High Performance Healthcare Buildings: A Roadmap to Improved Energy Efficiency

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Abstract

This document presents a road map for improving the energy efficiency of hospitals and other healthcare facilities. The report compiles input from a broad array of experts in healthcare facility design and operations. The initial section lists challenges and barriers to efficiency improvements in healthcare. Opportunities are organized around the following ten themes: understanding and benchmarking energy use; best practices and training; codes and standards; improved utilization of existing HVAC designs and technology; innovation in HVAC design and technology; electrical system design; lighting; medical equipment and process loads; economic and organizational issues; and the design of next generation sustainable hospitals. Achieving energy efficiency will require a broad set of activities including research, development, deployment, demonstration, training, etc., organized around 48 specific objectives. Specific activities are prioritized in consideration of potential impact, likelihood of near- or mid-term feasibility and anticipated cost-effectiveness. This document is intended to be broad in consideration though not exhaustive. Opportunities and needs are identified and described with the goal of focusing efforts and resources.

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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 knowledge designers and operators that energy use can be reduced substantially with net economic benefit to the industry.

Objectives

The overall objectives of this project were to identify and prioritize opportunities for energy savings in healthcare buildings. An interim objective was a review and analysis of existing information on energy use in healthcare buildings.

Approach

This report presents a road map for dramatic energy efficiency improvements in healthcare facilities. This document weaves together information from the following sources and activities: information obtained from a review of published databases and reports, interviewers with industry experts and stakeholders, input from a workshop held on 03 March 2009 at LBNL in Berkeley CA, and suggestions offered by participants at the kick-off meeting of the Hospital Energy Alliance on 30 March 2009 in Washington DC, and comments provided by expert reviewers of the draft version of this document. The most substantial input to this document was provided by participants of the March 2009 workshop at LBNL.

Results

The primary product of this research is a roadmap for energy efficient healthcare facilities summarized in this report. A review of available information on energy use in the healthcare sector is available in *Summary of Information and Resources Related to Energy Use in Healthcare Facilities - Version 1*.

The barriers to improved energy efficiency in healthcare facilities include challenges that are common across many types of commercial buildings as well as many issues specific to the healthcare industry. Stakeholders and experts offered a long list of hurdles that included issues of technology, practice, training, culture, economics, corporate structure and decision-making processes, and other areas. The barriers noted by experts in the venues mentioned above are compiled in this document around the following four themes: challenges related to the provision of medical services; challenges related to the organization, culture and structure of healthcare entities; challenges related to the legacy stock of buildings and facilities; and challenges related to codes and standards.

Energy efficiency opportunities and the associated tasks to achieve substantial energy savings were suggested by industry experts with additions and specific activities identified and compiled by the research team. Opportunities are organized around the following ten themes:

- Understanding and benchmarking energy use.
- Best practices and training.
- Codes and standards.
- Improved utilization of existing HVAC designs and technology.
- Innovation in HVAC design and technology.
- Electrical system design.

- Lighting.
- Medical equipment and process loads
- Economic and organizational issues.
- Design of sustainable hospitals.

Specific target areas are described within each theme; for each target area one or more specific activities are identified. As with the challenges, the target areas and specific activities include research, development, demonstration, deployment, and training. These are applied to component technologies, systems engineering, best practices for operations and design, organizational dynamics, economics and other fields. A table at the end of the document provides a complete list of needed activities with prioritization based on considerations of potential impact, likelihood of near- or mid-term feasibility and anticipated cost-effectiveness

Benefits to California

The central product of this project – a roadmap for energy efficient healthcare buildings – provides a blueprint of the key challenges, opportunities and associated tasks that are needed for dramatic improvements in the energy performance of California hospitals and other healthcare facilities. With input from a diverse and highly knowledgeable collection of experts in the areas of facility design and operations, key issues and opportunities were identified, described and prioritized. If even a fraction of the savings opportunities outlined in this document is realized, potential benefits to the hospital sector are estimated to be on the scale of tens of millions of dollars per year of energy savings.

1.0 Introduction

Health care is provided in facilities that range from tertiary care hospitals with highly specialized facility characteristics, code requirements, internal equipment and process needs to medical office buildings that are generally similar to other office buildings. An excellent overview of U.S. healthcare buildings is provided as Chapter 9 of "Who Plays and Who Decides" (Reed et al. 2004), a report on the U.S. commercial building sector funded by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy[2]. The report describes a sector that includes over 100,000 buildings containing 3 billion square feet of floor space, or which about two-thirds is associated with inpatient facilities and one third with outpatient services. Hospital industry data is collected and compiled by the American Hospital Association (AHA), and made publicly available through the AHA website in the form of tables, charts, reports, and other media compiled into *Trendwatch* reports and an annual *Chartbook*[3]. Data presented in the online 2008 *Chartbook* indicate that as of 2006 there were 5747 registered hospitals with 947,412 beds with expenses of roughly $610 billion. The 4927 facilities registered as community hospitals – defined as nonfederal, short-term, general and special hospitals whose facilities and services are available to the general public – comprised 86% of the U.S. total hospital population. In 2006, California had 357 community hospitals that comprised 67% of the state hospital system.

Hospitals, surgery centers and other acute care facilities are among the most energy intensive commercial buildings in the U.S. and in California. Nationally, the Commercial Building Energy Consumption Survey (CBECS) estimates that in 2003 hospitals used an average of 250 thousand British thermal units of energy on site per square foot of floor area per year (kBtu/sf-y); this is second only to food service among building applications. The California-specific Commercial End Use Survey (CEUS) estimate that in 2002 California hospitals used an average of about 230 kBtu/sf-y of energy on site. Accounting for fuel used to generate off-site electricity generation and losses during distribution, the total source total energy use is roughly double these numbers on average.

Healthcare facilities face special challenges related to improving energy efficiency, but their currently high energy use intensities offer opportunities for large reductions. This report seeks to document the challenges and identify promising opportunities for improving energy efficiency to achieve high performance healthcare facilities.

The overall objectives of this project were to identify and prioritize opportunities for energy savings in healthcare building; the a priori understanding was that the focus would be on efficiency practices and technologies, i.e. through approaches that would not adversely impact or alter the provision or medical services. An interim objective was a review and analysis of existing information on energy use in healthcare buildings.

This report focuses on a roadmap to achieve energy efficiency improvements in healthcare buildings. A review and analysis of existing information that was produced to aid in the development of this roadmap is described in *Summary of Information and Resources Related to Energy Use in Healthcare Facilities - Version 1*.

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[2] www.eere.energy.gov/buildings/highperformance/commercial_analysis.html
[3] www.aha.org/aha/research-and-trends/index.html

2.0 Methods

The project plan was developed around the following four tasks:

- Literature review and stakeholder interviews to characterize the market
- Identify technical potential and information gaps through data analysis
- Develop an energy RD&D framework (roadmap) addressing energy efficiency measures that have potential for improving the performance of healthcare buildings.
- Disseminate project findings and recommendations

The review and analysis of existing information is described in *Summary of Information and Resources Related to Energy Use in Healthcare Facilities - Version 1*.

The energy efficiency road map was developed with extensive input from experts in the design and operation of healthcare facilities. Input was obtained via interviews, participation in a workshop convened at LBNL (Berkeley, CA) on March 3, comments offered during the April 30 kickoff event of the Hospital Energy Alliance in Washington DC, and through comments offered by reviewers of drafts of this document. Lists of interviewees, workshop participants and those who offered comments on this document are provided as appendices.

3.0 Results

3.1. Challenges to achieving energy efficient healthcare facilities

The following list provides some useful context for efforts to reduce energy use and improve energy efficiency in the health care sector. Challenges are presented in groups relating to (a) the provision of medical services (operational mission), (b) organizational and cultural constraints, (c) issues specifically related to the legacy of existing facilities and (d) codes and standards. The vast majority of these issues were raised by industry experts via the venues described in the introduction. Reviewer comments on input offered in earlier venues are provided in italics.

Challenges related to the provision of medical services

- Many parts of hospitals operate 24 hours per day every day of the year. This contributes to overall energy intensity (energy used per square foot of facility floor area per year) and creates both challenges and opportunities in trying to reduce energy use, e.g. by limiting services to areas with down times.
    - Automated occupancy-based lighting must be highly robust, reliable, and designed to accommodate operational needs of medical staff.
    - Automated occupancy-based HVAC turn-down provides opportunity for vast energy savings, but must be designed to be highly robust, reliable, and designed to accommodate operational needs for both medical and facility staff.
- Operational needs and perceived needs create difficult to meet standards for technologies and practices that are commonly employed in other commercial buildings. For example, automated or occupancy-based lighting for many areas must highly robust, reliable, and designed specifically around the operational needs of medical staff.

- Due to life-safety concerns, healthcare facility electrical systems must be robust and meet both operational needs and requirements of various codes and standards.
    - Electrical systems are composed of four branches for life-safety, critical, equipment and normal loads; these systems are often complex and intermingled, making sub-metering expensive and complicated.
    - Hospitals must be able to operate "off-the-grid" with back-up generation for electrical power and some hospital equipment must be on uninterruptable power supplies; these constraints add complexity and contribute to system inefficiencies. [*Reviewer comment: At the same time, maximizing energy efficiency and minimizing start loads will reduce the cost of emergency backup. Some uninterruptable power supplies are available with 99% efficiency and computer power supplies are now available with greater than 80% efficiency.*]
    - Electrical system architectures can complicate the integration of renewable and other advanced energy sources.
    - Lack of down time complicates sub-meter installation. [*Reviewer comment: Current transformers up to 3000 amps can now be attached without interrupting operation.*]
- Medical facility ventilation systems are designed for infection control as defined by strict codes and standards. Ventilation challenges related to infection control include the following:
    - Requirements for relatively high outdoor air delivery rates create thermal conditioning energy loads (some of these could be reduced with energy recovery).
    - Requirements for high overall air exchange rates with filtration lead to substantial fan energy use as well as large heating and cooling loads..
    - Ventilation system design is complicated by life-safety requirements to maintain pressure differences between spaces to reduce airborne disease or contaminant transmission.*
    - Hospitals have generally high air filtration requirements with extreme filtration required for areas housing immunologically compromised patients and wards with highly contagious patients.
    - Infection control challenges are created by dust and molds that become airborne during renovation projects.*
- Diversity of operational needs for spaces within hospital creates widely varying needs for ventilation, temperature, humidity, and pressure differences between spaces.
    - Constant volume reheat systems are robust, common and inefficient. These systems cool air at central air handlers to a level that meets the maximum cooling or dehumidification demand; terminal reheat is then used for areas for which the distributed low temperature air is too cold. [*Reviewer comment: Much more efficient heat recovery chillers are now available so the reheat issues are not as costly as originally*

thought. I probably would not consider new hospital construction without a modern properly sized heat recovery chiller. Retrofits are also cost effective.]

- In-patient hospitals and nursing homes maintain higher than usual air temperatures for patient comfort.* [*Reviewer comment: For surgery rooms, high air exchange rates required by code combined with low temperatures demanded by surgeons create high cooling loads.* Modern LED lighting and HIR halide lighting dramatically reduce infrared heat at the patient so the surgery team may not need such low temperatures.*]

- Owing to system complexities, need for redundancy and other factors, the MEP (Mechanical / Electrical / Plumbing) systems comprise a larger fraction of design and construction costs in hospitals compared with other commercial buildings.* [*Reviewer comment: Redundancy requirement presents an opportunity for improved system efficiency. Multiple pumps and fans can be operated with variable speed at the same time to improve efficiency. "Fan Walls" and similar packages improve efficiency while minimizing the cost of redundant equipment.*]
- Hospital buildings can be used for 50-100 years. Over this time there are many changes to the provision of medical care, to the interior layout of departments, etc.
- Designers of new facilities must consider not just the current projected uses, but also anticipate growth in overall facility capacity and changes to space configurations; some services may thus be oversized to ensure sufficiency at higher loads. It is very difficult to "right-size" hospital mechanical and electrical systems. [*Reviewer comment: A good approach is to make space for future capacity but do not oversize existing motors in excess of 50%.*]
- In the context of the industry being under extreme financial pressure, spending on both capital improvements and operations focuses on medical services; anything not directly related to revenue generation and/or health care provision is a low priority.
- High-powered medical imaging equipment (e.g., MRI) is increasingly prevalent. Newer units operate at higher power for greater resolution; these allow advances in medical care and increased revenue for a facility while consuming more energy. Some previously centralized equipment (e.g. x-rays) are now distributed throughout facilities. [*Reviewer comment: Proper location can be critical in the efficient servicing from existing infrastructure.*]
- Distributed medical equipment is a large and believed by many in the industry to be a growing fraction of total energy loads in hospitals.
- Energy load profiles for medical devices are virtually unknown. [*Reviewer comment: It is important to know how much energy this equipment uses in order to make goals of how to IMPROVE that energy use.*]
- There are not currently any standard ratings for medical equipment.
    - Energy efficiency is not believed to be a priority for medical equipment designers (likely owing to lack of market or regulatory drivers).

