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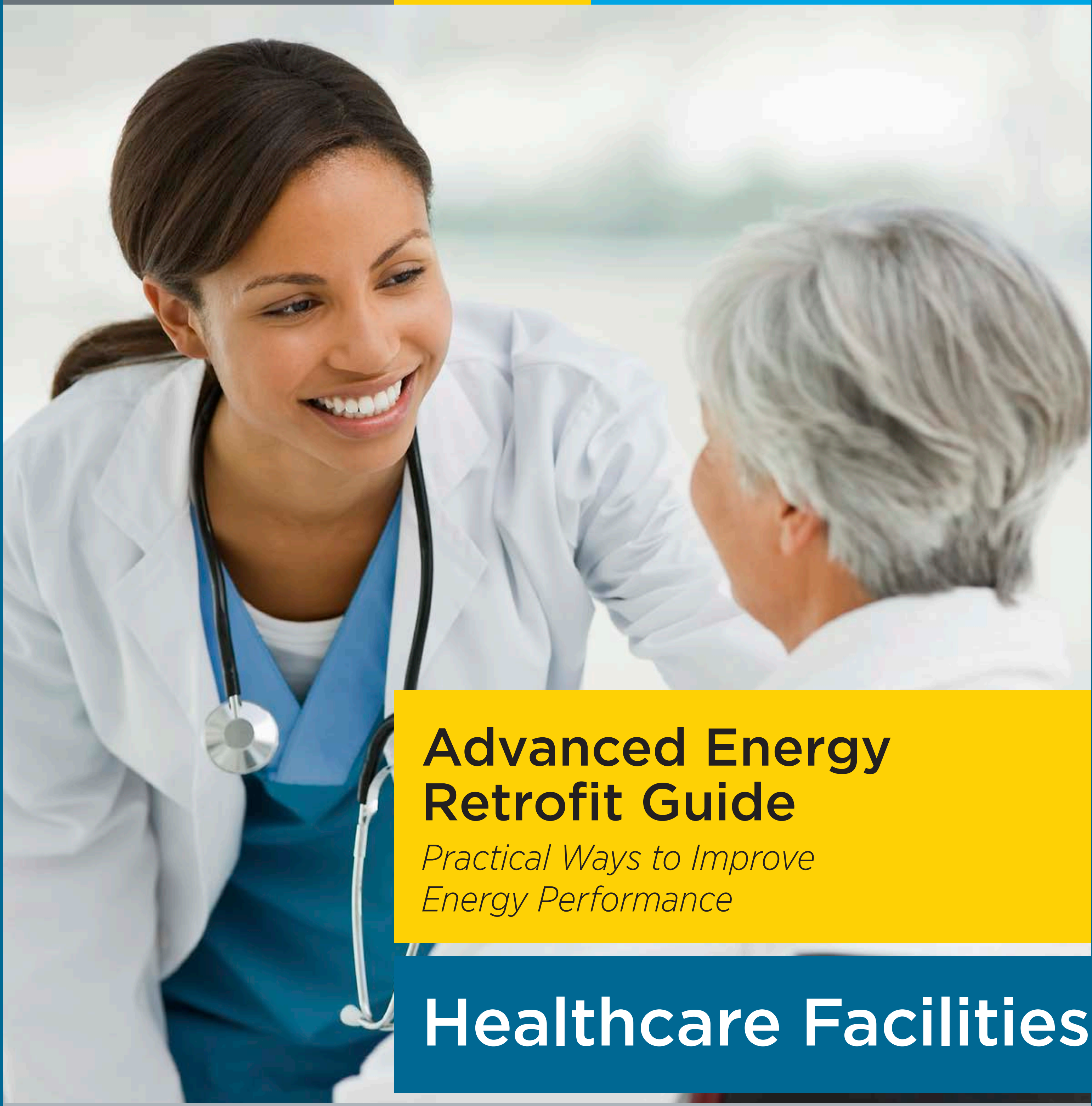

Advanced Energy Retrofit Guide

Practical Ways to Improve Energy Performance

Healthcare Facilities

Prepared by:

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Nomenclature

ACH	air changes per hour
ADR	asset depreciation range
AEDG	Advanced Energy Design Guide
AERG	Advanced Energy Retrofit Guide
AFUE	annual fuel utilization efficiency
AHU	air handling unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAS	building automation system
BOC	building operator certification
BOMA	Building Owners and Managers Association
Btu	British thermal unit
C_0	initial investment and related cash flows in Year 0
CAV	constant air volume
CBECS	Commercial Buildings Energy Consumption Survey
CDD	cooling degree day
$C_{depr,eem,t}$	tax deduction for depreciation of energy efficiency measure/package in Year t
$C_{depr,ref,t}$	tax deduction for depreciation of existing equipment in Year t
C_{disp}	disposal cost of existing equipment
CEC	California Energy Commission
$C_{energy,elec,t}$	annual electricity cost savings in Year t
$C_{energy,gas,t}$	annual natural gas cost savings in Year t
CFL	compact fluorescent lamp
cfm	cubic feet per minute
C_{incent}	NPV of financial incentives
C_{inst}	installation cost of measure/package
C_{mv}	additional M&V costs
CO_2	carbon dioxide
C_{om}	additional O&M costs
COP	coefficient of performance
C_{plan}	cost of project planning
C_{pur}	purchase cost of equipment
CRB	DOE Commercial Reference Building
$C_{rem,eem}$	remaining value of energy efficiency measure
$C_{rem,ref}$	remaining value of reference equipment

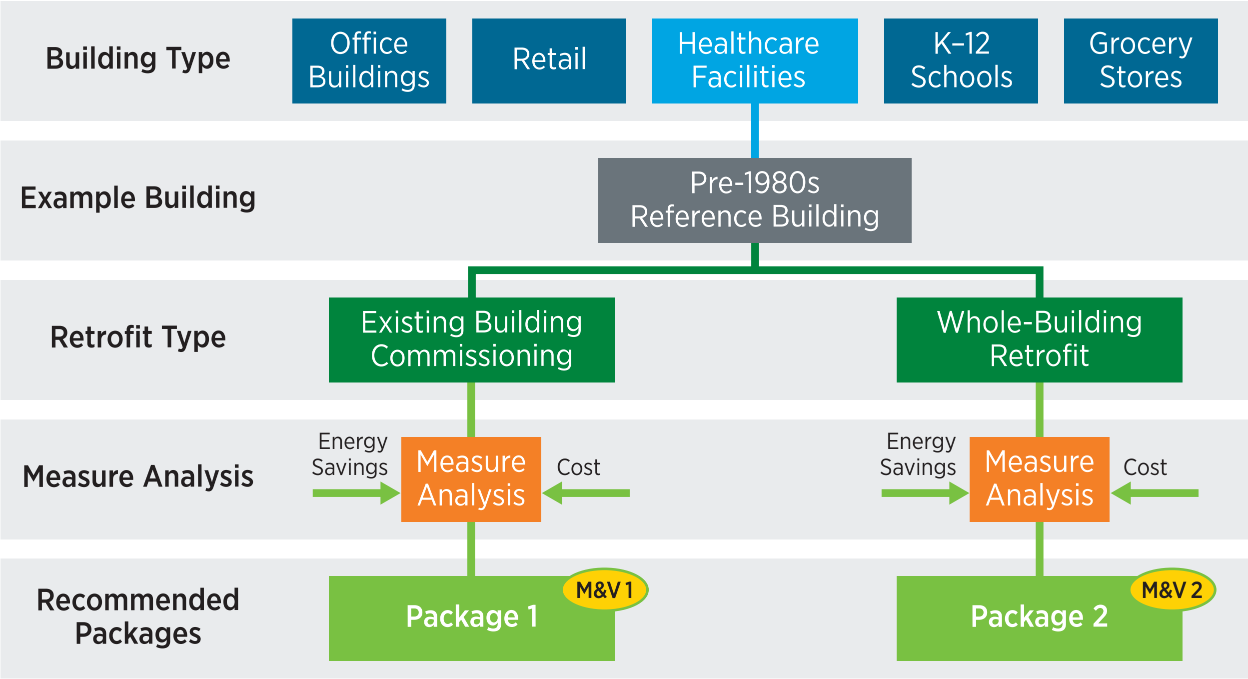
$C_{repl,eem}$	replacement cost for energy efficiency measure/package
$C_{repl,ref}$	replacement cost for reference case
$C_{salv,eem,20}$	salvage value of energy efficiency measure in Year 20
$C_{salv,ref}$	salvage value of existing equipment
$C_{salv,ref,20}$	salvage value of reference equipment in Year 20
C_t	sum of cash flows in Year t
$C_{tax,0}$	tax benefits associated with disposing of existing equipment in Year 0
CV	constant volume
DDC	direct digital control
DF	real discount factor
DOE	U.S. Department of Energy
DSIRE	Database of State Incentives for Renewables and Efficiency
DX	direct expansion
EBCx	existing building commissioning
EEM	energy efficiency measure
EIA	Energy Information Administration
EMS	energy management system
EPA	U.S. Environmental Protection Agency
EPS	expanded polystyrene
ERV	energy recovery ventilator, energy recovery ventilation
ESCO	energy service company
ESPC	energy savings performance contractor
EUI	energy use intensity
FDD	fault detection and diagnosis
FEMP	Federal Energy Management Program
ft^2	square foot, square feet
ft^3	cubic foot, cubic feet
HDD	heating degree day
gpm	gallons per minute
HVAC	heating, ventilation, and air-conditioning
IAQ	indoor air quality
IES	Illuminating Engineering Society
IPMVP	International Performance Measurement and Verification Protocol
IT	information technology
kBtu	thousand British thermal units
kW	kilowatt
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LCC	life cycle costs

LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
LPD	lighting power density
M&V	measurement and verification
MACRS	Modified Accelerated Cost Recovery System
MMBtu	million British thermal units
MH	metal halide
N	number of years in analysis period
NAESCO	National Association of Energy Service Companies
NEMA	National Electric Manufacturers Association
NPV	net present value
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
O&M	operations and maintenance
OA	outside air
OMETA	Operations, Maintenance, Engineering Support, Training and Administration
OPR	Owner Project Requirements
OV	operational verification
PBF	public benefit funds
PNNL	Pacific Northwest National Laboratory
PSZ	package single zone DX rooftop unit
PUE	power usage effectiveness
RCx	retrocommissioning
$R_{esc,elect}$	fuel price escalation rate for electricity
$R_{esc,gas}$	fuel price escalation rate for natural gas
RMI	Rocky Mountain Institute
$R_{tax,inc}$	federal corporate income tax rate
RTU	rooftop unit
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SV	savings verification
t	years after initial investment
TAB	testing, adjusting, and balancing
USGBC	U.S. Green Buildings Council
UV	ultra-violet
VAV	variable air volume
VFD	variable frequency drive
VSD	variable speed drive

Foreword: How To Use This Guide

The *Advanced Energy Retrofit Guide for Healthcare Facilities* is part of a series of retrofit guides commissioned by the U.S. Department of Energy. By presenting general project planning guidance as well as detailed descriptions and financial payback metrics for the most important and relevant energy efficiency measures (EEMs), the guides provide a practical roadmap for effectively planning and implementing performance improvements in existing buildings.

The Advanced Energy Retrofit Guides are intended to address key segments of the U.S. commercial building stock: retail stores, office buildings, K-12 schools, grocery stores, and healthcare facilities. The guides' general project planning considerations are applicable nationwide; the energy and cost savings estimates for recommended EEMs were developed based on energy simulations and cost estimates for an example hospital tailored to five distinct climate regions. These results can be extrapolated to other U.S. locations. Analysis is presented for individual EEMs, and for packages of recommended EEMs for two project types: existing building commissioning projects that apply low-cost and no-cost measures, and whole-building retrofits involving more capital-intensive measures. An overview of the AERG structure is shown below.



This guide was created to help healthcare facility decision-makers plan, design, and implement energy improvement projects in their facilities. It was designed with energy managers in mind, and presents practical guidance for kick-starting the process and maintaining momentum throughout the project life cycle. The guide was developed primarily as a reference document, allowing energy managers to consult sections that address the most pertinent topics, without reading the guide from cover to cover. Many other useful guides have been developed by other organizations, and those guides are cited throughout this document when appropriate. This guide endeavors to provide a comprehensive range of information tailored specifically to the needs of small outpatient facilities and large hospitals, with an emphasis on the most effective retro-commissioning and retrofit measures as identified by experienced retrofit experts who are familiar with the special opportunities and challenges associated with healthcare facilities. This guide presents a broad range of proven practices that can help energy managers take specific actions at any stage of the retrofit process, resulting in sustainable energy savings for many years to come.

The primary sections of the guide are shown in the figure below, along with indicators to help healthcare stakeholders determine the most relevant sections. Energy managers will find all sections helpful, as will other engineering or administrative staff with responsibility for planning and overseeing facility improvements that affect energy use. But an effective healthcare facility retrofit project requires the support of many stakeholders, particularly when the project can positively impact the quality of care provided to patients. The sections of greatest relevance to each audience are indicated in the figure.

	Energy Manager	Maintenance Staff	Hospital Adminis-trators	Medical Staff	Utilities and Auditors
1 Introduction	●	●	●	●	●
2 Overview: Plan, Execute, Follow-up	●		●		
3 Existing Building Commissioning	●	●			●
4 Building Retrofits	●		●		●
5 Measurement and Verification	●	●			
6 Operations and Maintenance	●	●			
7 Conclusion	●	●	●	●	●

We hope this guide will be a valuable resource to all healthcare facility energy managers, facility managers, administrators, and other decision-makers who seek to improve their buildings, save energy, and provide a healthier and more comfortable environment for their patients and medical staff.

1 Introduction

The U.S. Department of Energy (DOE) developed the Advanced Energy Retrofit Guides (AERGs) to provide specific methodologies, information, and guidance to help energy managers and other stakeholders plan and execute energy efficiency improvements in existing buildings. The AERG series emphasizes actionable information and recommendations, practical methodologies, diverse case studies, and unbiased evaluations of the most promising retrofit energy efficiency measures (EEMs) for each building type. A series of AERGs has been developed, addressing key segments of the commercial building stock. Healthcare facilities, including hospitals and outpatient facilities, were selected as one of the highest priority building sectors, because they represent one of the most energy-intensive market segments. The energy use intensity (EUI) for hospitals is approximately 250 kBtu/ft^2, ranking just behind the food service sector, and outpatient healthcare facilities use about 95 kBtu/ft^2 (see Figure 1–1). The EUI of hospitals and other inpatient healthcare facilities is nearly three times that of typical commercial buildings; and U.S. healthcare facilities spend $8.8 billion/year on energy (Benz and Rygielski 2011). On a per-building basis, hospitals use an average of 600,000 MMBtu, far outpacing any other building type (see Figure 1–2).

Section 2 provides an overview of important steps to help energy managers identify energy efficiency improvement opportunities and to successfully plan, implement, and evaluate any level of energy upgrade project. It addresses specific planning stages in subsections about benchmarking, energy auditing, and financing.

Section 3 provides a detailed discussion of existing building commissioning (EBCx) measures that should be considered as the first step in almost any healthcare facility upgrade project. The descriptions cover energy and cost savings, special opportunities and challenges, and climate-dependent considerations. Section 4 provides recommendations for increasing energy savings by implementing cost-effective (see sidebar) retrofit EEMs. The strengths and weaknesses of each EEM are addressed, and energy and cash flow analyses are provided for recommended packages when applied to an example building.

This guide to building energy retrofits offers practical methodologies, diverse case studies, and objective evaluations of the most promising retrofit measures for healthcare facilities. By combining modeled energy savings and estimated costs, this guide presents cost-effectiveness metrics for individual EEMs and for recommended packages of EEMs. This information can be used to support a business case for energy retrofit projects and to improve the energy performance of large and small healthcare facilities nationwide.

Barriers addressed by this guide:

- Identifying needs and starting a building energy retrofit
- Limited capital and competition for resources
- Shortage of actionable information tailored to healthcare facilities
- Accounting for energy and nonenergy benefits over project life
- Lack of specific integrated design methods adapted to healthcare facilities
- Need for reliable data to support business case
- Risk minimization

Cost-effective EEMs: In the context of this guide, EEMs with a positive net present value (NPV) over a specified time period are considered cost effective, as discussed in Section 2.6 and Appendix A.

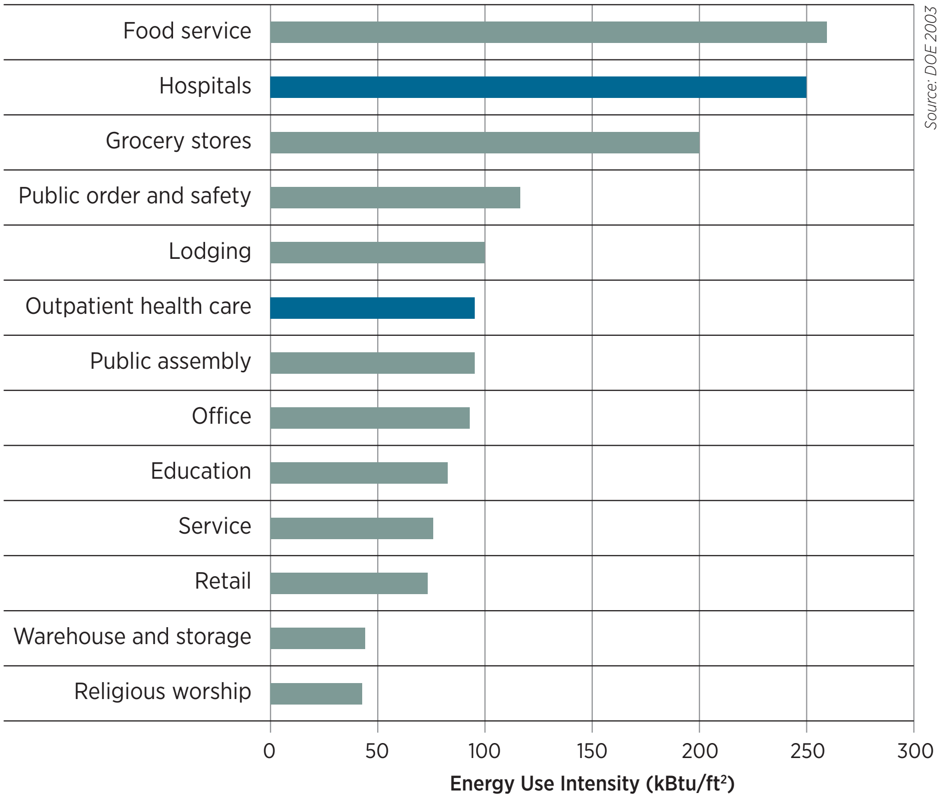


Figure 1–1 EUI for common commercial building types

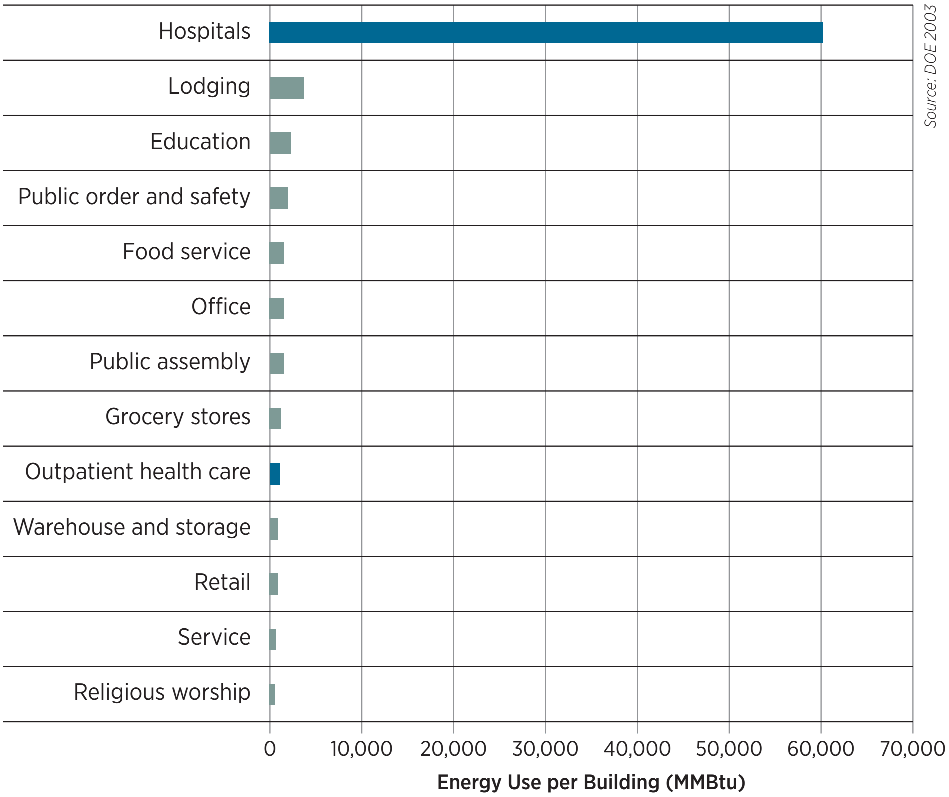


Figure 1–2 Energy use per building for common commercial building types

Sections 5 and 6 provide guidance for verifying and sustaining energy savings through measurement and verification (M&V) and operations and maintenance (O&M). The purpose of M&V is to make sure the improvements were implemented properly and achieve the expected level of energy savings. M&V is usually performed by examining utility bills and making direct measurements of energy use for important subsystems. O&M is a process for managing the operation of improved systems to ensure that the initial energy savings are not undermined over time through improper use or inadequate maintenance.

This guide also includes case studies that show how other healthcare facility energy managers have implemented energy upgrades, the savings they have achieved, and the challenges they faced. These case studies are distributed throughout the guide to illustrate the applications of key points.

An important goal of this AERG is to provide comprehensive analytical methods for evaluating the cost effectiveness of retrofit EEMs that are common in healthcare facilities. In the context of this guide, the term *cost effective* is synonymous with positive NPV based on incremental cash flows over a 20-year analysis period, whether referring to a single EEM or to an EEM package. NPV analysis assumptions are discussed in greater detail in Section 2.6 and Appendix A. These analytical methods are supplemented with a comprehensive and detailed example using the Pre-1980s Hospital Commercial Reference Building (CRB) energy model developed by DOE (Deru et al. 2011). The example represents a relatively small hospital (241,000 ft^2) built in the 1970s, with equipment that has been replaced at least once since the hospital was built. The optimal packages for larger hospitals and smaller outpatient healthcare facilities would vary significantly from the example, but it illustrates the application of EEMs and methodologies presented in the guide.

Because of the wide variation in healthcare facility starting conditions and financial constraints, three types of building upgrades are addressed in this guide: (1) low-cost and no-cost EBCx measures; (2) whole-building retrofits where a comprehensive package of measures is implemented in a short span of time using an integrated design approach (see sidebar); and (3) staged retrofit projects that leverage energy savings from each stage and more opportune timing of retrofits to achieve similar savings in an incremental fashion.

This approach broadens the applicability of the guide to a diverse set of situations, and each section builds on the recommendations of the previous one to create a logical progression. The guide addresses specific retrofit options and packages, along with the more general topics of project planning, financing mechanisms, investment analysis, O&M, and M&V within the framework of inpatient and outpatient healthcare facilities.

Integrated Design: A collaborative and iterative design process for building improvements in which a systems approach is employed to leverage multiple energy and nonenergy benefits from a capital improvement project, resulting in much higher energy savings than can be achieved using a piecemeal approach.

1.1 Purpose and Audience

The overall purpose of this AERG is to increase the number of retrofit projects in existing hospitals and small healthcare facilities, and enhance the quality and depth of energy savings for those projects. The material offered in the guide is designed to increase market uptake of high-impact, cost-effective improvements by providing objective, actionable information tailored specifically to the unique opportunities and constraints associated with healthcare facilities. In recognition of possible financial constraints and wide variations in the characteristics of existing facilities, several retrofit approaches are addressed. This provides greater flexibility to develop effective building improvement projects in a broad spectrum of situations.

The primary audience for this guide is healthcare facility energy managers who wish to significantly raise the efficiency of their buildings and generate a strong financial return that can increase profits, be reinvested in the facility, or be returned to patients through lower costs for hospital stays or medical services. Other stakeholders will also benefit from specific sections (see in Figure 1–3 and the following subsections).

	Energy Manager	Maintenance Staff	Hospital Adminis-trators	Medical Staff	Utilities and Auditors
1 Introduction	●	●	●	●	●
2 Overview: Plan, Execute, Follow-up	●		●		
3 Existing Building Commissioning	●	●			●
4 Building Retrofits	●		●		●
5 Measurement and Verification	●	●			
6 Operations and Maintenance	●	●			
7 Conclusion	●	●	●	●	●

Figure 1–3 Relevant sections for healthcare industry stakeholders

Energy Manager

The energy manager for a healthcare facility, or the staff member with equivalent responsibilities, must develop a strong justification for retrofit projects, and therefore requires sound economic and technical analysis methods and data before committing financial resources to a project. The energy manager is also responsible for overseeing the project's successful implementation. This guide is targeted to energy managers, and provides the practical guidance they need at each stage of the retrofit process.

Maintenance Staff

Members of the maintenance staff have important roles in implementing, verifying, and maintaining the measures discussed in this guide. In fact, many commissioning measures described in Section 3 can be performed in the normal course of facility maintenance activities, without any major capital investments that require special approval. The maintenance staff may also be interested in the sections describing good practices for M&V and O&M.

Hospital Administrators and Financial Managers

Hospital administrators and financial managers have essential responsibilities for authorizing and overseeing major capital investment projects, ensuring the well-being and quality of care for patients, and interacting with the community. This audience must make or approve many of the planning and financing decisions related to retrofit projects, and the information described in Section 2 is designed to assist with that process. Administrators and financial decision-makers may also be cognizant of necessary building renovations or other leveraging opportunities that create the potential for whole-building retrofits, as discussed in Section 4.

Medical Staff

Any energy retrofit project must ensure that medical staff can conduct important and delicate medical procedures in a safe and healthy environment. Doctors and nurses should be included in the planning and implementation of major retrofits, and their feedback is essential to ensure the well-being of patients and staff. Medical staff may find the introductory sections and conclusions informative and useful for understanding their roles and the interactions between building performance and quality healthcare.

Introduction

Utilities and Auditors

The prioritized commissioning and retrofit EEM descriptions provided in Sections 3 and 4 and Appendices E–G can stimulate ideas for auditors, utility companies, and retrofit contractors. Healthcare facility retrofit experts from across the country provided their insights and knowledge to identify the most important EEMs that should be evaluated for each project, and to describe the strengths, weaknesses, climate considerations, and application issues for each EEM in the context of healthcare facilities.

1.2 Structure of the Guide

This guide is most useful during the initial stages of a retrofit project, but it is also a valuable reference throughout the life of a project and beyond. It stimulates ideas for retrofit EEMs, describes important performance and cost tradeoffs, and identifies reliable and cost-effective O&M and M&V protocols. Figure 1–4 shows how each section fits into the general process of upgrading a healthcare facility. The sequencing illustrates a common approach to addressing retrofits, and is consistent with the order of topics in this guide, but alternate sequencing and additional steps may be included, depending on the situation. The planning and implementation processes are explained more fully in Section 2.

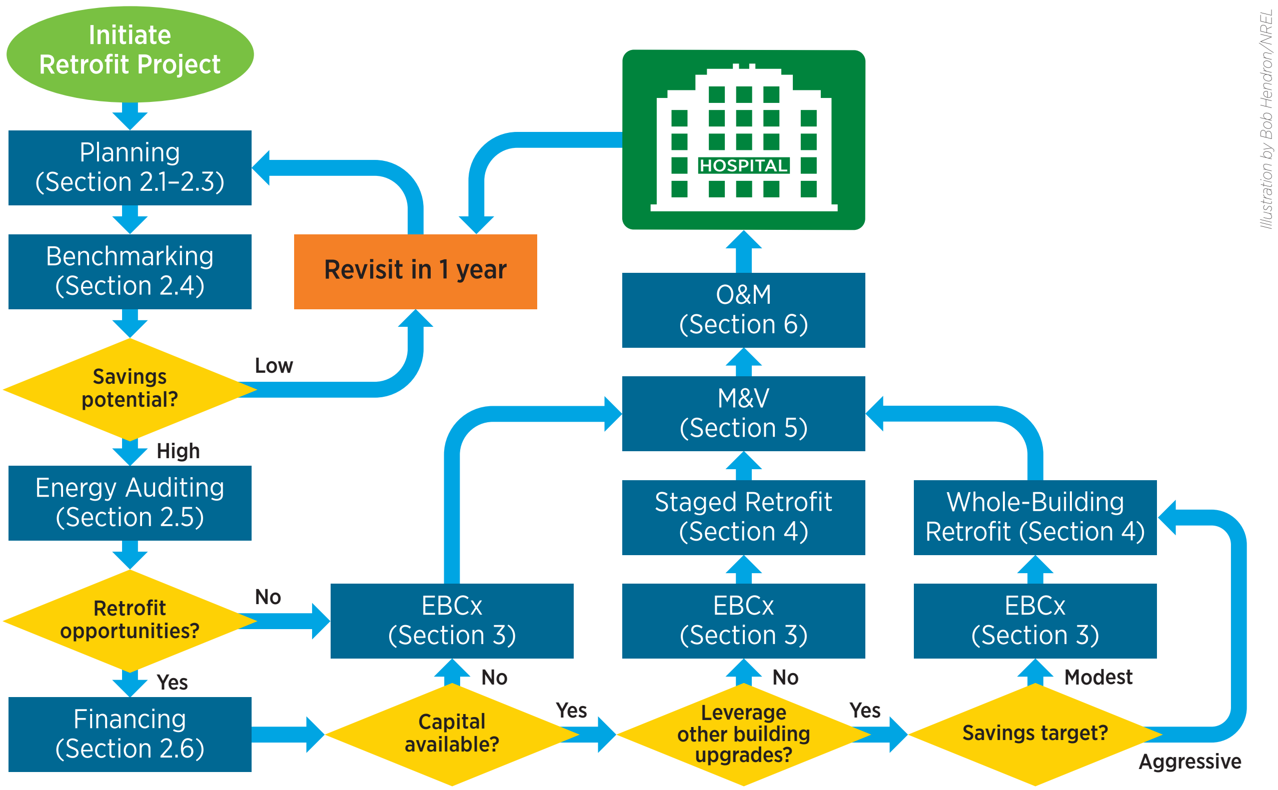


Figure 1–4 Structure of the guide relative to a typical retrofit decision-making process

This AERG provides guidance and example energy efficiency packages for achieving a significant level of energy savings in healthcare facilities. A strict minimum energy savings cannot be guaranteed because of the range of potential starting points, but this guide identifies multiple low-risk (see sidebar) EBCx and retrofit EEMs that are expected to meet strict cost-effectiveness requirements based on an example building that is representative of the stock of small hospitals across the United States.

Risk: Risk is defined in this guide as uncertain return on investment caused by variations in energy savings, installation costs, useful life, or O&M costs.

Three categories of retrofit are discussed in the following sections and summarized in Table 1–1. Example EEMs for each category are provided in Figure 1–5. For all categories of retrofit, cultural and behavioral changes are necessary to maintain sustainable savings. Staff can bypass or turn off many retrofit and EBCx efforts when they do not have sufficient understanding of the measures or involvement in the retrofit process.

Table 1–1 Three Categories of Retrofit Discussed in This Guide

EBCx
Significant savings can often be achieved with minimal risk and capital outlay by improving healthcare facility operations and restructuring maintenance procedures. This process is generally recommended even when retrofits are being considered, in order to determine the performance of the existing building systems under the most favorable conditions. A study of 28 healthcare facility commissioning projects by Lawrence Berkeley National Laboratory (LBNL) indicated that approximately 10%–15% energy savings could be achieved on average, with a payback period of 0.1–0.6 years for inpatient and outpatient facilities, respectively (Mills 2009). Additional savings are possible if cultural and behavioral changes are included in the EBCx process.
Whole-Building Retrofit
Whole-building retrofit projects use an integrated design approach to develop a package of EEMs that can be implemented as a single project over a short time. Often this approach leverages a major remodeling effort or a similar opportunity to address many systems at once. Whole-building retrofits offer greater potential savings because the packages are optimized and all system interactions are considered. Systems interactions and equipment downsizing are important components of this approach, and broader ranges of equipment replacements and envelope upgrades are often possible. In many situations, the best packages for whole-building retrofits will be very similar to the prescriptive packages recommended for new construction in the Advanced Energy Design Guides (AEDGs) for Large Hospitals (ASHRAE 2012) and Small Hospitals and Healthcare Facilities (ASHRAE 2009b). In an LBNL study of 30 healthcare facility retrofit projects conducted by energy service companies (ESCOs) (Hopper et al. 2005), median energy cost savings of about 18% were documented, and savings beyond 26% were not uncommon. Simple payback was typically 10 years or less for most projects, with a median of 5 years. Higher average savings are likely when an integrated whole-building approach is used, because many projects in the LBNL study were targeted system or component-level retrofits.
Staged Retrofit
Staged retrofits are implemented in several steps over a longer time than whole-building retrofits. This approach allows retrofits to be aligned more closely with the facility's capital improvement plans, reducing the incremental cost of the upgrades because equipment replacements occur near the end of useful life. An integrated design approach is recommended even for staged retrofits, but it can be more challenging to properly exploit system interactions when time passes between stages. It is important to plan all retrofits early in the process, even though they are implemented over time. This will help mitigate inefficiencies created if new contracts must be placed and different personnel are involved later. Some potential energy savings are delayed in a staged retrofit, but the economics can be much better than for a whole-building retrofit, where equipment may be replaced with a significant amount of useful life remaining.

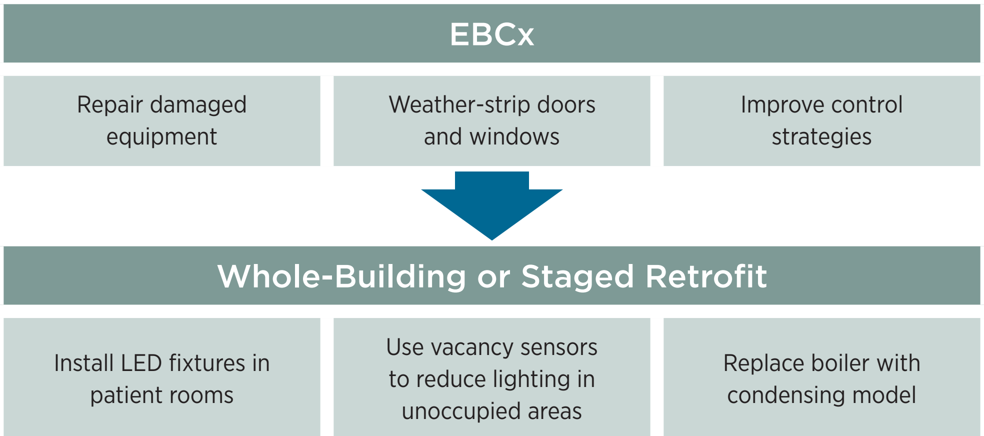


Figure 1–5 Example EEMs for the three categories of retrofit addressed in this guide

An energy manager can use several core elements of this guide as components of a comprehensive plan for upgrading a single healthcare facility or an entire portfolio:

- **General guidance describing the process and steps necessary to identify opportunities and to successfully plan, design, implement, and verify the energy savings for retrofit projects in healthcare facilities.** Because other organizations have already provided this type of guidance, this AERG provides only a concise summary of effective practices. Useful handbooks, standards, websites, and software tools are referenced extensively.
- **Descriptions of approximately 60 proven EEMs, including a short overview of each and how it can be applied to a healthcare facility.** Many additional EEMs are addressed in the context of integrated subsystem improvements for whole-building retrofits. Climate-specific considerations are discussed, along with other factors such as facility type and size, hours of operation, mechanical system type, and vintage. Special opportunities related to the age, condition, and efficiency of existing equipment are also discussed.
- **Recommended packages of energy efficiency improvements for a representative small hospital, tailored to five diverse U.S. climate regions.** These example packages illustrate the application of measures and analysis methods discussed in this guide, and provide a rough indication of the energy savings that can be expected in a typical application. However, cost effectiveness is very application specific, and the best package of measures may be very different in other situations.
- **Key leverage points during the life cycle of a healthcare facility that offer special opportunities to cost-effectively achieve more aggressive energy savings targets.** These catalyst opportunities include any situation that leads to major changes in building systems for nonenergy reasons, such as a change in building use (e.g., a medical office building converted to a surgery center), replacement of malfunctioning equipment, or major remodeling for cosmetic or functional reasons.
- **Techniques to ensure the expected level of energy savings is achieved after the retrofit, and persists throughout the life of the equipment.** These strategies include post-retrofit commissioning, optimizing control logic, establishing equipment set points, involving and educating staff, good practices for ongoing commissioning and maintenance, and the most appropriate M&V protocols at each energy savings level.
- **A diverse set of case studies that provide real-world examples of how these recommendations have been implemented in actual retrofit projects.** The case studies are accessible and objective, offering insights into opportunities, tradeoffs, and potential pitfalls. To the extent possible, actual cost, performance, and utility billing data have been included. Detailed case studies are a valuable component of an effective business case, because evidence that similar projects have been successful enables financial decision-makers to fund projects with greater confidence.

1.3 Business Case

Among the investments a healthcare facility owner may consider, energy efficiency upgrades are likely to offer some of the highest returns with the lowest risks. The direct cost reductions provided through reduced energy use are complemented by valuable nonenergy benefits. The primary drivers for most healthcare facility owners to invest in energy efficiency are to realize the direct benefits of reduced utility costs, while providing a healthier and more comfortable environment for patients. Nonenergy benefits may in fact be dominant project drivers in situations where energy costs are less important to the bottom line. For example, daylighting not only cuts energy use, but can be beneficial to patients (BetterBricks 2011a). These benefits are hard to quantify and are often omitted from financial analysis, but should be considered in the business case because they support the overall healthcare mission.

Funding is often the primary barrier to the implementation of retrofit projects in healthcare facilities. To overcome this barrier, financial decision-makers need reliable cost and energy savings data to evaluate the cost effectiveness and risk of a project. Practical analysis techniques and meaningful data are not common in existing retrofit guides, especially in the context of specific building types such as healthcare facilities, but are essential tools for robust and accurate analysis of energy and cost tradeoffs. In contrast, this guide provides an effective methodology for performing accurate economic analysis of building improvement options. The methodology uses both NPV and simple payback period, supplemented with example calculations based on a representative healthcare facility, and detailed case studies with well-documented project cost and energy savings data.

The guide provides detailed methods for accurately quantifying multiyear cash flows, including energy costs, demand reduction, replacement costs (including reduced energy savings if more efficient equipment would have been required by code), salvage value (if any), O&M costs, M&V costs, and possible tax implications for private healthcare facilities. Techniques and references are also provided for capturing the effects of temporary financial incentives offered by government agencies or utilities (rebates, low-interest loans, tax credits, etc.) on multiyear cash flows. Indirect benefits such as fewer accidents, faster patient recovery times, and greater staff retention rates are discussed qualitatively, but are not quantified in the cash flow analysis. Advice is provided for developing a comprehensive capital replacement plan, which is a necessary component of any multiyear cash flow analysis. The owner's chief financial officer should be involved throughout the process to ensure that appropriate financing, reimbursement, and depreciation considerations are factored into the retrofit plan.

This guide does not provide instructions for developing a comprehensive business case for a retrofit project. Instead, it focuses on specific EEMs, methodologies, and examples that contribute to a strong business plan. ASHRAE (2009a) recently published an informative resource for business case development. It is the first of a series of three technical guides that describe best practices for planning and implementing successful energy retrofit projects. Other valuable tools and resources for developing a business case and analyzing the economics of a retrofit project are discussed in Section 2.6.

1.4 Recommended Packages

EEM packages were developed for EBCx and for whole-building retrofit projects in the context of an example small hospital. Recommended packages for the staged approach were not developed, because the analysis is more complex and is highly dependent on the age of existing equipment and the capital improvement plan. To be selected, EEMs had to have a positive NPV when cash flows were analyzed over a 20-year analysis period. Spreadsheet analysis was used by the National Renewable Energy Laboratory (NREL) and Pacific Northwest National Laboratory (PNNL) to assist with the multiyear cash flow analysis needed for NPV and simple payback calculations.

A 20-year time horizon was selected because decision-makers are encouraged to take a long-term approach to energy efficiency improvements. Because most equipment improvements have lifetimes shorter than 20 years, this analysis period includes at least one replacement of each EEM except envelope improvements, resulting in a more stable projection of NPV than would result from a short-term analysis. Energy and maintenance savings often extend far beyond the simple payback period, which often must be as short as 3–5 years for most healthcare organizations. The same methodology can be used even if stricter financial return and payback criteria are necessary, with minor changes to the input parameters.

Packages range from low-cost/no-cost EBCx packages that are nearly always cost effective, to more capital-intensive standard retrofit packages with somewhat higher risks but greater life cycle returns. These packages illustrate the analysis methodologies discussed in this guide, and provide some sense of the energy savings that are achievable in a typical healthcare facility.

Unlike the recommended packages for new construction in the Advanced Energy Design Guides (AEDGs), ours are not prescriptive and are not evaluated against a code-minimum building. Because retrofit projects have a diverse range of starting points and building energy codes have varied applicability, prescriptive recommendations based on cost effectiveness are unsuitable. A recommended package might provide excellent financial returns in one situation, but would not be optimal—or even appropriate—in all situations. Your cost and energy savings will differ from the example, and you need to analyze the cost effectiveness of a particular set of EEMs in the context of the actual building, financing method, labor rates, rebates and tax credits, vendor prices, and utility rates.

Figure 1–6 illustrates the process used to narrow the original list of roughly 180 candidate EEMs to those included in the recommended packages. About 80 EEMs from the original list were deemed to save very little energy in the context of a healthcare facility, or were considered unlikely to be cost effective, and are not included in this guide.

