the time log of equipment use to identify the load profiles. The meters were installed in CAPE for two months and collected a power measurement every 10s.

While we continue to think that both the procedure based activity approach and the specific measure of monitoring equipment energy consumption during training have great potential, the pilot demonstration did not accomplish these objectives. During the metering period, log sheets showed only ten device types used during the period, and a much smaller number of procedures than had been anticipated. This may have resulted from a training schedule that included fewer procedures requiring live use of electronic medical equipment or incomplete record keeping owing to tight schedules.

3.7. Algorithms for analyzing time series power measurements to implement when obstacles to in-use metering are overcome.

The ideal case for a study such as this would be to install meters on hundreds of different devices in the hospital; this could be done with hundreds of meters installed in parallel or a smaller number moved serially through a collection of devices. Those meters would measure and report the power used by the devices over weeks to months of usage, and we could then take these data and draw high level conclusions regarding energy use. With a data point collected several times a minute for each of hundreds of meter installed, the quantity millions of data points are collected each day. When a large quantity of time-series data has been collected, the distillation of these time series data into useful quantities is a major challenge.

Such large data sets of time series power data for dozens of similar devices are not easily digestible into the time in power mode (activity) data needed for the aggregate power analysis performed in this report. An automatic breakdown of device energy use by power mode over a metering period is crucial to provide inputs to the analysis. Figure 8 is a chart showing the breakdown of time and energy in power mode for 19 computers used in a commercial building. These computers were monitored using the ACme devices referenced above, and an automatic analysis script written in Python determines the power level for each mode as well as the time and energy spent in that mode. In this chart, the computers are sorted left to right by increasing energy use so that the first bar represents the same computer in each chart. It is interesting to note that in this building roughly half of the computers are "on" about one-third of the time, but their energy consumption spans an order of magnitude. Note that computers with even small "on" times have their energy use dominated by this "on" time. This is a powerful example showing the value of low-power modes for equipment when they are sitting idle. Significant savings are possible when devices sleep when not in use, and it is possible this approach will be useful for medical equipment moving forward.

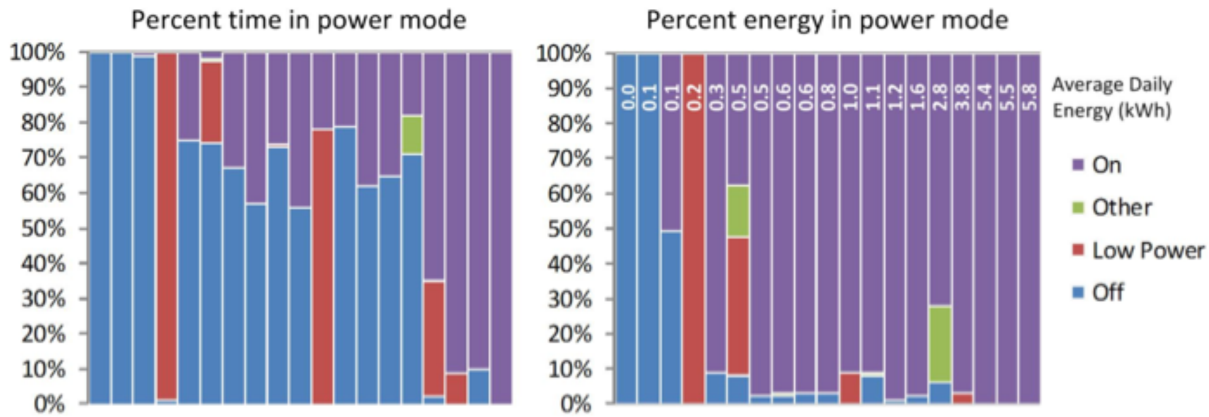

Figure 8. Percent time and energy in power modes for 19 computers metered over a work week in the medium office building. Each column represents an individual computer sorted from left to right by increasing energy use. Energy use is dominated by time in the "on" (active) mode, even when time in that mode is small.

Average load profiles for a device help provide input to internal gain models for building simulation, and automated analysis is required to generate these curves. Figure 9 shows the average weekday power consumption for computers (left) in the medium sized office building, and the light traces represent the average consumption of the individual computers. Figure 9 (right) is a similar figure for computer displays. The individual device traces have significant roughness primarily because of the short period over which these data were collected (5 days), and longer metering periods will result in more accurate results. From these figures we see that power management is not used as effectively on computers as on displays. There is a great deal of variation from device to device and significant usage during off-hours, but there is a clear shape showing the most common building occupancy trends. These traces were collected in a commercial office building rather than a hospital, and the charts show a more standard business day. Analysis like this, however, would show how the hospital load profile depends on occupancy and how internal gains would change with time.

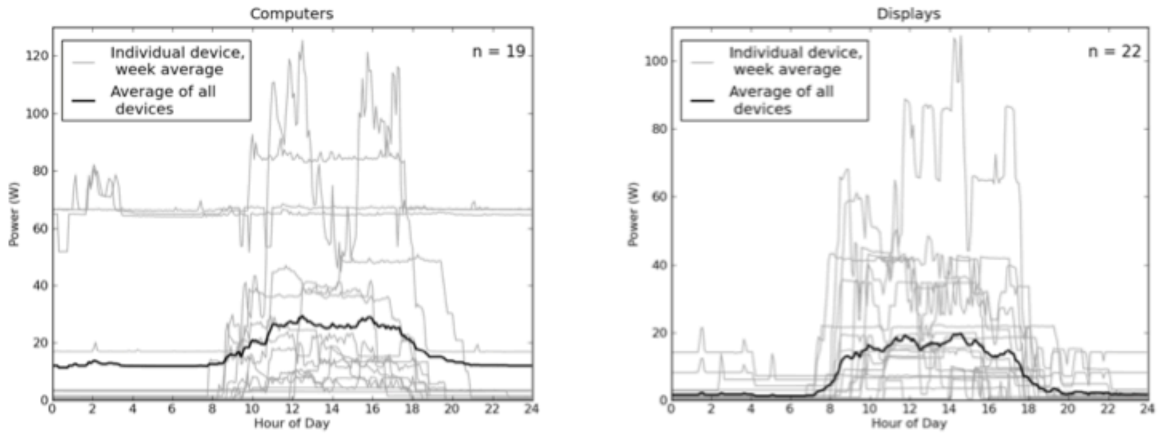

Figure 9. Weekday average power consumption for computers (left) and computer displays (right) taken from the medium office building. Power management is used more effectively on displays than on computers.

4.0 Summary and Conclusions

The overall goal of this project was to conduct research to advance energy efficiency in the healthcare sector. Specific objectives included the development of tools to advance hospital energy benchmarking and the development and demonstration of methodologies to quantify energy use of medical equipment and other miscellaneous electrical loads in hospitals.

Guidance documents to advance hospital energy benchmarking were developed by LBNL and collaborators based on input from hospital design engineers, facilities engineers and others working in the field of healthcare energy efficiency.

Based on the general approach used for miscellaneous loads in other commercial buildings, we developed a framework for quantifying power and energy consumption rates of medical equipment and miscellaneous electrical loads in hospitals. We worked collaboratively with staff from Stanford University Hospitals and Clinics and the Lucille Packard Children's Hospital to identify, understand and overcome challenges in adapting techniques for equipment inventory, use and power consumption data collection to the hospital environment.

A peer-reviewed companion document to the LBNL benchmarking guidance was developed by collaborators Mazzeti Nash Lipsey Burch (MNLB) through a case study of integrating energy end-use sub-metering into the design phase of a new hospital and also presents a cost estimate for installing energy end-use sub-metering in a hypothetical, typical existing hospital.

LBNL responded to MNLB companion document reviewer comments by creating a Hospital Energy Benchmarking Handbook that clearly and explicitly shows the equations for calculating the major energy end-use benchmark metrics. For clarity all data point names are either completely or nearly completely spelled out, and the few acronyms that are used follow common building control system point naming conventions.

We advanced the state of knowledge about medical equipment energy use in several ways. First, we identified and demonstrated that facilities inventories maintained for property management purposes could be utilized to obtain information about electrically powered beds and other equipment used for medical purposes. Tracking systems used to ensure regular maintenance and calibration of diagnostic and treatment devices were used to quantify the prevalence of these devices. And records of the information technology department were used to quantify the number of computers and peripheral devices.

We identified barriers to direct equipment monitoring in hospitals. These include (1) concerns about placing any device (e.g. a logging power meter) inline with the power supply to any device used for patient care, (2) the fact that many medical devices are mobile and moved frequently for use in different areas of the hospital, creating logistics issues with recovering any metering device, and (3) patient privacy concerns that increase the logistical costs of researchers gaining access to verify equipment inventories and install even non-invasive activity monitors.

Several alternative approaches were developed in an effort to obtain data on medical equipment energy use. We developed a protocol for hospital biomedical technicians to acquire data on power consumption during standby, operating and peak power modes. Data were obtained for roughly 130 individual devices covering roughly 30 device categories. We installed power meters to log activity in a medical treatment simulation facility; the intent was to extrapolate equipment and energy use during the simulated procedure to estimate aggregate energy use for all such procedures conducted at a hospital. While this approach did not result in useful data in this study, it could potentially be revisited in future studies.

With the objective of overcoming barriers to in-line metering, we developed and constructed a prototype logging current sensor that can be attached non-invasively to the power cord of any electronic equipment and calibrated to differentiate between any two desired levels of current induced electrical field. With two of these sensors, it would be possible to distinguish lower power standby and higher operating power modes for many devices.

5.0 References

Kawamoto, K., Koomey, J., Nordman, B., Brown, R. E., Piette, M., Ting, M., and Meier, A. (2002). "Electricity Used by Office Equipment and Network Equipment in the U.S." *Energy--The International Journal*, 27(3), 255-269

Singer BC, Mathew P, Greenberg S, Tschudi W, Sartor D, Strom S, Vernon W. Hospital Energy Benchmarking Guidance – Version 1.0. Lawrence Berkeley National Laboratory, Berkeley, CA. October 2009. LBNL-2738E.

Singer BC, Coughlin JM, Mathew PA. Summary of Information and Resources Related to Energy Use in Hospitals – Version 1.0. Lawrence Berkeley National Laboratory, Berkeley, CA. October 2009. LBNL-2744E.

Singer BC and Tschudi WF. High Performance Healthcare Buildings: A Roadmap to Improved Energy Efficiency. Lawrence Berkeley National Laboratory, Berkeley, CA. October 2009. LBNL-2737E.

Appendix A - Implementing the LBNL Hospital Energy Benchmarking Protocol

In October, 2009 the Ernesto Orlando Lawrence Berkeley National Laboratory issued its report "Hospital Energy Benchmarking Guidance – Version 1.0[1] (HEBG). That document proposed a framework for measuring and benchmarking the energy performance for hospital buildings that would yield insights into the ways in which energy was consumed at a much more granular level than the usual per campus or per building kind of metric. The value of more granular perspectives is that it can pick up opportunities for improvement that are necessarily obscured by an aggregated benchmark.