  - Institutional customers do not have information required to assess energy use and to purchase energy efficient equipment.
  - The specialized nature of medical equipment and frequent updates to designs and features may make it difficult to set standards.
  - Requiring accurate energy consumption requirements and properly sized heat exchangers prior to proposal acceptance is essential because manufactures tend to become uncooperative after award of contract.

- Since healthcare buildings are operated for the purpose of providing medical care, the expressed preferences or guidance from medical staff can lead to inefficient operation; one common example is surgeons requesting/demanding that surgery suites be held at low temperature at all times in case the room is needed for emergency surgery.
- There is an ever-increasing need to expand information technology infrastructure; this leads to increasing energy use for computers, communications-enabled medical equipment and data storage.
- Healthcare spaces have special lighting requirements.
- Hospitals have special process needs including steam for sterilization and humidification, and refrigeration.
- Hospital building form and internal layout are selected to maximize efficiency of medical operations ("programming"), not for energy efficiency.
- Since hospitals can have complicated mechanical and electrical systems, hospital building engineers require extensive training and experience. Many current staff members are inadequately trained and lack knowledge needed to optimize system designs, available controls and automated systems. The operation of healthcare buildings must balance code requirements while trying to create an indoor environment that is comfortable for both staff and patients; minimizing energy use and costs is desirable but only to the extent that it does not compromise the other objectives.
- Hospitals and other healthcare facilities can contain high-tech, energy-intensive areas (laboratory, clean room, data center) with specialized mechanical and electrical system requirements along with patient room areas having very different characteristics and opportunities for energy efficiency; all of these areas compete for the same funding.
- The lack of sub-metering limits the ability of facility operators to track system-level energy use and to assess effectiveness of potential or instituted energy-saving measures. [*Reviewer comment: Many hospitals have variable frequency drives (VFDs) on large motors including fans, pumps and even chillers. VFDs can provide power information to the Building Control System.*]

Challenges related to healthcare organization, structure, and culture

- The primary mission of healthcare facilities is to provide health care. Since health care is a life-and-death business; perceived medical needs trump other considerations. The

culture is to defer to medical staff and assume that accepted practices are essential for patient safety.

- For-profit companies have responsibility to maximize return on shareholder investment. Good citizenship and public health are secondary goals.
- As a relatively small fraction of operating cost (usually <5% and often only 2-3% for hospitals), energy is not a central concern for hospital administrators.
- With many hospitals and other healthcare facilities struggling to remain solvent, costs are being cut. Anything that does not directly contribute to the provision of medical care is a target. Cuts to operations & maintenance staff and resources reduce the capacity to pursue energy efficiency. Engineers and building operators are competing with medical staff for operating funds to make improvements. The financial situation is so precarious in some cases that even a payback period of a few years is seen as too long or too risky.
- Most healthcare companies have different budgets and decision structures for capital and operating funds. The sound financial argument of paying more for an efficient building that will cost less to operate over time does not mesh well with this structure.
- Hospitals and other healthcare facilities are designed and built with limited capital budgets. Prioritization is given to features and facilities that are seen as improving the capacity to provide medical care, to attract patients and to attract top medical staff; energy efficiency measures are not a priority.
- Hospital and other healthcare providers can be large institutions with substantial inertia; it is difficult to change attitudes, e.g. about the importance of reducing energy use and carbon emissions as being important to the community and public health mission of the hospital.
- The health care industry is highly risk-averse and conservative. There is reluctance to take steps that go beyond conventional and established approaches. Many approaches and technologies to improve energy efficiency can be seen as risky, potentially impacting medical services.
- Healthcare facilities have not been subject to (Title 24, Part 6) energy code requirements in California; there is great concern about the initial costs associated with energy code requirements. Any increase in first cost, even if paid back over a very short period is seen as problematic. There is also a feeling that the industry is already over-constrained by health and safety code issues; there is a consequent concern about adding requirements.
- Healthcare facilities are community institutions with perceived responsibilities and an expectation and sometimes an expressed mission for service to the community.
- Healthcare facilities can be highly stressful environments for both staff and patients. There is very little perceived capacity to experiment with changes to operation of building systems out of concern of upsetting some accepted status quo.

- Over-stretched operations and maintenance staff focus on maintaining operations and rely on short-term fixes that can create inefficiencies. For example, staff may increase fan speed instead of fixing dampers. This is common problem for commercial buildings but may be more acute in hospitals owing to high cost of interruption of service.
- Healthcare facilities have low risk tolerance for experimentation (e.g., for unconventional ventilation systems); hospitals want to use the most advanced systems, but only after their efficacy has been established by others. Advisors offered two explanations:
    - Hospitals are cautious of liability and fear lawsuits for hospital infections or lapses in medical care.
    - There are examples in the industry in which advanced and costly building mechanical or alternative power systems have not worked.
- Many energy efficiency efforts have focused on standard measures such as lighting and ignored large potential savings in medical operations including surgery suites because of lack of knowledge or unwillingness to mess with the "process" areas of the facility.
- Difficult to get capital expenditures for energy efficiency.
- There is perception among many hospital designers, operators and owners that cost-effective technologies are not available and that "green" is always more expensive.
- Energy not viewed as a strategic issue, companies lack strategic plans for energy; one-time or tactical energy-related efforts are oftentimes are regarded as having addressed the "energy problem".
- Concern over liabilities with any deviation from standard practice, e.g. related to efforts to reduce air change rates. One lawsuit could wipe out a lot of energy savings.
- The facilities department in general and energy-related equipment in particular is unseen until it goes wrong; many operators want to remain unseen and are thus reluctant to make changes in an effort to achieve improve energy efficiency. For facility operators energy efficiency efforts carry a lot of risk with little or no potential reward.
- If systems are too complex for operators and building users, inefficient operation will result.
- Many hospitals are designed as unique facilities, making it difficult to apply lessons learned to other facilities or to use lessons from other facilities that may be different enough as to raise questions about the applicability of such measures.

Challenges related to the legacy of current facility stock

- Hospital building stock is relatively old:
    - Hospitals are 50-100 year buildings.
    - Many hospitals are historically significant buildings; "landmark" status can limit options for energy efficient renovations and make them much more costly.

  - Older facilities may require costlier retrofits.
- Many hospital campuses still have large central steam facilities.
- Construction associated with retrofits and renovations can create infection control challenges (dust, mold, etc.).
- Retrofits can trigger code requirements for more extensive upgrades.
- Older facilities may be more difficult to benchmark owing to limited installed sub-metering capacity.
- Healthcare facilities have not been subject to Title 24 energy code in California
- Hospitals have long lifetimes, HVAC systems designed to accommodate expansion, reconfiguration and anticipated but unpredictable changes in space use.
- Given long expected lifetimes, it is critical to ensure that all new hospitals are as energy efficient as possible; urgency to include efficiency in the many hospitals that are being built now and will be built over 1-2 decades.
- Many hospitals designed as unique facilities; tougher to apply lessons or invest in more efficient designs (perceived this way).

Challenges related to codes and standards

- Hospitals are subject to multiple codes, standards and regulatory organizations.
  - U.S. facilities are designed according to the "Guidelines" (Guidelines for Design and Construction of Health Care Facilities) of the Facility Guideline Institute.
  - U.S. facilities seek accreditation by *Joint Commission on Accreditation of Healthcare Organizations* (*JCAHO*) or other accreditation bodies.
  - For California facilities, construction must be approved by the Office of Statewide Health Planning and Development (OSHPD), which maintains guidelines that roughly but do not precisely align with those of the FGI.
- California hospitals are required to meet upgraded seismic standards; new buildings and major renovations offer opportunity for improvements but also create large capital burden on healthcare providers.
- Retrofits can trigger code requirements for more extensive upgrades.
- Safety factor of 1.5 required for structural components (adds to building costs).
- HVAC codes to reduce the risk of infection:
  - High ventilation rates.
  - Pressure differences between spaces.
  - Relative humidity limits.

- Hospitals are required to be self-sufficient during an emergency; this includes requirements for back-up electricity generation and uninterrupted power for some services (uninterruptable power supplies and back-up generators add inefficiency to the electrical systems).
- Concern over liabilities with any deviation from standard practice, e.g. related to efforts to reduce air change rates. One lawsuit could wipe out a lot of energy savings.

3.2. Opportunities and Needs

Presented below are a series of broad areas that need to be addressed as part of the effort to improve the energy efficiency of healthcare facilities. Presented under each broad issue are sub-topics that identify specific opportunities and needs; associated with each sub-topic are one or more specific activities to advance the opportunity. The activities include research and development; documentation, demonstration and deployment of existing technologies and best practices; training; and other activities. The vast majority of the issues and activities listed below were offered by industry experts during interviews and at the March 3, 2009 workshop at LBNL. Most of these were offered for discussion (and thus vetted) at the workshop and, other than those offered by reviewers, all were included in the draft roadmap circulated for review. LBNL staff have not extensively evaluated the status or feasibility of all items listed.

1. Understand and Benchmark Energy Use

The lack of reliable information about resolved and system-level energy use in hospitals is suggested by many experts as one of the highest-priority needs to advance healthcare energy efficiency efforts. Reliable estimates of system-level energy use and other metrics are critical to establishing performance benchmarks and prioritization of research, development and demonstration project needs. The ability to benchmark is valuable to individual facility efforts to identify areas of focus and opportunities for improvement.

Regarding existing information, advisors with relevant experience express skepticism at the CBECS 2003 estimates of end-use energy breakdowns. Of specific concern are the large energy intensity (EUI) suggested for service hot water and the low values for ventilation and cooling. The CBECS methodology of statistical regression has critical limitations in this application. California's Commercial End Use Survey (CEUS) methodology of energy simulation modeling calibrated to monthly electricity and gas use with some sub-metering is thought to provide much more reliable values. While valuable, CEUS results are limited to California hospitals; thus they cover only a portion of U.S. climate conditions. Also, California hospitals are and have been subject to Office of Statewide Health Planning and Development (OSHPD) codes which over time have differed in some ways from the Facilities Guidelines Institute codes relevant to most other U.S. hospitals. Estimates of resolved energy use have been developed or could be calculated from results of detailed energy simulations of individual hospitals; these models have been developed for new building or renovation designs and in the context of energy audits. Results of these simulations are at this time available only through the expertise and accumulated knowledge of a relatively small number of hospital design engineers and energy experts.

1.1. Standard performance metrics.

Standard metrics provide a common basis to evaluate system and component performance, and thus establish a foundation for benchmarking. Version 1 of the LBNL Benchmarking System (LBNL-V1) provides a starting point for work on an industry standard. The set of metrics in the final Version 1 document should be distributed for review by healthcare energy experts across the U.S. with special effort to solicit feedback from healthcare energy committees of ASHRAE, ASHE, and other relevant professional societies.

- Work with healthcare energy experts and relevant professional societies to establish standard energy performance metrics for hospital systems and equipment.

1.2. Advance performance benchmarking.

The successful establishment of standard performance metrics paves the way for benchmarking. Benchmarks can be derived from engineering design judgment but are best when related to in-use performance achieved by existing facilities. LBNL-V1 provides benchmarks for selected metrics based on CEUS results for California. The LBNL benchmarking system includes a guidance document and summary protocol but lacks detailed guidance on measuring key parameters and calculating metrics for variations in system configurations. The LBNL-V1 benchmarking system should be expanded and revised based on input from relevant professional committees and input from other national hospital energy experts.

- Advance development of benchmarking system metrics and benchmarks.
- Advance development of protocol and guidance for data collection and computation of metrics.