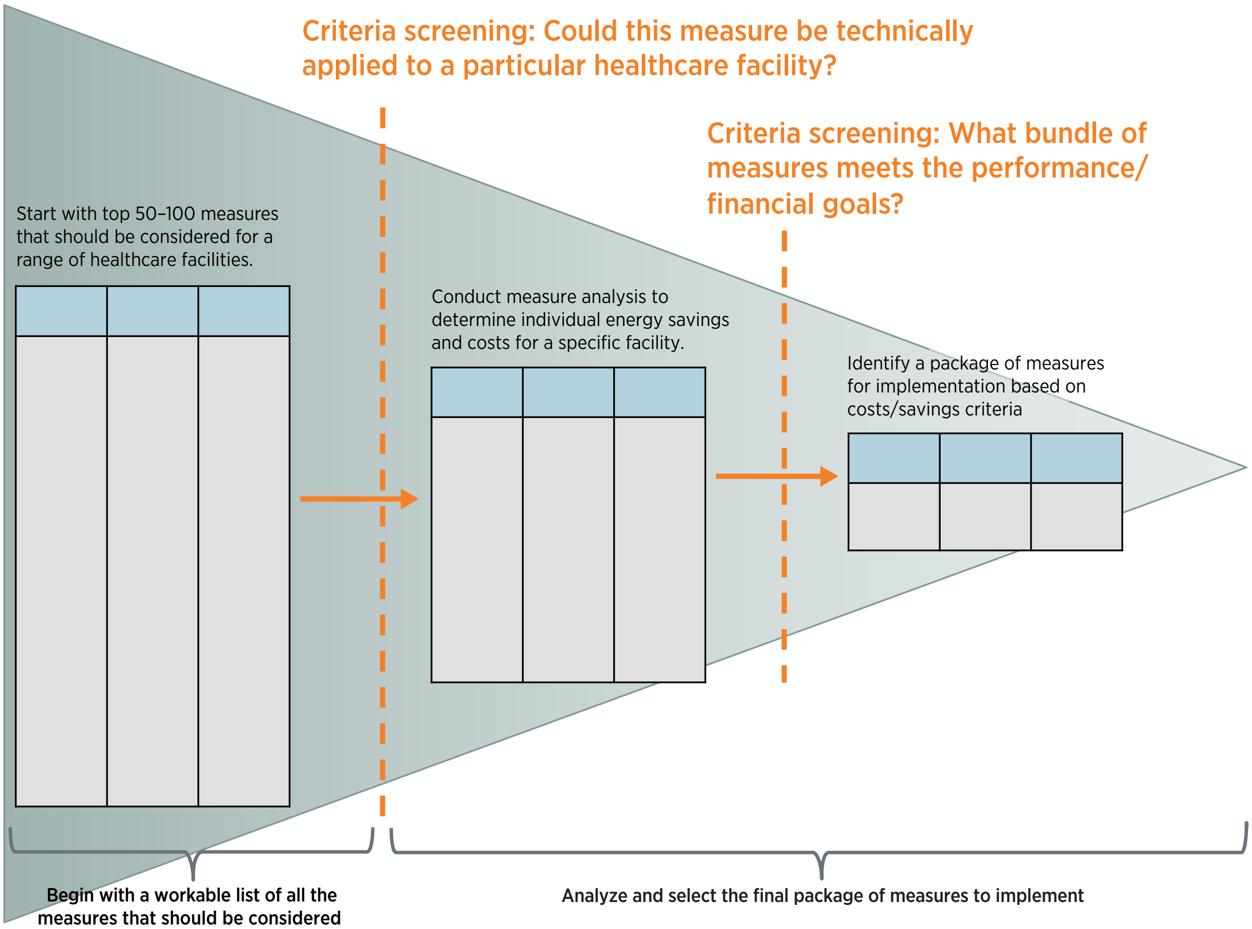


Figure 1–6 General process for selecting EEMs included in recommended packages

Approximately 100 were considered high potential, and are addressed in Sections 3–4 and Appendices E–G. About 50 were considered for the recommended packages at one or both levels of retrofit. The complete list of EEMs and their rankings is included in Appendix D.

The reference building energy model for the example analysis presented in this guide is the Pre-1980s Hospital CRB (Deru et al. 2011), which is one of a series of reference buildings developed by DOE to help standardize the analysis of EEMs when applied to specific building sectors. Details of the envelope characteristics and equipment included in the example building are presented in Appendix B.

The CRB and example packages are tailored to each of five important U.S. climate regions (see Figure 1–7), represented by the cities in parentheses:

- Hot-humid (Miami, Florida)
- Hot-dry (Las Vegas, Nevada)
- Marine (Seattle, Washington)
- Cold (Chicago, Illinois)
- Very cold (Duluth, Minnesota).

Though not comprehensive, these five cities provide a sense of the range of measures that might be included in EEM packages across the country. The climate region boundaries are defined in Table 3–2 of the AEDG for Large Hospitals (ASHRAE 2012).

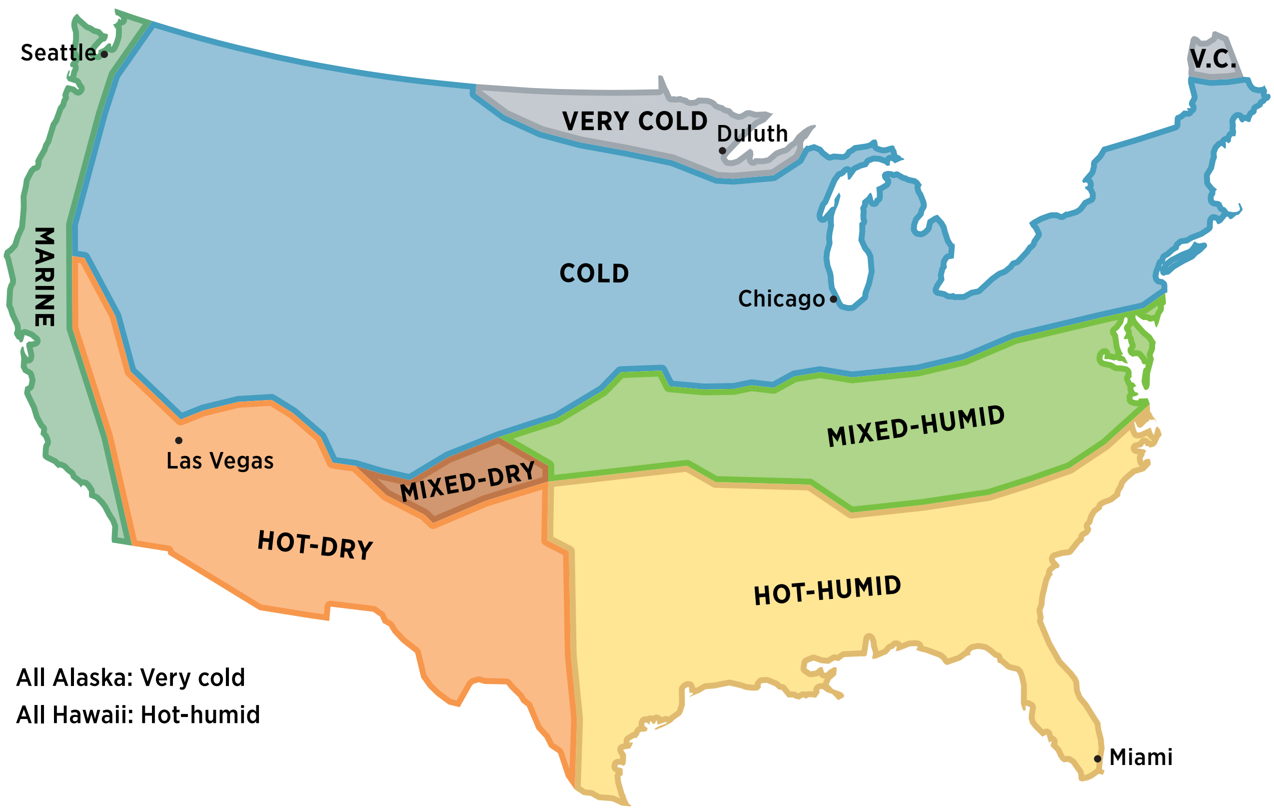


Figure 1–7 U.S. climate region map

It was assumed that the Pre-1980s Hospital CRB model represents a well-commissioned building, because the modeling inputs its developers applied to the model are not consistent with suboptimal operating schedules, building controls that are no longer active, or degraded equipment performance caused by wear and tear. Consequently, EBCx measures were not modeled. Instead, the recommended EBCx packages were developed based on subjective estimates of the likely energy savings of each EEM considered. Energy savings for the EBCx package were estimated based on data from actual projects, combined with the CRB physical characteristics and energy use. Further details of the process for selecting EBCx packages are provided in Appendix B.

The EEMs included in the recommended retrofit packages were chosen based on the cost effectiveness of each EEM when applied to the CRB model, using typical equipment costs and actual utility rates. Each EEM was analyzed individually and in combination with other EEMs when system interactions were significant. This sequencing allowed for the possibility of downsizing heating, ventilation, and air-conditioning (HVAC) equipment when heating and cooling loads were reduced. EEMs were selected for the recommended packages if their individual NPVs were greater than zero. Because of project resource limitations, a true integrated design approach was not applied. Additional discussion of the process used for selecting retrofit EEMs for the recommended packages is included in Appendix B.

2 Overview: Plan, Execute, Follow Up

Leaders in healthcare administration, design, and facilities management have long recognized the role that energy efficiency can play in reducing operating costs and improving the environment for patients and healthcare workers. Nearly every healthcare facility presents opportunities for improved energy performance. These come in many forms, including improved O&M practices, equipment retrofits, operational changes, and building envelope modifications. Over the life of a building, different opportunities will be available at different times, depending on functional and cosmetic changes to the building, remaining life of the equipment and assemblies, and availability of improved technologies.

Although the opportunities for energy efficiency improvements in existing healthcare facilities are significant, the process of identifying, analyzing, and implementing those improvements is not always straightforward.

This section provides a general picture of energy use in both inpatient and outpatient healthcare facilities, and presents an overview of important steps to help identify energy efficiency improvement opportunities and plan their implementation. It addresses energy efficiency roadmapping, financing options, performance assessment through benchmarking, and identifying cost-effective EEMs through energy auditing (see sidebar in Section 1.1 for the definition of *cost effective* used throughout this guide). Each section includes links to the extensive body of literature about these topics to provide more details.

2.1 Energy Picture

Healthcare is a significant industry in the United States, accounting for 16.2% of gross domestic product, 9% of energy use in commercial buildings, and 8% of greenhouse gas emissions (E Source 2010a). A 200,000-ft^2, 50-bed hospital in the United States would spend approximately $680,000 annually, or roughly $13,611 per bed, on energy costs (E Source 2010b). Efficiency improvements can reduce operating costs, improve the bottom line, and free up funds to invest in new technologies and improve patient care; however, implementing energy efficiency upgrade projects in healthcare facilities while ensuring optimal patient care requires knowledge of the aspects of energy use that affect indoor air quality (IAQ) and comfort levels, how and where energy is used, and options for reducing energy use.

Opportunities and Challenges

Energy upgrades for all types of buildings face numerous challenges:

- Establishing a baseline of energy use and tracking progress (see Sections 2.3 and 2.4).
- Training staff to properly maintain equipment so any gains from the upgrade will persist (see Section 5).
- Gaining familiarity with the latest technologies. No single resource covers all new energy technologies, but the Federal Energy Management Program's (FEMP) Technology Deployment List (FEMP 2011) is a good starting point.
- Dealing with the unpredictability of energy costs (for information about energy costs, visit the U.S. Energy Information Administration [EIA] website) (*www.eia.gov/*).

Healthcare facilities also face specific challenges of their own. The EUI of healthcare facilities is increasing as hospitals add additional amenities to patient rooms to improve the quality of service and attract patients. Hospitals also have continuous occupancy and must meet stringent health and safety regulations. Healthcare revenue is controlled through reimbursement rates set by insurance companies and the government. As a result, rising energy costs result in damaging revenue gaps because they cannot be easily offset by charging higher prices. Perhaps the largest barrier to energy efficiency in the healthcare industry is the high likelihood of competing capital budget priorities marginalizing even short-payback efficiency projects.

Several important opportunities also present themselves in healthcare facilities, including the potential for lower operating costs, improved patient care, and enhanced public image.

Lower Operating Costs

A recent survey found that 78% of hospitals indicated that high operating costs were the primary reason for implementing energy improvements (Carpenter 2008). Utility bills constitute 1.4% of hospital operating revenues on average, and hospitals in the United States spend approximately $8.3 billion on energy annually. Every dollar a nonprofit healthcare organization saves on energy has the same impact on the operating margin as increasing revenues by $20 for hospitals or $10 for medical offices, assuming an operating margin of 5% and 10%, respectively (EPA 2003a). For large hospitals, this can result in millions of dollars of savings annually.

Improved Patient Care

Energy efficiency upgrades also have the potential to improve the indoor environment. Research shows that more comfortable, pleasing surroundings help make hospitals safer, improve patient outcomes, and reduce potential liability (Ulrich et al. 2004). Improvements to HVAC systems boost IAQ and minimize the frequency of hospital-acquired airborne infections. IAQ improvements can reduce healthcare costs and work losses associated with airborne illnesses by 9%–20% (LBNL 2009). Lighting improvements can help eliminate patient falls, and daylighting improves mood, reduces anxiety and depression, and has been shown to decrease the length of a hospital stay (Sadler et al. 2008). Improvements to malfunctioning equipment can increase acoustic comfort and reduce noise. Excessive noise can cause stress to newborns, and can increase blood pressure and heart rate in cardiac patients (Ulrich et al. 2004).

Enhanced Public Image

Energy efficiency initiatives support the goal of environmental stewardship that many hospitals consider important to their public images and include as part of their core missions. In addition, managers realize the benefits of attracting new patients through environmental stewardship. Hundreds of small and large healthcare facilities participate in the U.S. Environmental Protection Agency's (EPA) ENERGY STAR® buildings program and the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) program, and have taken steps to improve energy efficiency and gain recognition for their achievements.

End Use Categories

To target energy-saving upgrades, it helps to know where most energy is used. For individual healthcare facilities this is best done by benchmarking and auditing, as discussed in Sections 2.4 and 2.5. Energy use in healthcare facilities varies widely with facility type and region. Hospitals are the most energy intensive of the various types of healthcare facilities, and are among the most energy intensive of all building types, using roughly twice as much energy per square foot as office buildings (E Source 2010a). Data from the EIA show that cooling, lighting, and ventilation account for 72% of electricity use in healthcare facilities, and space heating accounts for 56% of natural gas use (Figure 2–1 and Figure 2–2).

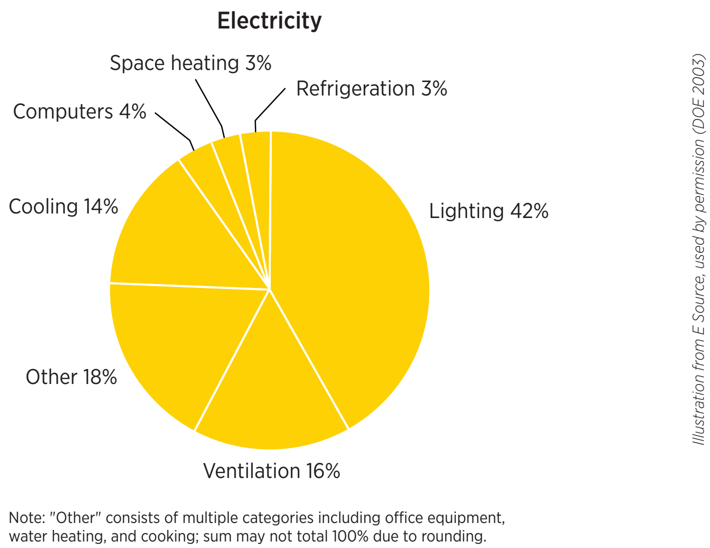


Figure 2–1 Average electricity end use profile for healthcare facilities

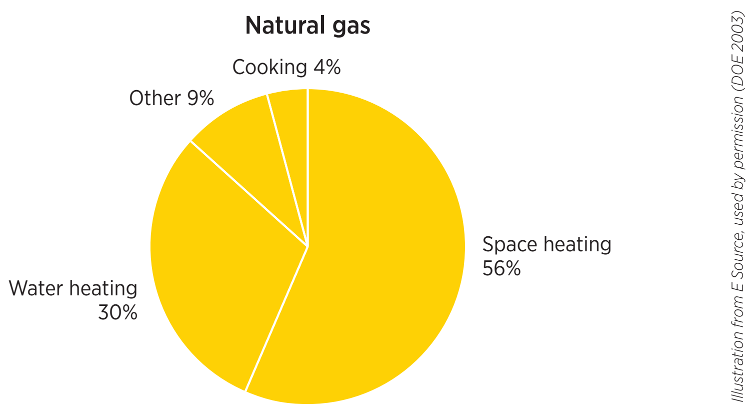


Figure 2–2 Average natural gas end use profile for healthcare facilities

According to the most recent data from EIA, hospitals consume an average of 259,000 Btu/ft^2 annually (Figure 2–3) (DOE 2003). Nursing homes and outpatient clinics use about half as much energy per square foot, followed by medical offices. Patterns of energy use also vary with facility type. Space heating and lighting consistently consume a large share of energy in both outpatient and inpatient facilities. However, water heating and ventilation are much larger loads in inpatient facilities because of their long occupancy hours and the requirement for continuous air exchange to decrease exposure to airborne infections (Figure 2–4).

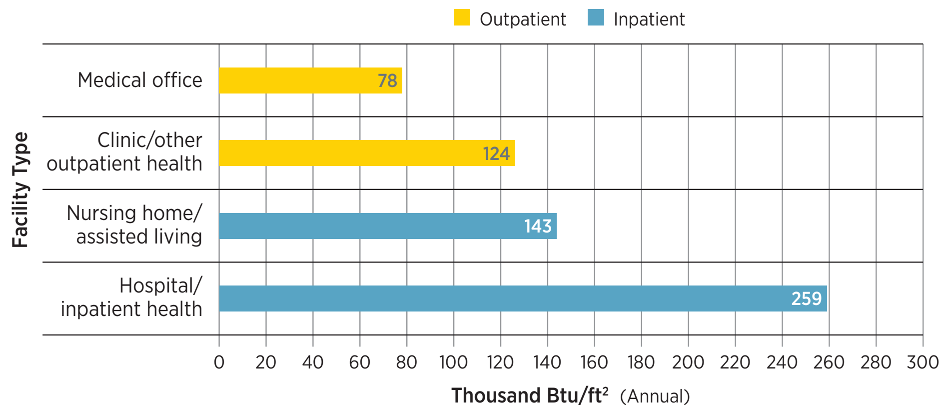


Figure 2–3 EUI of different healthcare facility types

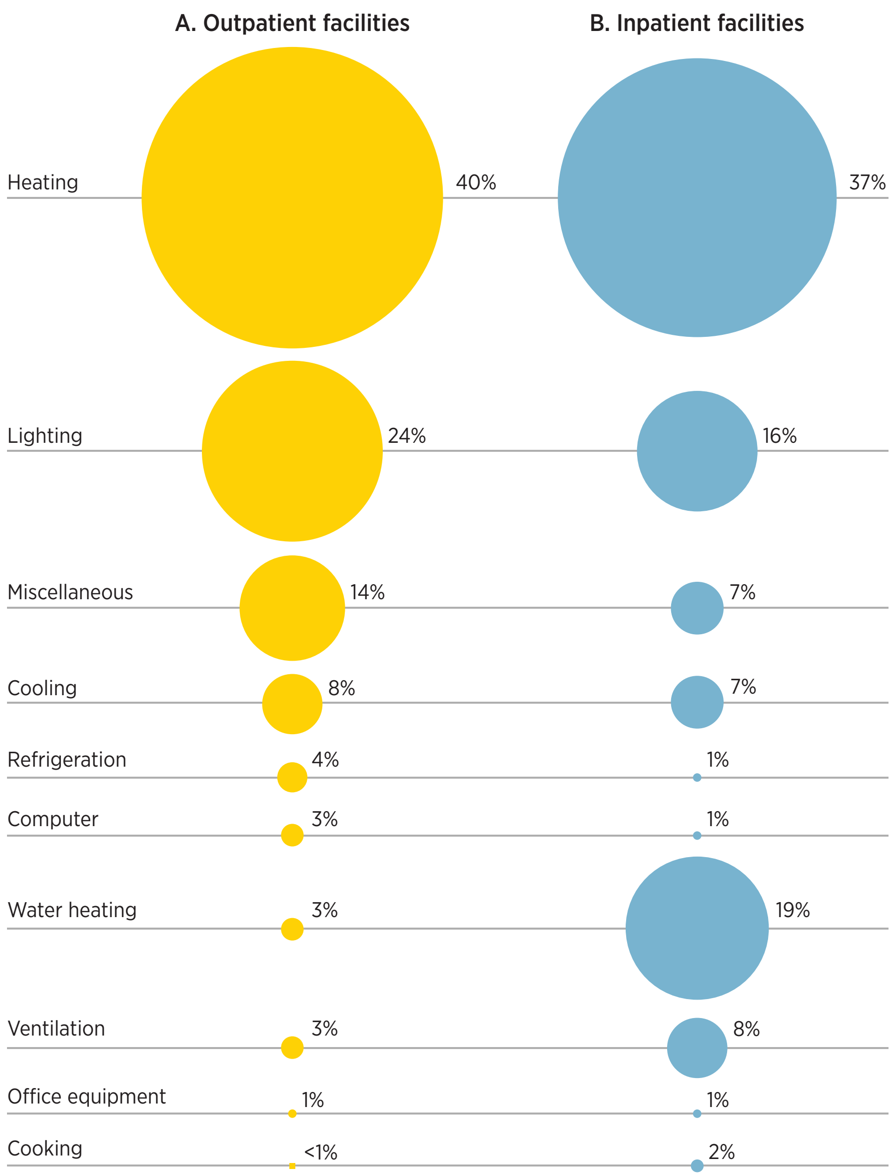


Figure 2–4 Energy end use in outpatient and inpatient facilities

Facilities in colder areas with larger heating loads have higher annual natural gas intensities; regions with larger cooling loads have higher electricity consumption (Figure 2–5).

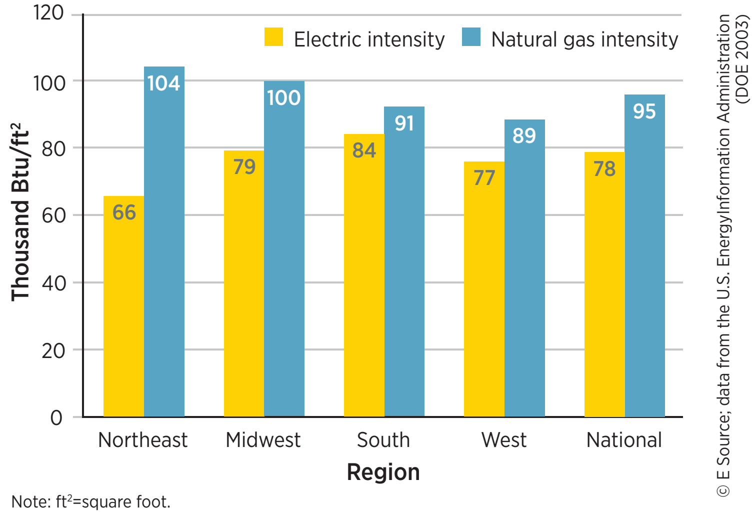


Figure 2–5 National average healthcare energy consumption by geographic region

2.2 Planning Retrofit Projects

A successful energy efficiency upgrade depends on well-defined goals and a carefully constructed scope. If your goal is simply to cut energy costs by 5%–10%, an EBCx (Section 3) program may be sufficient, but even that effort will require benchmarking (Section 2.4) to determine a baseline, a walk-through audit (Section 2.5) to identify the most promising EEMs for your situation, and M&V (Section 5) to determine whether you have reached your goal. If your goal is to be the top performer in the market, or to have your facility outperform similar healthcare facilities, the picture is more complicated, as illustrated by the example decision process flowchart in Figure 26.

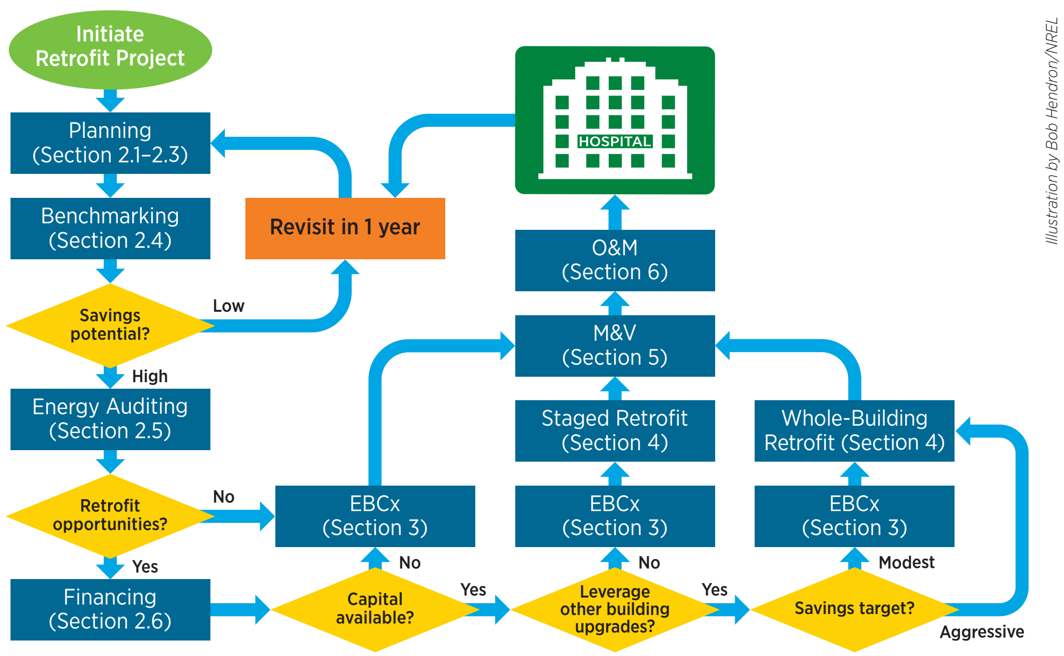


Figure 2–6 Example decision process for a retrofit project

The retrofit process typically begins with an assessment of the potential energy savings for a single building or an entire campus (benchmarking), followed by an evaluation of the cost effectiveness of possible retrofit EEMs (energy audit). If significant savings are achievable and cost effective, you should evaluate available financing sources and set energy savings targets. Also consider opportunities for leveraging planned facility upgrades. Depending on the results of these steps, you need to select some combination of EBCx, whole-building retrofits, and staged retrofits. After the retrofit project is implemented, appropriate M&V and O&M programs are undertaken to ensure the target energy savings are achieved and persist over time.

Although EBCx is often skipped in a comprehensive retrofit, you may still want to perform this step because it will provide quick savings and will help you determine how existing systems are performing under the most favorable conditions. That information will give you a better handle on what else needs to be done to meet your goals. If, for example, a lighting retrofit is called for, it may be worthwhile to precede the retrofit with EBCx measures to determine which lighting systems are already performing well. If it is apparent from the start that a major retrofit effort will be undertaken (for example, a new boiler will be installed in the near future), it may make sense to postpone some of the EBCx measures—a testing, adjustment, and balancing (TAB) project, for example—the new equipment will have to be commissioned anyway.

The benchmarking effort will help you to establish goals by showing how the performance of your facility compares to similar healthcare facilities. A more comprehensive audit will help you determine which retrofit measures are appropriate for your facility. In all cases, the most effective program will also include reviewing for continuous improvement:

- Management review of project results
- Modification of energy plan as needed
- Recognition of success.

Healthcare facilities can be upgraded on an individual basis, but the most effective way to reduce energy consumption is to engage in a system-wide approach for setting goals and assessing and improving energy efficiency in multiple buildings on a campus or in an owner's portfolio. This results in greater cost and energy savings than improvements to a single building, and enables owners to offset the costs of comprehensive energy efficiency projects in buildings that have higher upfront costs with the savings from projects in other buildings.

A system-wide approach also generates greater momentum for energy efficiency activities, which can lead to sustained commitment, continued savings, and market advantage. Raising community awareness about the environmental and cost-saving benefits of a project will help gain additional support, move the project forward, and potentially attract new patients. In a 2007 survey of healthcare professionals, 68% agreed that green hospitals have a marketing or public relations advantage over comparable conventional hospitals, and 56% agreed that green hospitals are more desirable to patients than standard facilities (Building and Construction 2007).

Coordinating energy efficiency upgrades with other maintenance and equipment upgrades will also improve cost effectiveness and minimize disruptions. For example, a roof can be insulated at the same time the membrane is replaced; or a hot water distribution system with condensing boilers can replace a steam heating system that is on its last legs.

The optimal timing of efficiency upgrades depends on several factors, including size and scope, availability of capital, and financial incentives. An EBCx project is relatively simple and low cost, and likely would not need to be coordinated with any existing capital project. On the other hand, a larger project such as roof insulation may make better economic and planning sense to implement before an impending boiler replacement, as the heating load would be reduced (which would mean the boiler could be smaller and less expensive). Also, government and local utility incentives are typically time dependent and could drive efficiency planning.

An energy manager might implement a comprehensive whole-building project (Section 4.1) to take advantage of incentives from government or local utilities. An energy manager might also implement upgrades in stages (Section 4.2), leveraging cost savings from initial energy efficiency improvements to pay for additional EEMs. In cases where resources such as funding and personnel are limited, an energy manager can apply the upgrade concepts to one or a few buildings. Successful outcomes can then be used to make a business case for further improvements, covering a broader range of buildings, when support and resources become available.

Additional Resources

Use these resources for more detailed information on planning a retrofit project.

Practice Greenhealth. This membership-based organization offers Web conferences, best practices guides, sample policies and brochures, forums, and other resources for healthcare professionals working on sustainability issues. *www.practicegreenhealth.org*

Green Guide for Health Care. This is a best practices guide for healthy and sustainable building design, construction, and operations for the healthcare industry. *www.gghc.org/tools.overview.php*

Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities: 30% Savings. This is a detailed guide for achieving a 30% reduction in energy consumption in small hospitals as a first step toward net-zero energy healthcare buildings. The focus is primarily on new construction; however, many recommendations are also applicable to renovations. *www.ashrae.org/standards-research--technology/advanced-energy-design-guides*

Advanced Energy Design Guide for Large Hospitals: 50% Savings. This guide provides guidance for achieving 50% energy savings in large hospitals, with a focus on new construction. Many of the energy efficiency strategies presented in the AEDGs can also be applied to retrofit projects, especially whole-building retrofits targeting deeper energy savings. *www.ashrae.org/standards-research--technology/advanced-energy-design-guides*

Department of Energy Better Buildings Alliance. The DOE Better Buildings Alliance for the Healthcare Sector brings together leading hospitals and national associations in a strategic alliance designed to improve energy efficiency and reduce greenhouse gas emissions of healthcare systems throughout the country. *www4.eere.energy.gov/alliance/sectors/private/healthcare*

Sustainability Roadmap for Hospitals. The American Society for Healthcare Engineering of the American Hospital Association published this roadmap to help healthcare organizations achieve their sustainability goals, including those related to energy efficiency, water conservation, and waste reduction. *www.sustainabilityroadmap.org/*

2.3 Key Steps in the Retrofit Process

Planning and implementing a successful upgrade project involves several steps: making a commitment, assessing performance through energy audits and benchmarking, evaluating financing options, implementing the project, evaluating its results, and developing an O&M program to ensure savings persist.

Get Started

Efficiency upgrade projects will have the greatest chance for success if senior management and decision-makers are committed. Commitment to a plan that meets a broad set of objectives that includes energy efficiency will help to secure adequate funding and gain staff support for efficiency-related projects.

A committed team or individual champion can initiate, lead, and guide implementation of the energy efficiency plan. Healthcare organizations that have had the greatest successes in creating an environmentally responsible organization have done so primarily through the guidance and oversight of a facility-wide point person (Practice GreenHealth 2008). This person or team will help keep the plan on track and ensure that there are no bureaucratic roadblocks, and will provide access to data, justify the project to decision-makers, and oversee implementation.

An energy policy with clearly stated goals can help secure support and is valuable in tracking and verifying efficiency improvements. It can also create awareness of the facility's environmental commitment and achievements within the local community and be an opportunity to gain market advantage. Communicating success, rewarding top achievers, and demonstrating money saved can ensure continued support for a successful program and provide momentum for further accomplishments.

Conduct an Energy Review

An energy upgrade plan begins with an assessment of how and where energy is used in existing healthcare facilities. To conduct this assessment, you need to identify and prioritize the most cost-effective opportunities to improve energy efficiency. The process requires data collection and analysis tasks in support of benchmarking and energy auditing.

- Benchmarking compares the baseline energy use of a hospital or outpatient facility with similar healthcare facilities. This information can help you target buildings for energy audits and energy efficiency investments. Many tools and methods are available to help identify energy use patterns in a set of buildings. *EPA's Portfolio Manager* (*www.energystar.gov/istar/pmpam/*) (EPA 2011a) is an online tool that can help you assess baseline energy performance in existing healthcare facilities and compile data across a large set of similar buildings. A more detailed discussion of benchmarking is provided in Section 2.4.
- An energy audit examines how energy is used in a facility, and identifies the most cost-effective improvements. Audits range from a simple in-house inspection to complex data gathering and analysis by a certified auditor. A comprehensive audit, sometimes called an investment-grade audit, accounts for all system interactions and provides a detailed, accurate analysis of project costs and savings for all available energy technology improvements. An audit report is essential for a strong business case. A well-designed business case will highlight the financial and health-related benefits and make a compelling argument for implementing the upgrades. A detailed discussion of various types of energy audits is presented in Section 2.5.

Based on results from these steps, you can set goals for improving energy efficiency. These can be established at different levels and over varying periods, from a short-term project for a single outpatient building to multiyear improvements to an entire medical campus. Many hospitals have established both short- and long-term goals that include quick cost savings that continue to accrue over time, helping to fund the longer term improvements.

Identify Sources of Financing

When coordinated with current upgrade plans, the added cost of efficiency may be minimal. In most cases, however, more financing is required and a range of options is available. Involving the finance and legal departments in the early stages can help identify these sources and prevent delays. Although policies vary widely, many states administer programs that provide incentives for energy efficiency investments to the healthcare industry. Many other healthcare facilities have identified and secured funding resources through external sources such as energy savings performance contracts (ESPCs). These contracts can be used to implement comprehensive energy efficiency upgrades at no upfront cost, usually through an ESCO. DOE's Federal Energy Management Program (FEMP) has developed a variety of resources to assist with selecting an ESCO and placing an ESPC (*http://www1.eere.energy.gov/femp/financing/espcs.html*). The resources were developed with federal agencies in mind, but much of the information applies equally well to institutional and commercial buildings.

Other funding sources include bonds and municipal leases from state governments and utility assistance programs. Many state utilities have implemented energy efficiency programs for healthcare facilities. For example, the New York State Energy Research and Development Authority's (NYSERDA) Focus on Healthcare is an initiative designed to help the healthcare industry reduce energy costs, improve the environment, and enhance patient treatment. The program provides energy studies, benchmarking, and financial incentives through the New York Energy Smart program (NYSERDA 2011). Many federal programs provide information and assistance for improving energy efficiency targeted at healthcare facilities. These include *ENERGY STAR for Healthcare*, DOE's *Better Buildings Alliance Healthcare Sector Group* (*www1.eere.energy.gov/buildings/alliances/hospital_energy_alliance.html*), and the USGBC's *LEED for Healthcare* (*www.usgbc.org/leed/rating-systems/healthcare*). Another resource is the *Database of State Incentives for Renewables and Efficiency (DSIRE 2011)* (*www.dsireusa.org*)—a comprehensive source of information about state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. These and other financial mechanisms are discussed in Section 2.6.

Implement Energy Management

The shape of the implementation phase depends on the extent of the upgrade. Simple EBCx measures are straightforward, but more comprehensive efforts require a methodical approach. Either a staged or a whole-building approach is recommended, accounting for all system interactions in a building (integrated design), and setting up an overall process to achieve the greatest energy and cost savings over the life of the project. See Section 4 and the EPA's *ENERGY STAR Building Upgrade Manual* (*www.energystar.gov/buildings/tools-and-resources/building-upgrade-manual*) for more information and alternative approaches to project implementation.

Measure Project Results

Measuring performance involves gathering energy use and cost data and analyzing the data to identify savings. These performance metrics can be compared with the project's baseline energy use and against established goals for energy and financial savings to determine the success of the project measures. This can be done by a third party to verify that the energy efficiency improvements have achieved their performance targets. This approach is common when healthcare facilities are part of an ESPC, and the ESCO must provide unbiased proof of the promised cost and energy savings. A detailed discussion of M&V is provided in Section 5.

Energy upgrades provide an initial efficiency boost, and a good O&M program will ensure the savings persist. All building systems degrade over time—light output decreases through natural lumen depreciation and dirt buildup, and control systems drift from set points. A good O&M program anticipates all the expected degradations and monitors building status to catch the unexpected ones. The action items can be proactive, such as prescheduled preventive maintenance plans, and reactive, responding to problems as they arise. Details on developing an O&M plan are covered in Section 6.

Review for Continuous Improvement

Once the retrofit project has been implemented, it is important to continually review the facility's performance and to identify new opportunities as they arise. Building systems that were working properly at the time of the retrofit may have degraded, new technologies may be available, and evolving medical practices may lead to remodeling efforts to improve or adapt the healthcare environment to better serve patient needs. Poorly performing retrofit EEMs should be re-evaluated and modified if necessary. Successful projects should be recognized by management, so the lessons learned can be applied to other healthcare facilities. Individuals who contributed to the project should also be recognized.

Additional Resources

ENERGY STAR for Healthcare. ENERGY STAR data can inform purchasing policies for lighting, computers and copiers, and kitchen, heating, and cooling equipment. The site also offers an energy benchmarking tool and a financial analysis calculator customized for the healthcare industry. *www.energystar.gov/buildings/sector-specific-resources/healthcare-resources*

BetterBricks is an initiative of the Northwest Energy Efficiency Alliance that is devoted to helping commercial entities—including healthcare facilities—reap financial benefits from energy management. *www.betterbricks.com/*

Information and Resources Related to Energy Use in Hospitals. This document from LBNL lists publically available sources of information on energy use in healthcare facilities. *http://hightech.lbl.gov/documents/healthcare/lbnl-2744e.pdf*

Whole Building Design Guide. This online reference covers many building types, including hospitals, nursing homes, outpatient clinics, and psychiatric facilities. *www.wbdg.org/design/health_care.php*

Department of Energy Better Buildings Alliance. The DOE Better Buildings Alliance for the Healthcare Sector brings together leading hospitals and national associations in a strategic alliance designed to improve energy efficiency and reduce greenhouse gas emissions of healthcare systems throughout the country. *www4.eere.energy.gov/alliance/sectors/private/healthcare*

Practice Greenhealth: This membership-based organization offers Web conferences, best practices guides, sample policies and brochures, forums, and other resources for healthcare professionals working on sustainability issues. *www.practicegreenhealth.org*

Green Guide for Health Care. A best practices guide for healthy and sustainable building design, construction, and operations for the healthcare industry. *www.gghc.org/tools.overview.php*

LEED for Healthcare: The new USGBC LEED rating system for healthcare guides the design and construction of new buildings and major renovations of existing buildings, and can be applied to inpatient, outpatient, and licensed long-term care facilities, medical offices, assisted living facilities, and medical education and research centers. *www.usgbc.org/leed/rating-systems/healthcare*

Database of State Incentives for Renewables and Efficiency (DSIRE): A comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. *www.dsireusa.org*

2.4 Benchmarking Current Performance

Energy performance benchmarking provides baseline information that will help you formulate energy management plans and strategies and identify upgrade opportunities. As the benchmarking effort moves forward, it will also provide metrics to gauge program effectiveness and evaluate upgrade alternatives.

The benchmarking process compares the energy use of one healthcare facility, a portfolio of buildings, or an entire campus with other facilities. It may also look at how energy use varies from an objective baseline. It shows how energy is used and helps to identify the influences on that use. As part of the benchmarking process, energy managers establish the best metrics for evaluating performance, select appropriate baselines to use for comparisons, and set their energy performance goals. For example, one common metric is EUI, which provides an energy use per square foot value. Benchmarking can also encourage ongoing improvement if performance is periodically compared to established baselines. The most appropriate benchmark used for making energy comparisons varies with project goals. The most commonly used metrics are listed in Table 2–1.

Table 2–1 Common Benchmarking Baselines

Benchmark Type	Description
Best in class	The performance level of the top performers sets the bar when comparing similar buildings
Performance goal	A specific performance level can be established as a target against which progress can be measured
Baseline	An initial performance baseline of the building that is established before any commissioning or other measures are taken can be used to track improvements over time
Above average	Percentages above an average can be used to establish a benchmark
Commissioned performance level	The performance level of a commissioned building can be used as a benchmark
National ratings	National performance ratings, such as those established by ENERGY STAR, can be used as performance targets for specific buildings

Energy managers can use the benchmarking data to determine best practices in their building portfolios and beyond, and identify the facilities where those practices can be implemented. These data also help to identify top-performing buildings so those responsible can earn recognition for their efforts, and to find poorly performing buildings that can be prioritized for improvement.

Benchmarking can be a complicated process, but tools are available to help. The most prominent is the ENERGY STAR *Portfolio Manager* (*www.energystar.gov/istar/pmpam/*) (EPA 2011a), a free, comprehensive, interactive online tool that provides a set of benchmarks developed specifically for healthcare facilities that can be used to assess energy performance. These benchmarks are developed from a national survey conducted by EIA (DOE 2003). You can set up private accounts to rate your buildings, set baselines, share information, and document results.

Other software products and consulting services are also available for benchmarking healthcare facilities. For example, ENERGY STAR's *Target Finder* (*www.energystar.gov/buildings/service-providers/design/step-step-process/evaluate-target/epa's-target-finder-calculator*) (EPA 2013) can help you select a target energy performance score or a percentage energy reduction target. LBNL (2011) offers an online benchmarking tool called *EnergyIQ* (*http://energyiq.lbl.gov/EnergyIQ/index.jsp*), an action-oriented tool used to assess opportunities and lay the groundwork for investment-grade audits. *Oak Ridge National Laboratory* (*http://eber.ed.ornl.gov/benchmark/bldgtype.htm*) provides EUI charts for hospitals and medical offices that provide a quick comparison snapshot (ORNL 2013). Two AEDG Technical Support Documents developed by NREL provide new construction EUI targets for small healthcare and large hospital buildings that are aggressive but often achievable for retrofit projects (Bonnema et al. 2010a, 2010b).

New York Presbyterian Hospital (NYPH) is among the top 5% of energy consumers in New York City. In 2003, managers faced rising energy costs while they were undertaking a major expansion project, and decided they needed a formal commitment to energy management. To aid with this process, the newly formed Office of Energy Management turned to Portfolio Manager. NYPH achieved a 10-point portfolio-wide improvement based on ratings in Portfolio Manager and realized $900,000 in energy savings. The hospital earned an ENERGY STAR Leader award (EPA 2011b).

Categories of Benchmarking

Energy benchmarking can be categorized in several ways: as internal or external (or sometimes a combination), and as qualitative or quantitative (see Table 2–2). Internal benchmarking keeps comparisons and data within an organization's building portfolio. The data are used to identify the top performers and the best practices that can be applied to lower performing buildings within the portfolio. External benchmarking includes hospitals and outpatient facilities outside of the organization, allowing energy managers to compare the energy performance of their buildings against national performance data and energy ratings. Broadening the scope in this manner helps energy managers find new energy management practices and strategies and increases their understanding of how to evaluate energy performance. Striving to become an ENERGY STAR building would be considered external benchmarking (EPA 2011d).

Table 2–2 Four Major Categories of Benchmarking

	Internal	External
Quantitative	Compare calculated metrics of your building's performance against its own historical performance or against other buildings in your portfolio	Compare calculated metrics of your building's performance against similar buildings in a defined geographic area
Qualitative	Compare management and operational practices in your building over time or against other buildings in your portfolio	Compare management and operational practices in your building against similar buildings in a defined geographic area

Whether internal or external, benchmarking may be either quantitative or qualitative. The quantitative approach compares numerical measures of performance, looking at how performance changes over time, or how a building's performance compares to other similar buildings. The qualitative approach analyzes management and operational practices across the entire building portfolio to identify best practices and the areas that need improvement. Benchmarking projects typically include both quantitative and qualitative measures.

Developing a Benchmarking Plan

A benchmarking plan begins with a definition of goals for the benchmarking process. The plan defines the scope of the effort, determines the metrics and the data needed, and identifies partners who may be asked to participate in the project.