The limits of the HEBG paper, though, were that it did not consider practical implementation of its ideas, including how the initial inclusion of such a system into a hospital design would affect not only the cost of that design, but the architecture of the system it was intended to monitor, in order to facilitate better measurements. The purpose of this document, then, is to explore those issues, and to propose certain approaches that can help the hospital owner and designer to actually implement the HEBG.

Before a discussion of some practical considerations, it's important to re-state the anticipated benefits that a facility operator can achieve through deploying and using a system such as the one envisioned by the HEBG. The practical deployment of an HEBG system will bump up against a number of balancing points, in which the designer and user will need to think about the benefits of the benchmarking to be achieved in the context of the burden of implementing the system. The benefits, then, of deploying and using a robust energy monitoring and benchmarking system include:

- Detection of poorly performing systems – so they can be improved
- Identification of inefficient systems – so they can be improved
- Allow prioritization of efforts to reduce consumption – so the facility can achieve the biggest return for a given investment

Three other potential advantages were not suggested by the HEBG, but are features of a carefully planned metering and benchmarking system. First, many Green Building rating systems award points for buildings that include sub-metering of various kinds of loads. Properly designed, a benchmarking system designed to accomplish the HEBG can also monitor some of the loads included in these documents and help the project team to achieve the point. Second, once the system is completed, the project team can use the metering system to validate that the building produced performs as the design projected, and can use them to detect and monitor needed adjustments to attain these results. Finally, readings of existing systems and existing buildings can provide data that can be used to predict future results for new buildings, as well as better informing the code development process.

[1] Brett C. Singer, Paul Matthew, Steve Greenberg, William Tsuchidi, Dale Sartor, Susan Strom, and Walt Vernon, Hospital Energy Benchmarking Guidance – Version 1.0, October 2009, LBNL Report LBNL-2738E.

On the other hand, some of the difficulties the energy manager will confront in implementing an energy measurement and benchmarking system include:

- Lack of data on meter location within a facility;
- Lack of data in general about the system design within a facility;
- Lack of staff who have the time and/or expertise to effectively operate an on-going metering and benchmarking system;
- Lack of reliable benchmarks against which to assess a building that has been so equipped; and
- Lack of capital (or will) to make improvements suggested by a well-implemented Benchmarking system.

Each of these hurdles (except lack of capital for energy efficiency improvement projects) will be discussed in the sections that follow.

The implementer of the HEBG must therefore balance the potential benefits of implementing an element of the protocol as compared to the burdens of doing so. When the implementer confronts one of the many challenges then, the measure that must tip the balance is the degree to which the three benefits can be achieved to deliver meaningful improvements.

Note, too, that the HEBG proposes a system of measures that appear right to the authors of that paper. The protocol makes a host of assumptions about the basic systems being used by the facility – experience with hospitals around the world demonstrates clearly that this protocol applies only to some hospitals in some places in California and the US. So, while the balance of this paper will focus on practical guidance for implementing the HEBG, the user of this Guide must understand the fundamental principles herein, and adapt it to the individual circumstances and designs of the building being managed.

Finally, this document intends to supplement the other work already performed by other organizations with respect to energy performance benchmarking. In particular, the ASHRAE/USGBC <u>Performance Measurement Protocol for Commercial Buildings</u>[2] provides advice for three levels of energy performance measurement (Basic, Intermediate, and Advanced). However, that document provides detailed discussion for only the Basic level (equivalent to a whole-building measurement similar to that of Energy Star) of measurement and benchmarking, and in a way that is not specific to healthcare. The complications of the design of hospital distribution systems, together with the potential benefits of more granular benchmarking, create the need for this document.

1. Additions and Updates to HEBG

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[2] Performance Measurement Protocols Project Committee, <u>Performance Measurement Protocol for Commercial Buildings</u>, 2010.

1.1. Measuring on-site produced energy

The 2009 Prescription ignored one important measureable metric – on-site produced renewable energy. In essence, the Benchmarking tool focused on demand sinks, and not on supply sources. The HEBG approach is meaningful; actual implementation, particularly when monitored over time, will be highly valuable to a building owner. But, it ignores a part of the bigger energy solution picture that is available to hospitals that are working towards better energy performance. Hospitals are beginning to approach the energy question from many different perspectives; some want to save money spent on energy; some want to reduce the energy they consume; some want to reduce their greenhouse gas emissions; some want to fix their energy costs so that they can protected from energy price fluctuations. And, the Benchmarking Scheme presented in 2009 provided tools to help in that quest. However, many of the goals that are meaningful to hospitals can also be met by deploying on-site renewable energy generation systems. So, the benchmarking protocol needs to be modified to add the following table:

Table: Energy derived from on-site renewable sources

ENERGY DERIVED FROM ON_SITE RENEWABLE SOURCES		
Metric	Data Required	Comments
Heat generated from solar thermal Site kBtu/yr	• Heating supplied by solar panels, from supply and return temp. (ΔT) and flow	• This table assumes a certain, most likely, form of solar thermal technology; others are possible but would require more exotic metering
Electricity generated from renewable sources Site kwh/yr.	• Energy (kwh)	• Renewable sources are those defined by the US National Renewable Energy Labs and defined by E Source.[3]
Energy created from conversion of renewable fuels Kwh/yr generated Site kBtu/yr. consumed Efficiency=generated/ Consumed	• Energy generated (kwh) • Fuel content of fuel consumed (kBtu)	• Hospitals will also want to consider technologies (i.e. fuel cells) that reduce emissions even as they consume either renewable or non-renewable liquid fuels. Efficiency of such sources would be of interest similar to the metric given here, but the true benefit of these technologies is in the reduction of emissions, more than the reduction of source energy.

[3] Green-e, *Energy National Standard for Renewable Electricity Products in all regions of the United States*, Dec. 5, 2008, WEB (http://www.green-e.org/docs/energy/Appendix%20D_Green-e%20Energy%20National%20Standard.pdf)

1.2. The problem of the Denominator

Several of the metrics suggested by the HEBG benchmark the energy consumption on a square footage basis. Many practitioners suggest that other metrics that are more functional in nature would be more appropriate. That is, rather than considering equipment and plug loads per square foot, it would be more appropriate to consider it per bed, or per OR, or even per Adjusted Patient Day, or Number of Procedures performed. The hypothesis behind these metrics is that different hospitals, with different kinds of procedures and different kinds of patients, can't be judged on energy per square foot in a meaningful way, and perhaps these and other more operational-based metrics would make better sense. A careful case study of two hospitals, using both kinds of metrics to determine the usefulness of the two would be worthy of further study to better answer this question.

2. Ways to "slice" the facility

Experience shows that buildings frequently develop with somewhat random and chaotic metering schemes, as relates to their primary energy sources. Healthcare Energy Management professionals frequently find very confused and incorrect energy billing records for the facilities they seek to improve. The first job in such instances is always to determine precisely the loads served by each meter, and, to the degree possible, to determine the energy consumption of individual buildings. All too often this exercise takes considerable effort and assumptions, due to the confused development, over time, of the metering systems. As the careful management of energy resources becomes more important, careful development of the metering systems becomes more central to the building design process.

A commonly used piece of medical equipment is a CT (computed tomography) scanner. The CT is able to create images at various "slices" through the body and as if looking from different angles. Each of these slices shows a different portion and a different perspective of the area of interest greatly increasing the opportunities to determine the precise issue and, therefore, the likeliest healthcare intervention. In the same way, metering systems, depending on the perspective from which they slice the facility energy pie, provide different perspectives on the energy consumption thus greatly increasing the opportunities to determine the precise opportunities for effective intervention and performance improvement.

In general, energy "slices" from metering systems includes looking at consumption from the geographical perspective, the system perspective, or the intersection of the two.

2.1. First slice; measure geographically (i.e. by building, floor, and/or department)

One dimension for slicing energy consumption is to measure consumption by geographical unit.

The first issue in the real world is, as discussed above, to be sure the metering systems measure the energy consumption of each and every building. While this sounds intuitive, and even trivial, in practice it is neither. As facilities age, they often undergo a series of Additions. Frequently, because existing systems have insufficient capacity or extension would entail high costs, the addition will have its own, dedicated utility (or Plant) services. In such cases, the facility will have MORE than one set of meters for like utilities, and a system that fails to acknowledge this could take the reading of one meter and assume it to be for the whole, and thus misunderstand the true energy picture for the building. Frequently, different utility systems will follow different patterns in serving such additions, so that one addition may get a new electrical service, but be served by the thermal system of the original building. These kinds of geographically haphazard system designs make sorting out the accurate data to determine energy consumption all the more difficult. These kinds of situations require totalizing meters for each such system to ensure correct data reporting.

The opposite kind of problem occurs when multiple buildings share the same meter. This can happen because several buildings develop at one time, and, therefore, share a common plant, or a common meter and energy distribution system. Because the addition of meters is not required and therefore creates a possibly avoidable expense, some owners elect not to sub meter the various buildings on the campus, making it extremely difficult for subsequent users to determine with any accuracy the actual energy performance of their buildings.

A similar result occurs when a facility constructs relatively small outbuildings, or portables, or even utility docks for mobile units. In these cases, if the one meter reflects only the total consumption of an energy source for the site, it will be very difficult to even use a system such as Energy Star to benchmark the performance of the building, because the energy consumption will not reflect the performance of the building itself. Just as it is difficult to cure a disease that is in part of a population if you only knew that it was infecting some of the people in that population, so too, is it difficult to determine the potential for energy savings for a site if you only knew that energy was being wasted *somewhere.* Clearly, in such situations, it is essential that the energy measurement systems precisely reflect the actual energy consumed by each building.

One factor that can complicate this kind of situation when it comes to per building measurement is land-use and parcel development, as well as Public Utility restrictions on the utility companies. Frequently, sites are developed that have different addresses or that have other land-use restrictions on them that can affect how the utility companies are permitted to serve them. Or, if an owner wants multiple services to a single address, they may be required to pay an additional fee for the metering, and so, elect to forego the additional metering. In all of these cases, the additional cost of the metering is one of the least cost investments the building owner can make to ensure its potential for long-run energy performance.

The issues of geography operate not only at the building level, but also at the level of areas within the building. A building operator may gain insight by monitoring consumption by parts of the building that again, will alert him to deviations and opportunities for improvement. That is, monitoring every floor of a building, or every wing, or every department can provide a different geographical perspective on energy consumption over time that will prove useful.

One consideration with respect to these geographical deployments of metering systems will be the significance of the geography surveyed. Here, there is a very practical balance that must be achieved. If a building is very small, for instance, relative to another building, or if it has a very small load, it will offer relatively little opportunity for improvement. This balancing of benefit versus burden will be met over and over in determining how to most effectively benchmark the energy performance of the system.

2.2. Measure by the system

The usual slice from which to look at energy consumption is by fuel system consumed – the electrical system, the natural gas system, and the district heat system. These measurements are usually rather simple since they frequently involve simply the collection of utility bills.