1.3. Database of performance metric values.

Once a standard set of performance metrics has been established, the next step is to compile a database that provides metric values and other information about the facilities for which the values have been obtained. The database will allow information about an individual facility to be considered in the context of other facilities sharing key characteristics (e.g. climate zone, size, types of HVAC systems, etc.), and for benchmark values to be set. The most cost-effective approach to building such a database is to make use of the potentially large pool of currently disaggregated information contained in energy simulation modeling results, energy audits and other individual facility reports. The collection of data from existing facilities – through building or energy management system trending or through new measurements acquired for this purpose – will allow further expansion of the database. With respect to performance metrics it is important to consider the variety of services offered. Some hospitals focus on providing basic services while other highly rated medical centers focus on specialty services with the latest diagnostic and treatment equipment. The high tech hospitals use more energy per square foot but presently there are no provisions for comparing a basic hospital to a “Top 10” research medical center.

- Identify and analyze existing information sources including energy audits and energy simulation models of existing or planned hospitals to expand database of performance metric data.
- Identify facilities with installed energy monitoring capability to obtain and compile data on performance and energy use.
- Apply LBNL-V1 benchmarking protocol to collect data from additional facilities.

- Set up online tool to allow users to enter data from existing energy monitoring systems and new benchmarking studies.

1.4. Expand capacity for energy monitoring and benchmarking through deployment of sensors and performance tracking systems in existing facilities.

Industry-wide there is a dearth of installed capacity for ongoing energy monitoring. Many facilities have sensors installed that – if functioning properly – can provide valuable information relevant to energy use. For example, the commonly present chilled water temperature and flow sensors can provide ongoing data about the amount of cooling provided, which is a major determinant of cooling energy use. In some cases, sensors are installed but the data are not being utilized. In many cases, only a subset of the sensors required for a performance metric are installed. An example of this is the calculation of cooling energy which requires tracking of energy (or for fixed speed equipment, use patterns) of all cooling equipment; a facility may have real or apparent power sensors on some but not all equipment. Most facilities have only a small fraction of the desirable monitoring capacity. In addition to the lack of sensors, many of the sensors that are installed are not functioning properly. The installation of monitoring sensors and the processing of data from installed sensors to calculate and track performance metrics represents a substantial opportunity to improve energy management in hospitals. Expanding capacity in this area will require substantial investment by facilities. This effort will be greatly facilitated by clear guidance on how to make best use of existing data streams, on the parameters which need to be monitored, and on the processing of collected measurements into performance metrics.

- Develop guidance on use of existing data streams (including utility bills and sensor for automated building management) to monitor and understand energy use; include guidance on calculating metrics and recommendations for time resolution of trending.
- Develop guidance on energy monitoring systems for new hospitals and retrofits.
- Development and demonstration of wireless overlay sensor systems for energy monitoring and management.
- Deployment of technology including installation of sensor systems and re-programming of existing building management systems.

1.5. Effective energy management systems.

Several advisors noted the critical importance of providing energy performance information to facility operators and managers in a form that is intuitive, meaningful and easy to access. Ideally the information should be provided with context such as desirable ranges, design values, and most valuably guidance on actions to take when values are outside of the specifications. The authors have not conducted a market review to determine what products are available or how well they meet the suggested characteristics. There are opportunities for product development, demonstration and expanding market awareness. Training and education related to energy management and the use of energy performance information is a closely related issue.

- Develop, demonstrate and/or promote market awareness of energy monitoring and management software.

1.6. Fill gaps in energy simulation models for hospitals.

Building simulation modeling is a valuable tool not only for design, but also for understanding system-level energy use and exploring opportunities for energy savings. Simulation models can accurately represent the energy-related performance characteristics of many major system design variations. When applied to existing buildings, models can be checked against monthly utility electric and gas bills to ensure a reasonable match to baseline conditions. Some engineers report consistently being able to predict energy use at the design stage that matches actual energy use of a constructed building to within 10% on a monthly basis. Advisors noted that this level of accuracy is not common and that existing models fall short in several areas. Broadly, these include process loads of specific relevance to hospitals (steam, medical equipment), energy losses in fan and duct systems, equipment efficiency curves over a range of operation, and simulation of advanced and unconventional HVAC systems. Advances in these areas will facilitate improved energy simulation of hospitals.

- Develop and validate model of fan and duct system losses.
- Energy use rates and patterns for medical equipment including large facilities (MRIs, etc.) and distributed equipment (standby and operational power).
- Capability to simulate advanced and unconventional HVAC systems including co-generation.

2. Best Practices and Training

For hospital energy efficiency, the concept of best practice is relevant to the design, operation, and retrofitting of hospitals and component systems. Widespread application of best practice involves two key elements: establishing which practices are best and disseminating knowledge of these approaches to the community of practitioners. Energy performance best practices ideally should be verified through resolved energy monitoring or validated modeling. Best practices may be specific to system or equipment configuration or more generally applicable in their nature. Raising awareness of best practices can be accomplished through formal training institutions, professional societies (including ongoing professional development course), and by providing information in easy to access, well organized media starting with the internet. Best practice guides and training materials can be developed by and for use within large hospital chains, by professional organizations, by educational institutions, government or other organizations. With the special needs associated with many hospital functional areas and the varied systems used to provide thermal services the volume of hospital best practices is likely to be large. Determination of best practice is tightly linked to energy monitoring and benchmarking. One reviewer cited training and support programs for enhanced operations and maintenance that achieves energy consumption reductions of at least 10%. It presently requires both formal training and focused support for changing the O&M culture. The reviewer noted the belief that best practices cannot be achieved without this cultural focus, and that designers also need a lot of support and contractual changes to reward the use of “best practices”.

2.1. Energy performance evaluations of system configurations, equipment and operations to determine best practice for energy.

Ideally the determination of best practice is made through validated quantitative assessment, such as measured or model-estimated energy use. The availability of system level monitoring allows assessment of energy use and other parameters with resolution suitable to identifying differences that may be small on the scale of the overall facility but substantial on the scale of a

system such as chilled water / cooling or domestic hot water. Identification of best practice designs may require larger data sets to account for potentially wide variation in operating patterns that can also affect energy use. Best practice operations may be broadly relevant (e.g. for lighting controls), or specific to the type of system (e.g. for cooling or heating). Best practices for heating and cooling should be resolved by climate.

- Use measurements or models to rate performance of systems and practices relevant to reference or standard practice.

2.2. Searchable database of best practices.

Once a best practice has been identified through evaluation then documented, it should be shared as widely as possible. The key to making the information accessible is to allow users to quickly and easily identify the best practices relevant to the systems with which they are working (for operators) or the design challenges which they face (for designers). Online, searchable best practice databases could accomplish these objectives. Databases should be intuitive, accessible, provide information at various levels so as to allow more fluid navigation, and provide appropriate context for the recommended best practice. To the extent that practices are validated or evaluated through performance measures in one or typically a set of specific facilities, the most direct way to organize the best practice database is through case studies. This raises potential issues with anonymity. Additional work is required to write best practice guides that use results from performance evaluations but go beyond case studies. The authors have found a number of best practice guides and case study compilations that are available free online and/or through professional societies. These vary widely in their scope, but very few provide measurement-based verification or context. Best practice design guides include a prescriptive path for achieving energy credits in the Green Guide for Healthcare (gghc.org), a soon-to-be-completed advanced energy design guide for small hospitals, the upcoming ASHRAE standard 189.2 for sustainable healthcare, and others. The needs associated with developing, populating and gaining market acceptance of a best practice guide are numerous. One key to success is coordinating the efforts of many industry stakeholders to establish this as an industry priority.

- Develop best practices database. First step is to develop architecture that includes variables for easy searching and verification of effectiveness. Work with users to ensure database provides information that is accessible and useful.
- Construct best practices database incorporating information from existing best practices guides.

2.3. Improved guidance, education and training for designers.

Design best practices should be codified in design guides published by relevant professional societies (ASHRAE, ASHE, etc.), taught in engineering design courses, and reinforced through performance expectations that ideally are established by the best in class hospitals. While there is a tension in some cases between the time delay associated with review and codification by panels of experts, and the benefit of providing information to the community as it becomes available, this is less of a problem for design best practice owing to the longevity of hospitals. Energy workshop participants noted that hospital design engineers do not consistently utilize efficiency opportunities; examples provided include the lack of waste heat capture and infrequent use of proven efficient technologies such as ground source heat pumps. Advisors

acknowledged that there is a "chicken-and-egg" problem in that there is not a strong market driver for highly energy efficient hospitals while the design community is also not doing all it can to advance efficiency in their designs. Nevertheless, there was a clear consensus of a need for improved training of hospital designers.

- Establish consensus on energy efficient designs by climate and in consideration of special medical operational needs
- Include energy efficiency best practice in design guides and standards.
- Conduct and document case study evaluations of energy and operational performance of standard and alternative systems.
- Connect and coordinate design guidance with operator training.

2.4. Improved training for hospital operators and facility engineers.

Operational best practices also are the purview of professional societies and training. Operational best practices ideally start with good designs but must also consider the challenge of making the most of whatever equipment is in place. In fact, while proper operation is needed to achieve optimal performance from even the best designed systems, there are great savings opportunities associated with minimizing the energy wasted in inefficiently designed systems. An example of this is identifying operational practices to reduce energy use of constant volume reheat HVAC systems. Improved training and operations – in connection to best practices – was one among the opportunities most frequently mentioned by industry advisors.

- Incorporate energy efficiency into standard industry training programs for hospital facility engineers and managers.
- Connect and coordinate training with developments in area of design.
- Expand professional training programs for operations staff.

2.5. Improved documentation of building systems to facilitate operation as designed.

A problem endemic to efforts to improve energy efficiency in all commercial buildings is the disconnection between design intent and operation. One key element to achieving consistency from design through commissioning to operation is creation and use of a building "owner's manual"; such a document should provide a clear description of system configurations, intended (design) operational ranges for key parameters (e.g. chilled water supply and return temperatures, air handler fan flow rates, etc.), and recommended commissioning schedules, among other guidance. User manuals should be created as well for existing buildings. Manuals should be updated as equipment is replaced and systems are retrofitted. Advisors expressed confidence that the cost of creating and maintaining this documentation would be more than offset by the benefits in both energy savings and simple operational effectiveness.

- Promulgation of standard formats for operating manuals.
- Creation of building operating manuals for existing facilities.

2.6. Guidance and expanded implementation of commissioning.

The underuse of commissioning is a problem for almost all types of buildings. The complexity of hospital ventilation, thermal, and electrical systems makes commissioning of hospitals essential. The authors have not specifically researched commissioning guides for hospitals. To the extent that guidance is available, it was not widely known to the advisors for this project.

- Development of guidance on commissioning schedules for hospitals (if not available).

- Development of evaluation metrics and reporting procedures to utilize and track information obtained during hospital commissioning.
- National goal of (retro-) commissioning of all existing hospitals.

2.7. Improved information on energy performance of building products.

Several advisors noted that facility operators lack information about the energy performance of products including ventilation filters, lighting products and equipment that they are charged with purchasing. This information would allow decision-makers to choose the less energy intensive products and, it was suggested, help to establish the market for such products. One reviewer noted that the Northwest Energy Efficiency Alliance (NEEA) is funding a study on the benefits of improved purchasing practices. This project has led to development of trial software tools to help determine the lowest Total Cost of Ownership for air filters and chillers. A purchasing table to help hospitals make better decisions for most energy consuming equipment is also being developed.

- Development and market adoption of consistent formats for information on energy use characteristics of consumables (e.g. filters, lighting products) and equipment

2.8. Improved maintenance.

Another issue that is common to many commercial buildings and acutely important in hospitals is the need for improved maintenance. Improved maintenance is related to training, the provision of adequate resources to facility staff, best practice guides and several other issues identified in this document. Enhancing O&M practices is an important process that requires both technical training and management/encouragement. Specific items mentioned by advisors to this project include the following:

- Eliminate compressor air leaks
- Reduce losses related to overloaded filters
- Regular cycling of ventilation louvers to avoid sticking and to more quickly identify inoperative components needing repair/replacement
- Steam trap maintenance

2.9. Strategies to reduce reheat through existing HVAC system management.

Many existing hospitals use constant air volume (CAV) systems that are designed to distribute over-cooled air with terminal reheat. The approach – which is wasteful from an energy perspective – provides supply air that is sufficiently cold to handle the most challenging cooling loads with each zone along with humidity control when needed. In addition to the need for improved designs to avoid CAV reheat systems, there may be opportunities to reduce energy losses through improved management of existing reheat systems. Sensors and control sequences can improve the management of economizers, chilled water temperatures and zonal flows, among other parameters to reduce reheat energy consumption. One of the workshop participants described an analysis showing that both typical and energy-efficient hospitals have enough internal heat gain to produce a net cooling need in many areas of the U.S. throughout much of the year. The available heat in principle could be managed to minimize the need for supplement heat / reheat. Reheat energy use can be reduced through heat recovery, improved zonal resolution of air supplies, reduced over-cooling of supply air, chilled water resets and more advanced cooling and heating system controls.