1. **Set goals.** Benchmarking goals should be consistent with the overall goals for the organization. Guidelines, such as those established by the *ENERGY STAR program* (*www.energystar.gov/buildings/tools-and-resources/energy-star-guidelines-energy-management*), suggest evaluating energy use across the entire organization; for example, all buildings in the owner's portfolio. The data can then be used to establish a baseline against which energy performance goals can be set and measured. These goals also help you identify areas for improvement and prioritize energy savings opportunities.
2. **Define scope.** Once you define your goals, you can address the scale, organizational focus, and time frame of the benchmarking effort. You might focus on an entire portfolio of healthcare facilities or on a subset of the portfolio, institute an internal or external organizational emphasis, and establish a weekly or annual time frame, depending on the goals.
3. **Identify data requirements.** The data collection requirements depend on the selected benchmarking metrics and the scope of the benchmarking analysis. Table 2–3 shows some of the common EUI metrics used when comparing buildings. The choice of metrics depends on the goals of the benchmarking project and the type of facility. Btu per square foot is the metric most commonly used for commercial buildings, but Btu per occupied bed is also common for inpatient healthcare facilities.

Table 2–3 Common EUI Metrics

Metric	Application
Btu/ft²	Any building
Btu/employee	Office building
Btu/unit of product	Assembly plant
Btu/lb of product	Manufacturer
Btu/lb of product processed	Refinery
Btu/number of beds occupied	Hotel or hospital
kWh/ft²	Lighting
kW/ton	Chilled water efficiency
W/ft3 airflow/min	HVAC systems

A wide range of variables influence energy use, and you should consider as many as possible in your comparisons. For example, a 75-bed hospital in Arizona cannot be directly compared to a 250-bed hospital in Oregon without normalizing certain factors, such as climate conditions and occupancy levels. This process of accounting for the important variables enables apples-to-apples comparisons. Although this can be a complicated task, Portfolio Manager automatically normalizes EUI metrics based on key variables for healthcare facilities.

Tracking a benchmarking project and calculating the normalized benchmark require gathering a variety of data points. Data such as energy purchases and hours of operations may already be recorded. Other types of data will require specific investigation or even additional measurements. Some hospitals and outpatient facilities use energy tracking software that automatically uploads utility data to Portfolio Manager. Case Study #1 shows how the University of Minnesota Medical Center installed an energy monitoring system to establish energy baselines and identify end uses to target in the retrocommissioning (RCx) process.

Common data types include energy use and cost information, physical building design, operational statistics, and climate variables. To start out, Portfolio Manager requires certain information for hospitals and medical offices, as listed in Table 2–4.

Table 2–4 Starting Data for Hospitals and Medical Offices

Hospitals	Medical Offices
Zip code	Zip code
Number of licensed beds	Number of workers on main shift
Gross floor area	Weekly operating hours
Number of floors	Gross floor area
Presence or absence of tertiary care	–

4. **Engage partners.** Other departments or utilities, especially those that own the data needed for benchmarking, can often help the benchmarking process run more smoothly. For a healthcare facility, this might be the corporate ownership, the facility managers, or the utility providers. For external benchmarking, look for other facilities or organizations with active energy management plans in place. These partners should be involved from the beginning of the process so that they understand the objectives, anticipated outcomes, and schedule. This step also helps all parties better understand the nature and importance of their roles.

The motivation behind an internal benchmarking project must be transparent so participants do not feel threatened by the process of monitoring their energy use and operations. Emphasizing the positive effect that benchmarking can have on a facility's bottom line and patient care can be helpful. Evidence-based design studies have shown that daylighting can reduce patient pain, anxiety, and length of stay, all while reducing energy costs (Ulrich et al. 2008). This same study also found that three hours of daylight exposure at work can lead to higher job satisfaction and lower stress, two critical factors in a labor-intensive workplace such as a hospital. Another point to emphasize is the positive effect energy efficiency has on the local community. Hospital missions typically include providing a healthier community overall, and increasing energy efficiency improves environmental sustainability. Expanded awareness of the benchmarking effort helps everyone involved understand the importance of the process and the positive contribution that energy efficiency has on the organization's bottom line, as well as the local community.

Implementing the Benchmarking Plan

Implementing the plan begins with a data collection effort, proceeds with an evaluation of benchmarking metrics, and concludes with the application of the findings. A variety of software and online tools are available to help with this process. Teams can also design custom spreadsheets to help in the analysis.

1. **Collect data.** Participants in the data collection effort need a common platform to share the data. Portfolio Manager allows users to share information easily, but organizations can also develop their own spreadsheets and report cards. Developing unique spreadsheets enables energy managers to quickly evaluate building performance based on metrics they deem to be high priority. *Hospital Energy Benchmarking Guidance* (*http://hightech.lbl.gov/documents/healthcare/lbnl-2738e.pdf*) from LBNL provides lists of useful data points (Singer et al. 2009).

2. **Evaluate benchmarks and apply the results.** With data in hand, the project team can calculate metrics for each building or facility under the project scope and analyze the results. The benchmarking results can be used for a variety of purposes, from ranking facilities and setting goals to recognizing achievements in improving building performance (Table 2–5). For example, benchmarking information may be used to define a goal of bringing below-average buildings up to the average performance, or to strive for a 10% decrease in energy use for all buildings.

Table 2–5 Applying Benchmarking Results

Purpose	Description
Rank facilities	Use data to compare or rank buildings
Set goals	Use initial results to set new goals at either the building or the organizational level
Identify and share best practices	Look at top performers to identify best practices and apply to lower performing facilities
Take action	Use the data to develop action plans across the facility portfolio, identifying sites with the most potential return
Track progress	Use data to track progress toward organizational energy management goals and identify the organization's best practices
Recognize achievements	Internal awards that recognize superior performance can encourage further efforts and build support for an energy management plan. External opportunities are also available through a variety of associations.

Case Study 1: University of Minnesota Medical Center

Quick Facts

- Facility Name: University of Minnesota Medical Center
- Owner: Fairview Health Services
- Location: Minneapolis, Minnesota
- Gross square footage: 600,000

Project Description

The University of Minnesota Medical Center was retro-commissioned in 2002 with the goal of reducing operating costs and improving IAQ. The hospital used in-house O&M staff to implement most of the recommendations provided by the Center for Energy and Environment, the commissioning provider. The project gave the staff an opportunity to develop a deeper understanding of overall system operation and the costs and benefits of the O&M decisions that they make regularly.

"The retrocommissioning study was a really good process for us. We learned about how our systems work and we were able to save a lot of money without having any negative impact on patient comfort."

—John Marshall, Director of Facility Services

Illustration from Center for Energy and Environment

University of Minnesota Medical Center

The project began with the installation of a monitoring system to determine baseline energy use and help target areas of investigation. Project engineers from the Center for Energy and the Environment then worked closely with staff to train them, investigate existing operating sequences, identify operational and comfort problems, develop commissioning measures, and supervise implementation.

The project achieved annual energy savings of $181,000 and a 1.2-year simple payback and improved in-house O&M staff technical skills.

Key EEMs				
• Installed energy monitoring system to provide baseline energy use. • Verified and optimized outside air (OA) economizer operation.		• Optimized hot water temperature reset schedule and on/off sequence. • Performed TAB of the ventilation system. • Repaired kinked flex ducts and leaky reheat control valves.		
Total Cost Without Incentives	**Financial Incentives**	**Actual Project Cost**	**Energy $ Savings**	**Simple Payback (Excluding Incentives)**
$208,000	$45,480	$162,520	$181,000/year	0.9 years (1.2 years)
Energy Use		**EUI**		**% Site Energy Savings**
Before	After	Before	After	23%
169,478 MMBtu	131,116 MMBtu	282 ktu/ft²	219 ktu/ft²	

Sources: *www.cacx.org/database/data/CEE_Hospital.pdf* • *www.nextstep.state.mn.us/energyconference/090122hancock.pdf*

Benchmarking data help you to identify best practices and decide on next steps—determine where to do onsite audits, determine which sites would benefit most from tune-ups and retrofits, and remind facility management personnel and medical staff about energy-efficient behaviors. Benchmarking efforts can be repeated to track progress against goals and to encourage continuous improvement. Tracking progress will also help to inform decisions about how to regularly set and achieve new goals to create an environment of continuous improvement, and can be used to recognize individual achievements.

Additional Resources

Use these resources for more detailed information on benchmarking health care facility energy use.

ENERGY STAR Portfolio Manager: A comprehensive, interactive tool that provides a set of benchmarks developed specifically for healthcare facilities that can be used to assess energy performance. *www.energystar.gov/istar/pmpam/*

ENERGY STAR Target Finder: A no-cost online tool that enables architects and building owners to set energy targets. *www.energystar.gov/buildings/service-providers/design/step-step-process/evaluate-target/epa's-target-finder-calculator*

Benchmarking Building Energy Performance: A website from Oak Ridge National Laboratory's Buildings Technology Center that covers several types of healthcare facilities. *http://eber.ed.ornl.gov/benchmark/homepage.htm*

EPA's Building Upgrade Manual: A strategic guide for planning and implementing a profitable energy-saving building upgrade following a five-stage process. Chapter 2 focuses on benchmarking. *www.energystar.gov/buildings/tools-and-resources/building-upgrade-manual*

ENERGY STAR for Healthcare: A set of resources for healthcare facilities from the ENERGY STAR program. *www.energystar.gov/buildings/sector-specific-resources/healthcare-resources*

LBNL's EnergyIQ: An action-oriented benchmarking tool for nonresidential buildings. *http://energyiq.lbl.gov/*

Better Bricks Healthcare: An initiative, managed by the NEEA, to work with leading healthcare organizations to provide unbiased advice and tools that reduce energy consumption. *www.betterbricks.com/healthcare/how-get-there*

Hospital Energy Benchmarking Guidance: A publication from LBNL that provides lists of useful data points. *http://hightech.lbl.gov/documents/healthcare/lbnl-2738e.pdf*

2.5 Energy Audits

An energy audit is a systematic assessment of a building's energy use that identifies how and where energy enters the building or piece of equipment, how it is used, and where it can be used more efficiently. Hospitals and healthcare facilities rank among the most complex sectors for conducting energy audits. Hospitals have additional mechanical equipment and specialty medical devices and must meet requirements to maintain high IAQ and adhere to strict health and safety licensing regulations. If major investments are contemplated, consider hiring a professional auditor who can perform a high-quality audit and provide detailed project cost and savings calculations with a high level of confidence. Outside resources, such as utility programs, are often available to help healthcare facilities conduct and finance audits. Case Study #2 shows how hospital staff and a third-party auditor worked together to identify low-cost RCx measures that saved $53,000/year at Shriners Hospital in Sacramento.

Case Study 2: Shriners Hospital Retrocommissioning

Quick Facts

- Facility Name: Shriners Hospital—Sacramento
- Owner: Shriners Hospitals for Children
- Location: Sacramento, California
- Gross square footage: 267,000

Shriners Hospital—Sacramento

Project Description

The Sacramento Shriners hospital is used as a children's hospital with areas for patient care, family accommodations, and research and office spaces.

> *"By 2001, electrical energy use dropped by 780,000 kWh or 7.7% relative to 1999, and peak load dropped by 63 kW or 3.3%. Natural gas use also dropped by 31,913 therms or 11.5%."*
>
> —California Commissioning Collaborative

During the RCx process, investigators identified 68 measures that could be acted on. The investigation was performed by an external commissioning provider, but the hospital's facility staff and engineers were also involved and provided meaningful suggestions and ideas. Energy savings and implementation cost calculations were performed on 29 measures, of which 19 were considered "low-cost" O&M measures. A total of 10 measures were implemented initially, resulting in annual energy savings of $53,000.

The successful RCx effort reduced operational costs and paved the way for additional projects. As a result, the hospital went on to implement more capital-intensive measures that were initially identified during RCx, such as installing variable frequency drives (VFDs) on existing air handling units (AHUs). These retrofit measures saved an additional $124,217/year, 14.7% of the baseline total energy cost.

Key EEMs	
• Optimized scheduling of AHUs. The commissioning study found that three AHUs were running for extended periods unnecessarily. This included two AHUs serving two large spaces from 7:00 a.m. to 4:30 p.m., 5 days per week, even though those spaces were rarely occupied for that length of time. The runtimes for all three AHUs were reduced, saving more than 12,000 therms of natural gas annually, in addition to significant electricity savings.	• Optimized lighting controls and scheduling, and turned off lights when not in use. Operating room lights were left on overnight, and boardroom lights were on from 7:00 a.m. to 4:30 p.m., 5 days per week, but were rarely needed. • Two separate atrium areas took advantage of natural daylight by turning off the recessed can lights during the day. As a result, the hospital saved more than 23,000 kWh annually.

Energy $ Savings (RCx measures only)	Total Costs	Simple Payback (years)
$53,500/year	$29,600/year	0.55 years

Energy Use		EUI		% Site Savings
Before	After	Before	After	
62,415 MMBtu/year	56,006 MMBtu/year*	234 kBtu/ft^2	210 kBtu/ft^{2*}	10.3%*

*These values reflect the savings from the EBCx measures that were actually implemented and reported in Tables 2 and 3 of the California Commissioning Collaborate Case Study *www.cacx.org/database/data/Shriners_Hospital.pdf*.

There are several types of audits, which vary in the level of effort and detail required. ASHRAE (2004) designates a preliminary analysis and three levels of energy audit, each expanding on the previous level: walk-through analysis (Level I), single system or targeted audits (Level II), and investment-grade audits (Level III). For each successive audit level, both the quality and the cost of the audit increase, as shown in Figure 2–7. Only investment-grade audits account for the interactions between building systems when estimating energy savings (Table 2–6). Posing the right questions can help energy managers select the right type of audit (Table 2–7) (CEC 2000).

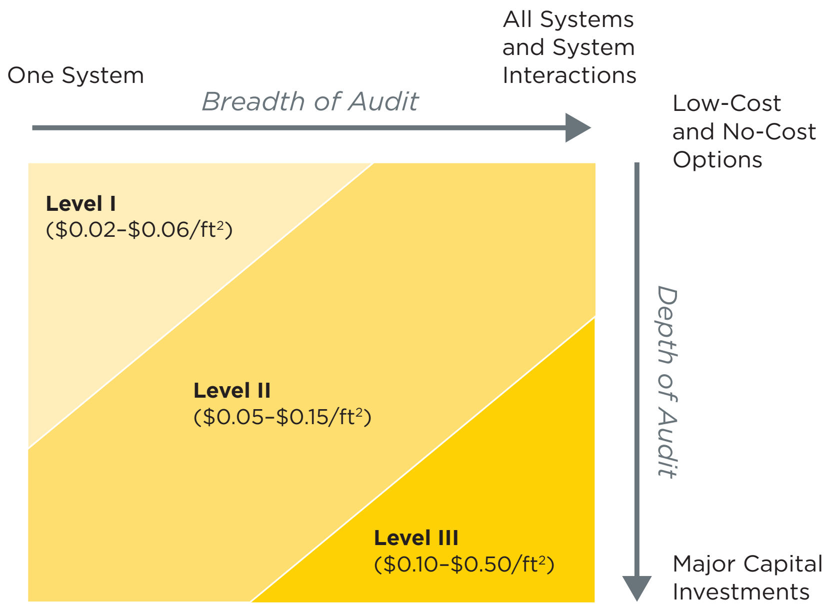


Figure 2–7 Cost and quality of the three levels of energy audits beyond preliminary analysis

Table 2–6 Types of Energy Audits

Audit Type	Accounts for Interactions?	Application Notes
Preliminary analysis	No	Indicates overall potential for improvement
Walk-through analysis	No	Identifies no-cost and low-cost measures
Single system/targeted audits	No	Considers single systems in detail
Investment-grade audits	Yes	Accounts for interactions among building systems

Table 2–7 Choosing the Right Energy Audit

Question	If "yes"	If "no"
Do you want a brief analysis of the energy-savings potential in your facility?	Walk-through analysis	Targeted or investment-grade audit
Has an energy audit been conducted recently?	Updating existing studies	Walk-through analysis, targeted, or investment-grade audit
Have some energy efficiency projects been implemented?	Target audit focusing on specific areas not previously analyzed	Walk-through analysis, targeted, or investment-grade audit
Do you have limited funding for an audit?	Walk-through analysis or targeted audit	Investment-grade audit
Do you know what projects you want to implement?	Targeted audit	Walk-through analysis or investment-grade audit
Do you want a document that will serve as an energy plan for your facility?	Investment-grade audit	Walk-through analysis or targeted audit
Are you concerned about the accuracy of predicted savings and costs?	Investment-grade audit	Walk-through analysis or targeted audit

Designating a Project Advocate

Before initiating any plans for energy audits or building upgrades, it is important to designate an employee (or group) as the project advocate who will have the time and dedication to ensure that the project will receive adequate attention. He or she will provide the necessary resources to an energy auditor to streamline the process and communicate the audit results to decision-makers. Projects with an advocate are more likely to proceed through actual implementation of an auditor's recommendations (E Source 1999).

Preliminary Analysis—Benchmarking

A preliminary or benchmarking analysis before the actual energy audit will show a building's current energy use and cost relative to other similar buildings and will indicate the overall potential for improvement. This is a critical step because it is necessary to understand how much energy a building is consuming in order to estimate how much energy can be saved. This step can also help to identify which buildings should be audited, in what order, and the appropriate audit level. Refer to Section 2.4 for more detail.

Walk-Through Analysis (ASHRAE Level I)

A walk-through analysis includes a study of utility bills and a visual survey of the facility. This process is simple, low cost, and usually takes less than a day. The goal is to identify low- or no-cost energy savings opportunities and estimate their potential. The walk-through analysis can highlight simple O&M measures such as turning off lights in unoccupied areas, performing regular equipment maintenance, and ensuring that automatic thermostat controls are working properly. This type of audit will also help energy managers decide if a more detailed energy audit is worth pursuing.

ESCOs or energy consultants often use the walk-through as a marketing tool, but this type of audit can often be performed in-house by a facility manager and used to decide whether to hire a consultant or auditor.

Reports from a walk-through audit typically provide rough estimates of energy savings and project costs based on back-of-the-envelope calculations. They do not take into account any interactions between systems, such as the reduced HVAC load that results from more efficient lighting. Energy savings estimates based on walk-throughs are not necessarily accurate and should not be used to make financing decisions.

The ENERGY STAR program provides an *Operation and Maintenance checklist* (*www.energystar.gov/ia/business/healthcare/low_cost_o&m_checklist.pdf*) specific to healthcare facilities that can be used for a walk-through audit to help identify opportunities for improvement. It provides steps to analyze O&M procedures for lighting, HVAC, building envelope, and water heating, and recommends simple measures in the areas of lighting and occupant behavior.

Single System or Targeted Audits (ASHRAE Level II)

The next level up in complexity is a single system audit, which provides a more detailed building survey and energy analysis. This type of audit yields a robust analysis of one or more EEMs. It may also recommend additional capital-intensive energy efficiency improvements that require more in-depth engineering analysis to estimate potential savings.

A targeted audit identifies energy use issues and provides a cost and savings analysis that meets a decision-maker's budget criteria. It does not account for system interactions and the potential savings and upgrades that might be beneficial for other systems. Typically, this type of audit is based on recommendations of a walk-through audit or the near-term need to repair or upgrade specific pieces of equipment. Specialty equipment vendors with a focus on lighting, HVAC, thermal storage systems, or energy management systems (EMSs) can perform these types of audits.

Targeted audits focus on the specific areas of need, and are less costly than more comprehensive audits. They do not provide a management plan for future improvements, may miss nontargeted opportunities, and can be biased, especially if the recommendations are provided by a vendor marketing the system in question.

Comprehensive Investment-Grade Audits (ASHRAE Level III)

The most comprehensive and accurate type of audit is an investment-grade audit, performed by a qualified energy auditor. It uses computer models to simulate building and equipment operations and covers the building envelope, lighting, hot water systems, and HVAC systems. It might also consider demand response, thermal energy storage, and combined heat and power opportunities.

The unique feature of an investment-grade audit is that it accounts for the interactive effects of all building systems improvements. This information allows for a rigorous total system engineering analysis that details the estimated costs and savings with a level of confidence sufficient for making financial decisions. Taking interactions into account may also lead to opportunities to reduce equipment size. For example, if an HVAC retrofit is planned, energy-efficient lighting and spectrally selective windows may reduce cooling loads enough to downsize the equipment. The audit produces a detailed implementation plan for single or multiphase energy upgrades.

This type of audit provides a comprehensive analysis of project costs and savings for all potential energy technology improvements available to the facility, accounts for all system interactions, and should provide a rational, unbiased plan for implementation. It is costly, however, and may identify more improvements than can be immediately implemented. In some cases, an ESCO can create a financially beneficial project plan and help secure financing to overcome this barrier as part of a performance contract (see Section 2.6 for more information about financing options).

Ashe Memorial Hospital performed a comprehensive audit to identify EEMs that cut operating costs and improved the IAQ and comfort for its patients. The hospital administrator used a government grant to pay for the audit, which identified substantial energy savings opportunities in several areas, including lighting and HVAC systems. As a result, incandescent and older fluorescent lighting was replaced with higher performing fluorescent lighting throughout the facility. The main chiller, which is critical to maintaining the desired temperature in operating rooms and laboratories, was running continuously, so it was supplemented with a packaged chiller to serve those specific areas. An EMS was installed to improve the HVAC control system. This fixed the inefficient overheating in one part of the hospital and overcooling in another, and allowed looser control in unoccupied areas (EPA 2011c).

Covering the Cost of an Energy Audit

The cost of an energy audit varies with the type of audit and the complexities of a specific facility. Healthcare facilities contain more sophisticated energy-using equipment, and are more costly to analyze than office buildings and schools, which usually have less complex mechanical systems. Many state and local incentive programs offer substantial rebates or even free energy audits. Check with your local utility about programs for which you may qualify. Many healthcare facilities have incorporated energy audits into Energy Savings Performance Contracts (ESPCs), where an Energy Service Company (ESCO) provides the energy audit as part of its design and planning services (see Section 2.6).

Presenting Audit Results

A completed audit can be a valuable tool for creating a business case for energy upgrades—if the audit results are presented in the right way to healthcare administrators and other decision-makers. A well-designed case will highlight the financial and patient benefits and make a compelling case for implementing the upgrades. Decision-makers will be most interested in current and historical energy spending, the benefits to the quality of patient care, and the effects of improvements on the operating budget. A comparison of energy use and costs with similar healthcare facilities in the area along with any local success stories will help get the attention of decision-makers. It is important to present various financing options, along with the economic calculations expressed in terms the decision-makers expect. For some, simple payback will be appropriate, but for others life cycle costs (LCC) and NPV will be more meaningful. Refer to Section 2.6 for more information about financing mechanisms and investment analysis.

Kingston General Hospital in Kingston, Ontario, chose to use an ESCO because this approach requires no capital funds. A detailed energy audit, included as part of the contract, identified at least 35 areas in which improvements to building operations could be made, most of them very cost effective. The energy audit identified potential savings of about $200,000/year, for an initial capital cost of slightly more than $1 million (NRC 2001).

Additional Resources

Use these resources for more detailed information on energy audits.

Energy Audit Workbook: A workbook from the Washington State University Energy Program that provides instructions, checklists, and worksheets for conducting an energy audit. *www.energy.wsu.edu/documents/audit2.pdf*

How to Hire an Energy Auditor to Identify Energy Efficiency Projects: A report from the California Energy Commission. *www.energy.ca.gov/reports/efficiency_handbooks/400-00-001C.PDF*

Procedures for Commercial Building Audits: A report from ASHRAE that provides purchasers and providers of energy audit services with a complete definition of good procedures for an energy survey and analysis. *www.ashrae.org/resources--publications/bookstore/procedures-for-commercial-building-energy-audits*

U.S. Department of Energy, Building Energy Software Tools Directory, Whole-Building Analysis: Retrofit Analysis: A website that describes a series of software tools that can aid the energy auditing and analysis process. Links to the tools—some available free of charge, some for purchase—are included. *http://apps1.eere.energy.gov/buildings/tools_directory/subjects.cfm/pagename=subjects/pagename_menu=whole_building_analysis/pagename_submenu=retrofit_analysis*

ENERGY STAR for Healthcare: A set of resources for healthcare facilities from the ENERGY STAR program. *www.energystar.gov/buildings/sector-specific-resources/healthcare-resources*

Case Study 3: Danbury Hospital

Quick Facts

- Facility Name: Danbury Hospital
- Facility Type: Healthcare
- Location: Danbury, Connecticut
- Year Built: 1885
- Gross square footage: ~810,000


Aerial view of Danbury Hospital

Project Description

Danbury Hospital was consuming 31% more electricity than the national average for hospitals of similar size, costing approximately $4.66 million/year. Working with NORESCO, an energy service company, the hospital addressed its high energy costs by reducing its electricity load and the cost of electricity, and leveraging close to $2 million in utility incentives and rebates to partially offset project costs.

Environmental Benefits: *Reduced annual carbon footprint by 43%, which is equivalent to saving 78.5 acres of forest, taking 1,490 homes off the grid, or taking 2,061 cars off the road.*

The primary solution to reduce energy cost was a combined heat and power system designed to meet almost the entire electricity load of the hospital and 97% of its thermal requirements. Additional capacity was provided to accommodate a planned 230,000-ft^2 expansion. The selected technology for the application was a 4.5-MW natural gas combustion turbine that generates electricity and directs its exhaust gases through a heat recovery steam generator to supply heat in the winter and power a 700-ton absorption chiller during the cooling season. Construction involved a new building addition and a two-mile natural gas line installation and EEMs, including condenser water system upgrades, thermal blanket installation, AHU upgrades, and a variable speed kitchen hood drive.

Key EEMs	
• Combined heat and power plant • Thermal blanket insulation	• Air distribution and control system upgrades • Condenser water system pumping upgrade

Audit Costs	Equipment Costs	Installation Costs	M&V Costs	Total Cost Without Incentives	Financial Incentives	Actual Project Costs
$259,000	$8,138,408	$8,967,300	$57,000	$17,421,708	$1,872,000	$15,549,708

Energy $ Savings	O&M $ Savings	Total Annual $ Savings	NPV	Simple Payback (Excluding Incentives)
$2,680,142/year	$20,600/year	$2,700,742/year	$42,754,025	4.5 years (6.5 years)

Energy Use*		EUI		% Site Energy Savings
Before	After	Before	After	
316,298 MMBtu/year	221,862 MMBtu/year	390 kBtu/ft^2	270 kBtu/ft^2	31%

2.6 Financing Options

Healthcare facility owners and financial managers face many challenges during the financial decision-making process when considering energy efficiency improvements. Upgrades provide clear benefits—reduced energy and maintenance costs as well as mission-related benefits such as improved IAQ. Nevertheless, the upfront capital required can be the largest barrier to an upgrade project; and many financial managers look for quick paybacks. Healthcare facilities have unique, pressing strains on their budgets, such as inspections and strict medical licensing requirements, which often take priority over energy efficiency improvements.

Healthcare facilities may be in use for 50 years or more, which gives managers the opportunity to take a long-term view and take full consideration of LCC when implementing upgrades. This long-term perspective provides the opportunity to minimize operating expenses and maximize energy efficiency. It also promotes a wider variety of energy efficiency improvements than other commercial facilities are prepared to undertake, because many hospitals may accept payback periods of 5 years, 10 years, or longer. Also, healthcare facilities that operate as nonprofit or public sector organizations may be considered tax-exempt organizations, allowing them to take advantage of lower interest rates. For-profit healthcare facilities can benefit from incentives such as energy efficiency tax deductions, tax credits, and accelerated depreciation. Case Study #3 shows how Danbury Hospital in Connecticut was able to leverage $2 million in utility incentives to help achieve 31% energy savings.

The best financing choice depends on many factors, including debt capacity, creditworthiness, risk level, in-house expertise, and project term. Financial analysis will provide insight into the financial mechanism to fund and implement an energy efficiency project. The nature and timing of cash flows will vary for every project and funding mechanism, and the resulting NPV should be used to assess the profitability of the energy upgrade investment. Financing categories include capital budget, issuing of bonds, bank loans, performance contracting, leasing, and on-bill financing.

Investment Analysis

NPV is the most accurate method for assessing the financial worth of a building upgrade project, but financial managers often use simple payback period to justify the investment. Simple payback is defined as the number of years required for an investment's cumulative cash flow, including upfront costs, to break even. For example, a project that costs $50,000 up front but immediately saves $10,000/year in energy and O&M costs would have a simple payback of 5 years. Simple payback does not provide an accurate measure of the long-term value of an investment, because it does not account for cash flows that occur after payback has been reached.

NPV is a measure of investment worth that explicitly accounts for the time value of money and is used to compare the profitability of multiple financing strategies. NPV is computed from the stream of cash flows that result from the investment. These cash flows are adjusted using a discount factor (DF) to increase the value of upfront costs and near-term savings and reduce the value of future costs or benefits. A higher NPV indicates a more profitable investment, so when comparing project financing options, the one with the higher NPV should be chosen. Public healthcare facility finance managers can use the *ENERGY STAR Cash Flow Opportunity Calculator* (*www.energystar.gov/buildings/tools-and-resources/cash-flow-opportunity-calculator-excel*) to analyze the NPVs of energy efficiency projects.

The DF is used to adjust a future cash flow to its present value. As the starting point, most organizations use their cost of capital—the rate of return that must be earned to pay interest on debt from loans, bonds, leases, or other financial mechanisms. For example, suppose an organization could obtain a loan to finance the entire cost of a building upgrade with an interest rate of 5%. The cost of capital for this project would be 5%. If the 5% DF results in an NPV greater than zero, the project would be financially worthwhile because the excess cash flow would be sufficient to repay the loan. Often a somewhat higher DF will be used to account for project risk or to provide an acceptable return on investment.

In general, if the DF and initial costs are high and the cost savings are more stretched out, the NPV of that investment will be lower. Projects with low initial costs and greater initial savings yield higher NPVs.

Consider two energy efficiency project options. One is a noncomprehensive retrofit project involving only lighting; the second is a more complex and comprehensive retrofit project that involves a mix of small and large EEMs. The simpler project has an initial capital cost of $100,000 and a simple payback of 2.5 years. The comprehensive project has an initial capital cost of $400,000, which is paid off through energy cost savings after 4 years. Table 2–8 illustrates the NPV calculation for both scenarios, assuming a DF of 3.5%. At first glance, the simpler project appears to be the better investment because it has a shorter simple payback period. However, the NPV calculation shows that the more comprehensive project is actually the more profitable because it has a higher overall NPV (DOE 2008a). More detailed information about NPV analysis in the context of a healthcare facility retrofit project can be found in Appendix A.

Table 2–8 Comparison of NPV for Two Projects

	Noncomprehensive Project			Comprehensive Project		
Year	Cash Flow ($)	DF (@ 3.5% rate)	NPV ($)	Cash Flow ($)	DF (@ 3.5% rate)	NPV ($)
0	–100,000	1.00	–100,000	–400,000	1.00	–400,000
1	40,000	0.966	38,647	100,000	0.966	96,618
2	40,000	0.902	36,078	100,000	0.902	90,194
3	40,000	0.814	32,540	100,000	0.814	81,350
4	40,000	0.709	28,357	100,000	0.709	70,892
5	40,000	0.597	23,876	100,000	0.597	59,689
6	40,000	0.486	19,423	100,000	0.486	48,557
7	40,000	0.382	15,266	100,000	0.382	38,165
8	40,000	0.290	11,593	100,000	0.290	28,983
9	40,000	0.213	8,506	100,000	0.213	21,266
10	40,000	0.151	6,030	100,000	0.151	15,076
11	40,000	0.103	4,130	100,000	0.103	10,326
12	40,000	0.068	2,733	100,000	0.068	6,834
13	40,000	0.044	1,748	100,000	0.044	4,369
14	40,000	0.027	1,080	100,000	0.027	2,699
15	40,000	0.016	644	100,000	0.016	1,611
16	40,000	0.009	372	100,000	0.009	929
17	40,000	0.005	207	100,000	0.005	518
18	40,000	0.003	111	100,000	0.003	279
19	40,000	0.001	58	100,000	0.001	145
20	40,000	0.001	29	100,000	0.001	73
Total*	**700,000**		**131,430**	**1,600,000**		**178,575**

Source: DOE 2008a

* Totals may not equal sums due to independent rounding.

To help with the financial analysis task, the ENERGY STAR program has created a set of Healthcare Energy Savings Financial Analysis Calculators that are designed to calculate the financial impact of energy efficiency upgrades. These calculators, which are available on the *ENERGY STAR website* (*www.energystar.gov/buildings/tools-and-resources/energy-star-healthcare-energy-savings-financial-analysis-calculators*), are specially designed for healthcare organizations to quantify cumulative cost savings.

Financing Mechanisms

Financing mechanisms for healthcare facilities range from traditional forms of financing, such as available capital and in-house resources, to approaches that involve third-party financing. Choosing the right financing mechanism depends on the specific needs and budget of a project.

Capital Budget

The simplest and most direct way to finance energy efficiency improvements is to use available capital, or internal funds. With internal financing, projects are paid for directly with available cash drawn from the healthcare facility's current capital funds. Upfront capital investments almost always result in a short-term negative cash flow, but the resulting savings in energy use and O&M costs eventually result in a neutral or positive net cash flow.

This approach presents a simple process that avoids complex contract negotiations or transaction delays and requires no financing costs (interest or transaction fees) paid to third parties. The healthcare facility retains all energy cost savings immediately, which decreases operating expenses in future years.

The use of capital budgets to pay for retrofit projects has several disadvantages, however. Healthcare facilities have increasingly tight budget constraints with little or no available capital, and other operating and capital investments often take priority over energy upgrades, inhibiting direct financing of energy efficiency improvements. Also, obtaining internal approval for capital expenditures takes significant time and effort. In-house expertise on energy audits, project design, cost estimation, and project management are required, and the facility owner assumes all risks associated with the investment.

Revolving Investment

Some organizations use revolving investment funds, which involve investing capital in energy efficiency projects, with some or all of the savings from avoided energy costs used to repay the revolving fund. Excess savings allow the fund to grow and be reinvested in additional phases of energy efficiency improvements. With revolving funds, realizing the full savings of energy upgrades can take a relatively long time, but healthcare facilities often have the flexibility to take advantage of such opportunities.

Bank Loan

The private sector often uses bank loans to finance small energy efficiency improvements such as equipment upgrades; this approach may be beneficial for small medical offices. A traditional loan has several benefits:

- The payments are fixed and structured to be lower than the anticipated energy savings, resulting in positive cash flow.
- The depreciation and interest are tax deductible when the owner is a for-profit entity.
- The cost savings of the upgrades are realized immediately.
- The borrower owns the equipment from the start.
- Loans are a simple mechanism to fund smaller projects and can be obtained quickly.

Loans do, however, typically require a substantial down payment, which can be difficult for healthcare facilities with competing resource needs. In addition, lenders usually do not cover the "soft costs" of a project, such as consulting and installation fees. For larger and more complicated projects, a public hospital may consider bond markets or leases, discussed in the next sections.

Bond Issue

Bonds are sold by public and private sector organizations to borrow money from capital markets. Municipal bonds are long-term debt obligations of states, local governments, and their authorities and agencies. They are usually exempt from federal and state taxes. They are most commonly issued to finance public buildings and may be used to finance capital improvements such as energy efficiency projects.

Bonds usually have a low, tax-exempt interest rate compared to other financing options. They also avoid the need to rely on precious internal capital and operating budgets, and the financing costs can be structured to be repaid from energy savings.

However, bonds are complex agreements that often require input from attorneys, accountants, and investment bankers. This adds administrative costs and fees to the original financing cost. Bonds also incur a debt that is reflected on the balance sheet, and issuing bonds is a lengthy process that requires multiple levels of approval from legislative bodies and voters.

NYPH contracted with six ESCOs and participated in 18 upgrade projects in multiple locations beginning in 2003. In response to audit recommendations performed by the ESCOs, NYPH performed upgrades of the HVAC and controls system, chillers, and lighting. In addition, a 7.5-MW cogeneration plant was installed in 2009. The estimated operational cost savings to NYPH is millions annually, and the hospital has been recognized and awarded as ENERGY STAR Partner of the year for its accomplishments (EPA 2011e).

Energy Savings Performance Contract

Though not a financing mechanism, an ESPC can help identify and facilitate appropriate financing for large-scale energy-efficient building upgrades in both the private and public sectors of the healthcare industry. It is a good approach for healthcare organizations that lack the necessary technical expertise, are budget restrained, require resources for other priorities, and do not have the time or experience to manage complex improvement projects. An ESPC is an agreement with a private ESCO to finance a group of EEMs with no capital investment by the building owner. The ESCO develops, installs, and manages the project from start to finish and works with the facility owner to identify sources of financing. The ESCO may also provide some maintenance services along with ongoing M&V. The ESCO guarantees performance of the project within the defined parameters of each party's contractual obligations.

The energy savings generated by the upgrades are used to repay the entire cost of the project. Any excess savings are distributed between the contracting organization and the ESCO as defined in the contract (Figure 2–8).

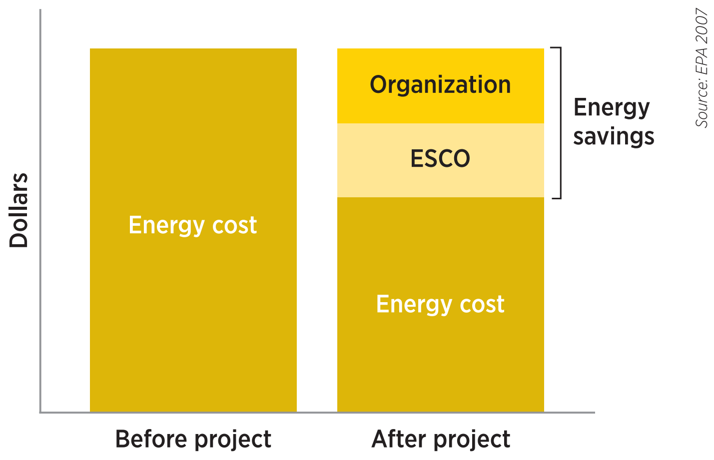


Figure 2–8 Performance contract economics

On the downside, the negotiations can be long and complex, the contracts tend to be long term (5–10 years), and part of the savings generated by the project goes to payments to the financier, which can make the project more costly than doing it in house. However, the cost of delay by waiting for cash or a lower interest rate may make up for that expense. The *Cash Flow Opportunity Calculator* (*www.energystar.gov/buildings/tools-and-resources/cash-flow-opportunity-calculator-excel*) is available to help you make the right choice.

A tax-exempt healthcare facility may benefit by separating the financing activity from the performance guarantees. Many public hospitals are tax-exempt organizations, so unbundling the financing from equipment performance may enable the hospital to take advantage of tax-exempt interest rates or combine this financing with the financing of other projects. The most common approach is to use a municipal lease or tax-exempt purchase agreement, discussed in the next section.

Lease Purchase

A lease is a loan in which the lender retains legal title to the property being leased. Leases tend to be quick and easy to implement compared to other forms of financing. Municipal leases are often used to finance comprehensive energy efficiency upgrades for healthcare facilities, whereas operating and capital leases are better for funding smaller projects such as equipment replacements.

Municipal leases

Municipal leases, also known as tax-exempt purchase agreements, were developed as an alternative to debt or internal financing. They are a common approach for tax-exempt entities, such as nonprofit hospitals, to finance building upgrades for energy efficiency improvements over long periods using operating budget dollars rather than capital budget dollars. The financing terms for municipal leases may be as long as 12–15 years, but are limited by the useful life of the equipment, so are more commonly 10 years or shorter.

Tax-exempt purchase agreements offer several other advantages over bonds. Compared to issuing a bond, a purchase agreement is fast and can typically be approved in weeks. Due to the nonappropriation language, it is considered an operating rather than a capital expenditure and does not require a voter referendum. The healthcare facility borrows only the cost of the project and avoids additional transaction and administrative fees that are standard with bond issues.

A lower financing rate is available because the interest part of the lease payment, which is income to the lessor, is exempt from federal taxation. Each lease payment builds equity toward the future ownership of equipment and improvements, and the lease payments are structured so that there is immediate cash flow from the dollars saved on utility bills. Because utility bill payments are already part of a hospital's year-to-year operating budget, there is no concern about exceeding operating budgets.

Municipal leases are a good choice for public and nonprofit hospitals and other tax-exempt public sector organizations if the projected energy savings will be greater than the cost of the equipment plus financing, especially when a reputable ESCO guarantees the savings through a performance contract (EPA 2004).

A unique advantage of municipal leases is that the healthcare facility owner's payment obligation usually ends if it fails to appropriate funds to meet lease payments. This is because a municipal lease usually contains nonappropriation language that allows the lease to be kept off the facility's balance sheet. If future funds cannot be appropriated, the payment obligation is terminated, but the equipment must be returned to the lender. Depending on the nature of the equipment, this process could be quite disruptive to building operations.

Municipal leases have several disadvantages:

- They entail a more complex approach for healthcare facility administrators.
- They produce tax implications for non-tax-exempt organizations.
- They require in-house project and financial expertise.
- The medical facility assumes all risk.

Bundling a municipal lease with a performance contract through an ESCO will overcome many of the disadvantages.

Operating leases

In an operating lease, the lessee rents equipment from the lender for a fixed monthly fee. At the end of the lease, the lessee has three options: purchase the equipment for fair market value, extend the lease, or return the equipment. Operating leases are simple and funded through operations budgets and are a good choice for short-term projects. The payments tend to be smaller than for capital leases and are tax deductible—with a capital lease, only the interest on the payment is deductible. The use of operating leases can be more complex for healthcare facilities. Operating leases may be viewed as a capital lease and subject to Medicare reimbursement rules. The chief financial officer should be consulted to determine the impact on financial statements.

Capital leases

Under a capital lease, the lender owns the equipment until the end of the lease term, when the title passes to the lessee. These types of leased assets are depreciated, so the depreciation amount and the interest portion of the payment are tax deductible. Compared to a traditional bank loan, capital leases require little or no down payment, involve little paperwork, and are approved more quickly. They can also be used to finance soft costs that are hard to fund through a bank loan. More than 100% of the value of equipment can be leased and the excess can be used to fund the soft costs.

On-Bill Financing

On-bill financing through local utilities is another way to fund energy efficiency improvements without heavy upfront capital spending. It is applicable to small and medium-sized projects in the private and public sectors. A utility or third-party financial institution incurs the upfront costs of improvements and recoups the investment by incorporating loan repayments into future energy bills. This approach eliminates upfront costs, and the repayment schedule is structured so the energy savings are greater than the payments. On-bill repayment is simple to initiate, as utilities already have established billing and access to information about a facility's energy use patterns and payment history. Utilities are often reluctant to take on role of financing, however, and agreements can be complex to set up.

Additional Resources

Use these resources for more detailed information on financing options for energy efficiency upgrades in healthcare facilities.