The insight provided by a per-fuel basis is helpful, but still limited in the value of the insights provided; thus, the system-level view proposed by the 2009 HEBG. The question of which systems or sub-systems are useful to measure is similar to the question of which geographical or sub-geographical units to measure; in both cases, it is a question of granularity. In both cases, there are wide ranges of degrees of granularity that can be measured and benchmarked – we could have one meter for each utility for each campus; or we could have meters for each electrical circuit and each branch duct. Indeed, some of the measures suggested in the HEBG operate at all of these levels.

One caution is in order. A recent study by the GSA reached the conclusion that its newer buildings tended to perform worse, from an energy perspective, than its older buildings, and that the reason for the difference was the complexity of the systems in the newer buildings, and the fact that these systems were beyond the ability of the staff to operate effectively.[4] The GSA buildings were *not* hospitals, leading to the inevitable conclusion that newer hospitals, with even more complex systems will exhibit even worse performance. And, if the staff is struggling to operate them effectively, inundating them with reams of granular data may be of low value. So, the granularity question is a real one, and should be approached with caution and in strong partnership with the hospital operator.

Obviously, the true value of a hospital metering and benchmarking system will come from that combination of granularity of geographical perspective, granularity of system view, and their intersection, in ways that will permit the facility operator to best ensure efficient operation of the facility and improvements to that system.

3. How to benchmark

As noted in the introduction, the HEBG suggests a protocol that offers two benefits that consist of benchmarking performance in order to diagnose opportunities for improvement (the third benefit allows an internal look at various opportunities in order to assess those that will likely yield higher returns). The problem with this is that it begs the question – benchmarked against what?

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[4] GSA Public Buildings Service, Office of Applied Science, "Assessing Green Building Performance, a Post Occupancy Evaluation of 12 GSA Buildings," June, 2008.

3.1. Benchmark against others

The EPA has been promoting its Energy Star protocol since 1992. Over that period of time, it has managed to have 3200 hospitals[5] – approximately 63% of total hospitals, assess their data against the rating metric. Importantly, the Energy Star does NOT collect the data supplied by the various facilities and use it to update its database of facilities and to improve its benchmarking scale. This is because the data being supplied by users is not necessarily reliable; it is likely collected in many ways by many people and with varying levels of rigor. Thus, the EPA can't use the user-supplied data, and the benchmarking system remains static, based on a sampling of buildings performed in 1997.

In 2010, the EPA issued a survey of users to determine the usefulness of the tool to them. Despite significant efforts to publicize the survey, including the threat that insufficient response could lead to cancellation of the entire program, EPA received survey responses, only slowly, requiring several postponements of the survey deadline.

The point of the Energy Star example is to show the difficulty that facilities have in supplying even the most basic of information, and the resulting difficulty in finding *external* sources of relevant benchmarking data. Some of the differences between facilities that will make the apples-to-apples comparisons difficult are discussed in the HEBG.

Having gone on and on about the difficulties of finding and using external benchmarks, such external measures have high value in assessing self-performance, and, where feasible, the energy manager implementing the HEBG should use them (some are suggested within the HEBG itself).

3.2. Benchmark against yourself

Obviously, then, the best way to benchmark a facility is going to be against itself.

A facility should first be considered in the context of its ownership. That is, it may be a stand-alone facility, or, more likely, part of a larger healthcare system. If it is part of a system, the system may be able to implement a benchmarking system across facilities, measuring all or a portion of the HEBG protocols, and it can then start to use its own data to compare results. Obviously, in this model, the facility will need to perform its own "normalization" of data to be able to use it to make meaningful actionable decisions.

Kaiser Permanente is in the process of implementing a national energy strategy, with the goal of reducing its overall consumption of energy derived from fossil fuels. A central element of that plan's implementation is to identify the lowest performing facilities – from an Energy Star perspective – and to perform audits on them to implement programs the following year for

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[5] See "Tracking Energy Performance," *Highlights for 2009*, available at http://www.energystar.gov/ia/partners/annual reports/2009_achievements.pdf.

upgrade. Then, the savings of that year will fund the next round of projects, and so on, in order to allow a financially feasible progression of energy performance improvement. This example uses a combination of external benchmarking (Energy Star) and internal benchmarking (the worst of the KP facilities) to create improvements, but the point is that internal benchmarking is a powerful means for prioritizing potential improvements – the third of the benefits suggested by HEBG.

The other way to self-benchmark is to track the performance of a system-geographical unit over time. It should be possible over time to use this data, particularly if it extends over several years, to assess current performance of that system; that is, as a minimum, is it better, worse, or the same as previous time periods. Here, there will need to be some normalization, depending on weather and relevant census, but the adjustments can be crude estimates, and can be performed for little cost and thus, high return.

There are various methods for diagnosing trends that may not be apparent from raw data. One method used for financial analysis is the trailing twelve month average. Using this system, a measure will be combined into a mean over the previous twelve months. This method smoothes the resulting curve, helps to eliminate monthly fluctuations, and shows real trends that can lead to further analysis and improvement.

Another opportunity for simple analysis would be a comparison of a benchmark (particularly where there is external data against which to benchmark) compared to Energy Star ratings to yield indirect indications of opportunities. That is, if a particular facility determined that it had a very good score for one of the HEBG benchmarks (and little or no data or external validation for the others) and a very bad score for Energy Star, that pair of results would lead to the necessary conclusion that other systems must be very bad indeed and offer significant opportunities for improvements.

One final opportunity for the use of the data, and in a way that might serve to minimize staff time required (see section following) would be to use past performance as a predictor of current and future performance. A system could be developed so that it would continuously predict system performance, and simply issue an alert when the system deviated from the suggested parameters. This way, the facilities operator would not need to ever look at and analyze anything, but only to react when the system failed to perform as it should (which is when they ought to respond, and it is when they can have a significant impact on keeping performance and costs under control).

4. Who will benchmark?

This paper is being written in the wake of legislation creating federal Healthcare reform. In gross terms, the implication of healthcare reform is to cut the money available to hospitals on a per-patient basis, while probably increasing the number of patients with serious health care needs who present themselves to the organization and who cost more to treat. This twin impact will put tremendous pressure on hospitals to reduce costs, and staff is the largest cost within the facility.

And, facilities staffs within hospitals are already under pressure to reduce FTEs to the point that available staff barely has time to change the burned-out light bulbs, much less to spend time poring over, analyzing, and building upon energy benchmarking data. Exacerbating this lack of staff is the continuing decline in the skill level brought by candidates for operating these facilities. The question, then, will be who will read and make use of the data created by a benchmarking system.

Three possibilities suggest themselves:

- The facility may be part of a healthcare system. Frequently, such systems will have a corporate energy manager. If the system were set up to report benchmarking data to that person, it would spare the time of the local facilities staff and offer the ability to direct resources to those facilities where the highest benefit could be achieved (similar to the Kaiser process noted above). The problem with this method would be the necessity of rolling out a common set of measures across all of the facilities, likely a time and money-consuming process, coupled with a process for reporting and aggregating the data in an easily accessible form.
- The facility might elect to direct resources to this task. Depending on the number of facilities and the number and granularity of measurements taken, and the process chosen for analysis, this task could create a relatively high value with relatively low effort, with a person of the right skill-set.
- Finally, the facility may elect to contract out this service. A few vendors are already providing external facility monitoring and alerting systems. This kind of service, if priced appropriately, and if staffed with people of the right skill-set, could provide very high value to a hospital owner wishing to use a tool like the HEBG to better manage facility energy consumption and/or cost.

5. *Relationship to Green Building Rating Systems*

Beginning with the Green Guide for Healthcare[6], healthcare-related green rating systems recognized that more granular monitoring of energy consumption within a hospital would permit a facility engineer to better control his systems and his facility to obtain the best possible performance, and lowest possible energy consumption. The Green Guide point requires:

"Metering for the following electrical and mechanical systems (as applicable to the scope of the project):

- Lighting system power and controls
- Motor loads (including air compressors, vacuum pumps and boiler systems)
- Chillers
- Data Centers
- Critical Equipment Electrical Distribution Systems
- Air distribution systems"

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[6] Most recent version available at www.gghc.org

At the time of this paper, LEED for Healthcare has not yet been released, but it appears from previous drafts released for public comment, that LEED-HC will be similar, if not identical, to the GGHC point requirements.

Obviously, many of the loads recommended by the HEBG, and otherwise suggested by this document overlap very closely those of the GGHC/LEED systems. A detailed comparison of these systems to the HEBG is beyond the scope of this paper, but the opportunities for (a) achieving the intent of both systems, and (b) synching these systems with the HEBG is clear.

6. System design to facilitate HEBG implementation

If the owners of a new building wish to implement a metering system to provide data for hospital energy benchmarking, the fact of the metering might lead to changes to the fundamental system design in order to make the metering more feasible. This section describes, on a system-by-system basis, potential issues raised by the general system design, and potential modifications that would make energy benchmarking easier to accomplish.

As a final, general observation, many of the metrics suggested by the HEBG require a small sample extrapolated to the whole. Experience shows that this often saves little in the way of time and expense, and risks a big potential miss on actual performance. This paper recommends metering these loads on a continuous basis with continuous monitoring.

6.1. Electrical

All of the electrical benchmarking points described below can be accomplished with a simple recording ammeter. Sections 6.1.1 through 6.1.3 discuss electrical input energy measurement, and system efficiencies are discussed under mechanical.

6.1.1. Cooling System Overall

This metric requires a consolidation of all power/energy to create and distribute cooling. Even assuming a single chilled water plant providing all cooling for the facility (see cooling section below for potential complications and alternatives to electric meters), this metric would lend itself to a single metered load center that serves all of these loads. This kind of design may be problematic; depending on the size of the chillers, in particular, but also the location of the cooling components (i.e. there may be chillers in different locations). Similarly, in any particular hospital, some chillers (and accessories) may be on emergency power and some on normal power, thus requiring multiple meters and a totalizing function. Grouping the loads thus could cause slight increases in construction cost. Probably more important is that many facilities will have cooling machinery distributed throughout the facility, rather than completely concentrated in one location. This kind of system requires metering of these distributed loads and totalizing them.

6.1.2. Heating & DHW system

This system requires a summation of electricity to all pumps and treatment systems. These systems tend to be simpler than the cooling system. Usually, these system pumps will be served from a common source, so it will make sense to provide a separate load center, again, to serve these pumps (the alternative being to monitor each one separately, and then to totalize them, together with the thermal energy input).

6.1.3. *Ventilation*

This metric requires power for each fan and total for each group of fan: supply, return, exhaust. Three problems will complicate this metric.

- First, the fans will likely be located all over the place, even for a very small geographical slice of the building. This consideration may be further complicated by the fact that fan systems may not have precisely aligned boundaries, so that totalizing them in comparison to cfm may be difficult (see Ventilating Systems below for alternatives to electric meters).
- Second, the fans will likely come from different sources. Here, we have the problem of normal versus emergency, noted earlier, but also the problem of voltages. So, some of the relevant fans may be 120 volts and some may be 480 volts, so that, even if they are both in the same area and on the same system, they will be on two different panels (which will likely have other loads on them, as well). Practically speaking, this metric can best be achieved by individually monitoring each fan circuit, and totalizing them appropriately, based on the relevant geography. Fans served by 120 volts are usually small and not worth metering, rather the tracking system could use a calculated value (see Ventilating Systems below).
- The final problem will be to have a system that provides the totalized fan energy compared to the collected cfm data (see Ventilating Systems below for alternatives to tracking cfm data).