- Development, demonstration, and evaluation of sensor and control systems to reduce reheat energy losses in existing constant volume reheat systems.
- Documentation and reporting of best practices for reheat management.

3. Codes and Standards

Codes and standards are critical to hospital energy efficiency efforts because (a) many are related to life-safety concerns having direct relevance to the mission of the facility, (b) failure to comply with standards could put hospitals at great legal and financial liability, and (c) standards have tremendous ripple effects throughout the design of ventilation, thermal and electrical systems.

The most important standards for most U.S. hospitals are the Guidelines promulgated by the Facilities Guidelines Institute (fgiguidelines.org). ASHRAE develops and publishes Standard 170 which covers required ventilation (air passing through filtration) and outdoor air delivery rates, pressurization, and relative humidity for defined operational areas of healthcare facilities. ASHRAE standards have been closely aligned with FGI and in future will be formally incorporated by FGI. California hospitals are subject to standards promulgated by OSHPD; these generally follow FGI with some differences.

Hospitals require accreditation by a deemed body to qualify for Medicare reimbursements. The largest of these in the US is the Joint Commission (JC, formerly the Joint Commission on Accreditation of Healthcare Organizations). Some states including Pennsylvania, Oklahoma, and Wisconsin have their own accrediting bodies. In California OSHPD approves hospital construction and has a joint role with JC to certify hospitals**.**

Codes and standards related to energy use include requirements for mechanical ventilation, ventilation rates including air change rates through filters (including recirculation) and outdoor air change rates, filtration, (de-)pressurization, relative humidity, minimum lighting levels and limits on window opening.

Codes and standard establish a standard of care. Failure to operate according to the standards could put a hospital in a position of financial and legal liability, e.g. for hospital acquired infections.

3.1. Performance-based criteria for ventilation standards.

Current ventilation standards are based on commonly used air distribution systems, viz. overhead diffusers. Alternative systems – including displacement ventilation – show potential to improve infection control performance with substantial energy savings from lower overall air change rates and higher cooled air supply temperatures. Advisors noted that one challenge facing the adoption of these and other potential alternative systems is the lack of a clear set of criteria for evaluating infection control performance. Related to this issue is the feeling by many experts that the research basis for the current ventilation standards is not adequately well understood and may not be sufficiently rigorous. One reviewer raised the specific issue of how much air exchange should be required for patient rooms; the reviewer questioned if the commonly used 6 air changes per hour (ach) is substantially more protective than e.g. 4 ach; an evidentiary evaluation of this issue would be valuable. There is an interest in establishing standard criteria and/or test methods to assess whether alternative ventilation systems adequately protect against disease transmission.

- Establish medically relevant performance metrics for determination of ventilation standards.
- Establish standard procedures to demonstrate compliance for ventilation systems.
- Comparison of European and U.S. hospital standards and practices and evidence for health outcomes and energy costs.

3.2. Research on energy performance and medical outcomes in hospitals with mixed mode ventilation.

Many participants in the energy workshop at LBNL expressed interest in designs that incorporate operable windows (natural ventilation) with the required capacity of mechanical ventilation systems, resulting in mixed mode ventilation. Design engineers noted the potential for substantial energy savings. Medical professionals noted the therapeutic value of providing contact to the outdoors and the converse harm that they observe when patients lack access to fresh air. One nurse commented that patients undergoing long stays report a desire for fresh air which is often completely unavailable to them. Several participants noted the availability of operable windows and natural ventilation for patient rooms (and even some treatment areas) in European and Scandinavian hospitals. Several participants indicated their understanding that rates of hospital acquired infections are no higher in places that allow mixed mode ventilation, though no specific sources were cited. Many hypothesized that medical outcomes could be improved by providing patients with greater connection to the outdoors through operable windows. Overall, there was a strong feeling that both the medical and energy implications of allowing hospitals to operate in natural ventilation mode and allowing operable windows are among the highest value opportunities explored during the workshop.

- Review and summarize existing information on energy and medical outcomes in European hospitals that allow operable windows and natural ventilation.
- Research and development examining opportunities and barriers to mixed mode ventilation in U.S. hospitals.

3.3. Change minimum relative humidity limits to 20%.

The ASHRAE and FGI standards specify a minimum relative humidity of 30%, creating a need for humidification and associated energy consumption. Several advisors had inquired about the rationale for setting the code at this level but found no clear evidentiary basis. (A study for data centers found that humidity was not a suitable control for electrostatic discharge.) Efforts are underway to have the minimum relative humidity limit reduced to 20%.

4. HVAC System Design (Utilization of Existing Technologies)

Hospital ventilation and thermal systems typically are designed for robustness and low first cost, not energy efficiency. Utilization of “waste” heat from HVAC equipment, especially chillers is not common and constant air volume systems are common. Insufficient zonal resolution leads to substantial overcooling and reheat. The energy penalties associated with sub-optimally designed HVAC systems are compounded by the longevity of hospital buildings (which may set the basic system layout and even equipment footprints), lack of funding and lack of priority for energy-related retrofits, and maintenance and operational challenges related to overworked facilities staff. There was an apparent consensus among advisors that existing technologies and codes allow much higher efficiency than is achieved in existing or even new facilities. Improving the design of new facilities, renovations, and retrofits will have a large

impact on energy use of both existing and new hospitals. Key opportunities include systems engineering management of heat and energy flows (e.g. to ensure that all "waste" heat – e.g. from chillers – is utilized). This section focuses on "proven" technologies and system design elements; the next section expands to include development and demonstration of innovative designs and technologies.

4.1. Assessments of energy use and total lifetime costs of common and alternative HVAC systems and equipment.

With recognition that such analyses will yet be insufficient to move many decision-makers, it is nevertheless important for the design industry to start to build the case that energy efficient systems can cost substantially less over time. Estimates of lifetime costs can be developed at the design stage using energy simulation models. The cost of developing such estimates for an energy efficient alternative design can be substantial and may be beyond the capacity of an individual firm without having sufficient a priori owner interest in such an evaluation. A priori model estimates and energy benchmarking of existing facilities featuring conventional and alternative systems offer information that could be compiled for use by the design community in making the case to building owners for energy efficiency.

- Develop standard metrics and approaches to evaluate total costs to purchase and operate systems.
- Conduct and document evaluations of system performance for database of best practices.

4.2. "Right-sizing" and part-load efficiency of HVAC equipment and systems.

While there was some disagreement among advisors about the potential to improve "right-sizing" of HVAC systems, there was widespread agreement that there is a lack of information about full-cycle (including part load) efficiency of many types, brands and models of HVAC equipment. Likewise, too little attention has been paid to how equipment configurations or systems impact the energy performance of individual components. The first step is to obtain information about the full cycle performance of each piece of major equipment in a system, then to evaluate the overall performance of the entire system based on operations as constrained by the system. Knowledge of these factors can improve design or operation of a system. Right sizing is challenging in light of sometimes unpredictable developments in process needs and the longer lifetimes of hospitals relative to other buildings. One reviewer noted that right-sizing may in some cases may be satisfied by incrementally larger equipment that operates efficiently with lower maintenance issues and offers flexibility for future capacity/growth.

- Develop best practice guidance to designers on right-sizing of HVAC systems.

4.3. Best practice guidance on designs to reduce or minimize reheat.

Constant volume reheat systems are relatively straightforward to design, robust in operation, and allow hospitals to meet code requirements for ventilation rates, pressures, and relative humidity. For these systems, the largest energy end-use is typically for heat, specifically for reheat. One of the workshop participants described an analysis showing that both typical and energy-efficient hospitals have enough internal heat gain to produce a net cooling need in many areas of the U.S. throughout much of the year. Available heat in theory can be managed to reduce the need for supplemental heat / reheat. Reheat energy use can be reduced through

process and equipment heat recovery (e.g. heat recover chillers), improved zonal resolution of air supplies, reduced over-cooling of supply air, chilled water resets and more advanced cooling and heating system controls. One reviewer noted that the complexity and cost of managing heat gains from internal loads by means other than cool ventilation air can be complicated and costly. Technologies to manage (reduce) humidity through means other than cooling and reheat are critical; these are address in section on 5.4.

- Develop best practice guidance on HVAC system designs to minimize reheat energy losses.

4.4. Evaluation and guidance on 100% outside air systems.

In connection to the assertion that use of outside air may be more energy efficient, one workshop participant indicated that more than half of Kaiser Hospitals are designed for 100% outside air. Current California standards allow lower air exchange rates if the ventilation supplied is 100% outside air. Understanding the potential energy benefits and costs of 100% outside air systems was identified by workshop participants as an important research question. A tool to evaluate free cooling potential by location has been developed for data centers can be used for other buildings[4]. Though not discussed at the meeting, outside air systems are vulnerable to events of severely polluted outdoor air, e.g. when there is a nearby forest fire. The use of outside air is connected but not limited to natural ventilation and alternative ventilation systems principally displacement ventilation.

- Develop design guidance for 100% outside air systems that incorporate adequate air cleaning for high pollution episodes.
- Evaluate overall energy use of 100% outside air systems including air cleaning.

4.5. Evaluation and guidance on displacement ventilation systems.

Displacement ventilation supplies cool air near (3-6 inches above) the floor and depends on the air rising in a piston-like motion through the room as it is heated, with exhaust near the top of the room. One of the workshop participants is coordinating a collaborative, multi-institution research effort to examine the relative performance of DV and conventional overhead diffuser systems for the purpose of minimizing infection control in patient rooms. The goal of this research is to provide technical basis for considering lower air exchange requirements for DV systems. DV requires (re-)heating separate from air supply; this can be provided by radiant systems.

- Achieve regulatory acceptance of DV systems for patient rooms with lower air exchange rates relative to standard diffuser and mixing approaches.
- Document DV demonstrations projects and publicize results to achieve market acceptance of the technology.
- Evaluate ventilation and energy performance of displacement ventilation systems.

4.6. Document performance evaluations of common energy-related design elements.

In the context of best practice guidance and justifying design variations that could have higher first cost but save money over time, several advisors suggested developing a catalog or database of estimates of energy savings attributable to specific design elements. The idea is that

[4] www.thegreengrid.org/en/sitecore/content/Global/Content/Tools/NAmericanFreeCoolingTool.aspx

as options are evaluated for specific projects, the results of the evaluation are documented in a relatively simple format that can then be considered for other projects. The hope is that this sharing of information will help focus future evaluations on the most promising options and/or establish that some design elements are generally cost-effective. The list below compiles suggestions from expert interviews and the energy workshops; it is not intended to represent a complete or thorough listing of systems to evaluate.

- Develop online database or wiki for sharing of cost and energy analysis of alternative and advanced design elements. Examples include the following:
  - Use of variable frequency drives, efficient motors and pumps.
  - Maximize use of VAV.
  - Improved management of air exchange rate and temperature in operating rooms to reduce energy use during periods of non-operation.
  - Improved management of installed filter systems using best in class low pressure drop filters; regular maintenance, etc.
  - Use redundant HVAC equipment (pumps and fans) to allow equipment to operate in higher efficiency region for energy savings; this may extend lifetime.
  - Check that that air supply meets but does not greatly exceed code requirements (target area for retro-commissioning). Reducing (ventilation) air volumes overall and especially for unused spaces.
  - Use of chilled water reset, economizers, etc.
  - Model-based evaluations of energy savings potential of higher cost, less energy intensive systems (e.g. cooling) to estimate payback period.
  - Reduce or eliminate heating and cooling of unoccupied spaces; provide turndown capability for spaces that are unoccupied for part of time (e.g. departments that operate on <24 h schedule).
  - Use of "low" (130 F) temperature water for heating.