ENERGY STAR Cash Flow Opportunity Calculator: A spreadsheet designed to help decision-makers quantify the costs of delaying an energy efficiency project. *www.energystar.gov/buildings/tools-and-resources/cash-flow-opportunity-calculator-excel*

ENERGY STAR Building Upgrade Manual: A strategic guide for planning and implementing a profitable energy-saving building upgrade following a five-stage process. Chapters 3 and 4 focus on investment analysis and financing. *www.energystar.gov/buildings/tools-and-resources/building-upgrade-manual*

Easy Access to Energy Improvement Funds in the Public Sector, Government Finance Review: An article that shows how the money saved from increased energy efficiency can be used to finance efficient equipment. *www.energystar.gov/ia/business/government/Financial_Energy_Efficiency_Projects.pdf*

ENERGY STAR for Healthcare: A set of resources for healthcare facilities from the ENERGY STAR program. *www.energystar.gov/buildings/sector-specific-resources/healthcare-resources*

Energy Savings Performance Contracts. This Web page from FEMP provides guidance on energy performance contracts. *http://www1.eere.energy.gov/femp/financing/espcs.html*

Energy Services Coalition. This group provides resources for energy performance contracting. *www.energyservicescoalition.org*

National Association of Energy Service Companies. NAESCO provides background information to users of energy service contracts. *www.naesco.org*

eValuator. This financial analysis software can be downloaded for free from the Energy Design Resources website. It calculates life cycle benefits of improved building design investments and provides financial information necessary for making sound building upgrade decisions. *www.energydesignresources.com/resources/software-tools/evaluator.aspx*

3 Existing Building Commissioning

Significant energy savings can often be achieved in healthcare facilities with minimal risk and capital outlay by improving building operations and restructuring maintenance procedures. This process, commonly known as EBCx, tunes up building performance to get the most out of existing systems. EBCx can take the form of *retro-commissioning* (RCx) when performed for the first time in an existing building, or *recommissioning* when it is performed as a follow-up to the original commissioning process. Besides being a highly cost-effective strategy for reducing energy use, EBCx can help reduce O&M costs and ensure proper operation persists. It is typically a good first step to improved energy performance with either a staged or a whole-building approach.

An EBCx process usually consists of four phases: planning, investigation, implementation, and hand-off. The EPA's *A Retrocommissioning Guide for Building Owners* (*www.peci.org/sites/default/files/epaguide_0.pdf*) includes a detailed discussion of the activities that take place in each phase (PECI 2007). This process may vary slightly for specific projects, but most EBCx projects follow the process shown in Figure 3–1.

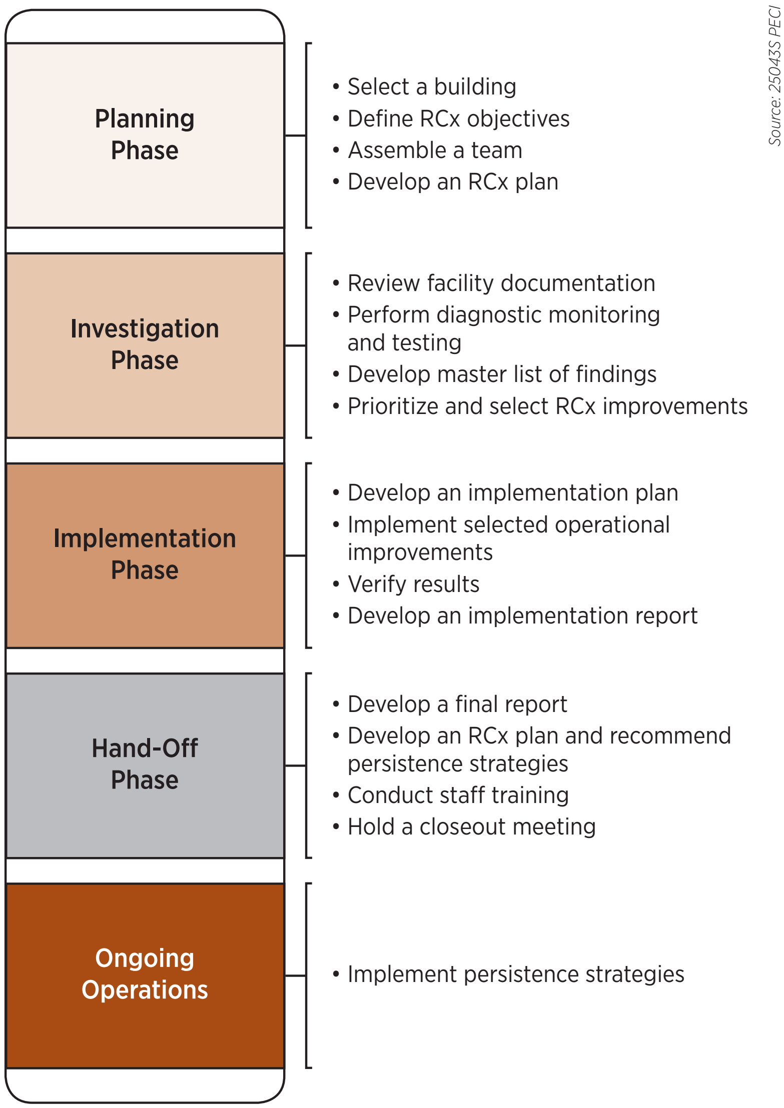


Figure 3–1 Phases of an effective EBCx project

Much of the effort and cost of EBCx are applied during the investigation phase. An outside EBCx provider, or an experienced energy manager for larger healthcare facilities, works with the facility manager to conduct an in-depth investigation into building operations. This investigation provides a detailed understanding of the systems and assemblies and identifies operational improvements. About half the overall project cost is usually devoted to the EBCx provider's work on the project, which includes this in-depth investigation. The other half is devoted to implementing the EEMs. Further considerations for cost and the choice of an EBCx provider are presented in Section 3.3.

Key members of the EBCx team include the third-party commissioning provider, the organization's energy manager, and the facility's maintenance staff. The team may also include the building owner, medical staff, and others who have insights into energy systems that may not be performing at an optimal level.

EBCx is generally recommended even when retrofits are being considered, to optimize building system operations before the retrofits are designed and implemented. This approach also enables savings to accrue even while planning proceeds for more comprehensive upgrades. However, if a facility has scheduled retrofits in the near future, it may make sense to delay implementation of some EBCx measures until those retrofits have occurred. Aside from being a highly cost-effective strategy for reducing energy use, EBCx can help reduce nonenergy costs and help ensure that proper operation persists. It provides a good first step to increased energy performance with either a staged or whole-building approach.

This section begins with an EBCx measure summary table that provides a list of the highest priority EEMs that should be considered as part of an EBCx project. The EEMs were identified by evaluating the most common and cost-effective EEM options currently being implemented in healthcare facilities. More detailed information about the application of each EBCx measure is provided in Appendix E, which presents a brief technical overview, addresses strengths and weaknesses, and discusses special considerations related to building vintage, size, and climate. It also presents a second tier of EBCx measures that may be worth exploring, depending on the current state of the building.

This section continues with a set of recommended packages of EBCx measures that were selected based on their appropriateness for the example hospital building in each climate region. Details of the approach used for cost-effectiveness analysis are provided in Appendices A and B. The analysis presented in this guide indicates that implementing the recommended packages can produce a large positive NPV and payback periods of less than 2 years in all regions of the country.

This section concludes with considerations for the EBCx process that address factors that can influence cost effectiveness, and aspects to consider when evaluating EEMs. Because each building is unique and has particular needs and opportunities for energy upgrades, healthcare facility owners are encouraged to consider how these aspects will influence their projects.

3.1 Existing Building Commissioning Measure Summary Table

A total of 38 EBCx measures suitable for healthcare facilities are presented in this section, and described in more detail in Appendix E. These EEMs were carefully selected by retrofit experts based on the likelihood that they will yield significant energy savings in typical healthcare facilities at little or no cost. Table 3–1 provides a summary of these EEMs and their applicability to each climate region, along with a reference to the section in Appendix E where further discussion is provided. Although simple lighting upgrades are often considered EBCx measures, this guide categorizes any measure that involves equipment replacement or installation as a retrofit (see Section 4). Most EBCx measures are worthwhile in all climates because a low threshold of energy savings is necessary to pay for the low cost of implementation. Certain measures are more relevant for either hospitals; some for small healthcare facilities. Application to specific building types is discussed more fully in Appendix E.

Table 3–1 EBCx Measure Summary Table

System	Measure Description	Applicable to: Miami	Las Vegas	Seattle	Chicago	Duluth	Stage (see Section 4.2)	Section
Lighting	Calibrate any existing lighting controls and optimize settings based on building usage patterns and daylight availability	✓	✓	✓	✓	✓	1	E.1.1
	Adjust light levels to within 10% of IES recommendations for the tasks conducted in each area by delamping and/or relamping	✓	✓	✓	✓	✓	1	E.1.2
Plug and process loads	Provide power strips in easy-to-access locations to facilitate equipment shutdown	✓	✓	✓	✓	✓	1	E.2.1
	Control computer power management settings facility-wide through software or logon scripts, except for computers in critical applications	✓	✓	✓	✓	✓	1	E.2.2
	Use timers or occupancy sensors for compressors and turn off lights on vending machines and water coolers	✓	✓	✓	✓	✓	1	E.2.3
	Verify or establish an effective maintenance protocol for cooking equipment in kitchen areas and break rooms, including cleaning exhaust vents, heating coils, and burners	✓	✓	✓	✓	✓	1	E.2.4
	Verify balanced three-phase power and proper voltage levels	✓	✓	✓	✓	✓	1	E.2.5
	Use pool covers when pool is not in use for an extended period	✓	✓	✓	✓	✓	1	E.2.6
Envelope	Weather-strip or caulk windows and doors where drafts can be felt	✓	✓	✓	✓	✓	1	E.3.1
Service water heating	Install low-flow aerators on faucets used for hand washing and install low-flow shower heads	✓	✓	✓	✓	✓	1	E.4.1
HVAC: Heating and cooling	Test, adjust, and balance (TAB) chilled water pumps, valves, and refrigerant lines to ensure that supply air temperatures meet cooling loads and no unnecessary flow restrictions are present	✓	✓	✓	✓	✓	1	E.5.1
	Verify or establish a comprehensive maintenance protocol for HVAC equipment, including cleaning cooling and heating coils, chiller tubes, burners, and radiators	✓	✓	✓	✓	✓	1	E.5.2
	Clean or replace air, water, and lubricant filters	✓	✓	✓	✓	✓	1	E.5.3
	Ensure that steam traps are operating and free of leaks	✓	✓	✓	✓	✓	1	E.5.4
	Check flue gas temperatures and concentrations for boilers and furnaces, and adjust combustion airflow if necessary	✓	✓	✓	✓	✓	1	E.5.5

Table 3–1 EBCx Measure Summary Table (cont'd)

System	Measure Description	Applicable to: Miami	Las Vegas	Seattle	Chicago	Duluth	Stage (see Section 4.2)	Section
HVAC: Heating and cooling	Verify correct operation of outside air economizer		✓	✓	✓		1	E.5.6
	Ensure correct refrigerant charge in cooling systems and heat pumps, and repair any refrigerant leaks	✓	✓	✓	✓	✓	1	E.5.7
	Turn off or set back HVAC equipment overnight in areas that are not being used (cafeterias, educational areas, office space)	✓	✓	✓	✓	✓	1	E.5.8
	Increase thermostat setback/setup when building is unoccupied	✓	✓	✓	✓	✓	1	E.5.9
	Turn off unneeded heating/cooling equipment during off seasons	✓	✓	✓	✓	✓	1	E.5.10
	Precool spaces to reduce peak demand charges	✓	✓	✓			1	E.5.11
	Reoptimize supply air temperature reset based on current building loads and usage patterns	✓	✓	✓	✓	✓	1	E.5.12
	Reoptimize boiler temperature reset based on current building loads and usage patterns	✓	✓	✓	✓	✓	1	E.5.13
	Reoptimize chilled water temperature reset based on current building loads and usage patterns	✓	✓	✓	✓	✓	1	E.5.14
	Reoptimize condenser temperature reset based on current building loads and usage patterns	✓	✓	✓	✓	✓	1	E.5.15
	Seal leaky ducts	✓	✓	✓	✓	✓	1	E.5.16
HVAC: Ventilation	Reduce ventilation levels when building is unoccupied	✓	✓	✓	✓	✓	1	E.6.1
	Reduce ventilation levels in operating rooms, delivery rooms, laboratories, and other intermittently used spaces when unoccupied, and maintain pressurization	✓	✓	✓	✓	✓	1	E.6.2

3.2 Recommended Packages

At-a-Glance Results

Table 3–2 shows a summary of estimated energy savings for the EBCx measures selected for the example hospital building. Eight of the EEMs from Section 3.1 that were deemed to be the largest energy savers—and that could be applied to the example building—have been recommended as an example package, but as discussed in Section 3.3, other EEMs may also be cost effective depending on the site specifics. Certain EEMs are not in the package because the example building does not have relevant equipment or envelope characteristics. For example, verifying that steam traps are operational is not included because the example hospital does not have a steam heating system. (See Appendix B for an explanation of the EEM selection process for EBCx projects and for further information about how energy savings were calculated for the example building.)

Table 3–2 EBCx Recommended Packages—Results of Common Metrics

Location	EUI (kBtu/ft²)*			Energy Cost/ft²*		
	Baseline	Post-EBCx	% Reduction From Baseline	Baseline	Post-EBCx	% Reduction From Baseline
Miami (Hot-Humid)	263	226	14%	$5.41	$5.08	6%
Las Vegas (Hot-Dry)	268	214	20%	$5.70	$5.17	9%
Seattle (Marine)	263	198	25%	$5.35	$4.68	12%
Chicago (Cold)	263	205	22%	$6.32	$5.69	10%
Duluth (Very Cold)	249	192	23%	$5.49	$4.89	11%
Average	261	207	21%	$5.65	$5.10	10%

* Annual cost and energy savings are first year values. Cost savings are expressed in 2011 dollars, and include the effects of annual M&V costs.

The measures included in the EBCx packages are shown in Table 3–3.

Table 3–3 EBCx Measures in Recommended Package

System	EEM Description	Climate Region	Section
Lighting	Calibrate lighting controls and optimize settings based on building usage patterns and daylight availability	All	E.1.1
Plug and process loads	Control computer power management settings facility wide through software or logon scripts, except for computers in critical applications in hospitals	All	E.2.2
HVAC	TAB AHUs, flow modulation devices, chilled water pumps and valves, and refrigerant lines to ensure that flow rates and supply air temperatures meet cooling loads and no unnecessary flow restrictions are present	All	E.5.1
	Verify correct operation of OA economizer if one is installed. In Miami and other hot-humid climates, it is important to confirm that the economizer is contributing to energy savings. In these climates, economizers can use more energy than they save, and maintenance costs can sometimes exceed energy cost savings.	All	E.5.6
	Turn off or set back HVAC equipment overnight in areas that are not being used (cafeterias, educational areas, office space) (hospitals only)	All	E.5.8
	Reoptimize supply air temperature reset based on current building loads and usage patterns	All	E.5.12
	Reoptimize boiler temperature reset based on current building loads and usage patterns	All	E.5.13
	Reduce ventilation levels in operating rooms, delivery rooms, laboratories, and other intermittently used spaces when unoccupied, while maintaining pressurization (hospital only)	All	E.6.2

Existing Building Commissioning

Rationale for Recommended Energy Efficiency Measures

The EEMs in the recommended EBCx package were chosen based on their common frequency of occurrence on EBCx projects, ease of implementation in the example building, and likelihood of implementation. They are only a subset of the EEMs listed in Table 3–1. An EBCx process typically identifies many opportunities for improved O&M and energy performance. Often, some of those opportunities are not implemented, for reasons such as budgeting, scheduling, and planned work that would affect the EEM. Also, the auditing process may indicate that some EEMs are unnecessary because O&M practices are already adequate. The EEMs in the EBCx package were chosen as a representative mix that could be implemented as part of an EBCx process in a typical healthcare facility. Further discussion of the process for developing recommended packages can be found in Appendix B.

Energy Savings

The detailed energy and demand savings for the recommended EBCx packages are shown in Table 3–4. These values were determined by applying the EEMs to the example hospital building described in Appendix B.

Table 3–4 EBCx Recommended Package Energy Savings Results

Location	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/ft^2)	Savings as % of Total Site Energy Use	Source EUI Savings (kBtu/ft^2)	Savings as % of Total Source Energy Use
Miami (Hot-Humid)	1,089,890	72	37,912	36	14%	70	9%
Las Vegas (Hot-Dry)	1,061,441	103	44,651	54	20%	71	10%
Seattle (Marine)	964,910	115	52,750	65	25%	70	10%
Chicago (Cold)	1,003,345	112	48,073	58	22%	70	10%
Duluth (Very Cold)	895,530	109	52,093	57	23%	67	10%

As shown in Table 3–4, EBCx measures can yield site energy savings as high as 25% in healthcare facilities. The overall reductions in building energy use shown in Table 3–4 were estimated for the example hospital based on a study of 15 commissioning projects in new and existing inpatient facilities (Mills 2009). The site-to-source conversion factors for electricity and gas were calculated using a nationwide average based on an NREL study of transmission and distribution losses (Deru and Torcellini 2007). Source energy savings tend to be smaller for EBCx measures, which often have a larger impact on natural gas heating energy than electricity.

Financial Analysis

The cost of individual EEMs can vary greatly, depending on the baseline condition of the facility and the work involved in implementing the EEMs. Studies have shown that the average cost for an EBCx project, including commissioning and minor repairs, is \$0.30/ft^2 (Mills 2009). Applying this value to the example hospital and applying inflation rates for the past 3 years gives an overall EBCx package cost of \$0.31/ft^2 (see Table 3–5). As shown, the EBCx measures listed in Table 3–3 are projected to have a fast simple payback (less than 1 year) and a positive NPV, making it an attractive method to achieve energy savings in a typical healthcare facility. Because the Mills study shows that EBCx impacts natural gas energy more than electricity, colder locations such as Duluth and Chicago may see a larger financial return than warmer locations such as Miami.

Table 3–5 EBCx Recommended Package Financial Analysis Results

Location	Total Measure Costs	Total Energy Cost Savings	Simple Payback (Years)	NPV
Miami (Hot-Humid)	$75,749	$84,062	0.9	$336,397
Las Vegas (Hot-Dry)	$75,749	$135,064	0.6	$586,434
Seattle (Marine)	$75,749	$168,194	0.5	$751,723
Chicago (Cold)	$75,749	$160,416	0.5	$709,423
Duluth (Very Cold)	$75,749	$150,625	0.5	$662,162

Nonenergy benefits, such as improved thermal comfort and extended equipment life, can also be achieved through the EBCx process. The estimated median quantifiable nonenergy impact of EBCx across a variety of building types is about $0.18/ft^2. This is significant when compared to the median energy savings of $0.29/ft^2 related to EBCx (Mills 2009). For healthcare facilities specifically, these values may be higher or lower, because typical equipment and HVAC systems are not necessarily representative of all commercial buildings. Although savings may be realized beyond the energy savings reported in Table 3–5, some costs may also increase. For example, energy use will increase in some facilities that were operating with insufficient lighting levels or ventilation rates. Additional O&M expenses may be required to maintain optimal energy performance after the EBCx process is complete. For the example building analysis, the additional nonenergy costs and benefits were assumed to cancel out.

To sustain the energy benefits related to EBCx measures, the performance of the related equipment and systems must be monitored and maintained. The financial analysis assumes that the effective life of EBCx is 5 years, with ongoing maintenance of the improvements. Full recommissioning should be performed every few years so the benefits persist over a longer time horizon. The cost of recommissioning is usually less than the cost of initial EBCx.

The EBCx measures proposed in the recommended packages above and comprehensive EBCx measure discussions in Appendix E provide a starting point for options to be considered for most healthcare facilities. However, not all measures will be applicable in all situations, because every building is unique. Other EBCx measures not included in the preceding discussion may be applicable to a specific building. Some are listed at the end of Appendix E. The EBCx process, which includes an in-depth investigation into building operations, identifies opportunities for improved performance, including energy performance, patient comfort, health and safety, O&M, and equipment performance. The range of opportunities identified will depend partly on the comprehensiveness of the EBCx scope.

Facility managers considering implementing the EBCx process will benefit from consulting the detailed measure descriptions in Appendix E to understand the types of measures that are typically implemented as part of an EBCx project. Appendix E includes a discussion of each measure's technical characteristics, special considerations, and technical assumptions for implementing the measure in the context of a typical healthcare facility.

3.3 Additional Considerations

An experienced EBCx provider can help determine if a building is a good candidate for EBCx. An ASHRAE Level I energy audit can help determine a building's suitability for EBCx and give greater confidence in proceeding with an EBCx project. Some indicators of a healthcare facility that is a good candidate for EBCx are (PECI 2007):

- High, unjustified energy use
- Low-performing building equipment or control systems
- High equipment failure rates

- The presence of electronic controls, or an EMS, which makes it easier to implement many of the EEMs
- Experienced and available in-house staff
- Up-to-date building documentation.

Patients and hospital staff can also signal the need for EBCx. A building with numerous comfort complaints is often a good candidate for EBCx. In such a building, the measures that will result from an EBCx project will save energy and may help to reduce patient recovery time and retain staff. Engaging occupants during the investigation and persistence phases of commissioning is essential.

When evaluating EBCx measures to apply in a specific facility, the following questions should be considered to help narrow the options to a more manageable number:

- Is the measure applicable to the systems and assemblies in the building? Certain measures may not be feasible because of the constraints of the installed systems. For example, adding equipment lockouts based on OA temperature may not be feasible for some types of HVAC systems.
- Is the measure relevant to the operations of the building? Measures that affect IAQ should be closely evaluated and considered, because they may impact patient health and comfort. Also, the capabilities of the service contractors and operations staff should be considered when evaluating measures.
- Do the contractors and staff have the necessary skills and knowledge to support the measure? If not, can they receive additional training?
- How difficult will it be to ensure that the measure persists? After measures are implemented, they require periodic monitoring to ensure that their benefits are realized over time. Sufficient resources and strategies must be put into place to ensure measure persistence.
- Will planned retrofits nullify the benefits of the EBCx measure? If a facility has scheduled retrofits in the near future, it may make sense to delay implementation of EBCx measures until those retrofits have occurred. For example, if the exterior lighting will soon be upgraded to more efficient fixtures, it may not be worth calibrating the lighting controls before the retrofit.

The cost of EBCx is an important consideration for most building owners. Much of the cost of EBCx relates to the provider cost for the planning, investigation, and hand-off phases of a typical project (Mills 2009). And most of the provider cost is spent during the in-depth investigation phase of the project. Although the cost of implementing EBCx measures is typically low, it is important to also consider this provider effort, which is necessary to identify the best opportunities. In-house staff or service contractors may be used, but EBCx providers are typically better suited for managing the process for the following reasons:

- The in-house staff or service contractors may not have the resources to lead the process, or the skills to perform the in-depth investigation.
- A third-party EBCx provider offers a "second set of eyes," with significant experience and without biased notions about how the building should perform.
- EBCx providers have the specialized tools for performing the work; e.g., data loggers, functional test forms, and power monitors.
- EBCx providers have the necessary analytic skills and resources for diagnosing performance issues and determining the cost effectiveness of identified improvements.

3.4 Additional Resources

ENERGY STAR Building Upgrade Manual (EPA): The building upgrade manual provides technical recommendations for retrocommissioning measures in existing buildings. *www.energystar.gov/buildings/tools-and-resources/building-upgrade-manual*

Environmental Protection Agency, A Retrocommissioning Guide for Building Owners, 2007: A comprehensive guide to the EBCx process. Also includes case studies, sections on lease structures and impacts to building financial metrics. *www.peci.org/sites/default/files/epaguide_0.pdf*

Mills. 2009. "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions." An investigation of the cost-effectiveness of EBCx that leverages past EBCx project data. *http://cx.lbl.gov/documents/2009-assessment/lbnl-cx-cost-benefit.pdf*.

U.S. Green Building Council, "Green Operations Guide: Integrating LEED into Commercial Property Management." 2011: A resource to assist building owners in reducing the environmental impact associated with commercial real estate operations, while also helping to facilitate LEED for Existing Buildings: O&M certification. Available for purchase online. *www.usgbc.org*

California Commissioning Collaborative: A source for case studies, tools, and templates related to EBCx projects. *www.cacx.org*

BetterBricks: A source for advice and resources related to building operations. *www.betterbricks.org*

PECI, "A Study on Energy Savings and Measure Cost Effectiveness of Existing Building Commissioning", 2009: A cost-effectiveness analysis of EBCx on a measure by measure basis. *www.peci.org/sites/default/files/annex_report.pdf*

PECI, "Functional Testing Guide", 2006: Guidance and sample tests for HVAC systems, as well as advice on how to achieve integrated operation. *www.peci.org/ftguide/*

Building Operator Certification (BOC): A nationally recognized training and certification program for building operators. The BOC training focuses on improving an operator's ability to operate and maintain comfortable, energy efficient facilities. *www.theboc.info*

Advanced Variable Air Volume System Design Guide from the California Energy Commission provides general guidelines for optimizing systems (CEC 2005). *www.energy.ca.gov/2003publications/CEC-500-2003-082/CEC-500-2003-082-A-11.PDF*

Functional Performance Test, Air-Side Economizer: PECI provides this free checklist for economizers. *www.peci.org/ftguide/ftg/SystemModules/AirHandlers/AHU_ReferenceGuide/CxTestProtocolLib/Documents/econtest.doc*

General Commissioning Procedure for Economizers: Pacific Gas and Electric developed these guidelines for commissioning economizers. *www.peci.org/ftguide/ftg/SystemModules/AirHandlers/AHU_ReferenceGuide/CxTestProtocolLib/Documents/EconomizerProcedure.doc*

Assessing Economizer Performance: An application note from Pacific Gas and Electric's Pacific Energy Center providing guidance on how to identify problem areas for economizers. *www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/toolbox/tll/appnotes/assessing_economizer_performance.pdf*

4 Building Retrofits

Building retrofit EEMs include equipment, system, and assembly enhancements or replacements. This section provides guidance for selecting the right package of EEMs, proven practices for implementing those EEMs in healthcare facilities, and case studies that apply the EEMs in real-world situations.

4.1 Whole-Building Approach

A whole-building approach to energy efficiency upgrades focuses on the retrofits of multiple building systems, with a package of EEMs of varying financial benefits being installed at the same time. For example, an energy manager may complete a lighting system retrofit at the same time the roof insulation and the HVAC system are improved.

The whole-building approach is well suited to energy managers who either have ambitious energy savings goals to be met in a short period of time, or have the opportunity to install comprehensive retrofit EEMs because of planned changes in a building's systems, such as those that occur when a healthcare facility undergoes a major renovation. From a financial perspective, implementing multiple EEMs simultaneously has two distinct benefits:

- The overall economics of the project are often improved. Cumulative project costs can be lower than the staged approach, because installing multiple EEMs at once has attendant efficiencies. Life cycle benefits may be simultaneously increased, as energy savings begin at a high level, rather than phasing in over time as stages are completed.
- The whole-building approach allows for optimization of equipment sizes when multiple building systems and assemblies are replaced simultaneously. For example, if lighting and HVAC systems are replaced, the HVAC system designer can take into account the reduced cooling load achieved by the lighting retrofit, resulting in a smaller cooling system. Though this can also occur in the staged approach, the whole-building approach is generally more conducive to identifying such opportunities.

The whole-building approach requires architects, design engineers, and potentially commissioning providers, maintenance personnel, and medical staff to work together as part of an integrated design process, where the various design disciplines coordinate closely to design and specify systems and assemblies that will meet the project needs and result in minimal energy use. Retrofit systems are designed in concert, rather than as a sum of individual parts, and the final design is evaluated using life cycle economics. This process aligns well with aggressive energy savings targets.

4.2 Staged Approach

The key to the staged upgrade approach is to complete improvements to buildings systems in the order that reflects the influence of one system on another. For example, waste heat from lighting systems adds cooling loads to spaces that must be met by the cooling equipment during the summer. By first upgrading the lighting systems, future cooling system improvements can be properly sized and better optimized in a subsequent stage of the project. Under the staged approach, projects are usually implemented in the order shown in Figure 4–1. It may be appropriate to skip EBCx for subsystems or components that will be replaced during Step 2, if the time between the two steps is short (less than 1 year), because the energy savings will likely be small over such a short timeframe. It may also be valuable to install an EMS during Step 1 to add flexibility in the selection of future retrofit EEMs and to increase their effectiveness.

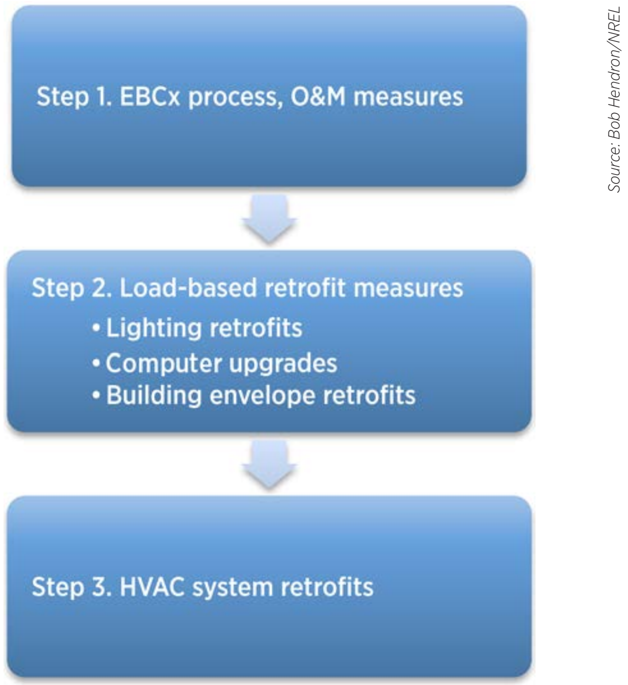


Figure 4–1 Recommended project phases for a staged approach to energy efficiency upgrades

EBCx optimizes existing equipment performance, which provides a better baseline for determining which retrofits will be cost effective. In some cases, EBCx can improve the cost effectiveness of subsequent EEMs by showing where systems can be downsized when operated efficiently. In addition, the typically low-cost and quick returns of O&M measures make them obvious first steps for energy managers who want to see immediate results with limited capital expense. The risk to completing EBCx first is that the system optimization may need to be repeated as subsequent retrofits are completed. Carefully documenting EBCx measures can reduce this effort. A more detailed discussion of EBCx is presented in Section 3.

After EBCx, retrofit EEMs that affect heating and cooling loads should be considered. A variety of EEMs fall into this category. Some directly reduce energy consumption with cooling savings as an indirect benefit, such as replacement of inefficient lighting in hallways, patient rooms, and examination areas. Others, such as adding low solar gain films to windows, reduce energy through indirect means. They all have an impact on the building's heating and cooling demands. The more efficient lights will emit less energy into the building as heat; they therefore reduce the building's cooling needs and may increase its heating needs. Window improvements may reduce solar heat gain and thereby lower cooling needs. By first completing retrofits to these systems, the next stage of retrofits can be optimized for the new heating and cooling demands.

In typical retrofit projects, it may be standard practice to progress from the EEMs affecting heating and cooling loads to a one-to-one replacement of components in the heating and cooling system. A 10-ton rooftop unit (RTU) is replaced with a more efficient 10-ton RTU. In this common approach, efficiency is no doubt improved, but a big cost-saving opportunity is missed. A carefully planned approach will look deeper to identify where the heating and cooling system can be resized to meet the demand of the optimized building. An engineering analysis may show that the 10-ton RTU could be replaced with an efficient 7½-ton RTU. The smaller RTU costs less and performs better because its capacity is more closely matched to the reduced cooling load. However, if loads are reduced in the earlier stages but HVAC equipment is never downsized, a significant amount of energy can be wasted by the oversized equipment.

Energy managers must tailor their plans to match the needs of the facility, so the staged approach presented here may not always fit. Departing from the stages shown here may be necessary at times, to deal for example with financial constraints or ongoing hospital operations. Energy managers should at least investigate the potential for implementing retrofit EEMs that will impact heating and cooling loads before embarking on a large-scale HVAC system retrofit. That way, the tradeoffs can be clearly examined.

In addition to implementing solutions in an optimal sequence, the staged retrofit process can reveal ways to piggyback EEMs onto scheduled building equipment or component replacements, thereby reducing the cost and inconvenience of standalone EEMs.

Another benefit of the staged approach is that the upfront project costs can be spread over a longer period. Retrofits with quick paybacks are typically completed first, and the savings from these early projects might be used to justify the costs of subsequent stages. Thus, the staged approach may be ideal for organizations that cannot justify one large upfront cost for a whole-building retrofit project. Case Study #4 shows how Gundersen Health System used a staged retrofit process to progress from lower cost, quick payback measures to major equipment upgrades coinciding with planned infrastructure improvements.

4.3 Leveraging Opportunities for Higher Savings

Several key leverage points during a building's life cycle offer opportunities to achieve much higher energy savings, regardless of whether a whole-building or a staged approach is being applied. Table 4–1 lists some of these key opportunities that can fundamentally change the economics for a retrofit project, helping to meet more aggressive energy savings targets of 50% and beyond. Some of the opportunities apply only to hospitals, or only to outpatient facilities.

A retrofit can also be used as a tool to identify EEMs that are tailored to the entire healthcare facility portfolio. Key elements to such an approach are grouping similar buildings together and conducting a pilot whole-building retrofit of the typical buildings. The more similar the typical buildings are to the group of buildings they represent, the more informative the findings will be, meaning less analysis will need to be conducted later.

To create groups of similar buildings, you should sort all the buildings in the portfolio by factors such as:

- Age and condition of systems and components
- Building size and shape
- HVAC system and envelope type
- Climate and micro-climate
- Building functions.

One typical building from the group of similar buildings should then be selected for the pilot renovation. This retrofit will address the following questions for all the buildings it represents:

1. Which groups of integrated EEMs were particularly cost effective?
The pilot retrofit team will identify the specifications, capital cost, and return on investment for one or more groups of integrated EEMs. This information will be critical for planning a larger and long-term investment across the rest of the portfolio.

2. Which groups of integrated EEMs will require further design work to be replicated?
A subset of the total identified EEMs may require tailoring to specific buildings. It will be important to indicate in the portfolio plan which measures will require this extra design work. For instance, replicating an EEM to install skylights may require some lighting design work to ensure correct placement for optimal light distribution.

3. Which building systems or components can be eliminated or combined with others?
A genuinely comprehensive pilot renovation will identify opportunities to downsize or combine heating, cooling, electrical, and lighting systems. The designer should explain the basic concepts and technologies used to achieve these results. With this information, designers of the retrofits of other buildings in the portfolio can streamline their analyses.

4. Which implementation team members were particularly creative or integrative?
The retrofit project can be a proving ground for the team charged with reducing energy across the portfolio. The team should include talented people who are not afraid to be unconventional and who want to go beyond incremental energy savings.

5. Which corporate or institutional policies would help or hinder implementation of the EEMs?
In many cases, decision-makers in a healthcare facility chain may not realize that their policies can either hinder or encourage efficiency. A thorough examination of a single building can reveal institutional impediments and enablers.

Case Study #5 shows how the Cleveland Clinic instituted a Patient Program that included a campus-wide effort to reduce energy waste and improve the overall patient experience.

Table 4–1 Special Opportunities for Higher Energy Savings

Point in Building Life Cycle	Opportunity
Adaptive reuse	Redeveloping an existing building for use as an outpatient healthcare facility will require significant capital expense to which the cost of an energy retrofit would be incremental and likely small in comparison
Market repositioning	Repositioning an existing hospital in the marketplace will increase rent, but will also require significant capital expense compared to which the cost of a retrofit would be incremental and likely small in comparison
Building greening	A desire to achieve green building or energy certification may require significant work on the building and its systems, which may then make a more aggressive retrofit economical
Roof, window, or siding replacement	Planned roof, window, and siding replacements provide opportunities for significant improvements in daylighting and efficiency at small incremental cost, providing the leverage for envelope improvements that reduces loads and therefore the cost of replacing major equipment such as HVAC systems and lighting
End (or near end) of life HVAC, lighting, or other major equipment replacement	Major equipment replacements provide opportunities to also address the envelope and other building systems as part of a comprehensive retrofit package. After reducing thermal and electrical loads, the marginal cost of replacing the major equipment with much smaller equipment (or no equipment at all) can be negative.
Upgrades to meet code	Life safety upgrades may require substantial disruption and cost, enough that the incremental investment and effort to radically improve the building efficiency becomes not only feasible but also profitable
New owner or refinancing	New ownership or refinancing can put in place attractively financed building upgrades as part of the transaction, which may not have been possible at other times
Large utility incentives	Many utilities will subsidize the cost for a retrofit project, covering initial evaluations through construction. In some regions, the incentives might be large enough to make more retrofit EEMs economical.
Fixing an "energy hog"	There are buildings, often unnoticed, with such high energy use or high energy prices (perhaps after a major rate increase) that comprehensive retrofits have good economics without leveraging any of the factors above
Healthcare facilities planning	As part of an ongoing energy management plan for a group of hospitals, the organization may desire a set of replicable EEMs; these can be developed from a comprehensive retrofit of an archetypical hospital

Case Study 4: Gunderson Health System

Quick Facts

- Facility Name: Gundersen Health System
- Facility Type: Inpatient, outpatient, medical office
- Owner: Gundersen Health System
- Location/climate region: Wisconsin/Cold
- Year built: 1929–2008
- Gross square footage: 2 million

Gundersen Health System—La Crosse Campus

Project Narrative Description

Gundersen Health System began an ambitious energy management program in 2008 that was driven by the chief executive officer's commitment to environmental stewardship. The program aims to improve the health of the community—from the local to the global scale—and to lower the cost of healthcare for Gundersen's patients. The executive director of Gundersen Envision, Jeff Rich, PE, and his team—hired specifically for their expertise in systems efficiency—focused on the drastic savings that could be achieved through the proper commissioning of their buildings and low-cost EEMs that had quick payback periods. As such, their first step was to retrocommission multiple campuses, after which they implemented numerous low- and no-cost measures that led to 14% improvement in energy efficiency across its building portfolio and saved Gundersen more than $1.3 million annually.

> *"Our mission is to improve the health of the community."*
>
> —Jeffrey Thompson, MD
> CEO of Gundersen Health System

At the same time, the team began looking into other ways to increase efficiency for its health system, which includes a hospital, multiple clinics, and other multiuse buildings, specifically for energy capital projects that had longer payback periods of 3–5 years, but could provide deep savings. This led to relamping of buildings, the installation of a heat recovery wheel, increased insulation around pipes, etc. Other EEMs included "right-timing" opportunities. Jeff Rich and his team identified potential infrastructure improvements that would increase efficiency coincident with necessary upgrade cycles. At this point all steam traps were replaced, as was an entire chiller, with significantly more efficient models. More detailed case studies, along with further information about Gundersen's energy check-up program, can be found on the Gundersen Envision website (*www.gundersenenvision.org/*).

Key Measures Applied to a Large Hospital Building

- November 2008: Replaced steam traps with more robust and efficient models ($35,590; 3.5-year payback)
- May 2009: Relamped and delamped buildings with more efficient lights ($119,670 annually; 5.9-year payback)
- June 2009: Replaced chiller ($70,000 annually; 3.6-year payback)
- Installed more efficient prepackaged gas burners ($46,802 annually; 11.6-year payback).

Total Costs	Annual Energy $ Savings	Simple Payback
$2,141,904	$1,300,000	1.6 years
Energy Use (All Health System Buildings)		**% Site Savings**
Before (2008)	After (2010)	13.5%
378,000 MMBtu/year	327,000 MMBtu/year	

Building Retrofits

Case Study 5: Cleveland Clinic Health System

Quick Facts

- Facility name: Cleveland Clinic
- Facility type: Academic Medical Campuses
- Owner: the Cleveland Clinic
- Location/climate region: Cleveland, Ohio/Cold
- Year built: 1921
- Gross square footage: 24 million

Sydell & Arnold Miller Family Pavilion at the Cleveland Clinic

Project Description

The Cleveland Clinic is a nonprofit healthcare organization that was founded in 1921 and has since grown into one of the leading healthcare facilities in the world. Now it is a multispecialty academic medical center that comprises a main campus and dozens of other regional hospitals, outpatient facilities, and specialized testing and treatment centers that directly employ more than 40,000 people. The central campus, which is the heart of the organization, consists of 50 buildings on 178 acres.

> *"We look for ways to positively impact patient outcomes, patient safety, and/or patient experience and then figure out how to save energy in the process."*
>
> —John D'Angelo, PE

Innovation was a core principle espoused by the clinic's founders, a value that has been continuously fostered since its inception almost a century ago. Thus, it is no small wonder that Cleveland Clinic is also pushing boundaries outside its laboratories and operating theaters with its EEMs.

After an energy audit that year revealed how inefficiently some of the clinic's systems were running, the facilities team embarked on a campus-wide mission to eliminate energy waste. Yet the senior director of facilities at the time, John D'Angelo, PE, remained adamant that he did not have, nor will ever have, an energy program. Rather, he explained, Cleveland Clinic has a "patient program," of which "energy is a part." Most measures are designed to maintain and improve overall building performance using the current building systems, rather than to dramatically increase energy efficiency through a complete system overhaul or replacement. Because of its success at dramatically increasing energy efficiency, Cleveland Clinic was named an ENERGY STAR Partner of the Year in 2011.

<table>
<tr><th colspan="4">Key Measures Applied to a Large Hospital Building</th></tr>
<tr><td colspan="2">• Replaced thousands of incandescent bulbs with light-emitting diodes (LEDs) throughout the clinic, and replaced T12 with T8 lamps.</td><td colspan="2">• Installed VFDs on all applicable main campus motors.
• Installed ultraviolet (UV) lights on applicable cooling coils throughout the main campus to avoid mold growth.</td></tr>
<tr><th>Total First Costs</th><th colspan="2">Total $Savings</th><th>Simple Payback (Various Measures)</th></tr>
<tr><td>~$825,000/year</td><td colspan="2">$5 million/year</td><td>0.6–10.9 years</td></tr>
<tr><th>Energy Savings (Campus-Wide)</th><th colspan="2">EUI</th><th>% Site Savings</th></tr>
<tr><td rowspan="2">135,000 MMBtu/year</td><td>Before</td><td>After</td><td rowspan="2">20%</td></tr>
<tr><td>304 kBtu/ft²</td><td>241 kBtu/ft²</td></tr>
</table>

4.4 Retrofit Energy Efficiency Measure Summary Table

The EEMs listed in Table 4–2 were identified as the best retrofit options for healthcare facilities, and are described in detail in Appendix F. These EEMs were carefully selected based on input from experts in energy retrofits for the healthcare industry. Handbooks, manuals, technical papers, and other external resources were consulted extensively, along with available case studies describing successful retrofit projects in both hospitals and outpatient facilities. Additional EEMs may be appropriate for specific projects; many of these ideas are also presented for consideration at the end of Appendix F.