6.1.4. *Cooling EUI*

Similar to cooling system efficiency discussed above.

6.1.5. Heating EUI & DHW EUI

Similar to heating and hw efficiency discussed above.

6.1.6. Ventilation EUI

Similar to Ventilation efficiency discussed above.

6.1.7. *Non-equipment electric EUI of hospital*

This metric requires the total of Normal, critical, and life safety branches, less fan energy. This should be a relatively straightforward measurement, with the exception of subtraction of fan energy (see fan energy sections above for design implications for measuring those loads).

6.1.8. Electrical EUI of patient care area:

This metric requires a summation of the normal and emergency branches for a sample patient bed area, extrapolated to other patient bed areas of hospital. Here, we run into the problem that a hospital will likely have loads from a 480-volt panel and loads from a 120-volt panel for each branch for each area. And, it might be that the panels for the two voltages from one branch derive from different places, and must, therefore, be totalized. However, it is even more likely that the boundaries of the at least four panels (120 volt normal, 120 volt critical, 480 volt normal, and 480 volt critical) won't overlap, making adjustments necessary. Finally, it is equally likely that any one panel will include loads from another area of the hospital. It would be possible to limit a set of panels so that they were dedicated to a single patient bed area during the design, and sometimes that will happen naturally. However, in some cases, this design might add some incremental cost to the system.

Another problem is the prescription that the data from one area be extrapolated to the whole. Bed areas today come in so many different forms (pediatric, neuro, labor and delivery, ICU, and so on) that it is difficult to see how any area is typical for very much of the facility. And so, the recommendation of this paper is that geographical areas be selected appropriately, as discussed above, that includes all patient areas, and that no extrapolation be done.

6.1.9. Non-equipment electrical EUI of D&T areas:

Similar to the discussion for Electrical EUI for patient room area.

6.1.10. Lighting power load of patient room area:

This is a one-time calculated number; no metering required. An interesting question is how this should be calculated; that is; it could be calculated by summing the connected loads of all the fixtures (including task lighting) at its simplest. As an alternative, it could be calculated as prescribed by one of the various energy protocols such as ASHRAE Standard 90.1[7] or California "Title 24" Energy Requirements.[8] Calculating with an energy protocol has the advantage of more

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[7] ASHRAE Standing Standard Project Committee 90.1, *Energy Standard for Buildings Except Low-Rise Residential Buildings,* 2007.

[8] California Energy Commission, *2008 Building Energy Efficiency Standards for Residential and Nonresidential Buildings*, December 2008, Effective January 1, 2010, Administrative Regulations, California Code of Regulations, Title 24, Part 1, available at http://www.energy.ca.gov/2008publications/CEC-400-2008-001/CEC-400-2008-001-CMF.PDF.

easily estimating energy saved by efficiency measures such as lighting controls and daylighting with automatic dimming.

6.1.11. Lighting EUI of Patient room area:

This metric requires measuring energy provided to lighting only. The metric as described in the HEBG offers an alternate, calculated path, but that path, requiring as it does the operating schedule for each fixture, is not feasible. Therefore, this metric must be directly measured. This metric will run into exactly the same problems as described above for Electrical EUI.

6.1.12. Illumination in patient room area:

This metric requires a one-time reading. The reality of this metric is that it will change over time, as the fixtures become dusty, and as lamps and ballasts degrade. This metric probably has very little use except perhaps in initial acceptance testing prior to beneficial occupancy.

6.1.13. Medical equipment, plug loads of patient room:

Similar to Lighting EUI of patient room area.

6.1.14. Energy Intensity of large medical equipment:

This metric requires energy measurement for each separable piece of large medical equipment, coupled with equipment-specific activity metric to better determine drivers for consumption. This prescription is much more relevant for a single implementation as research into this question to drive designs for more efficient equipment. The practical reality is that it is very doubtful that knowing this information will be of any value to the facility operator.

6.1.15. Other electrical considerations:

One final note is that the electrical designer ought to consider using one set of panels for each department in a hospital, to facilitate more effective measurement and benchmarking. This is particularly useful strategy for 120-volt panels that serve plug- and other similar kinds of loads.

Certain high-energy departments should certainly be monitored and benchmarked. Examples include dietary, central sterile, laundry (if there is one), and data center.

6.2. Cooling Systems

6.2.1. General

Cooling systems for new facilities often separate seasonal and 24/7 loads, resulting in simple or complicated energy systems. New facilities often have seasonal plants consisting of chillers, cooling towers, chilled water pumps and condensing water pumps. 24/7 services can be independent of the seasonal plant or integral, using the seasonal plant “in season” and evaporative cooling via plate and frame heat exchangers during “off season”. More sophisticated systems capture the “waste heat” from the cooling system to offset the thermal loads from heating, water heating or steam systems. Regardless of the system, metrics and metering approaches are consistent, albeit the more complicated the system, the more meters needed.

6.2.2. Seasonal Cooling Plants

New facilities usually have central seasonal cooling plant consisting of chillers, cooling towers, chilled water distribution pumps and condensing water pumps. The use of cooling energy, regardless of area served, is the delivered cooling BTU’s (Tons), as measured by the flow rate and delta temperature (return water minus supply water). The EUI of cooling is measured by the totality of input energy, including chillers, cooling towers, pumps and auxiliaries (See Section 6.1.1). The performance of the chiller plant (KW/ton usual metric) is the totalizing of the input (see electrical systems) divided by the output. New chillers have sophisticated controls that can integrate with building energy manage systems for simple data acquisition.

6.2.3. Multiple Buildings or Areas

Where cooling is delivered to multiple buildings or areas, the energy delivered to the building should be measured by a building BTU meter measuring flow rate and supply/return delta T. The input energy should be a prorated energy from the central pant plus pumping energy for the building or area.

6.2.4. 24/7 Cooling

The metrics and metering are the same as for the central plant. Energy delivered is measured by BTU meters. Input energy is the same as the central plant, except chillers can be off, increasing the efficiency.

6.2.5. Heat Recovery

Where heat from the central plant is recovered for heating or other process loads, the chiller plant metrics and metering remain the same. The recovered heat needs to be accounted in the respective thermal sources – see respective thermal use of energy.

6.2.6. Independent cooling

It is not uncommon to have independent cooling systems for specialty needs in hospitals, like imagining (MRI’s), data centers or even through-the-wall air conditioners. These are subsets of the total cooling metrics and - to the extent practical - need to be metered separately and totalized with cooling. Input energy and output energy are ideally metered. Where metering is not worthwhile, an overall plan can include a computation.

6.3. Ventilating System(s)

6.3.1. General:

Ventilating systems include all fan systems that move air by fans throughout a hospital, including supply, return and exhaust fans. The energy metric for these systems is limited to the fan energy; energy to heat or cool the air is covered in the heating and cooling sections. Fan energy is considerable in hospital due to 24/7 operation, code requirements for high air exchange rates and high fan pressures. Therefore, tracking fan energy is important in an overall energy management and reduction plan. Sustainable designs are addressing the reduction of fan energy through variable air volume, displacement ventilation, natural ventilation, low pressure/high efficiency fans, and direct outside air systems “DOAS” with decoupled heating and cooling.

Fan Input Energy:

Measuring fan energy is generally discussed in Section 5.1.3. The EUI for fan energy is simply the totality of all electric energy to fans. Considering the distributed nature of fans, the variety of sizes, and the variety of voltages, metering could be a challenge. However, Variable Frequency Drive (VFD) use in HVAC systems is standard practice so gathering electrical power information for specific fans from the VFDs can reduce or eliminate the necessity of installing additional electrical meters to record power usage. Many VFD’s provide output voltage, output current, output power in kW, and accumulated energy use in kW hours through a BACnet interface via the building energy management system. While the VFD output may only be 95% accurate, it is sufficient for tracking. Smaller fans without VFD’s are usually not worth metering, unless they are greater than three to five horsepower. In these cases, a tracking system should include a calculated energy use for these fans For example, a 2500 cfm exhaust fan operating a 0.75 inches water gage requires about 1.2 brake horsepower or about 1.0 kw (including drive losses) If the fan operates continuously, the annual energy use is 8760 kwh. The brake horsepower can be calculated or the actual amperage can be easily measured by a clamp on amp probe.

6.3.2. Fan Output Energy:

The actual output energy of fans is known as air horsepower and is a function of airflow (CFM) and static pressure. Measuring air horsepower is too complicated and expensive, so CFM alone is a surrogate for output energy. Measuring airflow with flow meters is also very expensive. When flow meters aren’t otherwise used, the current frequency of the VFD is proportional to CFM and can be used to compute CFM via the energy management system. Again, where flow meters or VFD’s aren’t present, the CFM delivered should be estimated using design drawings or balancing data. If neither is available, a balancer can quickly estimate CFM from a pitot tube traverse at the fan discharge. Thus, the metric of fan performance is input energy divided by output, kwh/CFM.

6.4. Heating Systems

6.4.1. General:

Heating systems are usually more complicated than cooling systems due to the variety of distribution, generation and energy sources. Most new hospitals distribute heating energy via pumped heating water systems. Heating water is generated by either hot water boilers or steam boilers with steam to heating water convertors. Boilers are fired with natural gas, oil or both. In older hospitals, systems may use steam directly for heating. In multi building facilities, steam may be distributed to buildings and converted to heating water at each building. In addition to heating, steam is also used directly for humidification, central sterile processes and other processes. In more sustainable hospitals, heating can be provided by heat pumps (simultaneous or ground loop), waste heat recovery, combined heat and power systems (cogeneration or fuel cells) and solar thermal. Heating energy is used to heat outside air and make up for heat loss through the envelope. With 24/7 operation and high outside air ventilation rates, the energy component to heat outside air is large. However, even larger is heating energy wasted to "reheat" cooled supply air. Central fans deliver cool supply air (55 F), based on the zone needing the most cooling. With prescribed high exchange rates most spaces need to reheat the supply air to match the thermal load. Sustainable hospitals are addressing wasted "reheat" energy with variable air volume systems, displacement ventilation, and decoupled heating and cooling systems. Regardless of the complexity of heating systems, the metrics for EUI and metering are straight forward, albeit the distribution or decentralization will dictate more metering locations.

6.4.2. Hot Water Boilers:

Hot water boilers are the simplest case for heating system EUIs. Boilers burn a fuel to generate hot water that is pumped throughout the facility. The use of heating energy, regardless of area served, is the delivered BTU's, as measured by the flow rate and delta temperature (supply water minus return water). The EUI of heating is measured by the totality of input energy, including fuel (gas and/or oil), burners and pumps. Each fuel source to boilers needs to be metered and fuels need to be converted to BTU equivalents. Boiler efficiency can be monitored as a separate metric; dividing delivered hot water BTU's by input fuel BTU's.