5. HVAC Technology and Design Innovation

Advances in technology and designs offer promise for substantial decreases in energy requirements for hospital ventilation and thermal systems. Key advances have been made in efficient co-generation, waste heat minimization and use, desiccant-based dehumidification, air cleaning technologies and system-based designs. Mixed mode designs that incorporate operable windows and natural ventilation for some areas also offers possibilities for improved energy performance. These designs and design elements are being used in Europe and study of their performance could inform the potential for their use in the US. These efforts must be intertwined with work to review and revise codes and standards as feasible. Non-conventional technologies may be investigated as part of the analysis for an advanced energy design guide for large hospitals.

5.1. Demonstration of energy-efficient HVAC technologies and equipment.

One panelist at the workshop suggested that HVAC technologies that are currently available can be used to build systems that are substantially more energy efficient than most current U.S. hospitals. Specific technologies include absorption chillers that utilize otherwise wasted heat streams, heat-recovery chillers, ground-source heat pumps (newer designs are greatly improved), condensing boilers, advanced control sequences to allow utilization of variable air volume systems, and lower temperature hot water heating systems. Documenting the utilization of these equipment components is important to establishing their viability and increasing the frequency of their use.

- Document operational and energy performance of non-conventional HVAC technologies and designs; compile in case studies and best practices databases.

5.2. Incorporate systems engineering principles into HVAC designs.

Both advanced and conventional technologies can be utilized with improved overall efficiency by incorporating systems engineering principles. Examples include use of absorption chillers when heat sources are available from other sources (e.g. steam boilers), use of lower temperature water for heating, heat recovery chillers and other approaches to match heating and cooling equipment. One workshop participant offered the example of a fan wall unit that provides substantial benefits in terms of filter maintenance (avoiding excess pressure drop from dirty filters) and potentially more efficient energy transfer from a more even flow of air over cooling coils; with variable frequency drives the fans may also operate more efficiently. Another example is designing systems with components operating within their peak efficiency ranges.

- Incorporate systems engineering principles and specific design strategies into hospital HVAC design guide published by ASHRAE.

5.3. Test bed facilities for new technologies and practices.

Many advisors stressed the importance of testing new (or new to hospital applications) technologies to establish acceptable performance before they will be accepted by hospital owners and operators. Installed pilot testing can also be an important step in the code or standard changes required for application of some new technologies. Workshop participants cited the example of a Kaiser facility in which displacement ventilation was installed in one area for in-use evaluation.

- Establish one or more test bed facilities – ideally with federal research funding – to facilitate evaluation of advanced HVAC systems and technologies.

5.4. Alternative dehumidification systems.

Dehumidification is a critical issue for energy use in some areas of the U.S. where latent energy removal constitutes a substantial fraction of the total cooling load. It is a less important issue for California. Desiccant systems and air-to-air total energy exchangers can reduce moisture independent of mechanical cooling under hot-humid conditions and retain latent energy through transfer to incoming air during cold and dry outdoor conditions. Pumped systems are being investigated for use in retrofits where ducting cannot be added. Analysis is needed to determine when the cost of the desiccant system is warranted by energy savings associated with reduced cooling for dehumidification. One reviewer noted that hospital operators are adamantly opposed to heat wheels due to cost, complexity, maintenance, reliability and perceived cross-contamination issues.

- Demonstration and in-use performance and energy evaluations of desiccant-based dehumidification systems.
- Building simulation analysis to identify climate and other conditions under which desiccant systems are likely to be cost-effective and result in net energy savings.

5.5. Chilled beam cooling.

Chilled beam cooling is a technology that is widely used in Europe but not in the U.S., where the application is limited by code requirements for a post-coil filter unit (which is infeasible for

chilled beams) and air change requirements. The key aspect of this approach is separation of cooling from clean air supply.

- Analyze potential energy savings and conditions under which chilled beam approach could be beneficial.
- Document case studies of chilled beam designs in European hospitals.

5.6. Part-load performance of HVAC equipment and systems.

There are several needs related to the installed performance of HVAC systems. The first question relates to part-load performance / efficiency. One workshop participant noted evidence that fans have much narrower "sweet spots" – ranges of efficient operation – than is commonly thought. These sweet spots may not be provided by equipment manufacturers or known by building operators. As a result, installed equipment may be operating in regions of relatively low efficiency. This issue may be relevant to a variety of equipment (fans, pumps, chillers) and may also apply to systems of connected components. Part-load performance is an issue at the component equipment and at the system levels. This information is critical to improving efficient operation of existing systems and to designing new systems. Research needs include standardized procedures and metrics of equipment and system efficiencies under conditions relevant to installed operation, benchmarking of installed systems, improved documentation and communication of these performance curves, and improved training of designers and building operators to understand and use this performance information.

- Develop (or promote as available) standard test methodologies and reporting requirements for full-cycle performance of HVAC equipment and systems.
- Training of healthcare facility designers and operators to advance understanding and ability to utilize equipment and system efficiency ratings in design and operations.

5.7. Air filtration and air cleaning.

A substantial fraction of ventilation energy use is associated with forcing air through filters and sorbent beds that remove particles and other pollutants. Air cleaning with ultraviolet (UV) photocatalytic and ozone systems can add to the energy burden. Air filtration and cleaning is important for recirculation (to avoid disease transmission and remove indoor air pollutants) and for 100% outside air systems (to efficiently remove outdoor air pollutants). Workshop participants felt there are likely opportunities to improve air quality and reduce energy use via improved air cleaning systems. Specific opportunities and needs in this area were not covered comprehensively or in depth. One participant noted a lack of clear information about the typical energy use associated with filtration products and suggested that a simplified rating system could be combined with improved education and training to help operators identify more energy efficient products. One of the reviewers noted that more cost effective final air filters are now available and many hospitals can substantially reduce fan energy use while maintaining required filter capture efficiency. The same reviewer noted the recent development of a tool to estimate total cost of filters including energy use related to pressure drop (see item 2.7). The propensity to allow by-pass was raised as an issue of concern to filter evaluations; by-pass reduces energy use at the expense of achieving the intended air cleaning.

- Develop simplified rating system for filter energy efficiency.
- Research and development to identify additional opportunities and needs related to filtration and air cleaning.

6. Electrical System Design

Hospital electrical systems are designed for reliability and to satisfy needs for emergency power with varying allowances for downtime. New facilities commonly have four electrical branches – life safety, critical, equipment and normal – with only the last not requiring emergency or back-up power. Hospital electrical systems currently are not designed for meaningful sub-metering. Power or current sub-meters represent a relatively small incremental expense at the time of construction and set-up of a building management system, yet they are often excluded from designs or removed during value engineering review.

6.1. Design to improve efficiency of electrical distribution systems.

Electrical systems, branches and circuits are typically oversized not only to accommodate expansion but also by design requirements that consider unrealistic electrical equipment (including medical equipment) use patterns and assumptions about maximum concurrent loads. This over-sizing leads to less efficient equipment where power conversions take place and more expensive distribution systems in general. Redundancy configuration also affects efficiency. The efficiency of a 2N system (two time each component) is much different than the efficiency of an N+1 system.

- Research to understand electrical equipment use patterns.
- Revise design standards based on more realistic load assumptions.
- Set standards for transformer and power distribution losses including UPS and standby generation systems.

6.2. Electrical system architectures for efficient and meaningful sub-metering.

In principle, electrical systems could be designed to allow for much more efficient sub-metering. This would include grouping of equipment for a given service (e.g. chillers, chilled water pumps, cooling tower fans) on common feeds or circuits with a sub-meter installed to read the power to all of this equipment. Equipment for a given service that remains distributed among separate circuits or branches could still be metered in groups with data fed to a calculation algorithm in the automated building management system. Some equipment – such as variable frequency drive controllers and chillers provide signals for electrical consumption. Sub-meters for current (apparent power) or true power are incrementally inexpensive to install in connection with new construction, major renovation, or installation of new energy management systems; installation to existing systems is substantially more expensive. Design guidance and demonstration of electrical systems that include sub-metering was considered by many advisors to be a high yield, high priority activity.

- Develop, demonstrate, and document electrical system architecture to facilitate sub-metering by system and if desired medical department.
- Include sub-meters for power or current during new construction and major renovations.

6.3. Integrate on-site renewable and co-generation power sources.

On-site solar power generation can improve system reliability by providing grid-independent power at times of maximum load (summer peak cooling hours) for both the overall system and the hospital. Geothermal systems should be considered in areas with reliable sources. Several advisors noted that new co-generation systems are cleaner, more efficient, and more reliable

than older designs. They can provide reliable grid-independent power with good overall efficiency performance through optimized use of steam and heat.

- Demonstrate electrical system designs that utilize renewable energy sources.
- Evaluate and document overall system performance of co-generation for hospital applications; compare to alternative advanced designs.

7. Lighting

Despite widespread implementation of more efficient lamps and ballasts, lighting remains a substantial fraction of electricity and overall source energy demand for most hospitals. Improved designs and technologies offer opportunities for substantial reductions in lighting energy use.

7.1. Expand utilization of daylight.

The expanded use of daylight should be a major focus in the design of new facilities or major renovations. Opportunities also exist in existing facilities that contain substantial window area. Opportunities include controls to reduce electric lighting when daylight is available, incorporation of window treatments and automated shading to reduce solar heat gain and glare.

- Maximize utilization of daylighting in new construction and major renovations.
- Demonstrate and document best practices for integrating passive design (orientation, overhangs, etc.) and technologies (glazing, automatic shading, etc.) to maximize available daylight in new facilities.
- Demonstrate utilization of daylight in existing facilities through use of technologies including window treatments and shading to control solar heat gain.
- Demonstrate and document energy savings associated with daylight-responsive electronic lighting controls in both new construction and retrofit applications.
- Incorporate daylighting best practices into hospital green design guides.
- Research to evaluate effect of daylight on patient outcomes.
- Research to evaluate effect of daylight on medical staff performance and satisfaction.

7.2. Lighting controls and technologies.

Most existing hospital lighting systems are relatively simple and provide illumination that exceeds necessary levels in many locations at many times. The use of lighting sensors and controls can substantially reduce lighting energy. Optimized systems can incorporate task lighting with dimmable fixtures and staged lighting. Development of optimal systems will require substantial input and feedback from medical staff to ensure that systems meet medical needs and are amenable to staff.

- With medical staff, conduct cooperative research and development to identify opportunities and understand operational constraints for use of lighting controls and efficient lighting systems.
- Implement demonstration projects of efficient lighting system retrofits in existing facilities and evaluate impact on lighting levels, energy use, and staff satisfaction; solicit feedback and recommendations from staff to guide improvements to control sequences.

7.3. Lighting best practices.

Advisors reported their sense that hospital lighting needs can be satisfied with much lower energy use. In addition to the demonstration and deployment of advanced sensor and control

technologies, there are opportunities to utilize relatively simple controls and administrative practices to reduce lighting energy use in existing facilities. These opportunities include reduction of lighting levels in areas during times of non-use, providing local control to manually reduce lighting levels in areas with daylight and non-medical areas, and confirming that lighting levels are not greatly in excess of standards.

- Document actual energy used by typical lighting design. We know installed w/sf, but we do not know how much energy is actually used by lighting systems. Determining where lighting is used will provide a roadmap to energy savings, creating prioritization for controls and energy efficient solutions.
- Document case studies of efficient and advanced lighting systems in new and existing facilities; codify the principles of efficient lighting design in best practices guides.
- Include lighting efficiency measures in best practice training for operations staff; include the following:
  - Check/confirm lighting intensity conforms to standards for healthcare spaces (avoid over-lighting)
  - Upgrade lighting equipment to current best in class efficiency
  - Utilize lighting controls (timer and sensor based dimmers and shut-offs) in non-medical areas and medical areas that are used non-continuously.

8. Medical Equipment and Process Loads

As noted above in the section on understanding energy use in hospitals, there is a crucial need for information about the energy use rates and operational schedules for hospital process loads principally steam for disinfection and medical equipment. Some work has been done in this area. ASHRAE funded a project to develop a method of test for medical imaging systems. The project was conducted by IES-Engineers (NC) and includes time-dependent power consumption measurements at 2 sec resolution. Several project advisors are involved in efforts to motivate the U.S. EPA to start an Energy Star labeling program for distributed medical equipment. The California Energy Commission is funding a study of the prevalence, use patterns and energy use rates of distributed medical equipment. Medical equipment is currently not covered under any regulations or voluntary standards for energy efficiency. Information on medical equipment and process loads specific to hospitals is important to ensure accurate energy modeling, efficient hospital system designs (electrical and thermal) and appropriate prioritization of efforts to further resolve and reduce energy use associated with these loads.