Table 4–2 Retrofit EEM Summary Table

System	EEM Description	Applicable to:					Stage (see Section 4.2)	Section
		Miami	Las Vegas	Seattle	Chicago	Duluth		
Lighting	Replace exit signs using incandescent lamps with LED exit signs	✓	✓	✓	✓	✓	2	F.1.1
	Replace T12 fluorescent lamps and older T8 lamps and magnetic ballasts with high-efficiency T8 lamps and instant-start electronic ballasts	✓	✓	✓	✓	✓	2	F.1.2
	Replace incandescent lamps with compact fluorescent lamps (CFLs)	✓	✓	✓	✓	✓	2	F.1.3
	Install more efficient exterior lighting for façades and parking lots	✓	✓	✓	✓	✓	2	F.1.4
	Install wireless motion sensors for lighting in rooms that are used intermittently	✓	✓	✓	✓	✓	2	F.1.5
	Install lighting timers in rooms that are used intermittently and for very short intervals	✓	✓	✓	✓	✓	2	F.1.6
	Install tubular daylighting devices or light shelves	✓	✓	✓	✓	✓	2	F.1.7
	Install photosensors and dimming ballasts to dim lights when daylighting is sufficient	✓	✓	✓	✓	✓	2	F.1.8
	Install LED fixtures in operating rooms, patient rooms, and examination rooms	✓	✓	✓	✓	✓	2	F.1.9
Plug and process loads	Consolidate equipment and improve cooling air movement in hospital data centers	✓	✓	✓	✓	✓	2	F.2.1
	Replace cafeteria appliances with ENERGY STAR models	✓	✓	✓	✓	✓	2	F.2.2
	Install VSD demand control for kitchen hood exhaust fans	✓	✓	✓	✓	✓	2	F.2.3
Envelope	Add continuous roof insulation	✓	✓	✓	✓	✓	2	F.3.1
	Install low solar gain window films	✓	✓	✓	✓		2	F.3.2
	Add reflective roof covering	✓	✓				2	F.3.3

Building Retrofits

Table 4–2 Retrofit EEM Summary Table (cont'd)

System	EEM Description	Applicable to: Miami	Las Vegas	Seattle	Chicago	Duluth	Stage (see Section 4.2)	Section
Service water heating	Install low-flow hot water fixtures	✓	✓	✓	✓	✓	2	F.4.1
	Add insulation to steam/hot water pipes	✓	✓	✓	✓	✓	2	F.4.2
HVAC: Heating and cooling	Improve hospital chiller and cooling tower design and controls	✓	✓	✓	✓	✓	3	F.5.1
	Install a coil bypass to reduce pressure drop when there is no need for heating and cooling	✓	✓	✓	✓	✓	3	F.5.2
	Install a stack economizer to recover waste heat	✓	✓	✓	✓	✓	3	F.5.3
	Install boiler controls to allow reset of hot water temperature or steam pressure, reduce excess combustion air and O_2 trim control system	✓	✓	✓	✓	✓	3	F.5.4
	Add controls to stage chillers	✓	✓	✓	✓		3	F.5.5
	Install a water-side economizer to bypass chiller	✓	✓	✓	✓	✓	3	F.5.6
	Install a dry-bulb air-side economizer		✓	✓	✓		3	F.5.7
	Add evaporative cooling to improve condenser performance		✓				3	F.5.8
	Add a small condensing boiler to handle the base load and summer load, with current inefficient boiler operating when heating loads are highest	✓	✓	✓	✓	✓	3	F.5.9
	Install VSDs on chilled-water and hot water pumps	✓	✓	✓	✓	✓	3	F.5.10
	Replace standard furnace with a high efficiency condensing furnace			✓	✓	✓	3	F.5.11
	Install an EMS and replace pneumatic controls with direct digital controls (DDCs)	✓	✓	✓	✓	✓	3	F.5.12
	Replace oversized, inefficient fans and motors with right-sized National Electric Manufacturers Association (NEMA) premium efficiency models	✓	✓	✓	✓	✓	3	F.5.13
	Convert CV air handling system to variable air volume (VAV) (add dampers, VSD fan motors)	✓	✓	✓	✓	✓	3	F.5.14
HVAC: Ventilation	Upgrade to DCV to reduce outdoor air (OA) flow during partial occupancy	✓	✓	✓	✓	✓	2	F.6.1
	Add heat and energy recovery to the ventilation system except quarantine areas	✓	✓	✓	✓	✓	2	F.6.2

LBNL and NAESCO partnered to develop a very large database of ESCO projects around the country. This database allows identification of the most common EEM categories implemented by ESCOs in healthcare facilities. Assuming ESCOs generally choose the optimal EEM combination, with simple payback well within the contract period, this database provides useful information about the likelihood that specific EEMs will be cost effective in a typical building. Figure 4–2 shows the estimated frequency at which various types of EEMs, encompassing all the measures listed above, are included in ESCO projects in healthcare facilities.

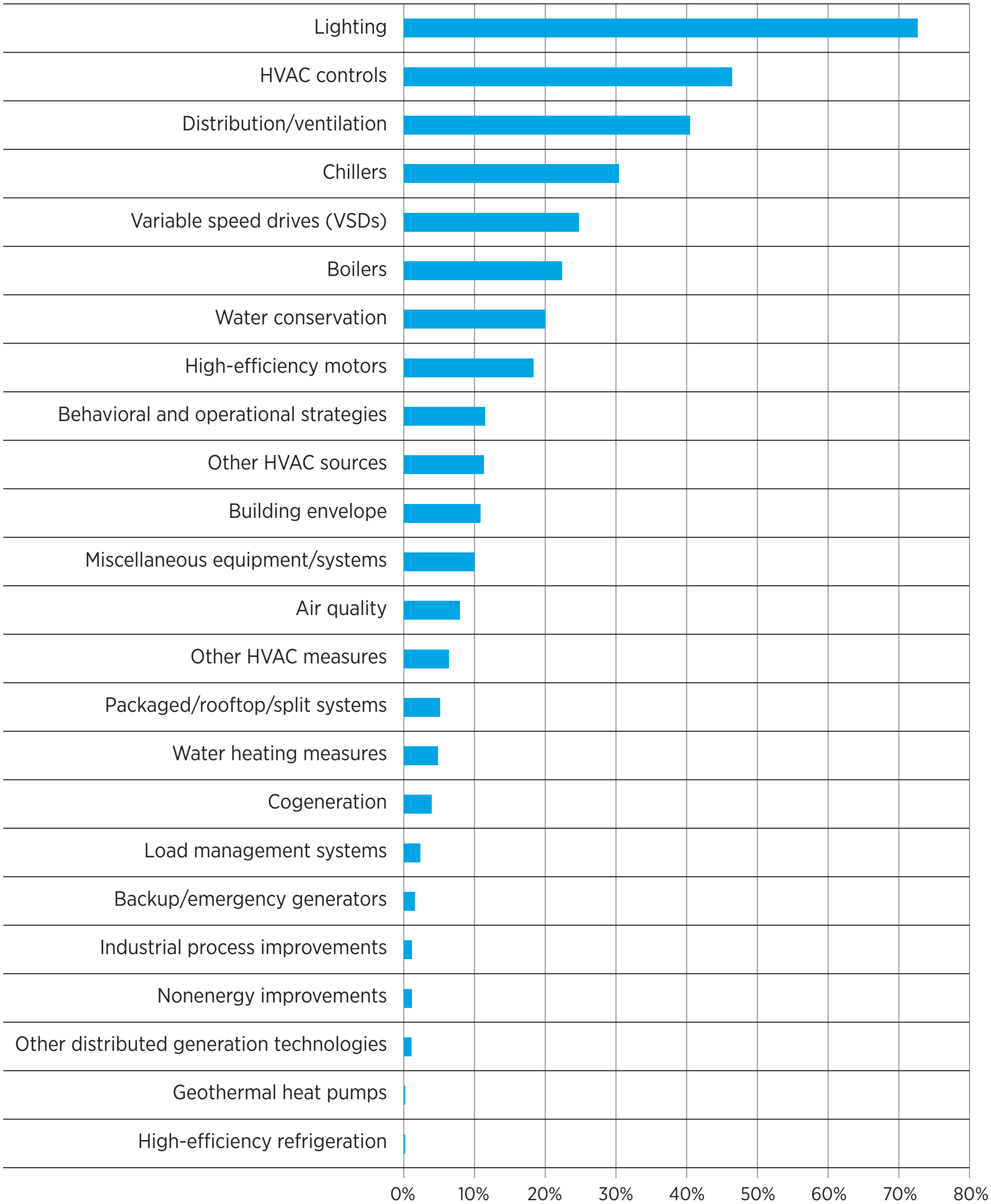


Figure 4–2 EEM categories most common in ESCO projects in healthcare facilities

4.5 Recommended Retrofit Packages

The following sections identify cost-effective (positive NPV) retrofit packages for the example small hospital in each of five geographic locations. All EEMs were selected from those listed in Table 4–2 and are discussed in detail in Appendix F. The analysis was performed in the context of a whole-building retrofit, with all EEMs implemented in the first year. These packages are not necessarily optimal, but are representative of the type of package that can be very cost effective in a typical healthcare facility, even before financial incentives are considered. Energy savings are based on analytical projections, and actual savings can be lower if high-quality workmanship is not enforced. The process for analyzing and selecting the EEMs for inclusion in each package is described in Appendix B.

At-a-Glance Results

Table 4–3 summarizes the results of the energy and financial analysis of the recommended packages of retrofit EEMs. In Duluth, the estimated energy savings was more than 18% because ventilation heat recovery was included in the package. Although the energy savings in other climates was less than 10% for the modeled packages, the annual energy cost savings were very significant, $0.18–$1.10/ft², or $45,000–$275,000/year for the 250,000-ft² example hospital.

Table 4–3 Recommended Retrofit Packages—Results of Common Metrics*

Location	EUI (kBtu/ft²)			Energy Cost/ft²		
	Baseline	Post- Retrofit	Percent Reduction	Baseline	Post- Retrofit	Percent Reduction
Miami (Hot-Humid)	263	257	2.1%	$4.97	$4.79	3.5%
Las Vegas (Hot-Dry)	268	262	2.2%	$4.83	$4.65	3.8%
Seattle (Marine)	263	240	8.6%	$5.33	$4.93	7.6%
Chicago (Cold)	263	253	3.6%	$5.92	$5.37	9.1%
Duluth (Very Cold)	249	204	18.1%	$5.11	$4.01	21.4%
Average	261	243	6.9%	$5.23	$4.75	9.1%

* Energy savings for retrofit packages do not include the effects of EBCx.

The retrofit EEMs included in the recommended packages are listed in Table 4–4. More details about the analysis of each EEM can be found in Appendix F.

Table 4–4 EEMs Included in the Recommended Retrofit Packages for the Example Building

System	EEM Description	Climate Region	Section
Lighting	Replace incandescent exit signs with LED exit signs	All	F.1.1
	Replace T-12 and older T-8 fluorescent lamps and magnetic ballasts with high-efficiency T-8 lamps and instant-start electronic ballasts	Cold, Very Cold	F.1.2
	Replace incandescent lamps with CFLs	All	F.1.3
	Replace metal halide with LED exterior lighting for façades and parking lot, with photocell control	All	F.1.4
	Install wireless motion sensors for lighting in rooms that are used intermittently	All	F.1.5
Plug and process loads	Replace cafeteria appliances with ENERGY STAR models	All	F.2.2
	Install VSDs and demand control for kitchen hood exhaust fans	All	F.2.3
HVAC	Replace current inefficient boiler with a condensing boiler	Marine	F.5.9
	Install VSDs on chilled-water and hot-water pumps	All, except Very Cold	F.5.10
	Add heat/energy recovery to ventilation systems except quarantine areas	Very Cold	F.6.2

Rationale for Recommended Energy Efficiency Measures

The EEMs were chosen for inclusion in each retrofit package based on their energy savings potential, cost effectiveness, and relatively simple application the example hospital building energy model. These are representative of EEMs that energy managers typically implement to realize energy cost savings. These EEMs may be very cost effective when equipment is being replaced anyway, but energy managers also often find it pays to install them before the affected equipment has reached the end of its useful life—that way they may have more time to consider multiple options. Other EEMs from Table 4–2 could be included as part of a retrofit package, depending on the particular healthcare building being retrofitted. Additional EEMs that may be considered are included at the end of Appendix F.

The EEMs included in each retrofit package may add functionality, replace a system component with a more efficient version, or modify a system to operate more efficiently. They represent a conservative set of EEMs, because they were not selected as part of an integrated design process, and do not include changes to system types. They can be implemented with minimal disruption to a hospital's normal operations. A more integrated design approach would reveal more opportunities and achieve higher savings. Further discussion of the process for selecting retrofit packages can be found in Appendix B.

Energy Savings

The recommended retrofit packages are estimated to result in savings of 2.1%–18.1% of site energy use, based on an analysis of each package when applied to the example small hospital. As shown in Table 4–5, each location achieves significant energy savings. For the energy savings and NPVs of retrofit EEMs applied individually, see the detailed analytical results in Appendix C.

Table 4–5 Recommended Retrofit Package Energy Savings Results*

Location	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/ft²)	Savings as % of Total Site Usage	Savings as % of Total Source Usage
Miami (Hot-Humid)	773,550	107.4	–13,039	5.5	2.1%	4.1%
Las Vegas (Hot-Dry)	816,744	123.7	–13,754	5.8	2.2%	4.5%
Seattle (Marine)	832,167	125.0	26,237	22.6	8.6%	8.0%
Chicago (Cold)	1,805,233	264.3	–39,036	9.3	3.6%	9.8%
Duluth (Very Cold)	2,817,978	223.8	12,857	45.2	18.1%	21.5%

* Energy savings for retrofit packages do not include the effects of EBCx.

Financial Analysis

The financial metrics associated with the retrofit packages for each location are shown in Table 4–6. For the financial metrics of all individual retrofit EEMs, see Appendix C. Each retrofit package has a simple payback of less than 9 years and positive NPV. Some of these packages are relatively aggressive, and in some cases it may be challenging to raise the initial capital even where the EEMs are cost effective.

Table 4–6 Retrofit Recommended Package Financial Analysis Results*

Location	Total Measure Costs	Total Energy Cost Savings	O&M Cost Savings	Total Annual $ Savings	Simple Payback (Years)	NPV
Miami (Hot-Humid)	$327,725	$29,510	$31,705	$61,215	5.4	$339,417
Las Vegas (Hot-Dry)	$359,194	$30,888	$34,413	$65,301	5.5	$353,553
Seattle (Marine)	$1,033,793	$68,223	$52,201	$120,424	8.6	$539,822
Chicago (Cold)	$1,147,647	$91,385	$68,538	$159,923	7.2	$708,387
Duluth (Very Cold)	$2,097,846	$184,790	$105,481	$290,271	7.2	$932,734

* Energy savings for retrofit packages are for the first year, and do not include the effects of EBCx. O&M cost savings include the effect of annual M&V costs.

4.6 Additional Considerations

The retrofit EEMs included in the recommended packages, along with the additional EEMs discussed in Appendix F, provide a starting point for retrofit options that should be considered for most healthcare facilities. However, not all EEMs will be applicable to all healthcare buildings, and additional EEMs may be applicable in certain situations. Building owners considering implementing specific EEMs should consult the detailed EEM descriptions in Appendix F to understand the application of each EEM to healthcare facilities of different types in various climate regions.

When evaluating EEMs for application to a specific facility, the following questions should be considered to help narrow the options to a manageable number:

- **Are the equipment and assemblies in the building nearing the end of their useful lives?** By identifying and evaluating equipment that is nearing the end of its life before it has failed, energy managers can evaluate multiple retrofit options and consider all potential costs and benefits instead of replacing the failing equipment with like equipment.
- **Is O&M of the EEM within the expertise of the facility manager?** The capabilities of the service contractors and operations staff should be considered when evaluating measures. If the staff members do not have the necessary skills and knowledge to support the measure, they should receive additional training.
- **Can load-based retrofits be considered and implemented before HVAC retrofits?** Using a staged approach for retrofits can produce greater savings and better performance than replacing systems and components with like-sized equipment. Implementing load-based retrofits first, which have an impact on the heating and cooling loads, can help lower the cost of subsequent HVAC retrofits, improve the performance of HVAC systems, and reduce the overall energy use.
- **Have the building characteristics changed over time in a way that could impact the retrofit?** When replacing equipment, it is important to evaluate whether the equipment should be replaced with like-sized equipment. As load-based retrofits occur over time in a building (e.g., envelope, lighting), the load on the HVAC equipment can change, which can impact the necessary size of the equipment. Also, if building operating criteria have changed over time, this can impact the new equipment. For example, if a hospital has been recently remodeled, this could impact the number and layout of fixtures installed in a lighting retrofit. Case Study #6 shows how a series of building additions and modifications at Sacred Heart Hospital over a 37-year span led to opportunities for integrated energy efficiency improvements achieving more than $250,000 in annual energy savings.
- **Do building codes apply to the retrofit?** Building codes often address the performance of the envelope and other building systems when there is a major renovation or building addition. Before embarking on a retrofit project, you need to ensure that the retrofit measures meet or exceed applicable local, state, and national codes for healthcare facilities.
- **Are incentives available that can help increase the cost effectiveness of a particular retrofit?** Many electric and gas utilities offer incentives for replacing old, inefficient equipment with new equipment that exceeds the energy efficiency standards. Your local utility can provide information about these incentive programs.
- **Do hospital operations need to continue during the remodel period?** Retrofits often include major renovations to building systems and assemblies. Impacts on hospital operations must be considered, and this aspect can be a limiting factor in how deep a retrofit can go. If sections of the hospital can be closed for the construction period, the retrofit can be more comprehensive than if all areas must remain open.
- **Will the project be commissioned?** Commissioning is highly recommended for all retrofits. It provides assurance that the project is designed and constructed to meet the stated requirements. The commissioning program can start during a retrofit's design phase and proceed through construction, to help the project team match the design with the needs of the facility, and to help ensure long-term maintainability. Commissioning is often most useful at the start of a project, when it can have the biggest impact.

Case Study 6: Sacred Heart Hospital

Quick Facts

- Facility Name: Sacred Heart Hospital
- Facility type: Healthcare
- Location: Allentown, Pennsylvania
- Number of Buildings: 5 buildings; 323,660 ft²
- Energy Savings Contract Term: 10 years

Project Description

Sacred Heart Hospital is a 233-bed medical center in downtown Allentown, Pennsylvania. Founded in 1912, it offers a wide range of advanced medical services ranging from acute rehabilitation and bariatric services to adult psychiatric services. A network of physician practices throughout Lehigh and Northampton Counties provide complete primary and pediatric medical care to the region's residents.

The original hospital was built in the early 1920s. Between 1947 and 1984, the hospital constructed five major additions to the original building. As with most hospitals built over many years, numerous building modifications have included a variety of system types. The hospital had limited information about its systems, particularly about the older portions of the building. Sacred Heart Hospital personnel were looking at ways to improve the building's comfort and solve some problems. They were interested in making improvements that would be paid for with energy and system savings.

In 1999, Chevron Energy Services performed an energy audit of the entire facility to identify energy and cost savings projects. The project moved into implementation and was completed on schedule in early 2001, resulting in annual energy and maintenance cost savings in excess of $250,000.

Nonenergy Benefits

- Improved productivity.
- Increased asset value.
- Improved IAQ by rerouting the air intake of exhaust fumes from the loading dock.
- Located and corrected an uncompleted exhaust duct in the bathroom area to improve IAQ.

Key Measures Applied to a Large Hospial Building			
• Energy management system (EMS) • New 600-ton chiller • Water-side economizer • New chilled water pumps with VFDs		• Continuous volume HVAC unit converted to variable air volume (VAV) • HVAC control repair and upgrades • Lighting and controls upgraded and retrofitted • New condenser water pump	
Total Costs	**Energy $ Savings**	**O&M $ Savings**	**Total $ Savings**
$1,508,724/year	$209,189/year	$58,617/year	$267,806/year
Annual Energy Use		**Simple Payback (years)**	**% Energy Cost Savings**
Before	After	10.0	14.0%
266 kBtu/ft²	230 kBtu/ft²		

4.7 Additional Resources

Rocky Mountain Institute's Retrofit Depot: Online resource for case studies, advice, and tools and resources related to retrofit project implementation, including deep retrofits. *www.retrofitdepot.org/*

EPA, ENERGY STAR Building Upgrade Manual, 2008: A strategic guide for planning and implementing a profitable energy-saving building upgrade following a five-stage process. *www.energystar.gov/buildings/tools-and-resources/building-upgrade-manual*

ASHRAE, "Energy Efficiency Guide for Existing Commercial Buildings: The Business Case for Building Owners and Managers," 2009: Includes guidance on planning for retrofits, specific methods for improving energy performance, and making the business case for energy retrofits. Available for purchase online. *www.techstreet.com*

ASHRAE, *Energy Efficiency Guide for Existing Commercial Buildings: Technical Implementation Guide*, 2011: Provides technical implementation considerations for common retrofit measures, including many of the measures discussed in this guide.

BOMA, BEEP (BOMA Energy Efficiency Program): A training program targeted at commercial real estate professionals on how to increase and maintain energy performance of commercial facilities. *www.boma.org/education/online-learning/beep/Pages/Curriculum and Registration.aspx*

Doty, *Energy Management Handbook*, 2009: Provides detailed coverage of effective energy management strategies.

LBNL, "Tips for daylighting with windows", 1997: Includes guidelines on cost-effective approaches to exterior zone lighting design. Available for free download online. *http://windows.lbl.gov/daylighting/designguide/designguide.htmlv*

New Buildings Institute (NBI), "Advanced Lighting Guidelines", 2010: Provides practical design information on lighting technologies for high-performance buildings. Available for purchase online. *www.algonline.org*

Rensselaer Polytechnic Institute (RPI) Lighting Research Center. This website provides a variety of resources for evaluating lighting retrofits. *www.lrc.rpi.edu/researchAreas/outdoor.asp*

"Main Street Net Zero Energy Buildings: The Zero Energy Method in Concept and Practice." Torcellini, Paul, Shanti Pless, Chad Lobato, David Okada, Tom Hootman. Proceedings of ASME 2010 4th International Conference on Energy Sustainability. *www.nrel.gov/sustainable_nrel/pdfs/47870.pdf*

Water in Buildings: an Architect's Guide to Moisture and Mold. Rose, William B. Hoboken, NJ: John Wiley & Sons, 2005.

Life Cycle Cost Analysis: Is it Worth the Effort. Buys, Aaron, Michael Bendewald, Kendra Tupper. Rocky Mountain Institute. *www.rmi.org/Knowledge-Center/Library/2010-24_LCCA*

American Institute of Architects, "Integrated Project Delivery: A Guide", 2007: A tool to assist owners, designers and builders to move toward integrated models and improved design, construction and operations processes. Available for free download online. *www.aia.org*

Energy Design Resources, "Integrated Building Design", 2002: Presents a six-step integrated design process for achieving maximum energy performance. Energy Design Resources provides other useful publications on integrated design and energy performance. Available for free download online. *www.energydesignresources.org*

Wulfinghoff, *Energy Efficiency Manual*, 1999: A primary reference, how-to guide, and sourcebook for energy efficiency upgrades in all building types. Available for purchase online.

ASHRAE, *Standard 189.1*, 2009: Provides minimum requirements for the siting, design, construction, and plan for operation of high-performance green buildings. More information available at *www.ashrae.org*.

5 Measurement and Verification

Determining the actual savings from an energy efficiency retrofit project is often important to prove the effectiveness of a project. Savings represent the absence of energy use, so they cannot be directly measured. Although pre- and post-retrofit measurements are used, simple comparisons of energy use before and after a retrofit are typically insufficient to accurately estimate energy savings, because they do not account for routine fluctuations in weather and building occupancy. M&V is the practice of measuring, computing, and reporting savings for energy savings projects. Proven M&V strategies provide a means to accurately calculate the energy savings by making adjustments to account for these fluctuations, allowing the comparison of baseline and post-installation energy use under the same conditions.

M&V activities include conducting site surveys, metering energy use, monitoring independent variables, executing engineering calculations, and reporting. The industry has several application guidebooks available; their foundation is the International Performance Measurement and Verification Protocol (IPMVP) (EVO 2010). It defines practices for conducting site-specific M&V and outlines four general approaches or options. These establish a range of methods that can be applied as part of a site-specific measurement plan to determine verified savings. The measurement plan describes the data that will be gathered and how they will be processed to determine changes in energy use from the retrofit. As such, the measurement plan is a key document in the retrofit process and should meet the needs of all concerned. Many of the key terms discussed in the IPMVP are defined in Table 5–1. See the *IPMVP sponsor's website* (*www.evo-world.org*) for detailed definitions of M&V concepts and copies of the IPMVP.

Table 5–1 M&V Terminology

Key IPMVP M&V Terminology	
EEM	A design or operational improvement made to a facility, system or piece of equipment that reduces energy use or peak demand
Measurement boundary	A hypothetical boundary drawn around equipment and/or systems to isolate its energy or mass flows relevant for determining energy savings
Independent variable	A parameter that is expected to change regularly and have a measurable impact on the energy use of the facility, system, or piece of equipment
Baseline period	The period of time chosen to represent operation of the facility or system before implementation of the energy efficiency project
Baseline energy	The energy use occurring during the baseline period, and its relation to driving independent variables
Adjusted baseline energy	The energy use of the baseline period, adjusted using regression analysis or simulation to a different set of operating conditions, typically those of the post-installation conditions
Savings	Typically, the adjusted baseline energy costs minus the post-installation energy costs

Source: RMI

The selected M&V approach should take into account the objectives for conducting M&V and the value that it can provide. Some owners may have an explicit need to include a savings verification (SV) component as part of their M&V efforts, such as those whose projects are using ESPCs, pursuing LEED New Construction M&V credits, or participating in utility incentive programs. Otherwise, they may focus their M&V activities on ensuring the building is performing as intended and has a high potential to achieve savings. Such projects would place less emphasis on quantifying savings. The methods used for M&V are flexible and can accommodate differing objectives.

5.1 Planning

An owner needs to determine early in the planning process whether M&V will be part of the project. If savings are to be verified, special planning is required and may involve metering and measurement activities before any changes are implemented. The baseline energy use and costs are established through metering and utility bill analysis. Before energy savings can be determined, the baseline energy use needs to be adjusted to represent energy costs that would occur under the same conditions as the post-retrofit costs. Savings are the difference between the adjusted baseline energy use and the post-retrofit energy use.

A key issue is the accuracy of the reported savings, which influences the scope and level of rigor of M&V activities. Proper planning can help integrate these activities into the project and may leverage related tasks, such as commissioning. A key goal is to keep the cost of M&V activities in line with the scope and needs of the project. Figure 5–1 shows a typical M&V timeline.

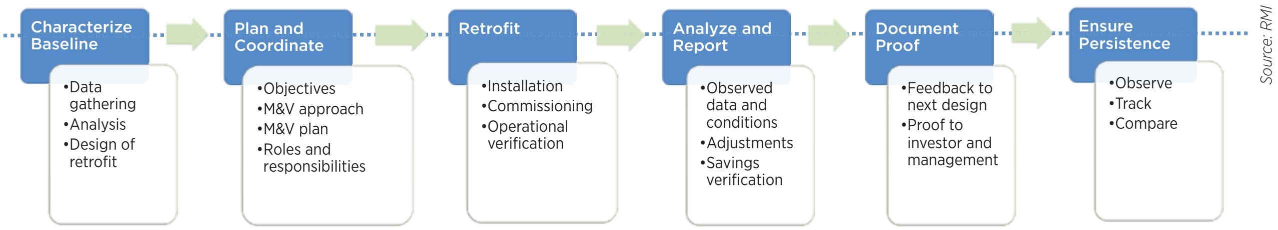


Figure 5–1 M&V timeline

5.2 Overview of Approaches

M&V has two essential components for any energy efficiency project:

- **Operational verification (OV).** This verifies that the EEMs are installed and operating properly. Activities include visual inspection, data trending, and functional testing.
- **Savings verification (SV).** This involves the calculation of energy savings resulting from the installed EEMs. Industry-accepted SV procedures are covered by the IPMVP.

OV and commissioning should be completed before the start of the M&V period for which savings are determined. This ensures the full savings attributed to EEMs and control and operational improvements are captured.

The four SV options defined by the IPMVP are:

- **Option A: Retrofit isolation with partial measurement.** Equipment is isolated and key parameters affected, such as load or hours of operation, are spot measured before and after the retrofit.
- **Option B: Retrofit isolation with full measurement.** Equipment is isolated and all energy-related parameters are measured before and after the retrofit for a sufficient period of time to characterize the range of operation. This strategy is preferred over Option A for systems with more variable energy use.
- **Option C: Whole building.** Utility data from the whole building are correlated with independent variables such as outdoor air temperature. Baseline and post-retrofit energy uses are adjusted to the same set of conditions and compared to determine energy savings.
- **Option D: Calibrated simulation.** Specialized software is used to model energy use before and after the retrofit and the models are adjusted so they accurately predict building energy use. The before and after models are adjusted to represent the same set of conditions and compared to determine energy savings.

These options are grouped into two general categories: retrofit isolation (Options A and B) and whole building (Options C and D). A fundamental difference between these approaches is where the savings boundary is drawn (see Figure 5–2). Retrofit isolation strategies focus on the individual retrofit and its impact on a specific piece of equipment or system. Whole-building methods are based on either utility billing analysis or a calibrated whole-building simulation. Whole-building approaches are most appropriate for comprehensive retrofits when savings are expected to be 10% or more of total electricity or gas use. Whole-building M&V examines the energy performance at the building level. In addition to their measurement boundaries, these methods vary in their requirements for measured data, their application appropriateness, and the level of effort and cost to implement. Table 5–2 summarizes the characteristics of each M&V option.

Retrofit-Isolation Measurement Boundary

Whole-Building Measurement Boundary

Photos by RMI

Figure 5–2 Measurement boundary for M&V options

Table 5–2 Overview of IPMVP Options

Method	Option A	Option B	Option C	Option D
Boundary	Retrofit isolation	Retrofit isolation	Whole building	Whole building
Measured data	Key parameters	All parameters	Utility bills	Utility bills, end use, system, equipment
Analysis	Engineering calculations	Regression analysis	Regression analysis	Calibrated simulation
Applications	Limited variation of some parameters impacting EEM savings	Individual EEM assessment	Estimated savings > 10% of total use, existing building projects, interacting EEMs	Estimated savings > 10% of total use, interacting EEMs

Source: RMI

The appropriateness of the M&V approach varies from project to project. Larger projects with larger savings can justify higher M&V expenses and more rigorous methods. Projects with a few EEMs, or EEMs with little interaction, may opt for a retrofit isolation approach instead of evaluating whole-building impacts. Utility data analysis using Option C can be a simple method for buildings undergoing whole-building retrofits where energy use is stable and has a strong correlation to weather. Alternatively, projects that have developed a detailed energy simulation model as a part of the retrofit evaluation process may be best suited to use Option D.

M&V may include several verification methods. EEMs with little impact, uncertainty, or variation in performance may require a less rigorous M&V approach. Low-cost or no-cost EEMs may rely solely on OV methods that identify their potential to save energy. If a retrofit isolation approach is chosen, some EEMs might follow Option A and others Option B. A project that uses Option C to determine whole-facility savings with utility billing analysis might be supported with submetering and trending activities of individual retrofits to ensure all systems perform as expected and savings are realized. If Option C savings fall below their anticipated level, trending from individual retrofits and/or Option B activities can help identify performance issues. For large projects following Option D, calibration might be supported with submetering and conducted at the utility, electricity end use, and equipment levels. Smaller projects may calibrate at the utility level only.

The IPMVP puts forward several general requirements to ensure the adequacy of an M&V effort. These include:

- Develop a complete M&V plan.
- Measure baseline energy use for all of the operating modes of the building or systems.
- Adjust energy use to the same set of conditions before calculating savings.
- Report savings for the post-installation measurement period only; do not extrapolate beyond this period.
- Establish the acceptable savings accuracy during the M&V planning process.

5.3 Developing the Plan

An effective verification effort must be planned in advance by developing a detailed M&V plan during the project planning phase. Each project must establish its own specific M&V plan that outlines all activities that will be conducted. The M&V plan should address the project's unique characteristics and be crafted to balance the cost of M&V with the value it provides.

Adherence to the IPMVP requires preparation of a project specific M&V plan that is consistent with IPMVP terminology. It must name the IPMVP option(s); metering, monitoring, and analysis methods to be used; quality assurance procedures to be followed; and person(s) responsible for the M&V. Key components of the M&V plan are outlined in Table 5–3.

Table 5–3 Components of an M&V Plan

Basic M&V Plan Components	
Project description	• Relevant site characteristics • Measurement boundary and metering requirements • Details and data of baseline conditions
Project savings and costs	• A description of the EEMs and performance expectations • Estimated energy and cost savings • All relevant utility rates • Expected M&V cost and accuracy
Scheduling	• Schedule for obtaining baseline information • Schedule for all post-installation M&V activities
Reporting	• All assumptions and sources of data • Identification of deviations from expected conditions • Delineation of post-retrofit period • Documentation of the design intent of the EEMs • Calculation method to be used (all equations shown)
M&V approach	• Selected option(s) (A, B, C, D) • Details on approach for baseline adjustments • Savings calculation details • OV strategies • Responsibilities for M&V activities and reporting • Content and format of M&V reports • Quality control/quality assurance procedures

Source: RMI

Goals and Objectives

The first step in developing the M&V plan is to identify the goals and objectives for the M&V activities. The value that M&V provides and costs that can be justified vary based on a project's objectives. For example, M&V cost savings used to determine payments within an ESPC will need to be more rigorous than an M&V effort conducted to meet LEED certification requirements. Many projects may have other uses for the M&V equipment and activities, such as tenant submetering or continuous optimization of building or system energy performance, which can help offset costs.

Verification activities can overlap with other project efforts (e.g., commissioning, energy modeling, or installation of energy information systems). If the commissioning agent is developing an Owner's Project Requirements (OPR), the M&V goals and objectives should also be stated in the OPR. Inclusion in the OPR will promote a coordinated team approach early on, which promotes leveraging complementary or overlapping efforts.

Determining the Best Approach

The basic purpose of M&V is to ensure the predicted energy savings are realized. Energy savings may not be achieved because of inadequate M&V methods, faulty engineering assumptions or analysis, uncertainty introduced from sampling or meter accuracy, or from EEMs being disabled (e.g., overriding controls for VFDs). The M&V approach needs to be adequate but not too expensive. In general, the cost for verification should not exceed about 10% of the annual savings from a project. Using this cost cap as a rule of thumb can help bound the verification activities. In general, the cost for M&V increases with the accuracy of the savings determination, which is impacted by the M&V approach specified as well as the number of metering points, metering duration, measurement sample size, and analysis requirements.

SV plans may call for a single whole-building approach addressing all EEMs for the project, or several M&V options to jointly cover various EEMs. Before deciding on the M&V options to use, a specific option must be assessed to determine how it will meet the project's goals and constraints, address savings risk, and fall within an acceptable budget. The cost of using a proposed M&V approach must be determined and compared to the risk of not accurately calculating savings. If the project's goals and savings risk do not justify the M&V expenses, the M&V approach should be reconsidered. All M&V plans should include OV activities for all EEMs. For low-cost and no-cost EEMs that have lower savings impacts, SV activities may not be warranted.

Plan for Ongoing Measurement and Verification Activities

For the full value of the retrofit efforts to be realized, ongoing M&V activities should be included in the plan. Some EEMs can be overridden or disabled, so ongoing M&V activities will help to ensure savings persist for the life of the equipment. With this in mind, the team should specify periodic performance verification activities. This effort may be composed of OV activities or a combination of OV and SV activities. Ongoing M&V activities may overlap with performance tracking efforts or ongoing commissioning activities (see Section 6 for more discussion of O&M). Often, these efforts can be combined and may be automated into the Building Automation System (BAS), an Energy Information System, or a fault detection and diagnosis system.

5.4 Recommendations for Specific Energy Efficiency Measures

Effective M&V methods that are appropriate for the healthcare facility EEMs discussed in Sections 3 and 4 are listed in Table 5–4. Included for each EEM are cost savings impacts, performance variability, OV activities, SV approach, SV activities, and suggestions for ongoing performance assurance. The methods listed are illustrative in the context of the example small hospital and should not be broadly applied to other projects because the nature and scope of the EEMs installed may vary. Further explanation of the methods used to develop the recommended M&V protocols is provided in the following sections.

Table 5–4 M&V Measures for Common EBCx (Tier 1) and Retrofit (Tier 2) Improvements

Tier	Description	EEM Information		OV Activities	SV Approach	SV Activities	Ongoing Performance Assurance
		Savings Impact	Performance Variability				
1	Calibrate any existing lighting controls and optimize settings based on building usage patterns and daylight availability	Medium	High	Short-term testing	Option B — Fully measured retrofit isolation	Measure wattages and run hours	Short-term testing
1	Provide power strips in easy to access locations to facilitate equipment shutdown	Medium	Medium	Visual inspection	Option B — Fully measured retrofit isolation	Measure wattage over time	Verify implementation of procedures
1	TAB chilled water pumps and valves, and refrigerant lines to ensure that supply air temperatures meet cooling loads and no unnecessary flow restrictions are present	Low	Medium	Verify existence of test reports	None	None	Regular maintenance
1	Verify correct operation of OA economizer	Low	Medium	BAS control logic and/or data trending and review	None	None	BAS control logic and/or data trending and review
1	Increase thermostat setback/ setup when building is unoccupied	Low	Low	Visual inspection	Whole-building approach	Utility data analysis <or> building simulation	BAS control logic and/or data trending and review
1	Reoptimize supply air temperature reset based on current building loads and usage patterns	Medium	Medium	Short-term testing	Whole-building approach	Utility data analysis <or> building simulation	BAS control logic and/or data trending and review
2	Replace T12 and older T8 fluorescent lamps and magnetic ballasts with high-efficiency T8 lamps and instant-start electronic ballasts	Medium	Low	Sample spot measurement	Option A — Partially measured retrofit Isolation	Measure wattage, estimate run hours	Visual inspection
2	Install wireless motion sensors for lighting in rooms that are used intermittently	Medium	Medium	Visual inspection	Option B — Fully measured retrofit isolation	Measure wattages and run hours	Visual inspection
2	Install photosensors and dimming ballasts to dim lights in perimeter zones when daylighting is sufficient	Medium	High	Short-term testing	Option B — Fully measured retrofit isolation	Measure wattages and run hours	Short-term testing

Measurement and Verification

Table 5–4 M&V Measures for Common EBCx (Tier 1) and Retrofit (Tier 2) Improvements (cont'd)

Tier	Description	EEM Information		OV Activities	SV Approach	SV Activities	Ongoing Performance Assurance
		Savings Impact	Performance Variability				
2	Add continuous roof insulation	Low	Low	Visual inspection	Whole-building approach	Utility data analysis <or> building simulation	Visual inspection
2	Add VSDs on the chiller compressors and cooling tower fans	High	High	Short-term testing	Whole-building approach	Utility data analysis <or> building simulation	Regular maintenance
2	Install VSDs on chilled-water and hot water pumps	Low	High	BAS control logic and/or data trending and review	Option B — Fully measured retrofit isolation	Measure wattages and run hours	BAS control logic and/or data trending and review
2	Install a stack economizer to recover waste heat from boiler combustion process	Medium	Low	Sample spot measurement	Option A — Partially measured retrofit Isolation	Measure wattages, estimate run hours	Visual inspection
2	Convert CV air handling system to VAV (add dampers, VSD fan motors) and adjust the ventilation rates to meet ASHRAE Standard 170 requirements	Medium	Medium	BAS control logic and/or data trending and review	Whole-building approach	Utility data analysis <or> building simulation	Visual inspection
2	Add heat/energy recovery to ventilation systems except quarantine areas	Medium	Low	Short-term testing	Whole-building approach	Utility data analysis <or> building simulation	Regular maintenance
2	Add clear high-performance film to existing glazing	Medium	Low	Visual inspection	Whole-building approach	Utility data analysis <or> building simulation	Visual inspection
2	Lighting controls that first switch power to 80%, with 100% requiring a manual up-switching for examination rooms, nurses' stations, and other areas	Medium	Medium	Visual inspection	Option B — Fully measured retrofit isolation	Measure wattages and run hours	Visual inspection
2	Provide red plug and green plug systems for workstations, patient rooms, work rooms. Red outlets never turn off, rest of equipment can all be switched off together to create a "room off" mode when not in use.	Medium	Medium	BAS control logic and/or data trending and review	Whole-building approach	Utility data analysis <or> building simulation	BAS control logic and/or data trending and review
2	Replace windows and frames with double-paned low-e, vinyl-framed windows, with high visible light transmittance	Low	Low	Visual inspection	Whole-building approach	Utility data analysis <or> building simulation	Regular maintenance
2	Install exterior automated louver shading systems on all sun-exposed windows	Medium	Medium	Short-term testing	Whole-building approach	Utility data analysis <or> building simulation	BAS control logic and/or data trending and review
2	Replace standard boilers with right-sized high-efficiency condensing boilers	High	High	Short-term testing	Option B — Fully measured retrofit isolation	Measure wattages and run hours	BAS control logic and/or data trending and review

Table 5–4 M&V Measures for Common EBCx (Tier 1) and Retrofit (Tier 2) Improvements (cont'd)

Tier	Description	EEM Information		OV Activities	SV Approach	SV Activities	Ongoing Performance Assurance
		Savings Impact	Performance Variability				
2	Decouple heating and cooling from ventilation and use radiant heating and point-of-use cooling (fan coils or radiant panels or surfaces)	Medium	Medium	Visual inspection	Whole-building approach	Utility data analysis <or> building simulation	Regular maintenance
2	Install a heat recovery chiller for process heating loads	Medium	Medium	Short-term testing	Option B — Fully measured retrofit isolation	Measure wattages and run hours	Regular maintenance
2	Install chilled beam cooling system for patient rooms (if codes allow)	Medium	Medium	Sample spot measurement	Whole-building approach	Utility data analysis <or> building simulation	Regular maintenance

Measure Characterization

Before the verification approach and supporting activities were specified, the characteristics of the individual EEMs as well as the overall package were considered. As previously discussed, the ultimate aim of M&V is to effectively balance the risk of losing savings against the cost needed to verify them. This risk is tied to the amount of anticipated energy cost savings and to the performance variability of the measures.

- **Energy cost savings impact** has been defined as low (0%–1%), medium (1%–3%), and high (> 3%) based on the overall retrofit cost savings.
- **Performance variability** has been defined as low, medium, and high, and is based on level of variability in the performance of the EEM, which may be influenced by hours of operation, user interaction, control sequences, or part-load performance. This criterion defines the likelihood that savings will vary from expectations because performance-related assumptions differ from actual. The performance of certain EEMs, such as envelope improvements, is static and should be as anticipated for an extended period of time if properly installed. These EEMs are ranked as low. EEMs that could vary in performance because of differences in operating hours or efficiency, but not likely both, are ranked as medium. These EEMs include automated measures that could be disabled or changed, such as adjustments to control set points. EEMs that could involve a wide range of efficiency with associated operating hours, such as VSDs, are ranked as high.

Operational Verification

OV should be performed as part of any project M&V program. It serves as a low-cost initial step for realizing savings potential and should precede SV activities. A range of OV methods can be applied, as outlined in Table 5–5. The approach selected will depend on the EEM's characteristics. However, it can also be influenced by the SV approach. For example, if Option B is being used to verify savings, a simple visual inspection may suffice for OV. However if Option A is applied, short-term testing might be conducted so that the EEM's performance characterization is complete.

Table 5–5 OV Approach and Application

OV Approach	Typical EEM Application	Activities
Visual inspection	EEM will perform as anticipated when properly installed; direct measurement of EEM performance is very difficult or impossible; examples: wall insulation, windows	View and verify the physical installation of the EEM
Sample spot measurements	Achieved EEM performance can vary from published data based on installation details or component load; examples: fixtures, lamps, ballasts, fans, pumps	Measure single or multiple key energy-use parameters for a representative sample of the EEM installations
Short-term testing	EEM performance may vary depending on actual load, controls, and/or interoperability of components; examples: Daylighting sensors and lighting dimming controls, VSD fans	Test for functionality and proper control. Measure key energy use parameters. May involve conducting tests designed to capture the component operating over its full range or performance data collection over sufficient period of time to characterize the full range of operation.
BAS control logic and/or data trending and review	EEM performance may vary depending on actual load and controls. Component or system is being monitored and controlled through the BAS; examples: demand control ventilation, boiler staging	Set up and review BAS data trends and/or BAS control logic. Measurement period may last for a few days to a few weeks, depending on the period needed to capture the full range of performance.