6.4.3. Steam Boilers:

Steam boilers are similar to hot water boilers, except it is necessary to meter steam at an intermediary energy medium. At the boiler, the output energy is steam and needs to be metered in Lbs/hour, converted to a BTU equivalent (based on pressure and assumed quality). The totality of energy input includes fuel, burners, boiler feed pumps and condensate return pumps (which are often remote). Because steam is usually distributed for multiple uses, the EUI of each use should be determined. If converted to heating water, the delivered BTUs should be metered as with hot water boilers, and the Lbs of steam converted to the boiler input energy per pound. If the steam is used for humidification, the Lbs of steam should be metered. Where 100 % of the steam is returned to the boiler, such as heating water convertors or domestic hot water generators, steam use can be metered with condensate meters that are less expensive than steam meters.

6.4.4. Multiple Buildings or Areas:

Where heating water is delivered to multiple buildings or areas, the energy delivered to the building should be measured by a building BTU meter measuring flow rate and supply/return delta T. The input energy should be a prorated energy from the central pant plus pumping energy for the building or area.

6.4.5. Heat Recovery:

Where heat is recovered and used for heating, the recovered heat needs to be counted a source of energy. The use of recovered heating energy is the same delivered BTU's, as measured by the flow rate and delta temperature (supply water minus return water). Total heating energy use should be divided between recovered and non-recovered. The EUI of heating is measured by the totality of input energy, often just pumps. However, input energy for recovered heat can be complicated in the case – for example – of heat pumps. One could argue that the input energy to the heat pump should be divided between cooling and heating. As cooling and heating happen simultaneously in varying amounts, complicating the allocation of input energy. A simple, and reasonable, approach might be to divide the input energy to the heat pump equally between cooling and heating. Each heat recovery situation needs to be evaluated on a case by case basis.

6.5. Water heating systems:

Water heating systems can be as complicated as heating systems. The good news is the metrics and metering of water heating are virtually the same as for heating water. The use of hot water energy is the delivered BTU's, as measured by the flow rate and delta temperature (supply water minus source water). Hot water can be generated in as many ways and at as many locations as heating water, but the EUI and input energies are exactly the same as for heating water discussed above.

7. System design for existing facilities

Implementing a metering system that will accomplish the HEBG goals will usually be complicated and expensive. Owners will need to think about hybrids of the recommended metrics that will be likely to yield the highest benefit in terms of future system improvements. As a general proposition, this will be likely to be the plant systems and non-equipment electric EUI. As a guide to how to approach a complicated circumstance, let's consider the following example.

7.1 Example existing hospital

7.1.1 General: 500,000 square feet built in three phases; original in 1968, 150,000 square feet; 1988 addition, 150,000 square feet; 2004 addition 200,000 square feet – a new nursing tower, and retrofit of old patient rooms to other uses. Renovations have been continual to keep up with technology such as imaging and data. This hospital has a diversity of electrical and mechanical systems and is as complicated as any existing hospital might be for metering.

7.1.2 Electrical Systems:

7.1.2.1 Normal Power: The 1988 addition is served from an upgraded service and switchgear in the 1968 building, with a single meter. The 2004 addition has a separate service and meter.

7.1.2.2 Emergency Power: Two 1.5 MW generators serve the 1968 and 1988 buildings, upgraded in 1988, no metering. Two 1.0 MW generators serve the 2004 addition, with meters.

7.1.2.3 Lighting: Lighting systems reflect the vintage of construction; the 1968 and 1988 building were retrofitted in the late 90's. The only lighting controls are occupancy sensors in administrative areas.

7.1.3 Mechanical Systems:

7.1.3.1: Cooling: The 1968 building has four 125 ton reciprocating chillers. A 500 ton centrifugal chiller was added in 1988. Chilled and condensing water is constant volume with dedicated pumps for each chiller. Two 500 ton cooling towers are forced draft; the newer one has a two speed fan. The 2004 addition has an independent plant with two 300 ton centrifugal chillers with constant primary, variable secondary chilled water pumps with VFD's. Constant volume condensing water pumps serve a two cell induced draft cooling tower with VFD fans. The chillers in the 2004 addition operate seasonally. The chillers in the 1968/1988 plant operate year round at reduced load to serve the 24/7 process loads and four pipe fan coil units in the 1968 building. No cooling systems have dedicated meters.

7.1.3.2: Heating: The 1968 building is served by two 300 boiler horsepower high pressure steam boilers, converted with dual fuel burners to fire oil and natural gas. A 300 boiler horsepower, dual fuel, hot water boiler was added to serve the 1988 addition. The 2004 addition is served by six 1000 MBH, gas fired, condensing, low temperature, hot water boilers. High pressure steam is reduced to 70 PSIG to serve central sterile, and to 15 PSIG to serve humidification, dietary, domestic hot water, steam coils in 100% outside air fans (1968 building), and heating water (via a convertor for the 1968 building). Heating water to the 1968/1988 building is delivered at 180 degrees F, with constant volume pumps and system bypass. Hot water is delivered to the 2004 building at 100 to 140 degrees F (reset on outdoor air) by VFD pumps.

7.1.3.3 Hot Water Systems. Domestic hot water for the 1968 and 1988 buildings is generated by 15 PSIG steam heat exchanger bundles in storage tanks, upgraded in 1988. Domestic hot water for the 2004 addition is generated by hot water heat exchangers and storage in the 1968/1988 building. Process hot water is steam generated similar to domestic hot water.

7.1.3.4 Fan systems: The 1968 building has four pipe fan coil units and constant volume 100% outside air ventilation fan units with steam coils and chilled water cooling coils. The 1988 addition has central air handling units with economizers, chilled water cooling coils and hot water heating coils, serving constant volume terminal units with hot water reheat coils. The 2004 addition has central air handling units with VFD's, economizers, chilled water cooling coils and hot water heating coils, serving variable volume terminal units with hot water reheat coils.

7.2 Metering Plan Overall Approach

7.2.1 First, assess what is already available, e.g. meters, VFD's, BACnet controllers (Chillers), Energy Management System capability and capacity. To visualize and account for systems and metering, an "energy roadmap" is a valuable tool. This is a compilation of energy systems diagrams, simplified to show flows of energy from sources to uses. The more complicated the hospital, the more involved the plan will be.

7.2.2 Second, prioritize systems based on likely energy use, and determine additional metering needed. Identify lower cost alternatives to fixed meters, including VFD's, one time measurements or calculations in lieu of meters.

7.2.3 Third, re-rank the systems qualitatively, based on return on investment of possible energy savings for investment in metering/monitoring

7.2.4 Last, create an implementation plan starting with the best return on investment until the investment is not deemed worthwhile.

7.3 System by system

7.3.1 General: Modify all existing meters and provide all meters to be compatible with the Building Management System (BMS); upgrade BMS capacity to monitor meters, VFD's and control panels; and connect all new devices. Where multiple devices serve the same function, combine multiple devices on one meter. For example, if chilled and condensing water pumps are all served from a dedicated motor control center, meter the motor control center.

7.3.1 Electric Power Use

7.3.1.1 Utility meters: Upgrade for digital output to BMS

7.3.1.2 Chiller Plants

7.3.1.2.1 1968/1988 Buildings: Add meter for chillers, cooling towers and pumps

7.3.1.2.2 2004 Addition: Monitor Chiller control panels, pump VFD's, and cooling tower fan VFD's

7.3.1.3 Heating Plants

7.3.1.3.1 1968/1988 Buildings: Add meters for boiler burners, boiler feed pumps, and heating water pumps. Calculate use of condensate return pumps.

7.3.1.3.2 2004 Addition: Add a meter for boilers. Monitor heating water pump VFD's.

7.3.1.4 Hot Water Heating: Calculate use of recirculation pumps

7.3.1.5 Fan Systems

7.3.1.5.1 1968 Building: Add meters for large outside air ventilation fans and large exhaust fans. Calculate use for fan coil units and small exhaust fans

7.3.1.5.2 1988 Building: Add meters for large air handlers and large exhaust fans. Calculate use for small supply fans and small exhaust fans.

7.3.1.5.3 2004 Addition: Monitor VFD's on large air handlers. Add meters for large exhaust fans. Calculate use for small supply fans and small exhaust fans.

7.3.1.6 Lighting: Calculate use for lighting systems in all buildings; consider energy modeling software.

7.3.1.7 Other Loads: Add meters for large electrical loads like MRI's and other imaging. Calculate use for other small loads.

7.3.2 Natural Gas Use

7.3.2.1 Utility meters: Upgrade for digital output to BMS

7.3.2.2 Heating Plants: Add meters for boiler burners in all buildings; separate steam boilers from hot water boilers

7.3.2.3 Dietary: Add meter

7.3.2.4 Lab and other: Calculate use for all buildings

7.3.3 Diesel Oil Use

7.3.3.1 Emergency Generators: Add meters at each plant

7.3.3.2 Boilers: Add meters to 1968/1988 boilers: separate steam boilers from hot water boilers

7.3.4 Chilled Water Use

7.3.4.1 1968/1988 Plant: Add BTU meters, one to each building

7.3.4.2 2004 Addition Plant: Monitor chiller panels for chilled water flow and delta temperature.

7.3.5 Steam Use

7.3.5.1 Boilers: Add steam meter to steam header

7.3.5.2 Heating Water: Add steam or condensate meter to heating water convertor

7.3.5.3 Domestic Hot Water Heater: Add steam or condensate meter to hot water generator

7.3.5.3 Humidification: Add steam meter at steam header

7.3.5.4 Central Sterile: Add steam meter at steam header

7.3.6 Heating Water Use

7.3.6.1 1968/1988 Plant: Add BTU meters, one to each building

7.3.6.2 2004 Addition: Add BTU meter

7.3.6.3 Domestic Hot Water Heater: Add BTU meter to hot water generator

7.3.7 Fan CFM

7.3.7.1 1968/1988 Buildings: Monitor any existing flow meters. Calculate air flow for all other fans

7.3.7.2 2004 Addition: Monitor VFD's on all air handlers and compute cfm, based on VFD frequency. Calculate air flow for all other fans

7.4. Electrical

In existing facilities, particularly older ones, renovations will likely have changed the boundaries between departments almost haphazardly. In addition, people will have added circuits all over the place, including from a panel in another building if that was where a space for a new breaker can be found. These kinds of practices will make it much harder to accurately measure and benchmark the systems.

7.5. *Cooling, ventilating, heating and water heating systems*

Existing facilities add complications for metering of mechanical energy systems as with electrical systems. Although the delineation of system is less clear, the metering and metrics remain the same. In existing facilities, the determination of the extent of metering for benchmarking is just more formidable. Each facility must be evaluated on a case-by-case basis.