8.1. Medical equipment energy use and operational patterns.

Medical equipment was assumed by most advisors to be a substantial and increasing fraction of hospital electrical loads total energy use, but this assumption is largely based on supposition rather than data. Medical equipment can be important as both an internal heat load and a time-dependent electrical load. Several workshop participants noted that distributed equipment typically is left in ready mode when not in use. If standby power consumption is non-negligible, this represents a potentially important opportunity for energy and cost savings. Medical imaging equipment draws large amounts of power when in use, but operation occurs over small bursts. A recent ASHRAE-funded research project produced data for energy use from a small sample of devices. Additional work is needed to obtain power consumption rates (resolved by operational mode) and operational patterns for medical imaging devices. Understanding use patterns and measurement of energy consumption rates may require cooperative involvement of medical staff.

- Research to quantify power consumption rates (by operational mode) and operational patterns for large medical imaging systems.
- Research to quantify power consumption rates (by mode or setting), operational patterns, and population statistics for distributed medical imaging systems.

8.2. Energy efficiency rating system(s) for medical equipment.

Rating systems should help to create a market for more efficient products by providing purchasers with information to choose more efficient products and allowing manufacturers the opportunity to differentiate their products from those of competitors. Several advisors are already advocating for an Energy Star type of rating; to accomplish this will require development of test procedures specific to each medical device. Given their extremely high cost and specialized functionality, it is doubtful whether an energy rating system would impact decisions on medical imaging equipment. Nevertheless, several advisors still regarded the documentation of energy use under some standard operational condition or pattern of operation to be valuable information that should be provided by manufacturers. Efficiency standards may be relevant to components of medical imaging systems such as transformers, power supplies, etc. One reviewer noted that there are substantial energy efficiency opportunities related to where the equipment is located and how it is integrated into the hospital's infrastructure, suggesting that this is a candidate for best practice guidance.

- Development of standard operating patterns and test procedures – by device – to assess energy use / energy efficiency of distributed medical devices.
- Establish rating or labeling system for medical equipment energy efficiency.
- Market promotion of rating system.

8.3. Distributed medical equipment standby loads.

As noted above, there may be an opportunity to reduce standby power consumption for the relatively large numbers of distributed medical devices that are present in modern hospitals. There also may be opportunities to reduce electricity consumption by components of large medical imaging systems and/or reduce cooling loads through more efficient cooling systems.

- Research to quantify standby power consumption for individual medical devices and for the population of distributed equipment.
- Research and development to identify opportunities to reduce component energy consumption for medical imaging systems.
- Best practice guidance for cooling of medical imaging systems.

8.4. Hospital process loads.

The attribution of energy use associated with process steam (e.g. for sterilization) may be challenging due to lack of sub-metering and the fact that this load is typically much smaller than the steam required for space heating (the amount required for humidification is highly variable by season and location). Information about the amount and temporal patterns of process steam requirements could lead to the design of more efficient steam / sterilization systems. The value of understanding other hospital process loads (e.g. refrigeration) was not raised by advisors or workshop participants, but could be of some relevance to hospital energy efficiency efforts.

- Research to understand patterns of process steam use in hospitals.
- Research and development of more efficient systems to satisfy process steam needs.

9. Economic and Organizational Issues

Almost every discussion of healthcare energy included repeated mention of the economic and organizational challenges that are seen by many as critical barriers to progress. The specific issues revolve around the question of how to motivate healthcare companies and organizations to invest in energy efficiency. Advisors offered many anecdotes about decision-makers unwilling or unable to make investments with payback periods on the time scale of even a few years or less. The opportunity and urgency of this challenge is clear: many energy efficiency technologies, designs and operational measures require some up-front investment; without the willingness to invest or even to experiment with zero-cost measures, energy efficiency efforts will be hampered. The items below focus on specific needs and actions related to economic and organizational challenges.

9.1. Strategies to overcome structural challenges to energy efficiency investment.

Structural challenges collectively represent one of the largest barriers to energy efficiency investments in the healthcare sector. Key issues include the separation of capital and operating funds and a lack of available funds for investment in energy efficiency, regardless of payback period (any funds that can be obtained are targeted to enhancing medical services). Motivating decision makers and analysis tools are discussed subsequently. One of the most promising ideas raised at both the LBNL workshop and the Hospital Energy Alliance (HEA) kick-off was the use of revolving funds. One LBNL workshop participant described a program at an academic medical center in which the institution offered seed money to facilities staff to invest in energy efficiency measures. Staff could then use funds from energy savings for additional efficiency investments. At the HEA event, one participant suggested that public sector funds (e.g. from a government grant or public utility efficiency program) could be used to initiate a revolving fund. Government incentives and programs such as the ratepayer-financed utility-run efficiency initiatives in California offer rebates for efficient equipment and retrofits, energy audits, and other forms of assistance; these programs represent an under-utilized financial resource for healthcare energy efficiency efforts. Increased market awareness and utilization of existing programs, expansion of program funding, and innovations that allow for direct financing of efficiency upgrades (removing the need for initial outlays by the facilities) should all help to accelerate implementation.

- Increase market awareness and utilization of existing energy efficiency financing and assistance programs.
- Innovative programs to reduce investment barriers for facilities to participate in rebate programs.
- Social science research to understand structural barriers and potential solutions.
- Development of innovative financing mechanisms to facilitate energy efficiency investments – especially at the time of new construction or renovations – that are paid back in energy savings.
- Document examples of revolving funds for efficiency investments (within and without healthcare industry) to establish feasibility; work with industry and government stakeholders to explore options for seed money to start a revolving fund.
- Explore and develop innovative ideas to overcome structural challenges; the following ideas were offered at the HEA event:
    - C-suite already has too much to deal with; facilities personnel need to be the managers of change.

- Link government reimbursements to efficiency and sustainability practices: provides market-based incentive for facilities to be more energy efficient.

9.2. Design tools to evaluate cost and energy implications of efficiency improvements.

Attempts to make a case for efficiency upgrades are bolstered by evidence and estimates of energy and cost savings. Tools can include models to estimate costs and energy benefits of specific projects and/or case study reports documenting energy savings in completed or planned projects. Tools should apply to both new and retrofit projects. Some financial and impacts tools already exist; advisors suggested the EPA target finder web site and EICHealth.org as examples (the availability or utility of tools at these sites has not been verified by the author).

- Promote available tools through industry associations, professional societies, etc.
- Develop tools further as needed.

9.3. Motivating energy efficiency investment among hospital decision-makers.

Participants at the LBNL workshop and the HEA kick-off offered many arguments that may be used in an effort to motivate decision-makers to invest in energy efficiency. While the general consensus among both groups was that these arguments are typically insufficient to overcome concerns deemed by the decision makers as more urgent and critical, the arguments are nevertheless presented below.

- Energy efficiency is way to reduce costs without impacting medical services.
- In new construction and major renovation projects, packages of efficiency measures can be implemented at no incremental cost; some individual measures are low or no cost.
- Many retrofit energy efficiency measures have excellent return on investment and payback periods of a few years or less.
- Lower energy demand and more robust systems reduce vulnerability to price spikes.
- As high-profile community institutions, hospitals can improve image through sustainable practices or face public scrutiny as highly energy intensive facilities.
- Energy efficient and robust facilities can improve "mission critical" performance.
- When energy is viewed as strategic challenge, leads to longer term plans, continuous improvement, reinvestment of savings, etc.

10. Designing Sustainable Hospitals

The increasing national attention to "sustainable" building design is reflected by several ongoing efforts related to healthcare facilities. The Green Guide for Health Care (gghc.org) lead the way with a self-assessment rating system covering energy, water, materials, indoor air quality and other impacts. GGHC has worked with the U.S. Green Building Council to develop a certified LEED for healthcare rating system. ASHRAE is developing a sustainability standard (Standard 189.2) for health care. An advanced energy design guide (AEDG) for small hospitals and clinics is close to completion and an AEDG for large hospitals is under development. Additionally, ASHRAE is including hospitals in their building energy performance standard (Standard 90.1). California's Green Building Code allows OSHPD to set mandatory standards, though to date most of the provisions are voluntary. EPA's Energy Star for Healthcare may be limited in scope (pertaining only to facility level energy use) but its simplicity and ease of access may provide useful lessons to other standards and rating systems. While some of the activities noted above push the envelope of conventional hospital designs, there is also a need to motivate consideration of dramatically different hospital designs that can achieve more robust sustainability goals including zero net energy use. Achieving sustainability goals may require

changes to ventilation and other codes and certainly will require major shifts in designs and design approaches.

10.1. Effect of building form and systems designs on patient outcomes.

Hospital building and operations codes (e.g. for ventilation rate) establish a standard of care that is presumed to be supported by research. In fact, advisors report, some code provisions are not supported by robust research and instead rely on rules of thumb and margins of safety to account for uncertainties. There is a general and substantial need for research to understand and quantify relationships between building parameters and medical outcomes. Building designs may directly impact patient well being or impact the performance of medical staff, with resulting indirect effect on patients. Examples include the use of daylight, provision of 100% outside air, access to outdoors, availability of operable windows, etc. Some of these design elements have been implemented in hospitals in Europe, so evaluation of their impacts on patients and staff may be feasible. Limited analysis indicates that the potential patient outcome benefits of these design elements far outweigh the energy savings benefits. This activity may require collaborations between building designers and researchers who focus on quantifiable metrics of healthcare performance and outcomes. The research should be of great interest to hospital operators as it related directly to the medical mission.

- Bring together researchers focusing on medical outcomes and sustainable hospital designers to develop research agenda and collaborations.
- Study and report building performance, staff performance and patient outcomes in advanced hospitals designs in Europe (the University of Washington is doing this).
- Communicate research and state of the art to codes and standards bodies in U.S.

10.2. Benefits of integrated design and systems engineering approaches.

The integrated design process brings together early on all key stakeholders (owner, designers, builders, users, operators and sometimes even the community) to foster clear communication of needs, goals, expectations, etc. This interactive process helps to ensure both the quality and the suitability of the facility. The integrated design process has great relevance to efforts to improve energy efficiency. In traditional design approaches, energy efficient components, sub-meters to monitor energy use, or other elements related to energy efficiency may be included by a designer but later removed in an effort to reduce project costs (value engineering). With integrated design, energy efficiency and sustainability can be incorporated as essential design goals by the entire project team. For example, the hospital layout can be designed with daylighting to reduce lighting loads and consequently reduce cooling requirements. Many LBNL workshop participants noted that the integrated design process has great potential to advance cost-effective reductions in energy intensity – often while improving building and indoor environmental quality – but there is a need to verify and document these benefits. Documented case studies may be the best approach to doing this. Additionally there is a need to raise awareness of the process and its potential benefits; this can be done through education, training and outreach programs. Integrated design considers the hospital from a systems perspective, leading to efficiency gains and cost reductions that are not achievable by ad-hoc use of efficient components. The trend of first cost increasing with addition of energy efficiency elements (substituted for lower cost, more energy intensive options) theoretically reverses as system effects drive down demand for cooling, heating, and lighting and allow for smaller less expensive systems to provide these services. There is a critical need to evaluate whether this

theoretical cost curve is reflected in the planning and construction of real facilities, and to determine if the theoretical curve leads only to lower overall (life cycle) costs or can lead to lower initial costs. Documented design and as-built case studies are needed. An often overlooked but related opportunity is to design systems that are reliable, robust and intuitive to operate efficiently; human factors engineering can contribute to this goal.

- Advance market awareness of integrated design and system approaches: incorporate into training and professional development programs for engineers and architects; promote via professional organizations of hospital owners and operators.
- Conduct and document design case studies of projected energy use and first cost for progressively lower energy intensity (develop cost curves).
- Document and disseminate achievements of system-based designs for healthcare facilities in U.S. and elsewhere.
- Research and development to incorporate robustness, reliability and intuitive operation with energy efficiency in building systems.