Savings Verification

Including an SV component as part of the project M&V is critical for some applications (e.g., ESPCs or LEED 2009 Design & Construction Energy & Atmosphere Credit 5 adherence). For small projects and EEMs with little savings potential or variability, only the simplest SV methods may be justified. Typically, SV is not conducted for maintenance-type measures or EEMs with small savings, especially those that are challenging to measure or where it is difficult to define their baselines. The following sections discuss the SV approaches introduced in Section 5.2 in the context of a healthcare facility.

Retrofit Isolation Approach

Option A: Retrofit isolation approach is less rigorous than Option B and is applied to measures that have low savings and low performance variability. Post-installation, either performance (e.g., wattage) or operation (e.g., operating hours) is measured. The value for the nonmeasured parameter is estimated or based on baseline measurements. Healthcare facility EEMs that would use an Option A SV approach include those involving equipment replacements that maintain the same operating schedule, such as appliance replacement, most furnace and boiler replacements, and on/off lighting system replacement.

Option B: Retrofit isolation approach fully characterizes the post-installation EEM by measuring all energy use parameters (e.g., wattage and operating hours). It is most appropriate for EEMs with higher savings, higher performance, or greater operating variability. Healthcare facility EEMs assigned an Option B SV approach include those involving equipment change-outs accompanied by changes in controls or part-load performance, such as active daylighting controls, VSD chilled water pumps, VSD chillers, and supplementing direct exchange cooling with indirect evaporative cooling.

Whole-Building Approach

A whole-building SV approach is most appropriate for projects that include interactive EEMs or those for which performance improvements are challenging to directly measure. If a whole-building approach is followed, the retrofit isolation methods are generally not implemented but might be conducted for select measures to verify savings at the EEM level. When relying on a whole-building approach, it is critical to include a strong OV component that includes ongoing, data-driven activities.

Option C: Utility billing analysis is generally selected as the whole-building approach for projects where the energy cost savings are not high enough to justify the higher costs associated with implementing Option D.

Option D: Whole-building calibrated simulation analysis can be justified if the project savings are high and results from the simulation can be used to evaluate and inform the building's optimized performance.

Approach for Retrofit Packages

The M&V approach for the three tiers should include an OV component. This will ensure that energy efficiency improvements are installed and have the potential to save energy. Because of the relatively low savings and higher cost associated with a tier-1 type package, the M&V will probably not include a verified savings component. Of course, rough savings calculations can be made to see if estimates are close to expectations, but the methods will not be considered to be IPMVP adherent.

For healthcare facility projects that can justify spending $5,000 or more on M&V (e.g., at least $50,000 estimated savings), verified savings can be determined by following either a retrofit isolation approach (Options A and B) or a whole-building Option C approach. Projects with lower savings or a smaller M&V budget will need to be more targeted in their efforts. For example, these projects can focus on the EEMs that have higher impact or more variable performance, or both. It is also possible to follow Option C but also include Option A and Option B on select EEMs and a strong OV component. Supplementing Option C with additional M&V efforts may be particularly warranted if Option C reveals lower savings than anticipated. If Option C is the primary method selected for verifying savings, ongoing performance monitoring should occur during the M&V period.

For healthcare facility projects that can justify spending at least $15,000 on M&V (e.g., at least $150,000 in savings), verified savings might be determined through an Option D approach. This approach is most feasible if the project already has an energy model that is available to support M&V. The benefit of using Option D instead of Option C is that you can compare expected and actual performance for major building end uses and systems. Some discrepancies will be due to modeling operating assumptions. Others can reveal shortcomings in actual operation that can be rectified for improved performance.

Persistence

Performance assurance activities are conducted to ensure EEM savings persist once the M&V period has passed. These activities follow the same categories as those described for OV.

5.5 Additional Resources

Use these resources for more detailed information about M&V best practices for existing buildings:

The IPMVP (EVO 2010) is available at *http://www.evo-world.org/index.php?option=com_content&task=view&id=272&Itemid=279*

The Building Performance Tracking Handbook was developed by PECI for the California Energy Commission (CEC 2011). *www.cacx.org/PIER/documents/bpt-handbook.pdf*

California Commissioning Collaborative, *Building Performance Tracking Handbook*, 2011: Includes a discussion of performance tracking tools relevant to M&V activities. Available for free download online. *www.cacx.org*

U.S. Department of Energy, "M&V Guidelines: Measurement and Verification for Federal Energy Projects, Version 3.0", 2008: Guidelines and methods for measuring and verifying energy, water, and cost savings associated with federal energy savings performance contracts (ESPCs); much of the content is relevant to M&V activities in private sector buildings. Available for free download online. *www.eere.energy.gov*

ASHRAE, "Guideline 14", 2008: A standard set of energy (and demand) savings calculation procedures for M&V activities. More information available at *www.ashrae.org*.

6 Continuous Improvement Through Operations and Maintenance

6.1 What Is Operations and Maintenance?

O&M is the combination of predictive, preventive, and corrective maintenance activities that are required to keep a building and its energy systems functioning at peak performance. Operations focus on the control and performance optimization of equipment, systems, and assemblies. Proper operations help ensure that equipment efficiently produces the required capacity when needed. Maintenance typically refers to routine, periodic physical activities that are conducted to prevent the failure or decline of equipment and assemblies. Proper physical care helps ensure that equipment maintains its required capacity and that assemblies maintain their integrity. O&M is an activity that almost all healthcare facility management staff members engage in, but the nature of that engagement varies. Some engage in reactive O&M, primarily responding to complaints and breakdowns; those with a well-planned comprehensive O&M program work proactively to prevent complaints and failures.

Implementing a comprehensive O&M program with limited resources is a common challenge in healthcare facilities. All too often, a lack of sufficient funding, time, manpower, or even training prevents holistic and optimized O&M implementation. Dedicating the resources can be advantageous, though, as a well-run O&M program can achieve the following benefits (DOE 2010):

- Energy savings of 5%–20% of whole-building energy use
- Minimal comfort complaints
- Equipment that operates adequately until the end of its planned useful life, or beyond
- IAQ maintenance
- Safe working conditions for healthcare facility staff.

Optimizing a building's O&M program is one of the most cost-effective approaches to ensure reliability and energy efficiency, as these practices can often be significantly enhanced with only minor initial investments (DOE 2010). Through low-cost improvements and operational tweaks, such as those implemented as part of an EBCx process, a building's energy use can be reduced while maintaining or even improving patient and staff comfort (ASHRAE 2009a).

When planning for energy upgrades, an energy manager needs to evaluate how each retrofit will impact the O&M program, and if current O&M practices are adequate. Additional training or resources may be required to maintain the systems and assemblies affected by the upgrade, or to maintain the associated benefits. For more modest retrofits, the O&M program may not be affected, as these retrofits usually replace systems and components with similar but more efficient systems and components. However, even in these instances it is important to evaluate the sufficiency of the current O&M program and consider devoting additional planning and resources to maintain the performance and benefits of the retrofits.

6.2 Management System

Successful O&M practices require the support and coordination of many people besides the operations staff. Integration across all levels of a healthcare organization is vital to empowering the right people at the right time to produce and sustain an energy-efficient facility. Five key elements of a management system that can produce a comprehensive and optimized O&M strategy are represented by the acronym “OMETA” (Operations, Maintenance, Engineering Support, Training and Administration) (Meador 1995).

- **Operations.** Effective operations plans and protocols to maximize building systems’ efficiency
- **Maintenance.** Effective maintenance plans and protocols to maximize building systems’ efficiency
- **Engineering support.** Availability of technical personnel who can effectively carry out an O&M program
- **Training.** Adequate training facilities, equipment, and materials to develop and improve the knowledge and skills necessary to perform assigned job functions
- **Administration.** Effective establishment and implementation of policies and planning related to O&M activities.

OMETA describes the key elements of O&M management. It is also vital to establish a clear framework for communication and cooperation among the various groups included in an O&M management structure. For a healthcare facility, these groups can include:

- Building owner
- Hospital administrators
- Energy managers
- In-house operations staff
- Service contractors
- Medical staff.

An individual responsible for maintaining the lines of communication between the various groups, referred to as an in-house champion, is a critical part of this framework. This champion must be knowledgeable about the building systems and involved in decision-making related to operations. This role is vital to the O&M process, because lack of support from any element of the structure can greatly reduce the benefits of O&M and limit the ability to achieve and retain a fully optimized building.

When implementing the EBCx process or retrofits in a building, buy-in needs to be obtained from all parties associated with the O&M program to maximize the persistence of upgrade-related benefits. The O&M team needs to be closely involved in all core building-related upgrades, because its members will maintain the systems and assemblies and ultimately define the sustainability of upgrades.

An additional O&M management consideration is how O&M can be affected if responsibilities are outsourced to a maintenance management firm, as is often the case with smaller outpatient facilities. These firms are often highly skilled and capable of implementing advanced O&M programs, but will do so only if it is specified in the service agreement. Building owners can review their existing service agreements and talk to their service providers to determine the currently contracted level of O&M activity and what may be lacking. When entering into a new service agreement, building owners are encouraged to seek out vendors that offer comprehensive O&M services.

6.3 Program Development

Implementing an O&M program serves a crucial role in an energy upgrade—upgrades provide an initial efficiency boost, and a good O&M program will ensure the savings persist. All building systems degrade over time—light output decreases through natural lumen depreciation and dirt buildup, control systems drift from set points, occupants override or disable optimal control settings, heat exchangers become fouled, and motors and drives wear out. Dozens of other problems can also arise.

A good O&M program anticipates all the expected degradations and monitors building status to catch the unexpected ones. The action items can be proactive, such as prescheduled preventive maintenance plans, and reactive, responding to problems as they arise.

For an O&M program to be successful, planners and participants must understand all the building systems and equipment and how they are operated and maintained. Most building systems interact with each other, so if one is operating inefficiently, others may follow suit. For example, if a building's lighting system is providing more light than necessary, the HVAC system will have to compensate for the additional heat added. Or, if building static pressure controls are not operating properly, the infiltration of unconditioned air will put an extra load on the HVAC system. These kinds of interactions can be hard to detect without a comprehensive approach to O&M.

Managers at Kalispell Regional Medical Center decided to work with the Northwest Energy Efficiency Alliance's BetterBricks initiative to improve its O&M practices and cut energy use. By conducting a number of operational improvements such as scheduling AHUs for certain areas to be off during nights and weekends, cleaning airflow sensors to restore accuracy (yielding slower fan speeds), correcting one AHU return fan that was operating in reverse, and reworking boiler controls to improve sequencing, Kalispell Regional Medical Center saved 550,000 kWh and 32,000 therms in 2010 (BetterBricks 2011b).

Developing an Effective Plan

Successful O&M starts with the energy upgrade plan—O&M is easier if it is considered in advance. A good program also requires defining and communicating the goals, and identifying partners who may either participate in, or contribute to, the program.

Design for maintenance. The best results come about when maintenance is addressed from the start of the energy upgrade process. For example, a lighting upgrade can include components that minimize lumen degradation, offer long lamp life, and minimize the number of different lamp types that must be stocked. If upgraded HVAC equipment is different in shape or size from current equipment, designers should make sure that there is still easy access for cleaning coils and filters. Coils and filters should be selected to minimize maintenance costs in the expected environment—dry versus humid, clean air versus dirty, and other factors.

Set goals. O&M program goals are to maintain the improved operational efficiency of building systems. Normal equipment degradation and building occupant adjustments can quickly reduce the benefits after an upgrade. O&M goals will guide building staff as they develop regularly scheduled maintenance activities to actively monitor building systems.

Establish communication. An O&M program will be most successful if all parties are informed of the goals and expected benefits—from hospital administration and facility managers to doctors, nurses, and service-based employees. It is also important to emphasize that savings might not be realized immediately but will accrue over time. A strong O&M program is one of the most cost-effective methods for maintaining or boosting energy efficiency, as well as ensuring the reliability and safety of a building's systems. Communicating this fact early on is crucial to a program's success (PNNL 2010).

Engage partners. The right team members for an O&M program increase its effectiveness. Owners, facility managers, building maintenance staff, and any other parties involved in hospital or medical center operations should be represented. Staff members with extensive knowledge of the building and its systems can add tremendous value when determining the objectives of the program and the implementation schedules.

The participation of other parties outside the facility often helps, particularly if staff members lack the expertise or time to carry out all aspects of the O&M program. Contact local utilities early in the process about options for obtaining energy use data in the most useful format. Sometimes utilities offer technical assistance with issues that arise during O&M implementation, such as interpreting submetered data and peak shaving impacts.

External consultants with O&M program experience can help hospitals set up, implement, and manage an O&M program. Facility managers and O&M staff can also look outside their own facilities to find other hospitals or medical facilities with active O&M programs and learn from their experiences. The *Better Bricks for Healthcare* (*www.betterbricks.com/healthcare/how-get-there*) program and the *Green Guide for Health Care* (*www.gghc.org/tools.overview.php*) both offer resources such as case studies and best practices that can assist hospitals that are interested in developing an O&M program. Another option for hospitals is DOE's *Better Building Alliance—Healthcare Sector* (*www1.eere.energy.gov/buildings/commercial/bba.html*), a collaborative group of hospitals and healthcare systems that focuses on energy-efficient design and operation of medical facilities. The alliance publishes an annual report summarizing the latest resources available to the sector, along with future research priorities (DOE 2012).

Be flexible. An O&M program should be flexible enough to adapt to changes that occur at a facility over time. These can include O&M and retrofit EEMs that are implemented throughout the life of the facility, such as those discussed in this guide. As EEMs are implemented, the O&M program should be revised to address the related equipment and assemblies. This will help maintain the capacity, reliability, and performance—including energy performance—of all building systems.

Training

Hospital administration and building staff need training on how to maintain optimum building operations after the upgrade. For major projects, the new systems will go through a commissioning process; the commissioning agent should also provide operator training. A hands-on workshop is an effective way of teaching staff members how to properly maintain and operate building equipment. By covering topics such as energy use and expected improvements, the training ties operations to maintenance. It is especially important that the maintenance staff members are trained in the operation of control systems and that they are properly motivated to optimize the system operations. Consider recording these training sessions as a resource for future training sessions.

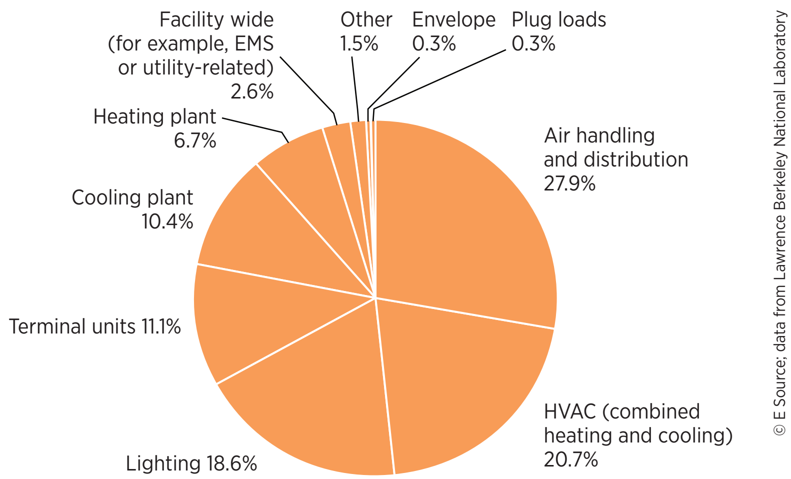
All employees must also be educated to understand how their actions impact the O&M program. Their contributions made during daily activities in the building are important to the program's overall success. The most successful O&M measures can be rendered ineffective by careless occupant behaviors; thus, training staff about the O&M measures and how their actions can affect measure effectiveness is vital.

Building Operator Certification (Northwest Energy Efficiency Council 2013) courses provide training in many locations around the United States. This series is designed to help building operators improve their ability to operate and maintain comfortable, efficient facilities.

Training should cover maintenance requirements for all equipment and systems. Those requirements should be performance-based rather than simple checklists—the intent is not to have maintenance personnel simply go through a set of steps, but to make sure that the desired performance result is achieved.

Recommissioning

Regular recommissioning can serve as the foundation of a good O&M program. An effective healthcare facility upgrade begins with an RCx effort that identifies building equipment upgrades and finds areas where building systems are not operating as planned (see Section 3). O&M programs identify low-cost and no-cost ways to maintain changes made as part of the RCx effort. Recommissioning will detect and correct any major systemic problems that develop over time, and ensure that savings persist. Timing for recommissioning will vary, but every 3–5 years is a typical recommendation. If utility bills are higher than expected, employees and patients are complaining about comfort, or O&M staff are constantly repairing the same equipment, it might be time to consider recommissioning. According to Mills (2009), RCx and recommissioning yield average whole-building energy savings of 16% and a simple payback of 1.1 years. Seventy-seven percent of problems identified were related to the HVAC system (see Figure 6–1). The most common deficiencies were sensors in need of calibration, and blocked or leaky ducts.



Note: EMS = energy management system.

Figure 6–1 Breakdown of common commissioning problems by system type

Ongoing commissioning can sometimes be a cost-effective approach as well. Monitoring equipment is installed to gather ongoing diagnostic information and signal when actions are required. This approach works best in hospitals or healthcare facilities with modern EMSs, and where staff is committed to the energy upgrade process. An up-to-date EMS provides a wide range of control strategies and usually tracks most of the data needed for diagnostics.

Good Operations and Maintenance Practices

The O&M program covers overall systems and building policies as well as specific areas, including lighting, HVAC, water heating, and miscellaneous systems.

Overall Systems and Policies

A good O&M program starts with collecting and creating O&M resource documents. It also covers BAS or EMS, and includes an O&M-friendly purchasing policy.

Collect reference materials. O&M staff members rely on equipment lists and reference manuals for the information they need to operate and maintain building systems and equipment. The upgrade process provides facility managers the opportunity to evaluate the status of O&M documentation and update or create new references as needed. Equipment lists provide basic information about each piece of equipment, including:

- Manufacturer's name
- Name plate information
- Unique name/number (if necessary)
- Vendor's name
- Installation date
- Location in the building.

Reference manuals should also be on file for all building systems. These could be equipment manuals from the manufacturers or system control documents explaining the new set points and operation sequences in place after the upgrade. The U.S. Department of Health and Human Services provides a blank template that O&M staff can fill in for each system and piece of equipment (HHS 2011). The template supplies sections for system descriptions, use, and maintenance, among other items. O&M staff can use these sections to help guide them to all the information necessary for a reference manual. O&M staff should also keep an open journal or log for each piece of equipment or system to chronicle all maintenance activities.

Use an EMS. When introducing a new O&M program, take advantage of any EMS that might be in place. One survey of 11 buildings with EMSs in New England found that five were not fully utilizing their EMSs, achieving only 55% of expected savings. Furthermore, one building realized no savings because operators never correctly implemented the intended EMS control strategies (Wortman et al. 1996). An EMS comprises automated systems that can be programmed to control setbacks, shutdowns, and startups, as well as other energy-saving actions. An EMS may have automated diagnostic capabilities to alert O&M staff of impending operational issues or other problems that are difficult to diagnose. It can also collect performance data that can be further analyzed for operational performance evaluation and benchmarking purposes. These systems can be costly and require intensive staff training, but when properly used, they help increase a building's efficiency.

Establish a green purchasing policy. Using inefficient replacement parts can undermine energy-saving efforts. A purchasing policy that emphasizes efficiency can ensure that only the most efficient options are used. For example, if a building upgrade includes the installation of high-performance T8 lamps, the purchasing policy should ensure that only those lamps are in stock. That way, if a nurse reports a lamp burnout in a common area or patient room, only the efficient version will be available to replace it.

The policy should also consider maintenance requirements for each item. Procurement staff should evaluate maintenance records and useful life of potential items and stock only those with proven track records. Procurement plans can decrease repair and replacement times by requiring the purchase of efficient items that need little or no maintenance. For example, purchasing air filters with three months of useful life that offer equivalent performance to filters with only one month of useful life will provide O&M staff additional time for other priorities.

ENERGY STAR and FEMP provide purchasing and procurement resources that can help organizations find energy-efficient products. These include lists of qualifying products, key product criteria, drop-in procurement language, and savings calculators. See the list of *ENERGY STAR products* (*http://www.energystar.gov/index.cfm?fuseaction=find_a_product.&s=mega*) (EPA 2011h) and visit the *FEMP website (www1.eere.energy.gov/femp/technologies/procuring_eeproducts.html*) (FEMP 2011) for products not covered under ENERGY STAR.

Lighting

Lighting systems lose efficiency over time. Some of these losses are inevitable—light sources naturally degrade as they age. But other efficiency losses—dirt accumulation on fixture lenses, reflectors, and lamps, or controls drifting out of calibration—can be avoided with regularly scheduled maintenance.

Clean. Lighting levels can decrease by as much as 15% without proper cleaning. Cleaning dirt and dust off lamps and their covers keeps light output at the maximum level. Lighting covers and diffusers darken with age and will eventually need replacement, but regular cleaning should extend their useful lives. Cleaning is most effective when built in with another O&M program, such as group relamping.

Check light levels. Once lights have been replaced and cleaned, measure the lighting levels to determine whether they are appropriate for the tasks performed in that space. Overlit and underlit areas should be adjusted to provide appropriate light levels.

Establish a group relamping program. A planned group relamping program is typically more cost effective than spot replacement of burned-out lamps. With group relamping, a number of lamps are replaced at the same time—usually at 60%–80% of rated lamp life. This process usually results in higher lamp costs, which are typically more than offset by lower labor costs. Healthcare facilities will also enjoy brighter and more uniform lighting because all lights will be replaced at similar points in the degradation process, before their output fully degrades. Another benefit is that additional lighting O&M activities, including cleaning and ballast inspection, can be coordinated with relamping.

Inspect controls. Inspect lighting control systems regularly to ensure that lights are off when spaces are unoccupied or to take advantage of daylighting opportunities. Evaluate and adjust automatic timers as needed and push the start time back as late as possible. Nighttime and outdoor lighting should be minimized as much as safety and local ordinances allow.

Heating, Ventilation, and Air-Conditioning

O&M activities for the HVAC system can have a large impact on building efficiency and comfort, considering that the heating and cooling systems typically account for more than half the energy consumed by hospitals and other healthcare facilities.

Maintain boilers. Boilers are commonly used to provide heating in hospitals, and usually consume more energy than any other piece of equipment. Boilers require regular maintenance throughout the year, and some states require regular inspections. The operating manual should provide tests and procedures for scheduled maintenance. Other good practices for boilers include:

- Review boiler controls to identify any unused efficiency strategies, such as OA reset, OA high temperature shutoff, and optimization of multiple boiler systems. If these strategies are not available in the onboard boiler controls, they can be added later as retrofits.
- Develop a program for treating makeup water to prevent equipment damage and efficiency losses.
- Install a boiler combustion monitoring system or have O&M staff periodically check the air-fuel ratio.
- Inspect set point temperatures and reset the boiler to the minimum required pressure if no temperature or pressure reset controls are in use.
- Initiate a steam trap maintenance program to identify and repair steam trap leaks.
- Conduct pressure relief valve and condensate pump system maintenance to ensure long term boiler performance.

Maintain furnaces. O&M programs for furnaces are similar to those for boilers. The manufacturer's operating manual should provide normal operation guidelines. O&M staff should also check for gas leaks regularly, inspect limit devices and flame sensors, and check the flue for blockage. Installing controls to set back the supply temperatures during unoccupied periods will help save energy as well.

Inspect cooling equipment. Refrigerant charge should be checked regularly, as over- and undercharged systems can significantly reduce efficiency. Regular inspections should also help O&M staff identify leaks. O&M staff should also conduct regular cooling tower maintenance and chilled water quality checks, including water treatment and filtration to prevent scale buildup and fouling.

Test AHUs. Airflow rates should be tested every few years to confirm that they meet minimum requirements. Lowering ventilation rates can save energy, but can also decrease IAQ. The right balance will depend on occupancy levels and climate. Desired airflow rates for each system should be stated in the O&M reference documents.

Maintain economizers. Economizers use controlled dampers to automatically open and close as indoor and outdoor conditions dictate. By design, they house many moving parts. Cleaning, lubricating, and inspecting these parts three or four times per year can keep the dampers from sticking in any position.

Inspect and clean coils. Dirty condenser and evaporator coils reduce airflow and cooling capabilities. Inspect both regularly and clean as necessary.

Inspect and clean fans. Cleaning fan blades annually can extend the life of the fan and gives O&M staff the chance to inspect for chips or cracks. Inspect the bearings and lubricate as the manufacturer recommends, usually at no longer than 6-month intervals. Examine the belts for wear and appropriate tightness.

Replace air filters. Dirty air filters block the airflow through the system. This blockage requires more power from the fan motor to push the air through. Consider using filters with larger cross-sections because they use less energy to move air through the filter. Most filters need to be replaced every 1–3 months as recommended by the manufacturer. O&M staff should inspect filters regularly and replace as needed.

Inspect air ducts. Air leaks can drastically reduce cooling system efficiencies. O&M staff should inspect all access panels and gaskets for leaks at regular intervals at least once each year. The entire duct system should also be inspected regularly, although not as frequently. Look over appropriate areas to ensure that nothing blocks access panels or air intakes.

Maintain controls. Regular maintenance of control systems is crucial because occupants may have changed settings or the systems may be defective or have drifted out of specification. Ensure that system settings are determined with energy efficiency in mind; O&M staff should test and verify all systems periodically, particularly those affected by seasonal changes.

Water Heating

Water heating is the next-largest energy consumer in healthcare facilities behind lighting and space heating (DOE 2003). Inspecting and evaluating the water heating and delivery system will prevent energy losses and extend equipment life.

Check storage tank insulation. Storage type water heaters can lose efficiency through heat loss from the water stored in the tank. If insulation was added as part of an energy upgrade, check to make sure its integrity is maintained.

Check pipe insulation. Hot water delivery pipes, particularly those in unconditioned spaces, should be insulated to minimize uncontrolled loss of heat from the system and reduce wait time at the fixtures. O&M staff should inspect this insulation regularly because it will deteriorate over time.

Tune up burners. Gas- and oil-fired burners should be tested and adjusted annually to maintain optimum operating efficiency.

Flush hot water fixtures. Hot water fixtures should be flushed occasionally to control bacteria growth. Water heaters with storage tanks should be flushed out annually to remove any sediment that reduces the system's heat transfer efficiency.

Reduce water use. Reducing hot water use throughout the building will lessen the water heating load. Finding and repairing leaks will also reduce the water heating load. If possible, consider turning off hot water zones or systems if the areas served are not occupied.

Miscellaneous

The O&M program should also cover a number of other areas, including the building envelope, plug loads, kitchen, and laundry equipment.

Seal the building envelope. Eliminate air and water leaks by sealing the building envelope. Inspect doors, windows, roofing, and the foundation for leaks and repair using caulking or weather-stripping. Complaints about drafty areas will help O&M staff locate these leaks. Other signs, such as doors that do not fully close and water marks on walls or ceilings, are indicators of an inefficient or leaky envelope.

Manage plug loads. Plug loads refer to the electricity drawn by any device plugged into a wall outlet. Managing these is vital for an effective O&M program. Employees need to participate because they are the most aware of plug loads and have the greatest ability to limit them. Turning computers and monitors off when not in use can save significant energy. Even setting computers to "hibernate" mode after periods of inactivity will reduce their power draw. Using smart strip surge protectors in equipment-heavy rooms, such as computer rooms, will help eliminate phantom loads, the power drawn by certain appliances when turned off or in standby mode. Simply unplugging devices when they are not in use can also help reduce energy consumption. McKenney et al. (2010) studied common plug loads in commercial buildings. This report can help O&M staff estimate how much standby power is being consumed throughout the building.

Clean kitchen appliances. Cleaning vents and heating coils will increase the efficiency of kitchen equipment. Ensuring that condenser coils are clean and unobstructed can keep refrigerators and freezers operating at maximum efficiency.

Maintain laundry equipment. Medical facilities with onsite laundry operations should consider a service contract for laundry equipment maintenance. As time passes, operational functions of timers, temperature settings, and spinning speeds, can fail. Unless building staff are trained to service and maintain laundry equipment, an annual service contract may be needed.

6.4 Additional Resources

Use these resources for more detailed information on O&M programs for healthcare facilities:

Building Upgrade Manual from ENERGY STAR, a strategic guide for energy saving building upgrades. *www.energystar.gov/buildings/tools-and-resources/building-upgrade-manual*

Operation and Maintenance Systems—A Best Practice for Energy-Efficient Building Operations: A manual from PECI that explains where to begin the process of developing an O&M program. *www.energystar.gov/ia/business/assessment.pdf*

Operations & Maintenance Best Practices – A Guide to Achieving Operational Efficiency, Release 3.0: A guide from the Federal Energy Management Program, that offers extensive discussions of best practices and O&M tips for many types of building equipment and systems. *www1.eere.energy.gov/femp/pdfs/omguide_complete.pdf*

A Retrocommissioning Guide for Building Owners: A guide from PECI that explains the retrocommissioning process, including a section on maintaining benefits long after the commissioning process is complete. *www.peci.org/sites/default/files/epaguide_0.pdf*

Better Bricks: An initiative, managed by the Northwest Energy Efficiency Alliance (NEEA), aimed at improving energy efficiency in commercial buildings. It offers a section dedicated to hospitals and healthcare facilities. *www.betterbricks.com/healthcare*

Green Guide for Health Care: A product of two non-profit organizations: Health Care Without Harm and Center for Maximum Potential Building Systems. The objective of this project is to advance the sustainable operations of healthcare facilities. *www.gghc.org/tools.overview.php*

Department of Energy Better Buildings Alliance. The DOE Better Buildings Alliance for the Healthcare Sector brings together leading hospitals and national associations in a strategic alliance designed to improve energy efficiency and reduce greenhouse gas emissions of healthcare systems throughout the country. *www4.eere.energy.gov/alliance/sectors/private/healthcare*

Building Operator Certification: BOC courses provide training for building operators to improve their ability to operate and maintain comfortable, efficient facilities. *www.theboc.info/*

ENERGY STAR Purchasing & Procurement: A webpage from ENERGY STAR that compiles ENERGY STAR qualified products as well as resources for developing efficient procurement policies. *www.energystar.gov/index.cfm?fuseaction=find_a_product.&s=mega*

Procuring Energy-Efficient Products: This webpage from FEMP is similar to the ENERGY STAR procurement page, with more information on procurement policies and energy-efficient product categories outside of ENERGY STAR. *www1.eere.energy.gov/femp/technologies/procuring_eeproducts.html*

BOMA, “Preventive Maintenance: Best Practices to Maintain Efficient & Sustainable Buildings”: A comprehensive guide to establishing and implementing a preventive maintenance program. Available for purchase online. *www.boma.org*

California Commissioning Collaborative, “Building Performance Tracking Handbook”, 2011: A guide to utilizing building performance tracking to maximize savings from energy upgrades. Available for free download online. *www.cacx.org*

PNNL: “Maintaining the solution to Operations and Maintenance efficiency improvement”, 1995: defines the key elements of a holistic approach to O&M management: Operations, Maintenance, Engineering Support, Training and Administration (OMETA). Available for free download online. *www.pnl.gov/dsom/publications/26005.pdf*

7 Conclusion

In the United States, inpatient and outpatient healthcare facilities spend $8.8 billion/year on energy (Benz and Rygielski 2011). The average hospital spends $675,000 on energy costs annually, exceeding the per-building energy costs of other building types by a factor of 10 (DOE 2003). As a result, healthcare facilities present many opportunities for energy efficiency improvements. This guide demonstrates that significant energy savings are relatively easy to achieve through EBCx, and that greater savings can be accessible for owners who are willing to use a whole-building or staged approach to invest in holistic retrofit projects. The rigorous financial analysis methods presented in this guide show that the long-term benefits from these retrofits considerably outweigh the costs. Rising energy costs, climate risks, regulatory risks, and growing market value placed on sustainability are other drivers moving building energy upgrades from a niche activity to an essential constituent of a comprehensive program to provide the highest quality patient healthcare while maintaining market competitiveness.

When analyzed in the context of the example small hospital, energy savings of 14%–25% for EBCx, and of 2%–18% for whole-building retrofit packages were identified (see Figure 7–1). For reference, the energy savings for the new construction packages recommended in the 50% Large Hospital AEDG (ASHRAE 2012) are also shown in the graph. Although the percent energy savings for the example retrofit packages are low in some climates, the dollar value can be high ($450,000 for 2.1% energy savings in Miami), and actual buildings are likely to present many additional retrofit opportunities beyond the limited number considered in the example analysis. Energy savings for retrofit packages are independent of EBCx, and the combined package will result in even higher energy savings, though less than the sum of the two separate packages, because the benefit of certain EBCx measures may be consumed by retrofit EEMs for the same system (such as cleaning or delamping lighting systems before replacing them entirely). The modeling of retrofits was very conservative for the example building, because many EEMs that are appropriate for comprehensive renovations (such as major equipment replacements and enhanced daylighting) were not considered, and an integrated design approach that considered the interactions among EEMs was not applied. Additional savings opportunities are very likely when applied to an actual healthcare facility, when all retrofit EEMs are considered, and when available financial incentives are included.

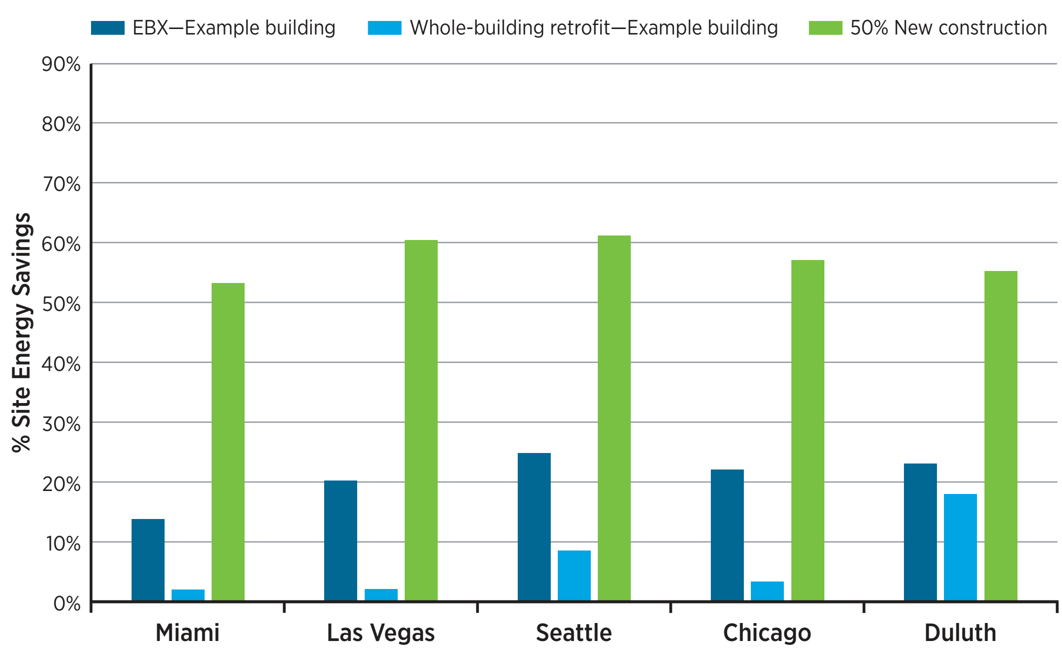


Figure 7–1 Site energy savings for example hospital

Conclusion

Policymakers may be interested in the source (or primary) energy savings associated with the recommended packages for the example building. Source energy includes the energy used on site, along with the energy lost or consumed during the generation, transmission, and distribution processes. The source energy multiplier for electricity is about 3.4, and the multiplier for natural gas is about 1.1. The energy savings expressed in terms of source energy are shown in Figure 7–2.

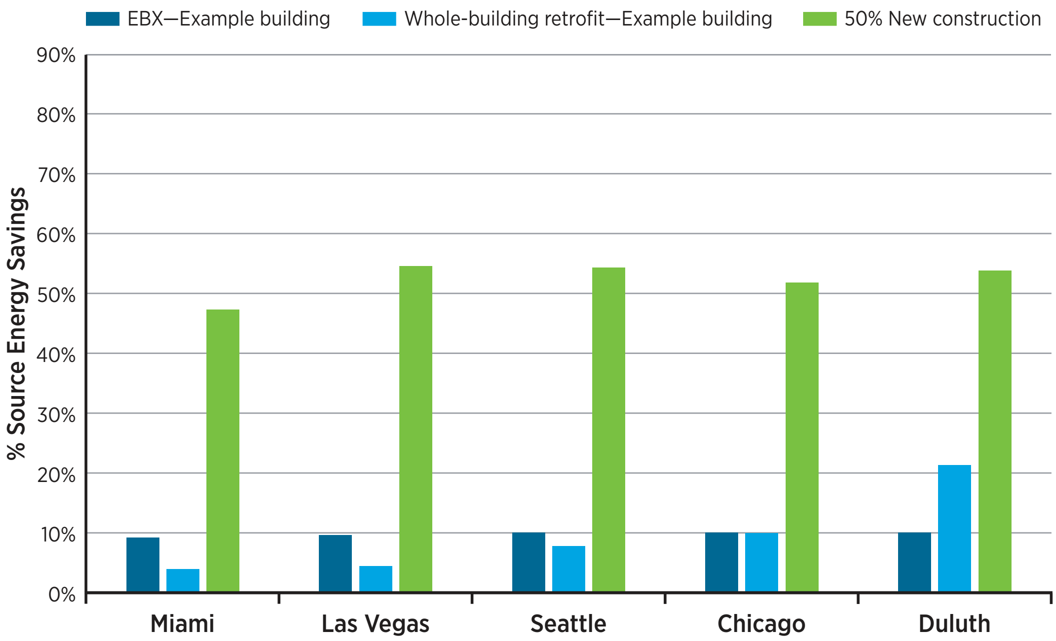


Figure 7–2 Source energy savings for example hospital

Although most would agree that improving building performance is the right thing to do, and acknowledge the wide range of options, navigating those options and developing a profitable long-term strategy have been far from easy. This guide breaks down the myriad options into prioritized retrofit EEMs and recommended packages adapted to a typical healthcare facility, providing a strong start to an aggressive building upgrade plan that saves energy and improves the performance of the facility and the well-being of patients and staff. The guide also presents cost-effectiveness metrics for each package that recognize the complexity of economic decisions related to healthcare investments.

Even the most compelling business case might fall short of success without sound planning and implementation. Therefore, this guide describes proven approaches to project planning and execution. Healthcare facility energy managers can drive their buildings toward higher performance by setting goals, creating a long-term plan, and carefully tracking progress. The roadmap presented in this guide can help energy managers recognize the opportunity and embark on the full journey that leads to high performance.

A wide array of resources is available to energy managers who seek to enhance the performance of healthcare facilities. This guide includes links to a host of other resources that energy managers may wish to consult. With the help of information and assistance offered by many government agencies, utility companies, and other organizations, nearly every healthcare facility energy manager is within easy reach of an energy savings project.

We hope this guide will give energy managers, healthcare professionals, and building owners the confidence to take or support aggressive actions to improve the energy efficiency of their healthcare facilities, and will be a valuable reference as building improvement projects are implemented.

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Appendix A

Cost-Effectiveness Analysis Methodology

The economic analysis of retrofit measures is one of the most challenging topics to address in a guidebook, yet is essential for building owners or facility managers who are trying to develop a convincing business case for a retrofit project. This guide provides clear methodologies for calculating both NPV and simple payback period. NPV is the preferred metric because it better captures the full range of benefits and costs associated with an investment over time, but simple payback remains the most commonly used metric for quantifying the cost effectiveness of energy retrofit projects.

In this appendix, the economic analyses of retrofit EEMs are addressed in a much more practical manner than has been attempted in other retrofit guides. Methods for accurately quantifying multiyear cash flows are provided, including energy costs, demand reduction, replacement costs (including reduced energy savings if more efficient equipment is required by code), salvage value, O&M costs, and M&V costs. Techniques and references are also provided for capturing the effect of temporary financial incentives offered by government agencies or utilities (such as rebates, low-interest loans, and tax credits) on multiyear cash flows. Although it can be challenging to quantify the cash flows associated with a project, many tools, including the free *LCCAid tool* (*www.rmi.org/ModelingTools*) developed by RMI, are available to help you calculate NPV and simple payback.

The recommended methodology described in this guide has been applied to an example hospital (see Appendix B), resulting in the selection of building improvement packages for retrofit projects in five locations. The example illustrates the economic analysis and EEM selection process in the context of a realistic scenario and provides an idea of the energy savings potential of the EEMs described in this guide. However, certain EEMs may be highly cost effective in the example building, but may be very poor choices in a different situation. Age of equipment, cost structure, financing terms, tax incentives, local weather conditions, and system interactions can have very large impacts on the cost effectiveness of a particular EEM.

A.1 Overall Net Present Value Calculation

As discussed in Section 2.6, NPV is the financial analysis metric that best captures the full economic value of a retrofit EEM or package of EEMs from the healthcare facility's perspective, especially when evaluating a staged retrofit. NPV is an integral component of LCC analysis, but the example analysis is limited to direct costs and benefits that impact a healthcare facility's budget. Societal and environmental costs are not addressed, except to the extent they are reflected in taxes, financial incentives, purchase costs, and disposal costs.

Equation A–1 provides the general definition of NPV used in this guide:

$$\mathrm{NPV} = C_0 + \sum_{t=1}^{N} \frac{C_t}{(1+DF)^t} \tag{A–1}$$

Where:

C_0 = initial investment and related cash flows in Year 0

C_t = sum of cash flows in Year t (current year dollars)

t = years after initial investment

N = number of years in analysis period

DF = real discount factor (does not include inflation)

A 20-year project analysis period is recommended. This is longer than the useful life of most EEMs that will be evaluated, and provides a fair cutoff point for energy savings and other benefits associated with an EEM. Major remodeling or other modifications to a building or its use are likely beyond a 20-year timeframe, which would negate the value of many retrofit EEMs. Finally, cash flows beyond 20 years are significantly discounted in the NPV calculation, and no longer hold much weight in the analysis.

DF is defined as the minimum rate of return required by the building owner, and is usually equal to the return that can be expected from alternative investment opportunities with similar risk. The appropriate DF can vary wildly depending on the risk tolerance of the building owner, type of financing, uncertainty in energy savings, and alternative investment options that may be available. For healthcare facilities owned by the local government, a religious institution, or some other nonprofit organization, a relatively small DF is usually appropriate (3%–5%). Larger DFs (7%–10%) are appropriate for private-sector, for-profit hospitals and outpatient facilities. If the required simple payback for an organization is known, the corresponding DF can be estimated using the graph in Figure A–1. This correlation was developed by calculating the internal rate of return over a 20-year period for a simple investment in Year 0 followed by a stream of equal positive cash flows consistent with the required payback period. The implied DF is that which, when applied to these cash flows, would result in an NPV of zero.