7.6. The metering system

Benchmarking existing facilities with temporary equipment can be difficult and labor intensive. The amount of effort required is highly dependent on what points and data are currently being used for building control and what the existing BAS capabilities are. Data generally needs to be collected manually or recorded data needs to be downloaded and compiled into a central file. A main concern with short term benchmarking is that annual use has to be extrapolated and it is difficult to adjust the data to account for seasonal fluctuations. The existing Building Automation

System (BAS) generally monitors some of the benchmarking parameters, but additional meters are commonly required to be installed to gather all the desired data.

8. System to measure, record and report necessary data

There are essentially four general options for implementing a system to perform the ongoing measurements needed to systematically collect the data required to perform the analysis and benchmarking described in this White Paper, with varying levels of initial cost and ease of use.

Key to all of these options is the compilation and reporting of the data in a form that is concise, readily understandable, and facilitates decisions. Most systems are good at monitoring and tracking data; however, most do not have features that effectively compile and report data. Nobody should invest time and money into an energy monitoring program only to receive an unmanageable pile of raw data on their desk each month. An implementation plan needs to carefully consider this final step in the communication process. An example of the expected output report should be part of the plan, including what metrics are reported and compared, and the frequency reported.

First, most building automation systems, combined with metering integral with the VFDs directly controlling the equipment, can provide most of the metering recommended by the HEBG. To get the complete picture, these systems will require provision of the ammeters as part of the system that is required to perform the electrical measurements, or else the ability to interface with other ammeters. This system is not required by any codes, but all but the electrical portions are routinely installed as good design practice. All meters need to be selected for compatibility of signal. The BMS needs to be programmed to monitor, record and accumulate data. This step is relatively straightforward with modern BMS systems; however, data storage and archiving need to be carefully planned. The difficult step is analyzing and reporting the data. Most BMS software requires custom programming to accomplish this step; and this critical step is not often executed well. A simpler alternative, but one that requires an extra step, is to set up the BMS to log and store data, export the data to a spreadsheet program, and implement the relatively simple benchmark calculations described in the HEBG in the spreadsheet.

Second, some vendors offer stand-alone metering systems. These systems are usually relatively expensive, and run on separate networks. These systems offer tremendous power, often far more than can be realistically used by most facility staff. In some cases, these systems can provide what is essentially redundant metering to that of the facility building automation system. This system will require programming to ensure delivery of the recommended metrics. This is generally the most expensive of the system options. The Case Study that concludes this paper included such a system for the electrical loads, using the Building Automation System and VFD sensors to provide the overall metering. That hybridized system added approximately $.017/square foot to the construction cost.

Third, there may be no metering system. Instead, the facility operator can make periodic, manual readings. Such readings, combined with utility meter readings, can provide some approximations of some of the measures described herein. This is obviously the least expensive system from a first-cost perspective, but the one that consumes the most time and yields the least useful results.

Finally, technology allowing circuit-by-circuit monitoring of electrical systems is being developed and may soon be cost effective. Such systems, particularly when coupled with data from the building automation system, would provide the most opportunities for precise monitoring of almost infinite measures of energy consumption. The key to the successful installation and use of such a system will be the careful consideration of useful metrics, and the programming to achieve these metrics. Cost estimates for such systems by various technology developers are in the range of $30/circuit currently.

9. *Case Study of Implementing Metering in Design Phase*

During the summer of 2010, a large California hospital was in early stages of design. The facility operators had high aspirations for energy performance of the facility, and, so, wanted to implement a system to measure the energy consumption as described in the HEBG. Accordingly, such a system as indicated on early version of the pricing documents.

The design team, working with facility operations staff, developed a slightly different metering protocol from the one identified by the HEBG, as one that would better allow them to monitor and control the loads they felt were most amenable to potential improvement over time. The design team used sensors in the equipment VFDs, coupled with the Building Automation system to monitor the thermal and ventilation loads and efficiencies. These measures added essentially nothing to the cost as they were features of the desired building automation system (BAS).

For the electrical distribution system, metered processes included:

- Mechanical Loads: the design practice segregated major mechanical equipment on its own distribution system, meaning that we had a separate Automatic Transfer Switch (ATS) and distribution board for this set of equipment. This made it simple to provide a single meter downstream of the ATS to provide data for major mechanical equipment. Doing this was simple and cost effective but in most cases did not allow us to distinguish between each mechanical process of Cooling, Heating and Air loads on the mechanical system. The design team also neglected miscellaneous mechanical loads that were not at centralized locations, such as Fan coil units at Telecom closets because the metering was prohibitively expensive. Instead, as mentioned, these devices were to be monitored by the BAS.
- Kitchen Loads: The design measured this system separately. For this hospital, the owner wanted the kitchen to be on emergency power, so it was simple to provide a single meter on a feeder that served the bulk of the equipment. Some miscellaneous loads were on the normal system and went unmetered, but this was a small minority of the total load.
- Imaging Equipment loads: Because of the large amount of imaging rooms within the project the design included a large centralized UPS that was able to back up the entire imaging suite and imaging equipment that was a part of interventional platform. This design, too, allowed metering at a single point.

- IT loads: All it loads in the project went through one of five UPSs. The monitoring system included a single meter on each of the five UPSs and totalized them.
- Lighting loads: The design provided 277-volt power to all lighting loads. The design included a single meter at each 480/277-volt branch circuit panel. This design only approximated the total lighting load, as some other miscellaneous loads were served from the same branch circuit panels. It would have been cost prohibitive to provide separate branch circuit panels for the very few loads that were not lighting loads.
- Plug-loads: The design served receptacle circuits, as well as many other miscellaneous loads from the same 120-volt branch circuit panels.

The electrical meters were designed to be very simple ammeters whose output would be monitored and recorded by a simple central system. Most meters in the market place are capable of much more than simple power consumption and have a price tag that reflects that. The cost of the design was provided by a cost estimator and a builder. The cost estimator priced the system as intended, but the builder priced it as a sophisticated monitoring system capable of much more, and costing approximately four times as much.

In the end the owner chose to proceed with neither electrical system, though they did keep the building automation system with VFD monitors. This owner felt the first cost of the system did not justify the potential performance improvements. This belief was largely on the basis of the perception that its facility staff were not sufficiently capable to make effective use of the data that the system might provide.

10. Table

Metric	Measurement required	What kind of meter	How many	Where in system	How much per unit
Thermal & Ventilation Services Provided to Hospital Building					
Cooling to hospital	a. Annual kBtu/sf-yr b. Chiller Plant Efficiency kw/Ton c. Hourly kBtu vs. outdoor temp.	BTU meter, chiller, cooling tower & pumps electrical power	One BTU meter, each chiller input via chiller control panel, cooling towers and pumps via VFD's	Chiller Plant	BTU Meter $ 4000, Chillers, Towers and Pumps $ 0 additional - via BMS software
Heating to hospital	a. Annual kBtu/sf-yr b. Base Btu/sf-day c. Hourly kBtu vs. outdoor temp.	BTU meter, boiler & Pumps electrical power	One BTU meter, one electrical meter per boiler (e.g. 4), pumps via VFD's	Heating Plant	BTU Meter $ 4000, boiler electrical meter $ 500 each, Pumps $ 0 additional via BMS software
Domestic hot water (DHW) to hospital (kBtu/sf-yr)	kBtu out/ kBtu in	BTU meter, Pumps electrical power	One BTU meter, pumps via VFD's	Hot Water Generators	BTU Meter $ 4000, Pumps $ 0 additional via BMS software
Ventilation supply airflow	a. Base cfm/sf b. Peak cfm/sf c. cfm/kWh in	VFD frequency and power	One per air handler (e.g. 12)	At air handler	$ 0 additional via BMS software
Thermal & Ventilation System Efficiencies					

DHW system efficiencies	Source kBtu/ Source kBtu to hospital	BTU meter, & Pumps electrical	One BTU meter, pumps via VFD's	Hot Water Generators	Electrical included elsewhere
Heating water boiler efficiency	kBtu out/ kBtu in	Fuel meters, BTU meter, boiler & Pumps electrical power	One Gas, One Oil, One BTU, One Elect per Boiler (e.g. 4), pumps via VFD's	Heating Plant	$ 1500 Gas, $ 1500 oil, BTU & Electrical included elsewhere
Steam boiler efficiency	kBtu out/ kBtu in	Steam meter, boiler & Pumps electrical power	One Gas, One Oil, One Steam, One Elect per Boiler (e.g. 4)	Heating Plant	$ 1500 Gas, $ 1500 oil, Steam $ 4000, Electrical included elsewhere
Electrical End Use Metrics					
Non-equipment electric EUI of hosp.	Site kWh/sf-yr	Ammeter	One for life safety branch, one for critical branch, and one for normal system not used for equipment. Use input data from fan VFDs.	One meter on the load side of the automatic transfer switch.	$1500 at each of approximately six locations.
Electrical EUI of patient room area	Site kWh/sf-wk	Ammeter	One per branch, if system designed such that all 120/208 volt loads derive from 277/480 volt panel associated with the same area.	At panel.	$1,000 each, total $3,000 (normal, critical, life safety).
Non-equipment electrical EUI, D&T	Site kWh/sf-wk	Ammeter	One at each distribution panel serving the D&T Area for life safety, critical and normal branches.	At panel main.	$1,000 each for a total of 3.
Lighting power in patient room area	Installed W/sf	Calculation	none	none	none
Illumination in patient room area: fc		Calculation	none	none	none
Medical equipment, plug loads of patient room areas	Site kWh/sf-wk	Ammeter	Need separate ammeter for all lighting loads. Probably one per branch, assuming lighting is 277 volt and receptacles are 120 volt.	At each branch circuit panel.	$750 each. Total depends on number of panels.
Energy intensity of large medical equipment	a. Site kWh/yr b. Site kWh/unit activity	Ammeter	One at each piece of equipment.	Downstream of the breaker serving the equipment.	$1,000 each. Total depends on number of machines.
Departments	Site kwh/wk	Ammeter	One at each branch for the area.	At branch panel main.	$750 each. Total depends on number of machines.

11. Conclusions

The 2009 paper outlined a proposed benchmarking protocol that would provide a number of benefits described therein, as well as some described here. However, the actual implementation of such a system, while technically rather simple, is, in practice, no small accomplishment. In fact, actually implementing such a system appears to be beyond the ability of most health systems due to limited available capital and limited available staff to make use of the data. However, it is clear that those facilities who want to invest in better performing buildings in order to permanently minimize their operating costs will need the kinds of metering systems and benchmarking suggested by that paper. In particular, new buildings seeking points on the various green building rating systems will be able to install systems that achieve both the points, but also the control and benchmarking suggested by the HEBG. A result of the analysis and peer review done in preparing this document is to suggest some pilot studies that should be done to better test the protocol, and some revisions to make it a more usable tool.

Appendix B – Hospital Energy Benchmark Handbook

Background

This is a companion handbook to the Hospital Energy Benchmarking Guide (Singer et al., 2009). This document explicitly describes calculation of benchmark metrics described in that document. This document is designed to make it clear and simple for hospital facility engineers and operators to set up their own spreadsheets to calculate benchmark metrics using their own building data.

Buildings or campuses can be benchmarked against themselves (internal benchmarking) or against other buildings and campuses in same portfolio or against outside facilities (external benchmarking).