10.3. Sustainable hospital standards and codes.

Mandatory codes and standards for energy (and other sustainability goals) set minimum requirements that can eliminate or greatly reduce the use of inefficient designs. Voluntary and aspirational standards and rating systems can be powerful drivers of innovation for both design and technology. Establishment of meaningful and consistent baselines and evaluation processes are important to standards that set targets or requirements for energy intensity reductions. The proliferation of codes, standards with overlapping objectives and target audiences can be confusing and off-putting to the uninitiated (viz. most hospital owners). Consideration should be given to coordination and consolidation of standards that serve very similar functions and audiences. Prediction of energy use for innovative hospital building and system designs will require advances in modeling of component systems (with validation based on installed performance).

- Coordination and potentially consolidation of energy and sustainability codes, standards and rating systems (to reduce confusion that can hamper widespread market adoption).
- White paper to clarify similarities and differences of energy and sustainability codes, standards and rating systems for healthcare facilities including comparison of baselines.
- In California, analysis to support application of suitable commercial building Energy Code (Part 6 of Title 24 building codes) into Green Code (Part 11 of Title 24) standards for healthcare facilities.
- Model development and verification for advanced HVAC and other systems.

10.4. Designing hospitals for people: collaboration and human factors engineering.

The overarching design priority for healthcare is to facilitate the provision of excellent medical care; efforts to design for sustainability therefore must be integrated with the medical mission. Such integration can be accomplished through close collaboration of medical staff with hospital designers and operators. Codifying common goals and establishing mechanisms for ongoing collaboration and coordination produces opportunities for research, development and adoption of sustainability-focused technologies and practices. Human factors engineering can advance sustainability goals by contributing to the design and construction of hospitals and systems that are intuitive for all users, including patients and visitors, staff, and building operators. Communication with users through integrated design and feedback is essential.

- Collaboration and coordination among medical staff, hospital designers and facility operators.
- Incorporate human factors engineering approaches to the design of energy using systems and equipment in healthcare facilities.

4.0 Prioritization of Issues and Activities

Presented below is a summary list of the issues and activities described above. A priority has been assigned to each issue and activity based on discussions with advisers, interviewees, and workshop participants. Prioritization is broadly based on the following considerations: the potential benefit in terms of energy savings; the likelihood of achieving real benefits; and the anticipated amount of time, effort and cost required to implement the activity or achieve the objective. The clear and substantial bias to the highest two priority levels reflects two factors. The first is that the expert advisors were asked to focus on efficiency opportunities that could be readily achieved with current technology and capabilities, and opportunities that are large and likely to be realized with a modest investment of research, development or demonstration effort. The second factor is that the advisors were able to identify a large number of these high reward opportunities. Metaphorically, advisors identified a lot of "low hanging fruit" (and what some described as fruit already on the ground) along with some even bigger and better fruit that will be reachable with just a bit of effort.

Table 1. Priority Tasks to Understand and Benchmark Energy Use

Topic / Activity	Priority 1. Highest	Priority 2.	Priority 3.	Priority 4. Lowest
1.1. Standard performance metrics.	X			
• Establish standard performance metrics.	X			
1.2. Advance performance benchmarking.	X			
• Advance development of benchmarking system metrics and benchmarks.	X			
• Advance development of protocol and guidance.	X			
1.3. Database of performance metric values.	X			
• Identify and analyze existing information.	X			
• Obtain and compile data on performance and energy use from existing systems.	X			
• Apply LBNL-V1 benchmarking protocol to collect data from additional facilities.		X		
• Online energy benchmarking database.		X		
1.4. Expand capacity for energy monitoring and benchmarking.	X			
• Guidance on use of existing data streams.	X			
• Guidance on energy monitoring systems for new facilities and retrofits.	X			
• Develop/demonstrate overlay systems for energy monitoring.		X		
• Deploy new sensor systems and capture data from existing sensors in buildings.	X			
1.5. Effective energy management systems.		X		
• Develop and promote awareness of energy monitoring and management software.		X		
1.6. Fill gaps in energy simulation models.		X		
• Model of fan and duct system losses		X		
• Energy use of medical equipment.		X		
• Simulate advanced HVAC systems.		X		

Table 2. Priority Tasks for Best Practices and Training

Topic / Activity	Priority 1. Highest	Priority 2.	Priority 3.	Priority 4. Lowest
2.1. Energy performance evaluations to determine best practice.		X		
• Rate performance of systems and practices relevant to reference or standard practice.		X		
2.2. Searchable database of best practices.		X		
• Design best practices database.		X		
• Construct database including information from existing best practices.		X		
2.3. Improved guidance, education and training for designers.	X			
• Consensus on efficient designs by climate and medical operational needs.		X		
• Include energy efficiency best practice in design guides and standards.		X		
• Case study evaluations of energy and operational performance.	X			
• Connect and coordinate design guidance with operator training.		X		
2.4. Improved training for hospital operators and facility engineers.	X			
• Incorporate energy efficiency into standard training programs.	X			
• Coordinate training with developments in area of design.		X		
• Expand ongoing training for operators.	X			
2.5. Improved documentation of building systems to facilitate operation as designed.		X		
• Standard formats for operating manuals.		X		
• Create manuals for existing facilities.		X		
2.6. Guidance and expanded implementation of commissioning (Cx).	X			
• Guidance on Cx schedules for healthcare.	X			
• Metrics and reporting to utilize information obtained during hospital commissioning.		X		
• Commission all existing hospitals.		X		

Topic / Activity	Priority 1. Highest	Priority 2.	Priority 3.	Priority 4. Lowest
2. Priority Task for Best Practices and Training (contd.)				
2.7. Information on energy performance of building products.	X			
• Consistent information on energy use of consumables and equipment.	X			
2.8. Improved maintenance.	X			
2.9. Strategies to reduce reheat through existing HVAC system management.	X			
• Sensor and control systems to reduce reheat energy losses in existing CAV systems.	X			
• Document best practices to manage reheat.	X			

Table 3. Priority Tasks for Codes and Standards

3.1. Performance-based criteria for ventilation standards.		X		
• Medically relevant performance metrics for determination of ventilation standards.	X			
• Standard procedures to demonstrate compliance for ventilation systems.		X		
• Compare European, U.S. standards, practices, health outcomes, and energy.		X		
3.2. Energy performance and medical outcomes in hospitals with mixed mode ventilation.		X		
• Review energy and medical outcomes in hospitals that allow operable windows and natural ventilation.		X		
• R&D examining opportunities and barriers to mixed mode ventilation in U.S. hospitals.		X		
3.3. Change minimum humidity limit to 20%.		X		

Table 4. Priority Tasks for HVAC System Design (Utilization of Existing Technologies)

Topic / Activity	Priority 1. Highest	Priority 2.	Priority 3.	Priority 4. Lowest
4.1. Assess energy use and lifetime costs of common and alternative HVAC systems.		X		
• Standard metrics and approaches to evaluate total costs to purchase and operate systems.		X		
• Evaluations of system performance for database of best practices.		X		
4.2. "Right-sizing" and part-load efficiency of HVAC equipment and systems.	X			
• Best practice guidance to designers on right-sizing of HVAC systems.	X			
4.3. Designs to reduce reheat.	X			
• Guidance to minimize reheat energy losses.	X			
4.4. 100% outside air systems.		X		
• Design guidance for 100% outside air with air cleaning for outdoor pollution episodes.		X		
• Evaluate overall energy use of 100% outside air systems including air cleaning.		X		
4.5. Displacement ventilation systems.		X		
• Regulatory acceptance of DV systems for patient rooms with lower air supply rate.		X		
• Demonstrate DV and publicize results to achieve market acceptance.		X		
• Evaluate ventilation and energy performance of installed DV.		X		
4.6. Document performance evaluations of common energy-related design elements.		X		
• Online database or wiki to share cost & energy analysis of design elements.		X		

Table 5. Priority Tasks for HVAC Technology and Design Innovation

Topic / Activity	Priority 1. Highest	Priority 2.	Priority 3.	Priority 4. Lowest
5.1. HVAC technologies and equipment.		X		
• Document performance of technologies and designs; document case studies.		X		
5.2. Incorporate systems engineering principles into HVAC designs.	X			
• Incorporate systems engineering principles to ASHRAE design guide.	X			
5.3. Test bed for technologies and practices.	X			
• Establish test bed facilities to evaluate advanced HVAC systems and technologies.	X			
5.4. Alternative dehumidification systems.	X			
• In-use performance evaluations of desiccant-based dehumidification systems.	X			
• Building simulation analysis to identify favorable climate conditions.		X		
5.5. Chilled beam cooling.			X	
• Analyze conditions for chilled beam use.			X	
• Document case studies of chilled beam designs in European hospitals.		X		
5.6. Part-load performance of HVAC equipment and systems.	X			
• Standard testing and reporting for full-cycle performance of HVAC equipment, systems.	X			
• Train designers and operators to utilize equipment and system efficiency ratings.		X		
5.7. Air filtration and air cleaning.		X		
• Develop simplified rating system for filter energy efficiency.		X		
• R&D on opportunities and needs related to filtration and air cleaning.		X		

Table 6. Priority Tasks for Electrical System Design

Topic / Activity	Priority 1. Highest	Priority 2.	Priority 3.	Priority 4. Lowest
6.1. Design to improve efficiency of electrical distribution systems.		X		
• Research to understand electrical equipment use patterns.		X		
• Revise design standards based on more realistic load assumptions.		X		
• Set standards for transformer and power distribution losses.		X		
6.2. Electrical system architectures for efficient and meaningful sub-metering.		X		
• Develop& demonstrate electrical system architecture to facilitate sub-metering	X			
• Include sub-meters during new construction and major renovations.	X			
6.3. Integrate on-site renewable and co-generation power sources.			X	
• Demonstrate electrical system designs that utilize renewable energy sources.			X	
• Evaluate and document overall system performance of co-generation.			X	

Table 7. Priority Tasks for Lighting

Topic / Activity	Priority 1. Highest	Priority 2.	Priority 3.	Priority 4. Lowest
7.1. Expand utilization of daylight.	X			
• Maximize utilization of daylighting in new construction and major renovations.	X			
• Best practice designs and technologies to maximize daylight in new facilities.	X			
• Daylight in existing facilities with window treatments and shading to control solar gain.	X			
• Evaluate daylight-responsive electronic lighting controls.	X			
• Incorporate daylighting best practices into hospital green design guides.	X			
• Research to evaluate effect of daylight on patient outcomes.	X			
• Research to evaluate effect of daylight on medical staff performance and satisfaction.	X			
7.2. Lighting controls and technologies.	X			
• R&D to understand operational constraints on light controls and efficient lighting.	X			
• Demonstrate/evaluate efficient lighting system retrofits in existing facilities.	X			
7.3. Lighting best practices.		X		
• Case studies of efficient and advanced lighting systems in new and existing.		X		
• Include lighting efficiency in best practice training for operations staff.		X		

Table 8. Priority Tasks for Medical Equipment and Process Loads

Topic / Activity	Priority 1. Highest	Priority 2.	Priority 3.	Priority 4. Lowest
8.1. Medical equipment energy use and operational patterns.		X		
• Research on energy use of large medical imaging systems.		X		
• Research on energy use of distributed medical imaging systems.		X		
8.2. Energy efficiency rating system(s) for medical equipment.		X		
• Develop operational patterns for energy testing of distributed medical devices.		X		
• Establish rating or labeling system for medical equipment energy efficiency.		X		
• Market promotion of rating system.			X	
8.3. Distributed medical equipment standby loads.		X		
• Research on standby power consumption for medical devices.		X		
• R&D to reduce component consumption of imaging systems.		X		
• Best practice guidance for cooling of medical imaging systems.		X		
8.4. Hospital process loads.		X		
• Research to understand patterns of process steam use in hospitals.		X		
• R&D on efficient systems to satisfy process steam needs.		X		

Table 9. Priority Tasks for Economic and Organizational Issues

Topic / Activity	Priority 1. Highest	Priority 2.	Priority 3.	Priority 4. Lowest
9.1. Strategies to overcome structural challenges to energy efficiency investment.	X			
• Increase market awareness and utilization of existing energy efficiency financing and assistance programs.	X			
• Innovative programs to reduce investment barriers for facilities to participate in rebate programs.	X			
• Social science research to understand structural barriers and potential solutions.		X		
• Innovative financing mechanisms to facilitate energy efficiency investments.		X		
• Evaluate revolving funds for efficiency investments; options for seed funding.	X			
• Ideas to overcome structural challenges.	X			
9.2. Design tools to evaluate cost and energy implications of efficiency improvements.	X			
• Promote available tools through industry associations, professional societies, etc.	X			
• Develop additional tools as needed.		X		
9.3. Motivating energy efficiency investment among hospital decision-makers.		X		