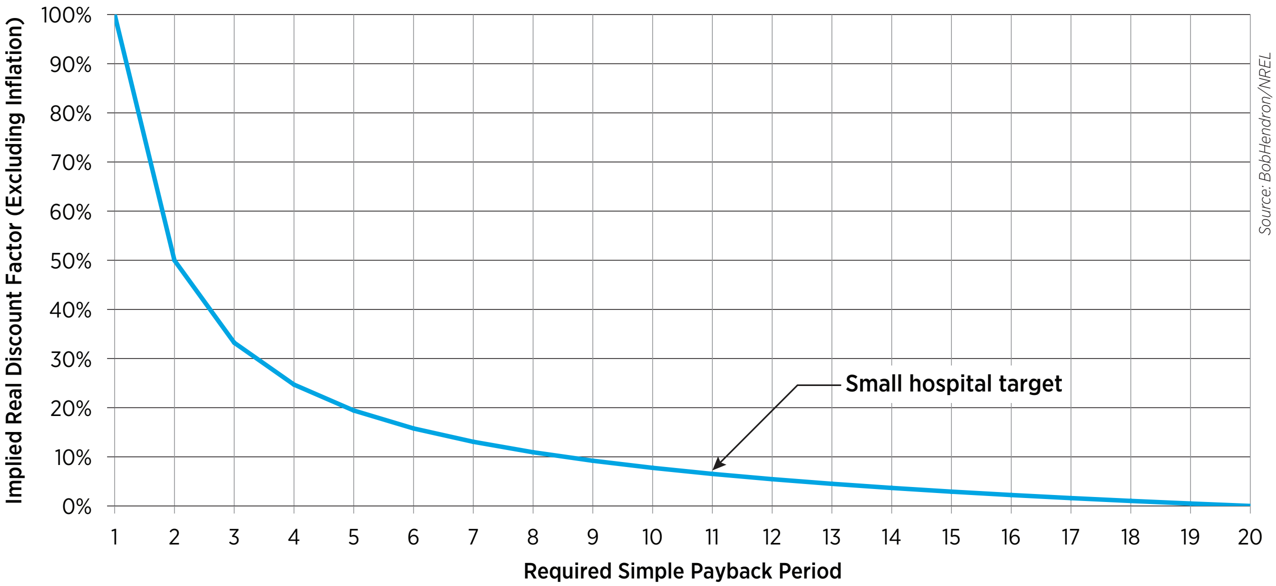

Figure A–1 Implied real DF as a function of required simple payback period (assumes investment in Year 0 with constant return for 20 years)

A recent study conducted by LBNL examined 1,634 retrofit projects performed by ESCOs throughout the United States, including 106 projects in hospitals and outpatient facilities. The study indicated that the median simple payback for retrofit projects in healthcare facilities is approximately 5 years, and 25% of the projects in the study had simple paybacks exceeding 11 years (Hopper et al. 2005). Because this guide targets relatively aggressive energy savings, an 11-year maximum payback period is recommended. According to Figure A–1, a required simple payback of 11 years is roughly equivalent to a 6% DF.

A.2 Components of Multiyear Cash Flows

Many cash flows, both positive and negative, can be associated with a particular retrofit EEM. Positive cash flows represent net inflows of money; negative cash flows represent net outflows or costs. All cash flows are "net" cash flows relative to the reference case. A positive cash flow may be a direct inflow of cash to an organization, such as the sale of equipment or a rebate from the utility company, or it may represent an avoided expenditure, such as energy cost savings or not purchasing replacement equipment when the original equipment would have reached the end of its useful life. Equations A–2 and A–3 identify the cash flows that are the most important for a meaningful NPV calculation. The cash flows are assumed to be in current year dollars (they do not include the effects of inflation).

$$C_0 = -C_{pur} - C_{inst} + C_{salv,ref} + C_{tax,0} + C_{incent} - (C_{disp} + C_{plan}) \times (1 - R_{tax,inc}) \qquad \text{(A–2)}$$

Where:

C_{pur} = purchase cost of equipment

C_{inst} = installation cost of EEM/package

$C_{salv,ref}$ = salvage value of existing equipment

$C_{tax,0}$ = tax benefits associated with disposing of existing equipment

C_{incent} = NPV of financial incentives (rebates, tax credits, etc.)

C_{disp} = disposal cost of existing equipment

C_{plan} = cost of project planning (= 0 for individual EEMs)

$R_{tax,inc}$ = federal corporate income tax rate (= 0 for most nonprofit healthcare facilities, 35% for large for-profit healthcare facilities)

$$C_t = [C_{energy,elec} \times (R_{esc,elec,t})^t + C_{energy,gas,t} \times (R_{esc,gas})^t - C_{om} - C_{mv}] \times (1 - R_{tax,inc}) - C_{repl,eem} + C_{repl,ref} + C_{depr,eem,t} - C_{dpr,ref,t} + C_{rem,eem,20} - C_{rem,ref,20} \qquad \text{(A–3)}$$

Where:

$C_{energy,elec,t}$ = annual electricity cost savings in Year t

$C_{energy,gas,t}$ = annual natural gas cost savings in Year t

$R_{esc,elect}$ = fuel price escalation rate for electricity = 0.5% (DOE 2011a)

$R_{esc,gas}$ = fuel price escalation rate for natural gas = 2.0% (DOE 2011a)

C_{om} = additional O&M costs (negative if O&M savings)

C_{mv} = additional M&V costs (= 0 for individual EEMs)

$C_{repl,eem}$ = replacement cost for EEM/package (= 0 except at end of useful life)

$C_{repl,ref}$ = replacement cost for reference case (must meet code) (= 0 except at end of useful life)

$C_{depr,eem,t}$ = tax deduction for depreciation of EEM/package in Year t

$C_{depr,ref,t}$ = tax deduction for depreciation of existing equipment in Year t

$C_{rem,eem,20}$ = remaining value of EEM (= 0 except in year 20)

$C_{rem,ref,20}$ = remaining value of reference equipment (= 0 except in year 20)

Guidance, assumptions, and technical resources for estimating each of these cash flows are presented in the following sections.

A.2.1 Purchase Cost (C_{pur})

The purchase cost of the EEM or package of EEMs includes the cost of equipment and associated materials. It does not include labor costs. If the purchase cost is financed over several years, it should be calculated as the NPV of the loan or lease payments over the term of the project. Purchase cost for a particular product or piece of equipment is relatively consistent from project to project, but may still vary depending on the financing mechanism, volume purchased, local competition, and any negotiated purchasing agreements with suppliers. For staged retrofit projects, multiple purchase costs will be applied at several points during the 20-year analysis period. For the example analysis, professional cost estimating software and databases were used to estimate purchase costs associated with each EEM based on the building type (hospital) and geographic location. It was assumed that the investment was funded using the hospital's capital budget, and no borrowing would be necessary.

A.2.2 Installation Cost (C_{inst})

Unlike purchase cost, the installation costs associated with an EEM can vary dramatically depending on the building being modified and the capabilities of the contractor. Costs may be higher for a variety of reasons:

- Systems are difficult to access.
- Complex integration with existing systems and controls is necessary.
- The work must be done piecemeal or in stages to avoid disrupting building operations.
- Hazardous materials (asbestos, mold) must be removed or controlled.

The example analysis for this guide assumes that none of these complications are present, and that typical installation costs based on similar projects in hospitals can be used, with adjustments for local labor rates. We assume all installation costs occur in Year 0, consistent with a whole-building retrofit.

A.2.3 Salvage Value of Existing Equipment ($C_{salv,ref}$)

For the most part, older equipment and materials removed from a building have very little salvage value. Newer equipment may have more value, but is less likely to be replaced as part of an energy retrofit. In the example analysis, it was assumed that equipment could not be reused, and that the value of recyclable components (such as copper, aluminum, and glass) is approximately the same as the cost of hauling the equipment away.

A.2.4 Tax Benefits Associated With Disposing of Existing Equipment ($C_{tax,0}$)

If capital equipment is replaced before it is fully depreciated, the difference between the undepreciated value of the equipment (or adjusted basis) and the salvage value (if any) is considered an operating loss, which can be deducted from corporate income taxes. In subsequent years, the depreciation tax deduction that would have been available is lost. $C_{tax,0}$ is equal to the NPV of these competing tax implications. For a healthcare facility owned by a nonprofit corporation or institution, this cash flow is zero.

A.2.5 Financial Incentives (C_{incent})

Financial incentives from utilities or government entities can take many forms, including rebates, subsidies, tax credits, accelerated depreciation, low-interest loans, guaranteed loans, and free energy audits. As discussed in Section 2.3, DSIRE provides detailed information about the nature and size of the incentives available in each state. These incentives can be quite significant, causing marginally cost-effective measures to produce large returns on investment. Financial incentives should not be ignored when evaluating measures for actual retrofit projects. For the example analysis, however, these incentives were not included because they come and go over time, and the intent of this guide is to identify EEM packages that pay for themselves strictly through energy cost savings and other predictable cash flows.

A.2.6 Disposal Cost of Existing Equipment (C_{disp})

Certain materials associated with the existing equipment may require special handling, recycling, or disposal procedures that can increase the overall cost of an EEM. Examples include fluorescent lamps, computers, refrigerators, and construction materials containing asbestos. These costs can be very different from one site to another, but generally are not very high compared to other costs associated with a project. For the example analysis, professional cost-estimating methods were used to estimate disposal costs.

A.2.7 Project Planning (C_{plan})

Overall project planning includes all the preparatory work conducted by healthcare facility staff before the EEMs are selected. After that point, management and coordination activities are most easily treated as overhead costs for individual measures. The following costs are examples of those included in project planning category:

- Form the internal project team.
- Perform energy benchmarking activities.
- Conduct a site energy audit.
- Write statements of work for subcontracted activities.
- Review bids and select contractors.

A study by Oak Ridge National Laboratory (Hughes et al. 2003) indicated that these planning costs are approximately $128,000 for a fairly large appropriations-funded retrofit project in a federal government facility. This is probably a reasonable estimate for many large projects in hospitals, and is the value we used for the example building analysis, but is probably too high for smaller healthcare facilities. Depending on the magnitude of the retrofit project and the nature of the processes and procedures that must be followed, a higher or lower cost estimate for project planning may be appropriate.

A.2.8 Electricity Cost Savings ($C_{energy,elec,t}$) and Natural Gas Cost Savings ($C_{energy,gas,t}$)

Even straightforward measures such as lighting improvements have significant interactions with space conditioning energy. As a result, oversimplified techniques to quantify energy savings are not recommended for complex projects that require large financial commitments and involve significant risk. DOE has assembled summaries of more than 300 building energy simulation tools (*http://apps1.eere.energy.gov/buildings/tools_directory/*), which can be quite helpful for organizations that do not have an established approach for energy analysis and may be seeking expert guidance to select the right tool.

Annual electricity cost savings include reductions in energy use (kilowatt-hours) and peak demand (kilowatts), but can also include changes to base utility charges if the healthcare facility becomes eligible for a different rate schedule. Natural gas cost savings are most often based simply on the volume of gas used (1000 ft^3). Utility rate structures are highly variable depending on geographic location, time of year, and facility size. Therefore, the actual utility rate schedule should be identified and used to calculate electricity cost savings. If actual utility rates cannot be found, estimated energy prices for each state are published by *EIA* (*www.eia.gov/*).

Energy savings can sometimes change over the life of a project. For example, if new equipment is not well maintained, its efficiency may degrade significantly or it may fail prematurely. The assumption for the example analysis is that the energy or facility manager implements comprehensive O&M and M&V protocols to ensure that the performance of new equipment persists. The cash flows associated with O&M and M&V are consistent with this assumption. When accounting for energy savings for a retrofit project over a long period of time, it is also important to keep in mind that the reference building must comply with local energy codes when equipment is replaced. If the reference building has a very old boiler with 70% combustion efficiency and 5 years of useful life remaining, that boiler is likely to be replaced in about 5 years by a new boiler with combustion efficiency greater than 80%, as required by the federal equipment standards. As a result, the net cash flow associated with energy savings for a boiler EEM would decrease in 5 years because the energy use for the reference building would have decreased even without application of the EEM.

Fuel price escalation rates may be applied to future energy savings cash flows. However, fuel prices are very volatile, and it is very difficult to predict energy prices with any degree of accuracy. The most authoritative reference for fuel price projections is the EIA, which publishes the *Annual Energy Outlook* (*www.eia.gov/forecasts/aeo/*). Fuel price escalation rates should not include the effects of inflation. All values in the cash flow analysis should be in base year dollars.

In the example hospital analysis, EnergyPlus software was used to calculate energy savings for each relevant EEM and for each package of EEMs presented in this guide. The actual 2011 electricity price schedules were used for each of the five cities, including appropriate time-of-day and seasonal adjustments, and rate changes associated with peak demand reductions. Natural gas prices were based on either current utility schedules or *state average gas prices* published by DOE (*www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm*). Fuel price escalation rates were taken from the *EIA Annual Energy Outlook 2011* (*www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf*) (DOE 2011a).

A.2.9 Additional Operation and Maintenance Costs (C_{om})

The effect of retrofit EEMs on O&M costs can be either positive or negative. Older equipment often breaks down or performs poorly, forcing maintenance personnel to invest a substantial amount of time into keeping it performing at an adequate level. In most cases, new energy-efficient equipment is more reliable, reducing the O&M costs associated with the equipment. But some newer equipment may be more complex and require additional interaction from O&M personnel to keep it running properly.

Many of the RCx measures discussed in this guide include heightened attention to O&M, such as regularly cleaning coils, replacing filters, calibrating sensors, and adjusting control settings. Ongoing costs associated with commissioning are almost always worthwhile from energy savings and equipment lifetime perspectives, but these costs should be quantified and included in the cash flow analysis to create a clear picture of the overall cost effectiveness of a building improvement project.

In general, a maintenance escalation rate is not much higher than the inflation rate, and the effect is small compared to the uncertainty in projecting future O&M costs. Maintenance escalation rates are not recommended unless O&M costs are very well defined.

For simplicity, repair and replacement costs are included in the O&M category. These should be limited to components or elements of each EEM (such as lamp or filter replacements), not replacement of the entire EEM.

For the example building analysis, professional cost estimators provided the relative O&M costs for each EEM. In some cases, there was insufficient basis for assuming any change to O&M costs, and a value of zero was used.

A.2.10 Additional Measurement and Verification Costs (C_{mv})

M&V costs are usually attributed to the project as a whole, but at times the performance of a particular piece of equipment may be tested or tracked very closely. In such cases it may be appropriate to attribute certain M&V costs to the EEM, to provide a more complete accounting of costs and benefits for that EEM.

For the example analysis, M&V costs were assigned to packages of EEMs as a whole. Consequently, a value of zero for C_{mv} was used when evaluating the NPV of individual EEMs. For packages of EEMs, annual M&V costs were assumed to be equal to 5% of the estimated energy cost savings, as discussed in Section 6.

A.2.11 Replacement Costs for Energy Efficiency Measures ($C_{repl,eem}$)

You should assume that each EEM is replaced at the end of its useful life with a system of the same type and efficiency. In some cases, replacement costs may be much less than the original installation costs, because the infrastructure is already in place and you have records of specific components, vendors, and procedures that were used the first time. In other cases the difference may be marginal.

The useful life can be estimated for most common EEMs using the table of service life estimates in Chapter 37 of the ASHRAE HVAC Applications Handbook (ASHRAE 2011). The list is primarily limited to HVAC EEMs. Recommended replacement schedules for most building component assemblies can also be found in the R.S. Means Facilities Maintenance & Repair Cost Data handbook (R.S. Means 2009). Professional cost estimators provided the values of $C_{repl,eem}$ used in the example analysis, which assumes a 20-year analysis period. Most EEMs that involve mechanical or electrical equipment are replaced at least once during that time period. Envelope EEMs usually last longer.

A.2.12 Replacement Costs for the Reference Case ($C_{repl,ref}$)

To correctly evaluate net cash flows associated with an EEM, a realistic reference case must be developed for comparison. This must include the equipment replacements and upgrades that would have occurred if the EEM were never implemented. In some cases, equipment would be replaced with similar equipment that has the same efficiency. In other cases, the worst-performing new equipment available on the market may be a significant upgrade over the existing equipment. This gradual improvement of the reference case over time also impacts energy savings.

Typically, equipment is replaced at the end of its useful life. In most scenarios, remaining useful life can be calculated by subtracting equipment age from the useful life estimated using the references discussed in the previous section.

In some cases, equipment may be considered at the end of its useful life because it is broken beyond repair, or if building modifications are underway for nonenergy reasons that necessitate equipment replacement. In such cases, the remaining useful life is zero, and equipment replacement for the reference case happens during the first year of the project analysis period. This allows the consolidation of $C_{repl,ref}$, C_{pur}, and C_{inst} into a single incremental cost for improved equipment over a newer version of the current equipment (or the worst equipment allowed by code). If the replacement equipment lifetimes are the same for both the measure and the reference case, $C_{repl,ref}$ and $C_{repl,eem}$ can also be combined into a single incremental cost for the improved equipment. Otherwise cash flows for equipment replacement must be tracked separately for the two scenarios and assigned to the appropriate year.

A.2.13 Tax Deductions for Depreciation ($C_{depr,eem,t}$ and $C_{depr,ref,t}$)

Most EEMs discussed in this guide are capital expenditures that must be depreciated over a number of years for tax purposes if the building owner is a for-profit entity. The depreciable basis for such EEMs includes both the purchase and installation costs of the equipment. The Internal Revenue Service requires that the Modified Accelerated Cost Recovery System (MACRS) be used for most equipment categories. Certain EEMs, including RCx measures and equipment with a useful life shorter than 1 year, may be treated as operating expenses and deducted immediately.

In many cases healthcare facilities are owned by public or nonprofit organizations, and the depreciation cash flows can be ignored. Additionally, if the building owner is a for-profit entity but the project does not include special tax incentives, such as the 179D Federal Energy Tax Deduction, these cash flows largely cancel out and are usually not worth the effort to analyze in detail. In such cases, the NPV can be reduced by the corporate tax rate (usually 35%) to approximate the overall effect of taxes on the investment.

A.2.14 Remaining Value of Energy Efficiency Measures and Reference Equipment at the End of the Analysis Period ($C_{rem,eem,20}$ and $C_{rem,ref,20}$)

At the end of the 20-year analysis period, both the EEM and the equipment in the reference building are likely to have some remaining value. To produce a fair estimate of NPV, you should assume that the equipment is sold at a price equal to the remaining value at Year 20. Unless better information is available for estimating the future value of installed equipment, the adjusted basis for depreciation can be used as a surrogate. Because the sale price is assumed to equal the "book value" of the equipment, there is no capital loss or gain at the end of the analysis period, and any tax implications can be neglected. The adjusted basis for depreciation comprises the original purchase and installation costs adjusted according to the MACRS schedule for the corresponding class of equipment (See Table A–1 and Table A–2).

For the example analysis in this guide, this approach was simplified, and a straight line decrease in value over time was assumed for both the EEM and the reference cases. In the context of a hospital, the effect of the simplification was negligible.

Table A–1 MACRS Depreciation Schedule

Recovery Year	3-Year Property (%)	5-Year Property (%)	7-Year Property	10-Year Property (%)	15-Year Property (%)	20-Year Property (%)
1	33.33	20.00	14.29	10.00	5.00	3.750
2	44.45	32.00	24.49	18.00	9.50	7.219
3	14.81	19.20	17.49	14.40	8.55	6.677
4	7.41	11.52	12.49	11.52	7.70	6.177
5		11.52	8.93	9.22	6.93	5.713
6		5.76	8.92	7.37	6.23	5.285
7			8.93	6.55	5.90	4.888
8			4.46	6.55	5.90	4.522
9				6.56	5.91	4.462
10				6.55	5.90	4.461
11				3.28	5.91	4.462
12					5.90	4.461
13					5.91	4.462
14					5.90	4.461
15					5.91	4.462
16					2.95	4.461
17						4.462
18						4.461
19						4.462
20						4.461
21						2.231

Table A–2 MACRS Property Class Table

Property Class	Personal Property (all property except real estate)
3-year property	• Property with asset depreciation range (ADR) class life of ≤ 4 years
5-year property	• Information systems; computers/peripherals • Property with ADR class life of > 4 years and < 10 years • Certain geothermal, solar, and wind energy properties
7-year property	• All other property not assigned to another class • Office furniture, fixtures, and equipment • Property with ADR class life of > 10 years and < 16 years
10-year property	• Property with ADR class life of ≥ 16 years and < 20 years
15-year property	• Property with ADR class life of ≥ 20 years and < 25 years
20-year property	• Property with ADR class life of ≥ 25 years

Appendix B

Detailed Approach for Selecting Recommended Packages

B.1 Overall Approach

Building energy simulation was used extensively to support the development of this guide. Because of its strong capability to model various HVAC systems and equipment, EnergyPlus version 6.0 was selected as the simulation program to assess and quantify the energy- and cost-saving potentials of individual EEMs. The quantified savings were then used together with the EEM implementation cost for the cost-effectiveness analysis (see Appendix A), which formed the basis to determine the retrofit packages. Each tiered package was then further evaluated to determine its total energy savings and cost effectiveness. Further details about the selection of EEMs for EBCx and whole-building retrofits are provided in Sections B.4 and B.5.

The following steps were followed to conduct the energy simulations in support of this guide:

- **Baseline building model development and evaluation.** A baseline building model was developed as a first step. This model was based on the DOE's Reference model for hospitals (Deru et al. 2011). The model was adjusted to reflect the most common building design and operation practices for pre-1980 vintage buildings in each climate location. These modifications are listed in Section B.3.
- **Individual retrofit EEM energy savings and cost-effectiveness analysis.** Each retrofit EEM was individually evaluated in terms of its energy savings and cost effectiveness. The new model and the reference model used the same hardcoded equipment sizes and settings such as air handler and chiller capacities. Site energy consumption was obtained by running EnergyPlus for the new model. Based on the predefined utility rates, EnergyPlus also calculated the energy cost, including energy consumption cost and electricity demand cost. The difference in site energy use between the reference and the new model was regarded as the energy savings for that EEM; the energy cost difference was the annual energy cost savings. This energy cost savings was then used together with the estimated EEM implementation cost to calculate cost-effectiveness metrics such as simple payback and NPV. Appendix C provides the detailed results of each individual retrofit EEM.
- **Retrofit EEM categorization.** Based on the energy savings and the cost-effectiveness metrics for the retrofit EEMs from the previous step, retrofit EEMs were selected for development of the recommended retrofit packages.
- **Retrofit package energy savings and cost-effectiveness analysis.** After the retrofit package was determined, its overall energy savings and cost effectiveness were estimated as a whole in comparison with the original baseline. The package analysis took into account the interactions between EEMs. Hence, the packaged energy savings is not simply the sum of total individual EEMs. The capacity of equipment that was not directly affected by the EEMs included in the package stayed the same between the new model and the reference model.

B.2 Commercial Reference Building Characteristics

The reference building for the example analysis is the Pre-1980s Hospital CRB (Deru et al. 2011), which is one of a series of reference buildings developed by DOE to help standardize the analysis of EEMs when applied to specific building sectors. It does not necessarily represent an average or typical hospital in the United States. Consequently, energy and cost savings calculations in the context of the example building should not be extrapolated to other individual healthcare facilities or to the stock of healthcare facilities as a whole. The Pre-1980s CRBs represent fairly old buildings, with one or more equipment replacements over at least 30 years, depending on the typical useful life of each piece of equipment. The original equipment was not assumed to still be in the building.

These CRBs take the form of EnergyPlus models. EnergyPlus is an accurate and flexible modeling program developed by DOE in partnership with modeling experts across the country. The CRB models have been thoroughly vetted by three national laboratories (NREL, PNNL, and LBNL), instilling a high degree of confidence that they are realistic and free of significant errors.

The CRB and recommended packages are tailored to each of five important U.S. climate regions. Simulations performed in support of the AEDGs indicated that there were limited differences in the optimal packages for new commercial buildings in cities within the same climate region. Climate dependence within the same region is expected to be even weaker for retrofit packages, and five locations should be able to provide sufficient diversity of results for this guide. The following climate regions were selected, represented by the city in parenthesis:

- Hot-humid (Miami, Florida)
- Hot-dry (Las Vegas, Nevada)
- Marine (Seattle, Washington)
- Cold (Chicago, Illinois)
- Very cold (Duluth, Minnesota).

Energy managers can use the values in Table B–1 to compare the climatic characteristics of their locations with those of the five locations in this guide. Approximate energy prices for the five cities are presented in Table B–2. Actual 2011 utility rate tariffs, which are considerably more complex, were used to analyze the example building.

Table B–1 Key Climatic Characteristics of the Five Cities Used in the Development of Recommended EEM Packages

	Winter Design Temperature (°F)	Summer Design Temperature (°F)	Summer Design Humidity* (% RH)	Annual Heating Degree Days (°F·day)	Annual Cooling Degree Days (°F·day)
Miami	47.7	91.8	53%	130	4,458
Las Vegas	30.5	108.3	11%	2,105	3,348
Seattle	24.5	84.9	34%	4,729	177
Chicago	–4	91.9	45%	6,311	842
Duluth	–19.5	84.5	49%	9,425	209

Source: ASHRAE 2011

* Not coincident with summer design temperature

Table B–2 Approximate Energy Prices for the Five Cities Used in the Analysis of Recommended EEM Packages

	Marginal Electricity Rate ($/kWh)	Demand Charge, Summer ($/kW)	Demand Charge, Winter ($/kW)	Duration of Summer Demand Rate (months)	Gas Rate ($/therm)	Energy Tax Rate
Miami	0.054	11.05	11.05	6	1.024	8.0%
Las Vegas	0.067	19.23	0.5	4	0.951	8.0%
Seattle	0.065	5.76	8.65	6	0.984	8.5%
Chicago	0.084	5.75	5.75	4	0.865	8.0%
Duluth	0.083	4.87	4.87	6	0.777	6.0%

A rendering of the CRB model is shown in Figure B–1. Note that the building modeled is rectangular; gaps in the geometry indicate the use of zone multipliers (energy consumption of duplicate zones is not modeled explicitly, but rather captured by multiplying the simulated energy consumption of a representative zone). Summary information about the building is provided in Table B–3, and the distribution of space types in the building is presented in Table B–4.

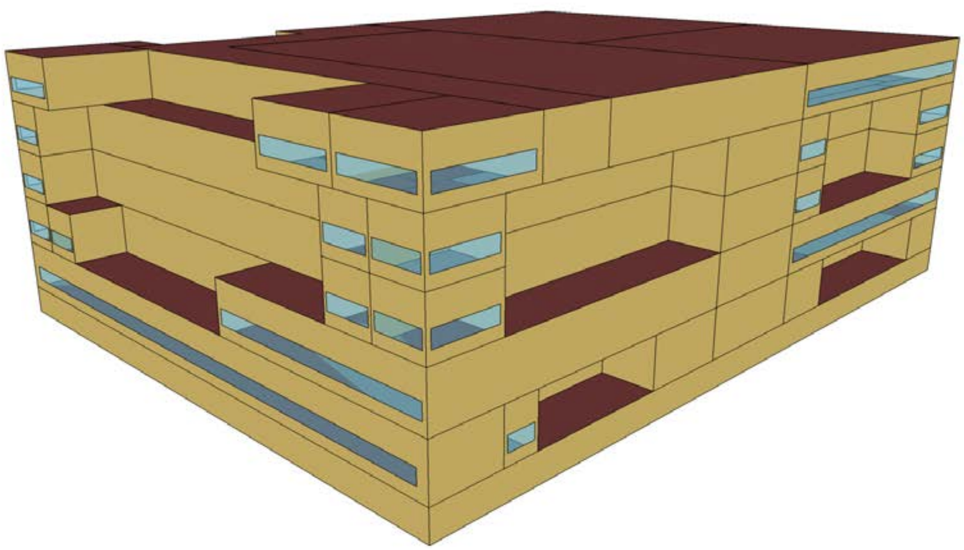

Illustration by Matt Leach/NREL

Figure B–1 Rendering of CRB (view from the southwest)

Table B–3 CRB Overview

Square footage	241,350 ft^2
Number of floors	5 floors plus a basement
Window-to-wall ratio	15%
Wall construction	Mass
Roof construction	Insulation entirely above deck

Table B–4 CRB Space Types and Floor Area Distribution

Space Type	Area (ft^2)	% of Total
Basement	40,250	16.7%
Cafeteria	7,500	3.1%
Corridor	42,050	17.4%
Emergency	4,200	1.7%
Intensive care	9,426	3.9%
Kitchen	10,000	4.1%
Laboratory	5,700	2.4%
Lobby	15,875	6.6%
Nurses' station	62,098	25.7%
Office	6,751	2.8%
Operating room	6,600	2.7%
Patient room	20,400	8.5%
Physical therapy	5,250	2.2%
Radiology	5,250	2.2%
Total	241,350	100.0%

The CRB is served by four separate HVAC systems. Each system is multizone with a central AHU that distributes air to zone-level air terminals. Heating and cooling are hydronic: hot water coils in the AHUs and hot water reheat coils in the zone-level air terminals are supplied by a central boiler; cold water coils in the AHUs are supplied by a central chiller. The AHUs supply air at 55°F to the terminals; hot water reheat coils at the terminals provide independent temperature control of each zone.

Two CAV systems serve critical space types (emergency room, intensive care, operating room, and patient room) and are equipped with humidifiers to meet hospital air quality requirements. Two VAV systems serve primarily noncritical space types (as well as a few critical spaces such as patient rooms and laboratories, to reflect typical layouts of real hospitals, where like space types cannot always be grouped together; note that only noncritical spaces have air terminals that can reduce airflow according to load). The VAV systems do not provide humidification. Both the CAV and VAV systems operate with fixed minimum OA fractions (33% for CAV, and 25% for VAV) to ensure that hospital ventilation requirements are met. Performance characteristics of the CRB HVAC systems are defined in Table B–5.

Table B–5 Performance Specifications for CRB HVAC System

Characteristic	Value
Heating plant	79% efficient natural gas heating (boiler)
Cooling plant	5.5 coefficient of performance (COP) cooling (water-cooled chiller)
Pumps	Constant-speed pumps; 90% motor efficiency for heating and cooling supply loops, 87% motor efficiency for cooling tower loop
AHU	60% total fan efficiency (constant-speed fan for CAV systems, variable-speed fan for VAV systems); 55°F deck temperature with reset based on worst-case zone temperature
Economizer	No economizer for CAV systems, dry-bulb economizer for VAV systems
Terminal units	Hot water reheat coils

Other details of the CRB can be found in Deru et al. (2011), in the spreadsheet summary posted online, or in the EnergyPlus input file.

B.3 Adjustments to the Hospital Commercial Reference Building To Create the Example Building

The following changes were made to the model of the Pre-1980s Hospital CRB to create an appropriate example building for the purposes of this guide.

B.3.1 Daylighting

- Allowed visible transmittance as a window input.

B.3.2 Heating, Ventilation, and Air Conditioning

- Changed HVAC sizing parameters from 1.2 to 1.5 to represent older building design practices.
- Changed from autosizing to hard sizes generated from the baseline model, unless equipment was replaced as part of the measure.
- Changed boiler and chiller pumps from variable speed to constant speed.
- Changed the chiller operation mode from variable flow to constant flow.
- Changed cooling tower operation set point from 0°F offset (between condenser loop input temperature and OA wet-bulb temperature) to 3.6°F offset.

B.3.3 Other

- Updated the utility tariffs to 2011 values.

B.4 Selection of Existing Building Commissioning Packages

The DOE CRBs are assumed to be well commissioned. The modeling inputs inherent in the CRBs are not consistent with suboptimal operating schedules, building controls that are no longer active, or degraded equipment performance caused by wear and tear. To model the energy savings for EBCx measures, it would have than necessary to artificially degrade the performance of the CRB and create a new reference building. Unfortunately, there have been no authoritative studies of typical degradation patterns that would enable uncommissioned versions of the CRBs to be constructed with a high degree of confidence. As a result, modeling of EBCx measures was not attempted.

Instead, the recommended EBCx packages were developed based on consideration of the likely energy savings of each measure. Energy savings were estimated for the EBCx package based on data from actual projects, combined with the CRB physical characteristics and energy use. Mills (2009) conducted a seminal study of commissioning projects across the country. This study provides very useful cost and energy savings data as a function of building size for several categories of buildings. The average source energy savings of 15% was used for inpatient healthcare facilities, and converted it to site energy based on the natural gas and electricity energy savings split for all building types. Adjustments were made to the energy savings for each of the five cities based on modeling of retrofit measures performed by PNNL in support of the Office Building AERG (PNNL and PECI 2011). Energy cost savings were calculated based on estimated site energy savings from the Mills study, and the actual 2011 utility rate schedules for the five cities. Peak demand savings (5%), initial cost ($\$0.31/ft^2$), useful life (5 years), and the number of commissioning measures in a typical project (7.3) were also estimated based on the Mills study.

B.5 Selection of Retrofit Packages

The measures included in the recommended retrofit packages were chosen based on the cost effectiveness of each EEM when applied to the example building model, using typical equipment costs and actual utility rates. A subset of the retrofit EEMs discussed in Section 4 were selected for inclusion in the detailed analysis, based on relevance to the example building, likelihood of producing significant energy savings, and complexity of implementation.

Each EEM was analyzed individually and in combination with other EEMs when system interactions were significant. This sequencing allowed for the possibility of downsizing HVAC equipment when heating and cooling loads decreased. EEMs were selected for the recommended packages if their individual NPVs were greater than zero. A final analysis of each recommended package was performed to capture all remaining system interactions and verify that the combined package met the positive NPV requirement. The energy savings for the final recommended retrofit packages do not include the effects of EBCx. If a project includes both EBCx and retrofit measures, there will likely be significant interactions. Therefore, the combined energy savings for the two packages are not strictly additive.

Appendix C

Detailed Analysis of Individual Retrofit Energy Efficiency Measures in the Example Building

This appendix documents the detailed simulation and cost analysis results that were used as the basis for the recommended retrofit packages for the example hospital. Table C–1 provides a summary of key results for the 14 EEMs that were analyzed. Most of these measures are discussed in detail in Appendix F; the others are listed at the end of that appendix under "Additional Measures for Consideration." The process for selecting measures was described in Appendix B. All reference case equipment and envelope components were assumed to be halfway through their useful lives.

Table C-1 Summary of Cost-Effectiveness Analysis for Individual Measures

System	EEM Description	Location	% Site Energy Savings (1st Year)	Estimated First Cost	NPV	Simple Payback (Years)	Included in Recommended Package?
Lighting	Replace incandescent exit signs with LED exit signs	Miami	0.2%	$35,223	$122,607	2.3	Yes
		Las Vegas	0.2%	$42,037	$114,202	2.7	Yes
		Seattle	0.1%	$41,454	$131,683	2.4	Yes
		Chicago	0.1%	$44,587	$141,808	2.4	Yes
		Duluth	0.1%	$40,845	$160,758	2.1	Yes
	Replace T12 and older T8 fluorescent lamps and magnetic ballasts with high-efficiency T8 lamps and instant-start electronic ballasts	Miami	0.8%	$563,238	($32,371)	13.3	No
		Las Vegas	0.7%	$709,152	($130,915)	15.8	No
		Seattle	0.4%	$690,710	($68,807)	14.0	No
		Chicago	0.3%	$705,098	$11,516	12.5	Yes
		Duluth	0.3%	$621,500	$120,207	10.6	Yes
	Replace incandescent lamps with CFLs	Miami	0.5%	$35,966	$147,037	2.4	Yes
		Las Vegas	0.4%	$46,305	$152,442	2.9	Yes
		Seattle	0.3%	$44,539	$162,309	2.6	Yes
		Chicago	0.3%	$50,207	$187,158	2.6	Yes
		Duluth	0.3%	$44,795	$192,119	2.3	Yes
	Replace metal halide (MH) with LED exterior lighting for façades and parking lot, with photocell control	Miami	0.2%	$16,449	$8,307	8.5	Yes
		Las Vegas	0.2%	$24,955	$1,806	12.2	Yes
		Seattle	0.2%	$23,089	$12,994	8.1	Yes
		Chicago	0.2%	$28,245	$11,016	9.1	Yes
		Duluth	0.2%	$23,300	$15,398	7.5	Yes
	Install wireless motion sensors for lighting in rooms that are used intermittently	Miami	0.2%	$4,915	$24,629	1.7	Yes
		Las Vegas	0.1%	$4,890	$23,930	1.7	Yes
		Seattle	0.1%	$5,103	$27,534	1.6	Yes
		Chicago	0.1%	$4,856	$31,161	1.4	Yes
		Duluth	0.1%	$4,928	$31,316	1.4	Yes

Table C-1 Summary of Cost-Effectiveness Analysis for Individual Measures (cont'd)

System	EEM Description	Location	% Site Energy Savings (1st Year)	Estimated First Cost	NPV	Simple Payback (Years)	Included in Recommended Package?
Lighting	Install photosensors and dimming ballasts to dim lights in perimeter zones when daylighting is sufficient	Miami	0.2%	$117,225	($76,535)	31.9	No
		Las Vegas	0.2%	$177,852	($117,041)	32.3	No
		Seattle	0.1%	$164,562	($136,649)	60.4	No
		Chicago	0.1%	$172,532	($134,206)	48.0	No
		Duluth	0.1%	$166,055	($133,875)	55.1	No
Plug and process loads	Replace cafeteria appliances (refrigerators, freezers, dishwashers, ovens, fryers, griddles, steam cookers, ice machines, hot food holding cabinets) with ENERGY STAR models	Miami	0.6%	$58,504	$58,220	8.0	Yes
		Las Vegas	0.6%	$59,625	$64,683	7.4	Yes
		Seattle	0.6%	$62,270	$68,169	7.4	Yes
		Chicago	0.6%	$61,499	$77,666	6.6	Yes
		Duluth	0.6%	$78,174	$46,440	10.9	Yes
	Install VSDs and demand control for kitchen hood exhaust fans	Miami	0.01%	$9,400	$17,281	2.9	Yes
		Las Vegas	0.01%	$10,350	$16,131	3.2	Yes
		Seattle	0.01%	$10,400	$16,326	3.2	Yes
		Chicago	0.01%	$10,950	$15,781	3.5	Yes
		Duluth	0.01%	$10,400	$16,376	3.2	Yes
Building enclosure	Add rigid insulating sheathing to roof assembly	Miami	0.0%	$326,282	($252,677)	261.7	No
		Las Vegas	0.3%	$355,892	($252,148)	91.6	No
		Seattle	0.5%	$363,807	($233,915)	64.3	No
		Chicago	0.5%	$382,970	($256,563)	66.5	No
		Duluth	0.6%	$421,902	($288,533)	98.9	No
	Replace windows and frames with double paned low-e, vinyl-framed windows, with high visible light transmittance	Miami	-1.0%	$453,903	($404,901)	Never	No
		Las Vegas	–0.4%	$481,563	($364,753)	109.2	No
		Seattle	1.6%	$475,832	($205,603)	30.1	No
		Chicago	1.4%	$509,603	($231,706)	29.2	No
		Duluth	2.3%	$615,223	($309,520)	36.2	No

Table C–1 Summary of Cost-Effectiveness Analysis for Individual Measures (cont'd)

System	EEM Description	Location	% Site Energy Savings (1st Year)	Estimated First Cost	NPV	Simple Payback (Years)	Included in Recommended Package?
Building enclosure	Add interior rigid insulation and a continuous air barrier to exterior walls	Miami	–1.2%	$1,106,391	($975,136)	Never	No
		Las Vegas	–0.4%	$1,437,495	($1,204,793)	Never	No
		Seattle	1.6%	$1,396,816	($991,729)	92.9	No
		Chicago	1.6%	$1,693,505	($1,279,683)	110.4	No
		Duluth	2.5%	$1,291,529	($847,752)	88.3	No
HVAC: Heating and cooling	Replace current inefficient boiler with a condensing boiler	Miami	4.2%	$712,200	($51,130)	19.5	No
		Las Vegas	4.9%	$742,400	($38,814)	18.8	No
		Seattle	5.9%	$762,100	$63,836	15.2	Yes
		Chicago	5.4%	$755,700	($16,007)	17.8	No
		Duluth	6.1%	$744,500	($88,558)	21.3	No
	Install VSDs on chilled-water and hot water pumps	Miami	0.6%	$38,780	$128,450	1.4	Yes
		Las Vegas	0.7%	$40,500	$148,619	1.4	Yes
		Seattle	0.9%	$41,500	$207,130	1.1	Yes
		Chicago	2.2%	$41,400	$497,635	0.5	Yes
		Duluth	1.9%	$40,650	$456,119	0.5	No*
HVAC: Ventilation	Add heat/energy recovery to ventilation systems except quarantine areas	Miami	–1.9%	$1,187,467	($1,471,079)	Never	No
		Las Vegas	–0.5%	$1,244,200	($1,408,395)	Never	No
		Seattle	–0.2%	$1,277,000	($1,369,155)	222.2	No
		Chicago	–0.1%	$1,272,200	($1,396,549)	Never	No
		Duluth	16.9%	$1,247,867	$734,945	5.6	Yes

* Despite positive NPV, measure not included because it interacts significantly with another measure with higher NPV (energy recovery ventilation)

C.1 Replace incandescent exit signs with LED exit signs

Implementation in Example Building

The example building was assumed to have two exit signs per 1000 ft² of floor area, amounting to 483 signs throughout the building. Exit signs were assumed to be evenly distributed throughout the building. The exit signs were replaced in their entirety (not just the lamps) with LED models. The energy reduction was modeled as a flat schedule reduction (exit sign lamps are assumed to be on 24 hours per day).

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–2.

Table C–2 Key Results of Energy Savings Analysis for LED Exit Signs

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings* (1st Year)
Miami	0.2%	157,983	–4,165	$6,445	$9,476
Las Vegas	0.2%	160,036	–4,303	$6,872	$8,992
Seattle	0.1%	161,042	–4,799	$8,001	$9,528
Chicago	0.1%	159,717	–4,810	$9,945	$8,765
Duluth	0.1%	160,978	–4,978	$10,731	$9,149

* O&M includes relamping for lighting measures

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–3.

Table C–3 Key Results of Cost-Effectiveness Analysis for LED Exit Signs

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$20,071	$15,152	$122,607	2.3	Yes
Las Vegas	$19,047	$22,990	$114,202	2.7	Yes
Seattle	$20,182	$21,272	$131,683	2.4	Yes
Chicago	$18,566	$26,021	$141,808	2.4	Yes
Duluth	$19,380	$21,465	$160,758	2.1	Yes

C.2 Replace T12 and older T8 fluorescent lamps and magnetic ballasts with high-efficiency T8 lamps and instant-start electronic ballasts

Implementation in Example Building

Most of the ambient lighting in the example building was assumed to be provided by T12 fluorescent lamps, mounted in two-lamp fixtures with magnetic ballasts. For this EEM, 9,548 T8 lamps were installed, along with 4,774 electronic ballasts. (In many situations, two fixtures—four lamps—can be tandem-wired to one ballast, reducing installation costs. To be conservative, it was assumed that this option was not available.) The EEM was modeled by reducing the LPD in each affected zone. There is a net reduction in relamping costs because T8 lamps tend to operate at a lower temperature and last longer on average; most high-performance T8 lamps also come with a maintenance warranty.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–4.

Table C–4 Key Results of Energy Savings Analysis for T8 Lamps and Ballasts

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings* (1st Year)
Miami	0.8%	761,861	–21,204	$37,335	$8,981
Las Vegas	0.7%	770,825	–21,722	$37,820	$11,307
Seattle	0.4%	774,867	–24,020	$42,852	$11,013
Chicago	0.3%	769,414	–24,086	$50,975	$11,242
Duluth	0.3%	774,897	–24,844	$54,686	$9,909

*O&M includes relamping for lighting measures

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–5. Even though the percent energy savings is lower in Chicago and Duluth compared to other locations, the NPV is better because the marginal electricity cost is higher

Table C–5 Key Results of Cost-Effectiveness Analysis for T8 Lamps and Ballasts

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$291,217	$272,021	($32,371)	13.3	No
Las Vegas	$296,443	$412,709	($130,915)	15.8	No
Seattle	$308,842	$381,868	($68,807)	14.0	No
Chicago	$311,680	$393,418	$11,516	12.5	Yes
Duluth	$296,959	$324,541	$120,207	10.6	Yes

C.3 Replace incandescent lamps with CFLs

Implementation in Example Building

The example building was assumed to have a significant amount of incandescent lighting of the screw-in variety, both for ambient lighting (in the kitchen, lobbies, basement, corridors, and emergency rooms) and for task lighting (in offices, patient rooms, and nurses' stations). A total of 1,974 incandescent lamps were replaced with CFLs producing equivalent light output. Ambient lamp replacement was modeled as an LPD reduction; task lamp replacement was modeled as a plug load density reduction. O&M costs were reduced on the basis of a sevenfold increase in lamp life for CFLs.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–6.