Calculating Hospital Energy Benchmark Metrics

Thermal and Ventilation Services Provided to Hospital

Cooling Load

The energy needed to meet the cooling load and make the hospital space comfortable is the same as the energy transferred from the supply air to the chilled water loop, which can be calculated using the difference between the chilled water return temperature and the chilled water supply temperature, the chilled water flow rate, and a conversion factor that represents the energy required to increase the temperature of water 1 F.

$$Cooling\_Load = 500 \times \left(CHWRT - CHWST\right) \times CHW\_FlowRate$$

Cooling_Load in units of Btu

CHWRT = chilled water return temperature in degrees F

CHWST = chilled water supply temperature in degrees F

CHW_FlowRate = chilled water loop flow rate in gallons per minute (gpm)

Calculating the cooling load for different time periods provides different insights to energy use and potential savings. If hourly or sub-hourly measurements of CHWRT, CHWST, and CHW_FlowRate are available along with hourly measurements of outdoor air temperature, T_{oa}, at (or near) the hospital make a plot of Cooling_Load vs. T_{oa} (See Figure B.1). The slope of a best-fit regression line through the scattered points is a measure of how cooling load varies with outside temperature and depends largely upon the building envelope (e.g. insulation and leakage). Tracking the value of the slope of the Cooling_Load vs T_{oa} is an effective way to track cooling system performance. An increase in slope may mean maintenance of the chilled water system is needed.

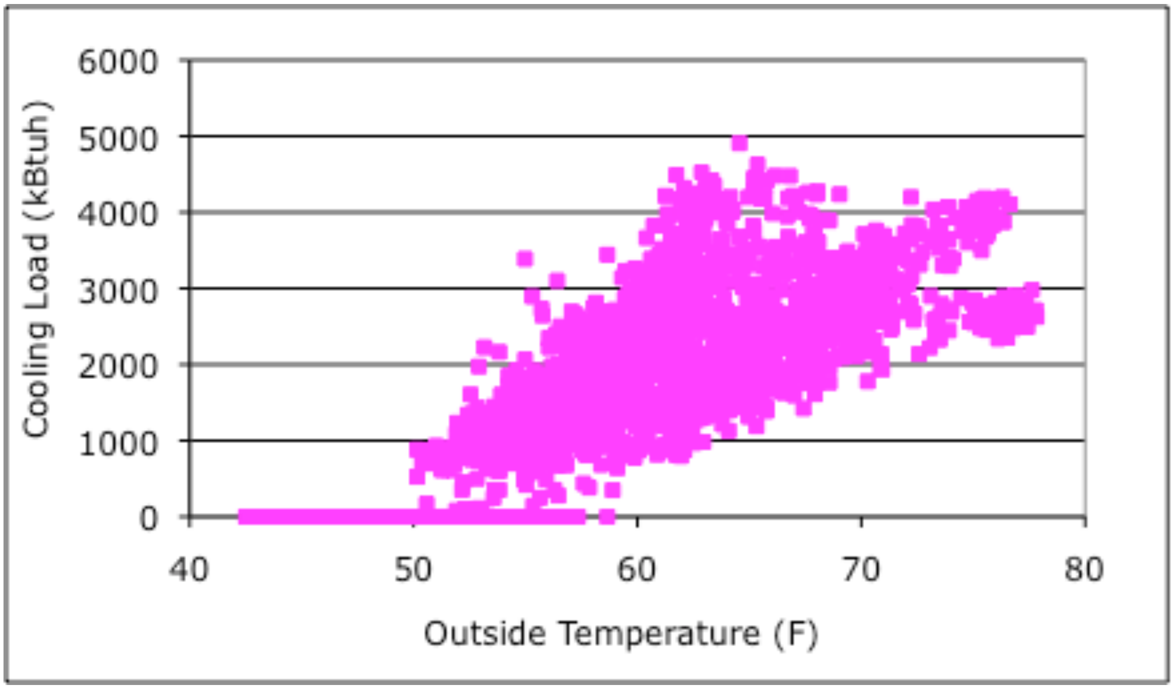

Figure B.1. Example plot of hospital cooling load versus outside air temperature (Toa). Data provided by QuEST.

If outdoor air temperature is not measured or logged on site local data can be acquired with internet-based tools such as www.weatherunderground.com.

If CHWRT, CHWST, and/or CHW_FlowRate are logged at sub-hourly intervals then average to get hourly measurements. For example, if point X is logged at 15 minute intervals then hourly values can be calculated using the simple average function.

$$X_{hh} = \frac{X_{hh:00} + X_{hh:15} + X_{hh:30} + X_{hh:45}}{4}$$

X_{hh}=Value of X at hour hh

$X_{hh:mm}$=Value of X at hour, hh, and minute, mm

Daily_Cooling_Load is calculated by summing each hourly cooling load value over a 24-hr period.

$$Daily\_Cooling\_Load = 500 \times \sum_{t=1}^{24}\left(\left(CHWRT_t - CHWST_t\right) \times CHW\_FlowRate_t\right)$$

Daily_Cooling_Load in units of Btu/day

$CHWRT_t$ = chilled water return temperature at time t in degrees F

$CHWST_t$ = chilled water supply temperature at time t in degrees F

$CHW\_FlowRate_t$ = chilled water loop flow rate at time t in gallons per minute (gpm)

Base_Cooling_Load is the cooling load that meets occupancy and process loads. To estimate Base_Cooling_Load calculate Daily_Cooling_Load for days in which the outdoor air temperature is "neutral", in other words conditioning outside air does not contribute to cooling load.

Annual cooling load is calculated by summing each hourly cooling load value for a one-year period.

$$Annual\_Cooling\_Load = 500 \times \sum_{t=1}^{87,600} \left(\left(CHWRT_t - CHWST_t \right) \times CHW\_FlowRate_t \right)$$

Annual_Cooling_Load typically expressed in kBtu instead of Btu.

Heating Load

$$Heating\_Load = 500 \times \left(HWRT - HWST \right) \times HW\_FlowRate$$

Heating_Load in units of Btu

HWRT = hot water return temperature in degrees F

HWST = hot water supply temperature in degrees F

HW_FlowRate = hot water loop flow rate in gallons per minute (gpm)

Daily_Heating_Load is calculated by summing each hourly heating load value over a 24-hr period.

$$Daily\_Heating\_Load = 500 \times \sum_{t=1}^{24} \left(\left(HWRT_t - HWST_t \right) \times HW\_FlowRate_t \right)$$

Daily_Heating_Load in units of Btu/day

$HWRT_t$ = hot water return temperature at time t in degrees F

$HWST_t$ = hot water supply temperature at time t in degrees F

$HW\_FlowRate_t$ = hot water loop flow rate at time t in gallons per minute (gpm)

Annual heating load is calculated by summing each hourly heating load value for a one-year period.

$$Annual\_Heating\_Load = 500 \times \sum_{t=1}^{87,600} \left(\left(HWRT_t - HWST_t \right) \times HW\_FlowRate_t \right)$$

Annual_Heating_Load typically expressed in kBtu instead of Btu.

Domestic Hot Water Load

$$Domestic\_Hot\_Water\_Load = 500 \times \left(DHWRT - DHWST \right) \times DHW\_FlowRate$$

Domestic_Hot_Water_Load in units of Btu

DHWRT = domestic hot water return temperature in degrees F

DHWST = domestic hot water supply temperature in degrees F

DHW_FlowRate = domestic hot water loop flow rate in gallons per minute (gpm)

Daily_Domestic_Hot_Water_Load is calculated by summing each hourly Domestic_Hot_Water load value over a 24-hr period.

$$Daily\_Domestic\_Hot\_Water\_Load = 500 \times \sum_{t=1}^{24}\left(\left(DHWRT_t - DHWST_t\right) \times DHW\_FlowRate_t\right)$$

Daily_Domestic_Hot_Water_Load in units of Btu/day

$DHWRT_t$ = domestic hot water return temperature at time t in degrees F

$DHWST_t$ = domestic hot water supply temperature at time t in degrees F

$DHW\_FlowRate_t$ = domestic hot water loop flow rate at time t in gallons per minute (gpm)

Annual Domestic_Hot_Water load is calculated by summing each hourly Domestic_Hot_Water load value for a one-year period.

$$Annual\_Domestic\_Hot\_Water\_Load = 500 \times \sum_{t=1}^{87,600}\left(\left(DHWRT_t - DHWST_t\right) \times DHW\_FlowRate_t\right)$$

Annual_Domestic_Hot_Water_Load typically expressed in kBtu instead of Btu.

Ventilation

Ventilation requirements vary depending on function of space (e.g. patient room, operating room, etc.). Ventilation metrics should be calculated for each air handling unit (AHU).

Outside air ventilation vs. outside air ventilation required by code

$$OA\_Ventilation\_vs\_Code = \frac{OA\_ACH\_Zone}{OA\_ACH\_Zone\_Code}$$

$$OA\_ACH\_Zone = 60 \times \frac{OA\_FlowRate\_Zone}{Zone\_Vol}$$

$$OA\_FlowRate\_Zone = \frac{OA\_FlowRate\_AHU}{SupplyAir\_FlowRate\_AHU} \times SupplyAir\_FlowRate\_Zone$$

OA_ACH_Zone = Actual outdoor air changes per hour in Zone

OA_ACH_Zone_Code = Code required outdoor air changes per hour for Zone

OA_FlowRate_Zone = Actual outdoor air flow rate to Zone in cfm

Zone_Vol = Zone volume in ft^3

OA_FlowRate_AHU = Actual outdoor air flow rate into AHU in cfm

SupplyAir_FlowRate_AHU = Actual supply air flow rate at AHU in cfm

SupplyAir_FlowRate_Zone = Actual supply air flow rate at Zone in cfm

Total air ventilation vs. total air ventilation required by code

$$Total\_Ventilation\_vs\_Code = \frac{Total\_ACH\_Zone}{Total\_ACH\_Zone\_Code}$$

$$Total\_ACH\_Zone = 60 \times \frac{SupplyAir\_FlowRate\_Zone}{Zone\_Vol}$$

Total_ACH_Zone = Actual total air changes per hour in Zone

Total_ACH_Zone_Code = Code required total air changes per hour for Zone

If OA_Ventilation_vs_Code is much greater than one then potential energy savings may be achieved by decreasing OA_FR_Actual. If Total_Ventilation_vs_Code is much greater than one then potential energy savings may be achieved by decreasing Supply_FR_Actual.