Table 10. Priority Tasks for Designing Sustainable Hospitals

Topic / Activity	Priority 1. Highest	Priority 2.	Priority 3.	Priority 4. Lowest
10.1. Effect of building form and systems designs on patient outcomes.		X		
• Coordinate research on medical outcomes and sustainable hospital designs.		X		
• Study building & staff performance, patient outcomes and energy in advanced hospitals.	X			
• Communicate research and state of the art to codes and standards bodies in U.S.		X		
10.2. Benefits of integrated design and systems engineering approaches.		X		
• Advance market awareness and incorporate into training and professional development.		X		
• Case study cost curves for energy efficiency in new facility and renovation designs.	X			
• Evaluate performance of system-based designs in U.S. and elsewhere.		X		
• R&D to incorporate robustness, reliability and intuitive operation with energy efficiency in building systems.		X		
10.3. Sustainable hospital standards and codes.		X		
• Coordinate energy and sustainability codes, standards and rating systems.		X		
• Summary of energy & sustainability codes.		X		
• Analysis of costs, benefits of Energy Code standards for healthcare facilities (CA).		X		
• Model development and verification for advanced HVAC and other systems.		X		
10.4. Designing hospitals for people: collaboration and human factors engineering.		X		
• Collaboration among medical staff, hospital designers and facility operators.		X		
• Incorporate human factors engineering approaches.		X		

Appendix A. Contributors

Listed below are individuals who contributed to the development of the road map for energy efficiency healthcare facilities. Affiliations are provided for identification purposes only. Neither the individuals listed below nor their organizations should be regarded as having endorsed the complete content of this document. In addition to the contributions of individuals listed below, the authors incorporated both specific comments and general concepts offered at the kick-off meeting of the Hospital Energy Alliance (http://www1.eere.energy.gov/buildings/hospital/) and the Healthcare Energy sub-committee of the American Society of Heating, Refrigeration, and Air-Conditioning Engineers' Healthcare Technical Committee (TC9.6).

Interviews

9/15/08: Jeffrey Keyak, Senior Energy Consultant, National Facilities Service, Kaiser Permanente

9/19/08: Shanti Pless, Building System Integration Center, National Renewable Energy Lab

9/25/08: Clark Reed, National Healthcare Energy Manager, Energy Star, U.S. EPA

10/17/08: Arash Guity, Mazzetti Nash Lispey Burch (focus on ventilation and infection control)

10/27/08: Steve Greenberg, Lawrence Berkeley National Laboratory (high-tech buildings)

12/15/08: Don Rainey, U. Washington and Better Bricks Program

12/22/08: Peter Gardner, Torcon (ventilation)

12/30/08: Walt Vernon, Mazzetti Nash Lispey Burch

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San Lecharoen	St. Joseph Health System
Paul Mathew	Lawrence Berkeley National Laboratory

Kevin Maxson	Dept. of Veterans Affairs – VISN 21 Energy Manager
Paul Ninomura	Indian Health Services and ASHRAE Standard 170 Deputy Chair
Shanti Pless	National Renewable Energy Lab (Advanced Energy Design Guide)
Xiaobo Quan	Center for Health Design
Roger Richter	California Society for Healthcare Engineering
Francois Rongere	Pacific Gas & Electric
Chris Scruton	California Energy Commission
Brett Singer	Lawrence Berkeley National Laboratory
Susan Strom	Mazzetti Nash Lispey Burch
Bill Tschudi	Lawrence Berkeley National Laboratory
Ben Venktash	Energy Resource Associates
Walt Vernon	Mazzetti Nash Lispey Burch (also Green Guide for Health Care and other roles)
Mohammed Yazdi	PG&E (Health Care Energy Efficiency Senior Program Manager)

Review and/or comments on draft final road map document

Heather Burpee	University of Washington Integrated Design Lab
Regina Larabee	Veterans Administration
Don Rainey	U. Washington and Better Bricks Program
Michael Sheerin	Principal, TLC Engineering for Architecture
Mohammed Yazdi	PG&E (Health Care Energy Efficiency Senior Program Manager)

Contributors and advisors not included above

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Brian Hans	Mazzetti Nash Lispey Burch
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Patricia Ledonne	U.S. DOE Energy Smart Hospitals Program
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Ronald Westbrook	ASHRAE TC9.6-Energy, SUNY Upstate Medical Center

Appendix B. Healthcare Energy Workshop Final Program

Location and Date:
Perseverance Hall, Lawrence Berkeley National Laboratory
Tuesday, March 3, 2009

Goal:
Identify and prioritize the research, development, deployment, and demonstration (RD&D[5]) needs to advance energy efficiency in the healthcare sector.

Overview of this document
This document first provides background and context in the form of (1) potential RD&D activities and (2) an organizational scheme to facilitate discussion of challenges to improving energy efficiency in healthcare facilities.

Context: RD&D Activities
Our intent is that this workshop and the resulting road map will consider a very broad scope of RD&D activities. The list below provides examples of the types of activities to be considered for the road map.

Technology Development
- Development of new component technologies and engineered systems

Design Innovation
- Integrated design, incorporation of models from other advanced buildings

New Technology and Design Evaluation
- Research level evaluations for promising technologies and systems
- Develop metrics and protocols for systematic evaluation
- Standardize procedures for evaluation

Demonstration & Deployment of Existing Technologies and Practices
- Document performance, economics, and operational issues; evaluate suitability
- Effects on patients, staff, etc.
- Best practice and technology guides (Advanced Energy Design Guide in progress)

Economics and Organizational Research
- Overcome barriers to investment in higher first cost designs and technologies
- Economic models

Training, Behavior and Human Factors Engineering
- Improve interfaces between technologies and users
- Overcome barriers to adoption of unfamiliar or advanced systems

Codes and Standards
- Research activities specifically on providing a basis for codes and standards

[5] Convener note: acknowledged that there should be 3 D's, but it is hard enough to say/read with even the 2 D's.

Focus Areas

The organizational scheme presented below is provided to facilitate an orderly discussion of the challenges and RD&D opportunities for improving energy efficiency in healthcare facilities.

Thermal Services (Cooling, Heating, DHW, Steam)

These are considered as a group in recognition of the opportunities that exist for efficient integration of the systems used to provide the services.

- Efficient component technologies
- Integrated systems
- Humidification / dehumidification
- Durability and robustness of equipment and systems
- Human factors engineering for operation of advanced systems
- Flexibility and expandability
- Advanced, robust and intuitive controls
- Combined heat and power

Ventilation (Infection control, Natural ventilation, Filtration)

- Standardized scenarios and tests for evaluating ventilation alternatives: CFD & experimental
- Demonstration and in-situ evaluation studies of alternative technologies / approaches
- Demonstration and deployment of efficient filtrations alternatives
- Effect of operable windows on patient outcomes, experiences
- Passive ventilation

Lighting (Controls, Daylighting)

- Design and demonstration of controls suitable to healthcare environment
- Effects of daylight on patient outcomes, medical staff performance, patient and staff experience

Medical equipment

- Baseline information on operational patterns and energy use
- Testing, labeling and standards for energy performance
- Improve energy efficiency of equipment and components (power supplies, etc.)

Energy monitoring, assessment, and management systems

- Design guidance for electrical systems to facilitate sub-metering
- Energy monitoring and management systems targeted for new construction
- Energy monitoring and management systems for existing facilities
- End use assessments and benchmarking of existing facilities
- Platforms to integrate medical operations with building operation (e.g. for steam)

Energy modeling and economic analysis tools (suitable for healthcare facilities)

Cross-cutting activities:

- Operations and maintenance best practices
- Training needs and opportunities
- Human factors engineering
- Codes and standards

WORKSHOP AGENDA

0745 Informal Introductions Coffee, Fruit and Danish (15 min)

0800 Welcome and Orientation

Workshop goals; Overview of hospital energy use; Road map process: B. Singer

0830 Small Group Exercise: Challenges and Existing Opportunities (30 min)

Participants will be organized into groups of 5-8 to offer input to the following questions:

- Special characteristics and challenges that lead to higher energy use in heath care?
- Energy savings opportunities in hospitals and other health care facilities?

Consolidated lists will be posted; participants will be invited to add to lists throughout day.

0900 Technical Focus Panels

Each session will begin with a brief introduction designed to orient those without expertise and to set the tone for a discussion that allows and welcomes input from the entire group. Each panel member will then have an opportunity to provide pre-considered comments identifying challenges and/or RD&D opportunities in the area. A moderated discussion among panelists with input from other workshop participants will follow. Sessions durations are estimates and may be adjusted by the moderator.
NOTE: There will be either a short (10-min) or a rolling break mid-morning.

Thermal systems (40-50 min)
Intro: Tschudi ***Panel: Guttmann, Kobali, Lecharoen, Yazdi***

Ventilation systems and standards (40-50 min)
Intro: Guity ***Panel: Borba, Gale, Guity, Ninomura, Venktash***

Electrical system architecture, lighting, med equipment & plug loads (20-30 min)
Intro: Strom ***Panel: Burpee, Strom, Vernon***

Monitoring, controls and energy management systems (20-30 min)
Intro: Guttmann ***Panel: Guttmann, Kobali, Yazdi***

1130 Lunch

1200 Technical Focus Panels (Continued)

Operations, training, and best practices (40-50 min)
Intro: Venktash ***Panel: Keyak, Maxson, Scruton, Venktash, Yazdi***

Integrated design (30-40 min)
Intro: Burpee ***Panel: Brunel, Gale, Burpee, Guttman, Pless***

Cross-cutting and open discussion (20-30 min)
Intro: Singer ***Panel: Borba, Richter, Vernon***

1400 Working Groups (Organized around focus areas)

Prioritize and expand lists from AM sessions; outline summary for each opportunity

1430 Wrap-up session

Invited feedback from medical professionals, EE program specialists, funders
Opportunities for additional comments by participants, e.g. anything we missed

1500 Adjourn and Vacate (Follow-up discussions in cafeteria)

Healthcare Energy Workshop – Participant List*

Perseverance Hall, Lawrence Berkeley National Laboratory
Tuesday, March 3, 2009

Convener
Brett Singer, Lawrence Berkeley National Laboratory

California Energy Agencies
Chris Scruton, California Energy Commission

Hospital Energy Experts, including Systems and Operations
Karl Brown, California Institute for Energy and Environment
Heather Burpee, Integrated Design Lab, U. Wash. & Better Bricks
Thomas Gale, Kaiser Permanente
Jeff Keyak, Kaiser Permanente
Marty Kobaly, El Camino Hospital
San Lecharoen, St. Joseph Health System
Kevin Maxson, Dept. of Veterans Affairs – VISN 21 Energy Manager
Shanti Pless, National Renewable Energy Lab (Advanced Energy Design Guide, Small Hospitals)
Ben Venktash, Energy Resource Associates

Hospital Architects and Design Engineers
Kyle Brunel, Smithgroup
Steve Guttmann, Guttmann & Blaevoet
Xiaobo Quan, Center for Health Design
Susan Strom, Mazzetti

Policy, Codes and Standards Experts
Walt Vernon, Mazzetti (Green Guide for Health Care and Other Activities)
Duane Borba, California Office of Statewide Health Planning and Development (OSHPD)
Roger Richter, California Society for Healthcare Engineering

Energy Efficiency Program Specialists (PG&E, CEC)
Eric Eberhardt, PG&E Corporate Accounts
Mohammed Yazdi, PG&E Health Care Energy Efficiency
Paul Delaney, Southern California Edison

Medical Professionals
Dr. Jeff Ilfeld, Clinician at Kaiser Permanente
Dr. Marion Guyer, Kaiser Oakland Green Team
Erika Kimball, RN, Pacific Medical Center Green Team

Infection Control and Ventilation Standards
Arash Guity, Mazzetti
Paul Ninomura, Indian Health Services and ASHRAE Standard 170 Deputy Chair

High Tech Building Energy Experts
Bill Tschudi, LBNL
Paul Mathew, LBNL
Francois Rongere, PG&E

*Each participant is listed only once, though most have expertise in multiple areas.