Thermal Load Intensities

To better compare energy performance to other hospitals, calculate energy intensity. Intensity normalizes to a characteristic of the facility, most often floor area, but could also be number of bed, patients, procedures, etc.

$$Annual\_Cooling\_Load\_Intensity = \frac{Annual\_Cooling\_Load}{Floor\_Area}$$

Annual_Cooling_Load_Intensity in units of kBtu/ft^2-yr

Annual_Cooling_Load calculation shown in section 2.1 in units of kBtu/yr

Floor_Area of zones being cooled

$$Annual\_Heating\_Load\_Intensity = \frac{Annual\_Heating\_Load}{Floor\_Area}$$

Annual_Heating_Load_Intensity in units of kBtu/ft^2-yr

Annual_Heating_Load calculation shown in section 2.2 in units of kBtu/yr

Floor_Area of zones being heated

$$Annual\_Domestic\_Hot\_Water\_Load\_Intensity = \frac{Annual\_Domestic\_Hot\_Water\_Load}{Floor\_Area}$$

Annual_Domestic_Hot_Water_Load_Intensity in units of kBtu/ft^2-yr

Annual_Domestic_Hot_Water_Load calculation shown in section 2.3 in units of kBtu/yr

Floor_Area of zones being heated

Thermal and Ventilation System Efficiencies

Thermal and ventilation system efficiency metrics require either 1. Power meters on electrical equipment (e.g. chillers, fans, etc.) and gas flow meters on boilers or 2. Logging of power measurements often provided by variable frequency drive (VFD) controllers often found on newer or retrofitted chillers, pumps, fan motors, etc. Not likely to have power meters on each piece of equipment or on circuit panels serving only specific pieces of equipment, but let's assume sufficient sub-metering or power data from VFD controllers is available for the following metrics

$$Cooling\_Effic = \frac{Cooling\_Equip\_Energy}{Cooling\_Load}$$

Cooling_Effic is in units of kWh/ton-h

Cooling_Equip_Energy = energy consumption of all cooling system components (e.g. electrical consumption of chillers, large chilled water pumps; do not include pumps < 2 hp to simplify and save on metering) in units of kWh

Cooling_Load calculation is shown in section 2.1; in units of ton-h (1 ton-h = 12000 Btu)

Cooling_Effic should be calculated for at least a one-week period during the cooling season, and the closer to the peak of the cooling season the better. For internal benchmarking, plotting daily kWh vs daily ton-h continuously will provide valuable insight into cooling system performance for optimization and cost-effective maintenance.

$$Heating\_Effic = \frac{Heating\_Equip\_Energy}{Heating\_Load}$$

Heating_Effic is in units of kBtu/kBtu

Heating_Equip_Energy = energy consumption of all heating system components (e.g. gas consumption of boilers, electrical consumption of hot water pumps; do not include pumps < 2 hp to simplify and save on metering) in units of kBtu (1 kWh = 3.41 kBtu)

Heating_Load calculation is shown in section 2.1; in units kBtu (1 kBtu = 1000 Btu)

$$Domestic\_Hot\_Water\_Effic = \frac{Domestic\_Hot\_Water\_Equip\_Energy}{Domestic\_Hot\_Water\_Load}$$

Domestic_Hot_Water_Equip_Energy = energy consumption of all domestic hot water system components (e.g. gas consumption of boilers, electrical consumption of domestic hot water pumps; do not include pumps < 2 hp to simplify and save on metering) in units of kBtu (1 kWh = 3.41 kBtu)

Domestic_Hot_Water_Load calculation is shown in section 2.1; in units of kBtu (1 kBtu = 1000 Btu)

$$Steam\_Effic = \frac{Steam\_Equip\_Energy}{Steam\_Energy}$$

Steam_Effic is in units of kBtu/kBtu

Steam_Equip_Energy = energy consumption of all steam system components (e.g. gas consumption of boilers) and should be in units of kBtu (1 kWh = 3.41 kBtu)

Steam_Energy = energy of steam produced in units of kBtu (1 lbs steam/h = 0.96 kBtu)

$$Bldg\_Ventilation\_Effic = \frac{Bldg\_Fan\_Power}{Bldg\_Ventilation\_FlowRate}$$

Bldg_Ventilation _Effic in units of W/cfm

Bldg_Fan_Power = power consumed by all building AHU supply, return, and exhaust fans in units of W

Bldg_Ventilation_FlowRate = Sum of supply fan flow rates

Thermal and Ventilation System Energy Use Intensities (EUI)

Calculate energy use intensities (EUI) for monthly or annual periods for external benchmarking. For internal benchmarking shorter periods (weekly, daily, or even hourly) can be useful for optimizing energy performance, troubleshooting, and fault detection. EUI metrics below are shown per floor area, but other metrics can be calculated per number of beds, patients, or procedures.

$$Cooling\_EUI = \frac{Cooling\_Equip\_Energy}{Bldg\_Floor\_Area}$$

Cooling_EUI in units of kWh/ft^2

Cooling_Equip_Energy is shown in section 2.3; in units of kWh

Bldg_Floor_Area = area served by cooling equipment in units of ft^2

$$Heating\_EUI = \frac{Heating\_Equip\_Energy}{Bldg\_Floor\_Area}$$

Heating_EUI in units of $kBtu/ft^2$

Heating_Equip_Energy is shown in section 2.3; in units of kBtu

Bldg_Floor_Area = area served by heating equipment in units of ft^2

$$Domestic\_Hot\_Water\_EUI = \frac{Domestic\_Hot\_Water\_Equip\_Energy}{Bldg\_Floor\_Area}$$

Domestic_Hot_Water_EUI in units of $kBtu/ft^2$

Domestic_Hot_Water _Equip_Energy is shown in section 2.3; in units of kBtu

Bldg_Floor_Area = area served by domestic hot water equipment in units of ft^2

$$Steam\_EUI = \frac{Steam\_Equip\_Energy}{Bldg\_Floor\_Area}$$

Steam_EUI in units of $kBtu/ft^2$

Steam_Equip_Energy is shown in section 2.3; in units of kBtu

Bldg_Floor_Area = area served by steam equipment in units of ft^2

$$Bldg\_Ventilation\_EUI = \frac{Bldg\_Fan\_Energy}{Bldg\_Floor\_Area}$$

Building_Ventilation_EUI in units of kW/ft^2

Bldg_Fan_Energy = energy consumed by all AHU fans in building in units of kW

Bldg_Floor_Area = area served by AHU fans in units of ft^2

$$Zone\_Ventilation\_EUI = \frac{AHU\_Fan\_Energy}{Zone\_Floor\_Area}$$

Zone_Ventilation_EUI in units of kW/ft^2

AHU_Fan_Energy = energy consumed by AHU fans serving one AHU zone in units of kW

Zone_Floor_Area = area served by cooling equipment in units of ft^2

Sub-metering Prioritization

Prioritization of meters and sub-meters based on best "bang for the buck" for identifying savings opportunities (see Table B.1). Meter locations may not apply to all hospitals.

Table B.1. Prioritization for energy sub-metering of hospital systems and components.

Level of Detail	Meter Location
	ELECTRICAL
Low	1. Campus main electrical service
	2. Whole building electrical service for each building
	3. Whole building electrical service for central plant(s)
Low-Med	4a. Electrical service to central plant chilled water equipment (e.g. chillers, pumps)
	4b. Electrical service to central plant hot water equipment (e.g. boilers, pumps)
	4c. Electrical service to central plant steam equipment (e.g. boilers, pumps)

	5. Electrical service to air handling mechanical rooms in each building on campus
Med-High	6. Electrical service to all lighting in each building (if circuit layout permits)
	7. Electrical service to all major plug loads (e.g. imaging equipment centers and data centers)
	8. Electrical service to all plug loads in each building (if circuit layout permits)
High	9. Electrical service to individual major components in central plant
	10. Electrical service to individual major components in AHU mechanical rooms
	11. Electrical service to lighting in each space type or zone (e.g. patient rooms)
	12. Electrical service to plug loads in each space type or zone (e.g. patient rooms)
	GAS
Low	1. Campus main gas service
	2. Whole building gas service for each building
	3. Whole building gas service for central plant(s)
Low-Med	4a. Gas service to central plant hot water equipment (e.g. boilers, pumps)
	4b. Gas service to central plant steam equipment (e.g. boilers, pumps)
	4c. Gas service to central plant domestic hot water equipment (e.g. boilers, pumps)
	THERMAL & VENTILATION SERVICES
Med-High	1a. Btu meters on central plant chilled water loops
	1b. Btu meters on central plant hot water loops
	1b. Btu meters on central plant steam service
High	2. Supply air flow rates and temperatures in each zone

Partitioning Central Plant Outputs to Multiple Buildings

Central plants can serve multiple buildings that all serve the same basic function or different functions (e.g. hospital, clinic, medical office building, etc.). Even buildings of the same type can have significantly different energy loads. For example, a children's hospital can have very different energy loads than a hospital specializing in cancer treatment.

Energy flows from central plants or district water or district steam supplies can be apportioned to building by floor area and function. See Table B.2. for CBECs median values of various end-uses for different medical campus building types—hospital, clinic, and medical office building (MOB). Use the median values as weighting factors or apportion factors (e.g. Hosp_AppFact) for apportioning central plant loads to the three building types often found on medical campuses.

$$Cooling\_Load\_Hospital\_A = \frac{Cooling\_Load\_Total \times Hosp\_AppFact}{Hosp\_AppFact \times Num\_Hosp + MOB\_AppFact \times Num\_MOB + Clinic\_AppFact \times Num\_Clinic}$$

Table B.2. Weighting factors to apportion central plant loads to campus buildings

End Use	Hospital (kBtu/ft^2-yr)	MOB (kBtu/ft^2-yr)	Clinic (kBtu/ft^2-yr)
Cooling	13.4	2.0	4.0
Heating	62.3	14.3	14.8
Service HW	43.4	0.3	0.6

Supporting Information

Abbreviations

Btu British thermal unit, unit of energy

Btu-h Btu per hour

cfm cubic feet per minute, unit of flow rate

kW kilowatt, unit of power

kW-h kilowatt-hour, unit of energy

Ton-h ton-hour, unit of cooling energy

W Watt, unit of power

Conversion Factors

1 kWh = 3,412 Btu

1 ton AC = 12,000 Btuh cooling = 15,000 Btuh heat rejection

1 therm = 100,000 Btuh

1 lbs steam = 960 Btuh

1 gpm = 500 lbs steam/hr

Preparing data for processing

Handling missing data

If one time step is missing interpolate—average value for timestep immediately before missing data point with value immediately following missing data point. For example, nth time step value of X is missing:

$$X_n = \frac{X_{n-1} + X_{n+1}}{2}$$

If more than one consecutive time steps is missing in X need to flag any metrics calculated using X.

Handling "bad" data

Criteria depends on the point (X), but generally any value that is 10x lower or higher than trend should be discarded as well as any zero values that appear during periods confident that point should have non-zero values only.

Math functions

Summation

$$\sum_{t=1}^{T} X_i$$

Simply means add values of X for each timestep from t=1 to t=T. For example, to calculate total power consumed in one day, P_d, using hourly measurements,

$$P_d = \sum_{t=1}^{24} P_t = P_1 + P_2 + P_3 + \ldots + P_{23} + P_{24}$$

References

Singer BC, Mathew P, Greenberg S, Tschudi W, Sartor D, Strom S, Vernon W. Hospital Energy Benchmarking Guidance – Version 1.0. Lawrence Berkeley National Laboratory, Berkeley, CA. October 2009. LBNL-2738E.