Table C–6 Key Results of Energy Savings Analysis for CFL Retrofit

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings* (1st Year)
Miami	0.5%	196,447	–3,734	$11,895	$5,241
Las Vegas	0.4%	200,147	–4,034	$11,767	$6,747
Seattle	0.3%	201,644	–4,905	$12,942	$6,490
Chicago	0.3%	199,372	–4,895	$14,796	$7,316
Duluth	0.3%	201,528	–5,183	$15,430	$6,527

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–7.

Table C–7 Key Results of Cost-Effectiveness Analysis for CFL Retrofit

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$14,497	$21,469	$147,037	2.4	Yes
Las Vegas	$13,732	$32,573	$152,442	2.9	Yes
Seattle	$14,400	$30,139	$162,309	2.6	Yes
Chicago	$13,340	$36,867	$187,158	2.6	Yes
Duluth	$14,382	$30,413	$192,119	2.3	Yes

C.4 Replace MH with LED exterior lighting for façades and parking lot, with photocell control

Implementation in Example Building

MH lamps were assumed for all façade and parking lot lighting in the example building. When implementing this EEM, all MH lighting on the façade and in the parking lot was replaced with LEDs. It was also that assumed motion sensors could be used to control the level of lighting in the parking lot based on whether anyone was present. O&M costs were reduced slightly from the combination of longer LED life with higher relamping costs.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–8.

Table C–8 Key Results of Energy Savings Analysis for Exterior Lighting Retrofit

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings* (1st Year)
Miami	0.2%	37,150	0	$2,046	$11
Las Vegas	0.2%	37,092	0	$2,102	$15
Seattle	0.2%	37,031	0	$2,975	$14
Chicago	0.2%	37,042	0	$3,184	$17
Duluth	0.2%	37,014	0	$3,207	$14

*O&M includes relamping for lighting measures

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–9.

Table C–9 Key Results of Cost-Effectiveness Analysis for Exterior Lighting Retrofit

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$14,344	$2,104	$8,307	8.5	Yes
Las Vegas	$21,763	$3,192	$1,806	12.2	Yes
Seattle	$20,135	$2,953	$12,994	8.1	Yes
Chicago	$24,632	$3,613	$11,016	9.1	Yes
Duluth	$20,320	$2,980	$15,398	7.5	Yes

C.5 Install wireless motion sensors for lighting in rooms that are used intermittently

Implementation in Example Building

Lighting in exam rooms, offices, and the basement was assumed to be controlled manually by hospital staff. A total of 40 motion sensors and associated lighting controls were installed in these space types for this EEM. The effect of motion sensors was modeled as a flat 10% reduction in LPD in each affected zone. There is a slight net savings in O&M costs for this EEM (lamps are on fewer hours per day, resulting in less frequent lamp replacement; on the other hand, some maintenance is required to ensure sensors operate correctly).

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–10.

Table C–10 Key Results of Energy Savings Analysis for Motion Sensors

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings (1st Year)
Miami	0.2%	38,986	–337	$2,862	$44
Las Vegas	0.1%	39,611	–403	$2,780	$66
Seattle	0.1%	39,797	–470	$3,153	$61
Chicago	0.1%	39,297	–481	$3,433	$75
Duluth	0.1%	39,578	–502	$3,454	$62

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–11.

Table C–11 Key Results of Cost-Effectiveness Analysis for Motion Sensors

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$4,480	$435	$24,629	1.7	Yes
Las Vegas	$4,230	$660	$23,930	1.7	Yes
Seattle	$4,493	$610	$27,534	1.6	Yes
Chicago	$4,110	$746	$31,161	1.4	Yes
Duluth	$4,312	$616	$31,316	1.4	Yes

C.6 Install photosensors and dimming ballasts to dim lights in perimeter zones when daylighting is sufficient

Implementation in Example Building

This EEM was applied to lobbies, offices, nurses' stations, and the cafeteria. EnergyPlus was used to calculate the necessary electric lighting to achieve 40 footcandles of illumination at a point 20 ft from the windows and 3 ft from the floor. A total of 21 lighting sensors (and associated dimming controls) and 947 dimmable ballasts were installed in 21 zones (17 offices, 2 nurses' stations, 1 lobby, and 1 cafeteria) for this EEM.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–12.

Table C–12 Key Results of Energy Savings Analysis for Photosensors

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings* (1st Year)
Miami	0.2%	56,628	–517	$3,948	$0
Las Vegas	0.2%	75,592	–975	$5,799	$0
Seattle	0.1%	53,378	–1,266	$2,902	$0
Chicago	0.1%	47,414	–1,091	$3,818	$0
Duluth	0.1%	39,569	–1,015	$3,196	$0

*O&M includes relamping for lighting measures

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–13.

Table C–13 Key Results of Cost-Effectiveness Analysis for Photosensors

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$90,903	$26,322	($76,535)	31.9	No
Las Vegas	$137,917	$39,935	($117,041)	32.3	No
Seattle	$127,611	$36,951	($136,649)	60.4	No
Chicago	$126,333	$46,199	($134,206)	48.0	No
Duluth	$128,769	$37,286	($133,875)	55.1	No

C.7 Replace cafeteria appliances with ENERGY STAR models

Implementation in Example Building

A typical collection of kitchen and cafeteria appliances were assumed for the example hospital based on a survey of kitchen equipment in schools conducted by the University of Mississippi (Meyers 1997). No similar survey for hospitals was available. Appliance efficiencies, hours of operation, peak power, and other equipment parameters for the example building were estimated based on the EPA Commercial Kitchen Equipment Savings Calculator (EPA 2011f). Kitchen appliances, not including refrigeration, meeting the minimum requirements for ENERGY STAR appliances were selected from the Qualified Products List (EPA 2011g) for pricing and modeling this EEM. Energy cost savings resulting from electricity use, electricity demand, natural gas use, and hot water use were all considered. O&M savings were neglected, although advanced controls could decrease the operating time and consequent wear and tear.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–14.

Table C–14 Key Results of Energy Savings Analysis for Cafeteria Appliance Replacement

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings (1st Year)
Miami	0.6%	27,003	2,809	$4,915	$2,589
Las Vegas	0.6%	28,050	2,663	$4,656	$3,742
Seattle	0.6%	28,731	2,578	$5,216	$3,536
Chicago	0.6%	28,225	2,580	$5,208	$4,609
Duluth	0.6%	28,667	2,583	$4,549	$2,795

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–15.

Table C–15 Key Results of Cost-Effectiveness Analysis for Cafeteria Appliance Replacement

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$55,098	$3,405	$58,220	8.0	Yes
Las Vegas	$54,703	$4,921	$64,683	7.4	Yes
Seattle	$57,619	$4,651	$68,169	7.4	Yes
Chicago	$55,437	$6,062	$77,666	6.6	Yes
Duluth	$74,498	$3,676	$46,440	10.9	Yes

C.8 Install VSD and demand control on kitchen exhaust hood fans

Implementation in Example Building

The example building was assumed to have one Type 1 and one Type 2 kitchen exhaust hood, removing 3,500 cfm and 1,600 cfm of exhaust air, respectively. Based on a study of five projects conducted by Fisher (2002), this EEM was modeled as a 30% reduction (from demand control) in average exhaust flow rate with a corresponding VSD efficiency of 69% (DOE 2008b), resulting in a 50% net reduction in average power. Flow rate control based on both temperature and optical sensors was assumed. The effect of reduced exhaust flow on total infiltration was not modeled.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–16.

Table C–16 Key Results of Energy Savings Analysis for Kitchen Exhaust Hood Retrofit

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings (1st Year)
Miami	0.01%	1,714	0	$154	$2,300
Las Vegas	0.01%	1,714	0	$144	$2,300
Seattle	0.01%	1,714	0	$165	$2,300
Chicago	0.01%	1,714	0	$176	$2,300
Duluth	0.01%	1,714	0	$170	$2,300

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–17.

Table C–17 Key Results of Cost-Effectiveness Analysis for Kitchen Exhaust Hood Retrofit

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$7,300	$2,100	$17,281	2.9	Yes
Las Vegas	$7,350	$3,000	$16,131	3.2	Yes
Seattle	$7,600	$2,800	$16,326	3.2	Yes
Chicago	$7,300	$3,650	$15,781	3.5	Yes
Duluth	$7,400	$3,000	$16,376	3.2	Yes

C.9 Add rigid insulating sheathing to roof assembly

Implementation in Example Building

The example building was assumed to include 3–6 in. (greater thickness in colder climates) of partially degraded expanded polystyrene (EPS) rigid insulation entirely above the roof deck. This EEM replaces the existing degraded insulation with 8 in. of fresh EPS insulation, resulting in a total roof assembly R-value of 33 $h \cdot ft^2 \cdot °F/Btu$. Higher or lower levels of insulation may be appropriate depending on climate, but a single value was chosen to simplify the analysis of the example building.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–18.

Table C–18 Key Results of Energy Savings Analysis for Roof Insulation and Reflective Roof

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings (1st Year)
Miami	0.0%	–1,717	–249	($408)	$4,503
Las Vegas	0.3%	–1,769	1,717	$1,529	$6,507
Seattle	0.5%	–636	3,263	$3,436	$2,306
Chicago	0.5%	–947	3,017	$2,888	$8,016
Duluth	0.6%	–286	3,397	$2,472	$1,823

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–19.

Table C–19 Key Results of Cost-Effectiveness Analysis for Roof Insulation and Reflective Roof

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$255,635	$70,647	($252,677)	261.7	No
Las Vegas	$253,803	$102,088	($252,148)	91.6	No
Seattle	$267,331	$96,477	($233,915)	64.3	No
Chicago	$257,205	$125,766	($256,563)	66.5	No
Duluth	$345,643	$76,259	($288,533)	98.9	No

C.10 Replace windows and frames with double-paned low-e, vinyl-framed windows, with high visible light transmittance

Implementation in Example Building

The example building was assumed to have single-paned tinted glass in the warmer climates (Miami, Las Vegas, Seattle), and double-paned tinted glass in colder climates (Chicago, Duluth). Aluminum frames with no thermal break were assumed in all climates. For the EEM, 506 tinted windows were replaced with double-glazed, low-e windows, with reduced solar heat gain and insulated vinyl frames with thermal breaks. A 50% reduction in air leakage through the windows (approximately 6.6% of total infiltration) was assumed for the replacement windows. Alternative window specifications may be appropriate depending on climate, but a single window type was chosen to simplify the analysis of the example building.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–20. The simulations predict that the measure will not save energy in the warmer climates, because the reduced solar heat gain increases the amount of reheat energy needed to maintain space temperatures, and there is less benefit for reducing heating loads. When a reheat system is used, this measure is not likely to be cost effective in hot climates.

Table C–20 Key Results of Energy Savings Analysis for Window Replacement

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings (1st Year)
Miami	–1.0%	–3,983	–6,014	($6,605)	$5,066
Las Vegas	–0.4%	64	–2,765	($2,758)	$7,321
Seattle	1.6%	–203	9,846	$10,491	$5,384
Chicago	1.4%	636	8,831	$8,731	$9,018
Duluth	2.3%	900	13,641	$10,097	$6,961

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–21.

Table C–21 Key Results of Cost-Effectiveness Analysis for Window Replacement

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$385,546	$68,357	($404,901)	Never	No
Las Vegas	$382,784	$98,779	($364,753)	109.2	No
Seattle	$403,186	$72,646	($205,603)	30.1	No
Chicago	$387,914	$121,689	($231,706)	29.2	No
Duluth	$521,296	$93,927	($309,520)	36.2	No

C.11 Add interior rigid insulation and a continuous air barrier to exterior walls

Implementation in Example Building

The example building was assumed to have mass walls, with a small amount of partially degraded EPS rigid insulation on the exterior (1–2 in. depending on geographic location). This EEM replaces the existing degraded insulation with 6 in. of fresh EPS insulation, resulting in a total exterior wall assembly R-value of 26 h·ft²·°F/Btu. Higher or lower levels of insulation may be appropriate depending on climate, but a single value was chosen to simplify the analysis of the example building.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–22.

Table C–22 Key Results of Energy Savings Analysis for Wall Insulation Retrofit

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings (1st Year)
Miami	–1.2%	–10,214	–7,417	($8,373)	$2,814
Las Vegas	–0.4%	5,414	–2,685	($2,321)	$4,067
Seattle	1.6%	3,500	10,059	$11,056	$3,843
Chicago	1.6%	5,300	9,913	$10,216	$5,010
Duluth	2.5%	7,842	14,578	$11,432	$3,038

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–23.

Table C–23 Key Results of Cost-Effectiveness Analysis for Wall Insulation Retrofit

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$356,677	$749,714	($975,136)	Never	No
Las Vegas	$354,122	$1,083,373	($1,204,793)	Never	No
Seattle	$372,996	$1,023,820	($991,729)	92.9	No
Chicago	$358,868	$1,334,637	($1,279,683)	110.4	No
Duluth	$482,263	$809,267	($847,752)	88.3	No

C.12 Replace current inefficient boiler with a condensing boiler

Implementation in Example Building

The example building was assumed to be heated by a single standard-efficiency (79% nominal thermal efficiency) boiler. This EEM replaces that boiler with a high-efficiency (90% nominal thermal efficiency) condensing boiler.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–24.

Table C–24 Key Results of Energy Savings Analysis for Condensing Boiler

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings (1st Year)
Miami	4.2%	0	26,590	$27,987	$3,500
Las Vegas	4.9%	0	31,608	$30,744	$3,500
Seattle	5.9%	0	37,551	$40,072	$3,500
Chicago	5.4%	0	33,918	$33,342	$3,500
Duluth	6.1%	0	36,561	$26,909	$3,500

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–25.

Table C–25 Key Results of Cost-Effectiveness Analysis for Condensing Boiler

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$661,500	$50,700	($51,130)	19.5	No
Las Vegas	$668,900	$73,500	($38,814)	18.8	No
Seattle	$692,900	$69,200	$63,836	15.2	Yes
Chicago	$665,500	$90,200	($16,007)	17.8	No
Duluth	$671,600	$72,900	($88,558)	21.3	No

C.13 Install VSDs on chilled-water and hot-water pumps

Implementation in Example Building

The example building was assumed to have one large boiler and one large chiller, with two constant-speed pumps each (one primary and one backup). For this EEM, VSDs were installed on each pump (four in total), such that flow rates could be reduced when heating or cooling loads were small.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–26.

Table C–26 Key Results of Energy Savings Analysis for Variable-Speed Pumps

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings (1st Year)
Miami	0.6%	317,706	–7,240	$14,470	$1,500
Las Vegas	0.7%	354,503	–7,377	$16,457	$1,500
Seattle	0.9%	367,239	–7,051	$21,923	$1,500
Chicago	2.2%	632,381	–7,804	$48,233	$1,500
Duluth	1.9%	566,875	–7,843	$44,113	$1,500

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–27.

Table C–27 Key Results of Cost-Effectiveness Analysis for Variable-Speed Pumps

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$35,500	$3,280	$128,450	1.4	Yes
Las Vegas	$35,700	$4,800	$148,619	1.4	Yes
Seattle	$37,000	$4,500	$207,130	1.1	Yes
Chicago	$35,500	$5,900	$497,635	0.5	Yes
Duluth	$35,900	$4,750	$456,119	0.5	No*

*Despite positive NPV, measure not included because it had significant interactions with another measure with higher NPV (energy recovery ventilation)

C.14 Add energy recovery to ventilation systems except quarantine areas

Implementation in Example Building

For this EEM, desiccant wheel energy recovery ventilators (ERVs) were added to the two VAV systems (which serve primarily noncritical spaces). In drier locations, less expensive heat recovery ventilators would be more cost effective, but it was decided to keep the EEM consistent across all climates for the example analysis. ERVs were modeled without bypass; the wheel can be stopped when no heat recovery is needed, but the pressure drop associated with pulling air through the wheel remains a constant during HVAC operation. The ERV was controlled using a static temperature set point (equivalent to the leaving temperature set point for the central air handler). The combination of static temperature control and return air recirculation results in the potential for scenarios (when it is too cold to economize but not cold enough to necessitate the ERV running at full capacity) in which the ERV provides more heat recovery than is needed, requiring additional cooling energy to achieve the desired AHU leaving temperature.

The extent to which ERV performance is degraded by this control scheme depends on how often the OA temperature falls within a certain temperature band (in which it is cold but not very cold) and whether economizing is possible during those times (if economizing allows the system to operate in a 100% OA mode, the potential problem is solved). This will not be an issue in warm climates, where it rarely (if ever) becomes cold enough to need to recover heat from the exhaust air stream. It is also less likely to be an issue in very cold climates such as Duluth. This issue can be avoided by applying the ERV to a dedicated OA system (for which there is no recirculation) or by applying a dynamic control scheme that specifies the ERV leaving set point according to the OA flow fraction and the conditions of the OA and return air streams. In warmer climates, the increased fan energy needed to overcome the pressure drop of the energy recovery wheel exceeds the savings in heating and cooling energy.

Energy Savings Analysis

The results of the energy simulations are summarized in Table C–28. ERVs are most often cost effective in cold to very cold climates; this is because of the greater temperature differences available for heat exchange (a 100°F OA temperature results in a heat exchange temperature difference of approximately 25°F, whereas a 0°F OA temperature results in a temperature difference of approximately 75°F). Because hospitals have large, year-round cooling loads, significant central heating is needed only in extremely cold climates such as Duluth; even in a climate as cold as Chicago, very little central heating is needed. Accordingly, only in Duluth did the modeling results indicate that the savings generated through energy recovery (combined heating and cooling) were able to overcome the energy penalty (both in terms of fan energy and the cooling energy required to offset the additional fan heat) associated with the added pressure drop created by pulling OA through the desiccant wheel.

Table C–28 Key Results of Energy Savings Analysis for ERV

Location	% Site Energy Savings (1st Year)	Electricity Savings (kWh) (1st Year)	Natural Gas Savings (therms) (1st Year)	Energy Cost Savings (1st Year)	O&M Cost Savings (1st Year)
Miami	–1.9%	–350,972	10	($20,285)	$10,900
Las Vegas	–0.5%	–96,525	–46	($8,328)	$10,900
Seattle	–0.2%	–29,442	3	($2,338)	$10,900
Chicago	–0.1%	–84,817	2,538	($5,022)	$10,900
Duluth	16.9%	1,689,767	43,743	$181,718	$10,900

Cash Flow Analysis

The results of the cost-effectiveness analysis are summarized in Table C–29.

Table C–29 Key Results of Cost-Effectiveness Analysis for ERV

Location	Purchase Cost	Installation First Cost	NPV	Simple Payback (Years)	Include in Recommended Package?
Miami	$1,087,133	$100,333	($1,471,079)	Never	No
Las Vegas	$1,099,200	$145,000	($1,408,395)	Never	No
Seattle	$1,140,000	$137,000	($1,369,155)	222.2	No
Chicago	$1,093,733	$178,467	($1,396,549)	Never	No
Duluth	$1,103,667	$144,200	$734,945	5.6	Yes

Appendix D

Prioritization of All Measures Considered

A total of 178 measures were originally considered for this guide, based on the literature and several healthcare facility case studies. As discussed in Section 1.4, this list was narrowed down in several stages to determine the most important measures to describe in the guide, and the measures that were most appropriate to evaluate in the example building analysis. Table D–1 and Table D–2 provide the full list of EBCx and retrofit measures that were considered, along with the recommended prioritization when considering a retrofit project.

Table D–1 Prioritization of EBCx Measures

Priority	EEM Description
1. Recommended in example packages	Control computer power-management settings facility-wide through software or logon scripts, except for computers in critical applications
	Verify correct operation of OA economizer
	Turn off or set back HVAC equipment overnight in areas that are not being used (cafeterias, educational areas, office space) (hospitals only)
	Reoptimize boiler temperature reset based on current building loads and usage patterns
	TAB AHUs, flow modulation devices, chilled water pumps and valves, and refrigerant lines to ensure that flow rates and supply air temperatures meet cooling loads and no unnecessary flow restrictions are present
	Reoptimize supply air temperature reset based on current building loads and usage patterns
	Calibrate any lighting controls and optimize settings based on building usage patterns and daylight availability
	Reduce ventilation levels in operating rooms, delivery rooms, laboratories, and other intermittently used spaces when unoccupied, while maintaining pressurization
2. Important measures that should be considered for all projects (discussed in this guide)	Verify adequate deadband between heating and cooling
	Provide power strips in easy-to-access locations to facilitate equipment shutdown
	Utilize timers or occupancy sensors for compressors and turn off lights on vending machines and water coolers
	Verify or establish an effective maintenance protocol for cooking equipment in kitchen areas and break rooms, including cleaning exhaust vents, heating coils, and burners
	Verify balanced 3-phase power and proper voltage levels
	Weather-strip/caulk windows and doors where drafts can be felt
	Adjust light levels to within 10% of IES recommendations for the tasks conducted in each area by delamping and/or relamping.
	Install low-flow faucets and shower heads
	Optimize equipment start/stop procedures
	Verify or establish a comprehensive maintenance protocol for HVAC equipment, including cleaning cooling and heating coils, compressor scrolls, chiller tubes, burners, and radiators

Table D–1 Prioritization of EBCx Measures (cont'd)

Priority	EEM Description
2. Important measures that should be considered for all projects (discussed in this guide)	Clean and/or replace air, water, and lubricant filters
	Verify steam traps are operating and free of leaks
	Check flue gas temperature and concentrations for boilers and furnaces, and adjust combustion airflow if necessary
	Ensure correct refrigerant charge in cooling systems and heat pumps, and repair any refrigerant leaks
	Increase thermostat setback/setup when building is unoccupied
	Turn off unneeded heating/cooling equipment during off seasons
	Precool spaces to reduce peak demand charges
	Reoptimize chilled water temperature reset based on current building loads and usage patterns
	Reoptimize condenser temperature reset based on current building loads and usage patterns
	Optimize equipment staging/sequence of operation
	Seal leaky ducts
	Replace or repair leaky and broken dampers
	Test and adjust ventilation flow rates as needed (if possible) to meet ASHRAE Standard 170 requirements (ASHRAE 2008)
	Reduce ventilation levels when building is unoccupied
3. Additional measures that should be considered in certain situations (mentioned in this guide)	Clean lamps, fixtures, and diffusers
	Improve occupancy and daylight sensor locations, and move line-of-sight obstacles
	Calibrate cooking equipment temperature settings, repair broken knobs, and ensure pilot lights are not overlit
	Schedule cooking activities to use equipment at full capacity
	Check electrical connections and clean terminals
	Verify that airflow paths around transformers are not blocked
	Cap unused air chases
	Repair any broken or cracked windows
	Repair any leaky pipes and fixtures
	Reduce hot water set point to 120°F, with boost heating for dishwashers
	Repair any damaged or missing hot water pipe and tank insulation
	Align/tighten belts and pulleys
	Repair leaky pipes, valves, and fittings
	Move improperly located thermostats to prevent over- or undercooling

Table D–1 Prioritization of EBCx Measures (cont'd)

Priority	EEM Description
4. Lower priority measures considered less likely to be cost effective or to save a significant amount of energy in most healthcare facilities (not addressed in this guide)	Activate any disabled controls if the reason for disabling can be addressed or if no reason for disabling is evident
	For fixtures with one or more burned-out lamps, replace all lamps with lower wattage versions that produce equivalent or superior light output and quality
	Improve janitorial workflow to consolidate activities in each area, allowing a reduction in operating hours for lighting
	Install occupancy sensors on workstation equipment and lights
	Flush hot water system to remove sediment
	Disable circulation pumps when building is unoccupied
	Clean coils and vents for major appliances in kitchen areas and break rooms
	Inspect oven door seals and hinges and repair if necessary
	Group cooking equipment with similar ventilation requirements (Type 1 or 2, light or heavy duty, condensing or heat/fume hood), provide only the ventilation rate needed, and align equipment with hood exhausts
	Boil water at minimum setting possible
	Turn off refrigerator door heaters
	Install wash curtains and operate conveyer dishwashers in "auto" mode
	Utilize pool covers when pool is not in use for an extended period
	Obtain lower electricity rates by allowing the utility to disable nonessential equipment during peak load periods
	If the building has an attic, make sure the vents are open and clear of debris
	Clean heating coils, burners, radiators, and other heating system components
	Check mechanical equipment lubricant levels, pressures, and colors, refilling/replacing as needed
	Post the correct operating parameters near each piece of equipment
	Update and maintain a systems manual with O&M requirements
	Improve boiler blowdown and chemical treatment procedures
	Correct motor shaft misalignments
	Secure motor, compressor, and fan mountings to prevent vibration
	Calibrate time clocks
	Implement optimized control of VAV supply fan, based on furthest open VAV damper
	Verify that exhaust air is released outside the building
	Disable any humidifiers that are not needed to maintain comfort

Table D–2 Prioritization of Retrofit Measures

Priority	EEM Description
1. Recommended in all example packages	Replace incandescent exit signs with LED exit signs
	Replace incandescent lamps with CFLs
	Replace mercury vapor with MH or LED exterior lighting for façades and parking lot, with photocell control
	Install wireless motion sensors for lighting in rooms that are used intermittently
	Install photosensors and dimming ballasts to dim lights in perimeter zones when daylighting is sufficient
	Replace cafeteria appliances (refrigerators, freezers, dishwashers, ovens, fryers, griddles, steam cookers, ice machines, hot food holding cabinets) with ENERGY STAR models (hospitals only)
	Install VSDs and demand control for kitchen hood exhaust fans
	Install VSDs on chilled-water and hot water pumps
2. Recommended in some example packages	Replace current inefficient boiler with a condensing boiler
	Replace T12 and older T8 fluorescent lamps and magnetic ballasts with high-efficiency T8 lamps and instant-start electronic ballasts
	Add heat/energy recovery to ventilation systems except quarantine areas
3. Important measures that should be considered for all projects (discussed in this guide)	Consolidate equipment and improve cooling air movement in data centers
	Add continuous roof insulation
	Add clear high-performance film to existing glazing
	Add VSDs to the chiller compressors and cooling tower fans
	Add insulation to steam/hot water pipes
	Install a stack economizer to recover waste heat from boiler combustion process
	Replace standard furnace with a high-efficiency condensing furnace
	Use excess cooling tower capacity by plumbing them in parallel and installing VSDs for cooling tower fans
	Install an EMS to control, track, and report energy use, and replace pneumatic controls with DDC
	Install controls to allow hot water temperature or steam pressure reset for boilers, and reduce excess combustion air by installing a combustion monitoring and trim control system
	Add controls to stage chillers to operate closer to full capacity
	Install a dry-bulb air-side economizer (differential enthalpy in humid climates)
	Install a water-side economizer to bypass chiller when conditions permit (dry climates only)

Table D–2 Prioritization of Retrofit EEMs (cont'd)

Priority	EEM Description
3. Important measures that should be considered for all projects (discussed in this guide)	Upgrade to demand control ventilation to reduce outdoor airflow during partial occupancy, using timers or occupancy sensors for outpatient healthcare, and carbon dioxide (CO_2) sensors for hospitals
	Replace oversized, inefficient fans and motors with right-sized NEMA premium efficiency
	Convert CV air handling system to VAV (add dampers, VSDs, fan motors) and adjust the ventilation rates to meet American Institute of Architects and ASHRAE 62.1 requirements
	Install a coil bypass to reduce pressure drop when there is no call for heating or cooling
4. Additional measures that should be considered in certain situations (mentioned in this guide)	Replace lighting system with a more efficient approach (reduced ambient light, greater use of task lighting, indirect T5 fixtures in place of direct T12 fixtures)
	Install dimming control for nighttime setback in corridors and at nurses' stations, with upgraded task lighting
	Use lighting controls that first switch power to 80%, with 100% requiring manual up-switching for exam rooms, nurses' stations, and other areas
	Install LEDs in all patient rooms, exam rooms, and operating rooms
	Install automated louver shading systems on all sun-exposed windows
	Install tubular daylighting devices or light shelves
	Direct heat recovery off all large radiology equipment
	Specify medical equipment that has low standby mode electricity use, and equipment that can be powered down or off when not in use
	Provide red plug and green plug systems for workstations, patient rooms, and work rooms. Red outlets never turn off, remaining equipment can all be switched off together to create a "room off" mode when not in use
	Replace electrical transformers with right-sized, higher efficiency models
	Replace windows and frames with double-paned low-e, thermally broken vinyl-framed windows, with high visible light transmittance (or alternative window assembly depending on climate)
	Modify window areas/locations to optimize daylighting
	Add skylights to increase daylighting
	Install vestibules with inner and outer doors
	Add interior rigid insulation and a continuous air barrier to exterior walls
	Add a high albedo/reflective roof covering (hot climates only)
	Install solar hot water preheat
	Use localized/decentralized boilers at point of use rather than one centralized boiler
	Replace air-cooled chiller with high-efficiency, right-sized water-cooled chiller
	Replace air- or water-cooled heat pump with a right-sized ground source heat pump
	Replace standard boilers with right-sized high-efficiency condensing boilers

Table D–2 Prioritization of Retrofit EEMs (cont'd)

Priority	EEM Description
4. Additional measures that should be considered in certain situations (mentioned in this guide)	Replace single large boiler with several smaller, staged boilers
	Replace DX cooling system with more efficient right-sized model with evaporative condenser
	Decouple heating and cooling from ventilation and use radiant heating and point of use cooling
	Install a point-of-use steam system with hot water boiler
	Install a heat recovery chiller for process heating loads or reheat loads
	Install chilled beam cooling system for patient rooms (if codes allow)
	Install dedicated outdoor air systems with high-efficiency heat recovery, reducing the heating, cooling, and dehumidification loads
	Convert to displacement ventilation system (where ceilings are higher than 9 feet)
	Replace air-cooled chiller with high-efficiency, right-sized air-cooled chiller
5. Lower priority measures considered less likely to be cost-effective or to save a significant amount of energy in most healthcare facilities (not addressed in this guide)	Replace standard T8 fluorescent lamps with high-efficiency T8s
	Install LEDs in all downlights and ambient sources (such as kick-lights or accents)
	Replace broken and yellowed diffusers, and delamp if possible
	Install specular reflectors and delamp
	Install timer controls for nonessential lighting when area is unoccupied
	Harvest daylight in all public areas
	Install dimming controls on all corridor lighting for nightime set-back
	Install regenerative VFD motors for elevators
	Institute a "green purchasing" policy (replacement with ENERGY STAR at end of useful life)
	Add insulation to water heaters and pipes
	Install low-flow prerinse spray valves in kitchen
	Install automatic shutoff controls for sinks
	Install water heater temperature setback controls
	Replace storage water heaters with high-efficiency condensing tankless
	Use heat pump-based domestic hot water supply (assuming heat pump for space conditioning)
	Heat recovery off all kitchen hoods
	Consolidate loads on uninterruptible power supplies (UPS)
	Install a cogeneration system
	Drill and fill insulation in exterior wood-framed walls
	Replace uninsulated exterior doors with insulated doors
	If the building has a crawlspace, apply spray foam insulation to ceiling

Table D–2 Prioritization of Retrofit EEMs (cont'd)

Priority	EEM Description
5. Lower priority measures considered less likely to be cost effective or to save a significant amount of energy in most healthcare facilities (not addressed in this guide)	Add rigid insulation to basement walls
	Add slab insulation
	Ensure all spaces have a maximum exfiltration of 0.5 ACH @ 50 Pascals
	Add evaporative precooling of supply air (in dry climates only)
	Add a small condensing boiler to handle the base load and summer load, with current inefficient boiler operating when heating loads are highest
	Replace electric resistance furnaces with water source heat pumps
	Supplement DX cooling system with an indirect evaporative cooler sized to meet small and medium cooling loads (in dry climates only)
	Improve condensing boiler efficiency by reducing return water temperature
	Install radiant cooling system.
	Install a ground-couple central chilled-water plant (central geothermal system)
	Install controls to allow hot water temperature or steam pressure reset for boilers
	Implement "dual maximums" control strategies for VAV terminals
	Implement 90% turndowns in off-hours in operating room
	Install pleated or angled filters to reduce pressure drop
	Add duct insulation
	Upgrade to cogged or synchronous belts
	Install desiccant dehumidification system (should be considered in humid climates)
	Replace outside air pool dehumidification system with desiccant or DX
	Install direct drive motors on roof exhaust fans, eliminating fan belts
	Install direct drive motors in walk-in freezers

Appendix E

Detailed Existing Building Commissioning Measure Descriptions

The following sections provide general overviews of the EBCx measures that are most likely to be effective in typical healthcare facilities. Each section includes a technical overview, strengths and weaknesses, and special considerations to help energy managers select the measures that best meet their needs.

E.1 Lighting

E.1.1 Calibrate lighting controls and optimize settings based on building usage patterns and daylight availability

Healthcare facilities may use a variety of strategies and technologies to provide automatic control of light levels. Control may be based on time-of-day, occupancy, and light levels. Even if these controls were properly installed and commissioned to begin with, they may have drifted away from their optimum settings, they may have been tampered with by hospital personnel, or conditions may have changed. For example, if lighting is automatically turned on or off based on business hours and maintenance schedules, and those schedules change, the set points will have to be changed.

If a hospital makes use of daylight harvesting, in which electric lighting levels are adjusted up or down based on the amount of daylight present, the photosensors in the system may need to be recalibrated, especially if the layout or use of the space has changed, leading to different levels of reflectivity near the sensors.

The effectiveness of lights controlled by occupancy or motion sensors depends on setting the right sensitivity and time-delay for particular spaces. Correct positioning of the sensor will help to optimize coverage of the occupied area. If the healthcare facility has been remodeled or furnishings moved so that the sensors are obstructed, the sensors should be moved. For details on settings and positioning of occupancy sensors, see the EPA's *Building Upgrade Manual*, Chapter 6 (*www.energystar.gov/buildings/tools-and-resources/building-upgrade-manual*) (EPA 2008).

Checking these controls and their associated sensors will ensure the safety and recovery of patients and provide maximum energy savings for the hospital. The savings that can be achieved by tuning lighting controls will depend on how extensively controls are used and how poorly they have been maintained. Problems with lighting controls are fairly common. For example, one study of daylight harvesting systems in more than 100 buildings of various types found that the systems often do not provide the expected energy savings (Vaidya et al. 2004). Another study found a high failure rate among the connectors in lighting control wiring (DOE 2002).

E.1.2 Adjust light levels to within 10% of IES recommendations for the tasks conducted in each area by delamping and/or relamping

Suggested light levels for various areas in hospitals and healthcare facilities can be found in ANSI/IESNA RP-29-06 Lighting for Hospitals and Health Care Facilities, from IES (2006). If areas are overlit, existing lamps can be replaced with lower wattage lamps, or lamps can be removed from fixtures with multiple lamps. To carry out the process, clean the reflectors, measure existing light levels, compare them to recommendations from the IES, identify areas that are overlit, and consider removing lamps in those areas. If removing a lamp will decrease output too much, install a reflector to make up the difference. It can also be worthwhile to delamp by replacing all existing lamps with a smaller number of high-performance lamps, especially if lamps are near the end of their useful lives. Mark fixtures where lamps have been removed so that the lamps are not replaced by unwary maintenance staff. Afterward, make sure that light levels are still adequate and that the light distribution is satisfactory. Part of the process can include cleaning lenses on fixtures, which will also increase light output. Light levels and energy use can also be decreased by replacing existing ballasts with units that have a lower ballast factor.

E.2 Plug and Process Loads

E.2.1 Provide power strips in easy-to-access locations to facilitate equipment shutdown

Most medical equipment in hospitals and healthcare facilities requires constant power and special medical-grade power strips. However, hospitals use a variety of plug-in devices such as printers, fax machines, computers, and copiers for office areas, and televisions in patient rooms. Even when turned off, this equipment uses a small amount of "phantom" electricity. Using power strips for computers and peripheral equipment allows the power supply to be completely disconnected from the power source, eliminating this standby power consumption. Easily accessible power strips allow quick shutdown of multiple pieces of equipment at once. "Smart" power strips with built-in occupancy sensors, built-in logic that senses when attached devices are idle, or timers, can shut off printers and copiers when no users are present.

Some power strips have combination outlets, with certain outlets featuring automatic shutoff functions and others continuously supplying electricity. This enables equipment, such as fax machines, that need to remain on when idle, to be plugged into the same power strip as other equipment, such as copy machines, that can be shut off.

The actual level of savings achieved using power strips depends on such factors as the control strategy employed, the type and number of appliances connected to a strip, and the existing usage patterns. In the right applications, smart power strips can be very cost effective—often with simple payback periods of less than 2 years.

To estimate the level of energy savings, multiply the difference in power draw between the fully off and idle modes (for all attached equipment) by the amount of time that the attached equipment is likely to be turned off. To obtain estimates of standby power draw for various types of equipment, see the TIAX report entitled, C*ommercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type*, which includes measured data for a wide range of devices (McKenney et al. 2010). Because the amount of time any equipment will be turned off by the strip depends on the specific control technology used and the consumer's usage patterns, it generally needs to be estimated on a case-by-case basis (E Source 2011).

E.2.2 Control computer power management settings facility-wide through software or logon scripts, except for computers in critical applications

Hospitals rely on computers and data centers for billing and administrative tasks, as well as for operating medical equipment and analyzing results. Ensuring that appropriate power management settings are set for all noncritical computers and servers through a centrally managed network can significantly reduce electricity consumption. The EPA provides a *Computer Power Management Savings Calculator* (*www.energystar.gov/ia/products/power_mgt/LowCarbonITSavingsCalc.xlsx*) that estimates potential energy savings from the use of ENERGY STAR computers and power management settings.

A network administrator can develop and deploy group policy objects or log-on scripts that control power management settings at the server level. This approach prevents users from changing settings and allows flexibility to create groups of users with similar computing habits to accommodate different operating needs. When implemented properly, group policy objects and log-on scripts can be a cost-effective strategy because they ensure that power management settings will be enabled and maintained at the appropriate level for each user without the need to purchase additional software. The EPA offers EZ GPO, a free Windows-based tool to help network administrators create group policy objects.

If your facility has multiple types of hardware and operating systems on the same network, power management software is a good solution. Software is installed on each computer and centrally controlled through the Internet or hospital network. Depending on the program used, information technology (IT) staff can manually wake up computers for maintenance, monitor energy consumption and savings, and apply different settings to different groups of computers. These programs generally cost $10–$20 per computer and are often available at discounted rates for bulk purchases. With average annual savings of $25–$75 per machine, the payback period is typically less than 1 year for a desktop computer (E Source 2010c).

The University of Pittsburgh Medical Center installed power management software to manage power settings for 25,000 personal computers across its network, setting them to sleep at night. As a result, personal computer power use was cut by 50%, saving an estimated $350,000 annually (DOE 2011b).

Several technical challenges might deter implementation of facility-wide power management settings. Some healthcare facilities may not have the IT staff capability to install third-party power management software. Depending on the software, concerns may also arise about how to ensure that sleeping computers receive critical administrative software updates, such as security patches and antivirus updates. The EPA provides technical consultations to answer questions about the various options for keeping sleeping computers up to date with security and other software patches while running its free software tool.

E.2.3 Use timers or occupancy sensors for compressors and turn off lights on vending machines and water coolers

Hospitals provide access to vending machines in cafeterias and waiting rooms for patients and visitors. Refrigerated vending machines often operate 24 hours per day, seven days per week. In addition to consuming more than 3,000 kWh/year of electricity, they add to cooling loads in the spaces they occupy. At $0.10/kWh, annual operating costs typically exceed $300 (Sanchez et al. 2007). Timers or occupancy sensors can yield significant savings because they allow the machines to turn on only when a customer is present or when the compressor must run to maintain the product at the desired temperature. Some vending machine suppliers will install a timer for free, if asked. At least one device now on the market uses a passive infrared occupancy sensor to turn off the compressor and fluorescent lights in the vending machine when no one is around; a temperature sensor will power up the machine only as needed to keep products cool. Typical energy savings can be 20%–40% for occupancy-sensor based systems, which cost about $90 per machine (NPCC 2007). An independent study also found that these types of system could reduce maintenance costs by reducing compressor cycling (Foster Miller 2002).

Deactivating the fluorescent lamps that typically illuminate a vending machine can also save energy—990 kWh/yr according to one study. Vending machines built before 2002 typically use T12 fluorescent lighting and could save 385 kWh/yr through an upgrade to T8 lighting. In most cases that kind of retrofit cannot be done in the field (NPCC 2007), but the lamps can be removed.

E.2.4 Verify or establish an effective maintenance protocol for cooking equipment in kitchen areas and break rooms, including cleaning exhaust vents, heating coils, and burners

Maintaining clean vents, coils, and burners also helps to ensure that refrigeration and cooking equipment runs efficiently; scheduling can significantly reduce kitchen energy use. According to Pacific Gas and Electric's Food Service Technology Center, the commercial food sector wastes up to 80% of the energy that is purchased (DOE 2009). Simply reducing the amount of operating time of cooking equipment in a healthcare facility kitchen can greatly reduce energy use. For example, there is no need to preheat ovens for longer than 15 minutes, and oven fans and vent hoods should be used only when necessary to maintain comfort and air quality. Appliances such as warmers and mixers should be turned on only as needed. Keeping refrigerator coils clean and free of obstructions will improve their efficiency. Staff training will help to encourage efficient practices. Training should cover equipment maintenance, operational schedules and set points, startup and shutdown procedures, and emergency procedures.

E.2.5 Verify balanced three-phase power and proper voltage levels

In a three-phase electrical system, the phase voltages should be symmetrical, have equal magnitude, and be separated by 120 degrees. Phase imbalance of 5% or less is usually acceptable, although motors and other electrical equipment sometimes require a smaller phase imbalance to prevent voiding the manufacturer's warranty. NEMA MG-1 requires motors to be derated when the voltage imbalance exceeds 1% (NEMA 2011). At 5% imbalance, the motor is derated to 75% of nameplate horsepower. As the phase imbalance increases, electrical equipment overheats, which reduces efficiency and eventually leads to equipment malfunction. If the load power per phase is unbalanced, two methods can minimize the associated voltage imbalance: (1) balance the three single-phase loads equally; and (2) separate any single-phase loads that disrupt the load balance by feeding them from another line.

Improper voltage levels can also affect the efficiency of electrical equipment. Operating equipment at voltages higher or lower than the equipment rating will lead to excessive heat and shorten the equipment's useful life. To mitigate this isssue, try to select electrical equipment that operates most efficiently at the average load level instead of at the maximum load. For example, NEMA TP-1 compliant transformers are most efficient at lower percent loading,

Maintenance staff should inspect voltage levels and phase balance annually as part of regularly scheduled maintenance. More frequent inspections should be performed if certain electrical equipment is consistently shorting out or failing.

E.3 Building Enclosure

E.3.1 Weather-strip/caulk windows and doors where drafts can be felt

Windows are an important part of the building envelope, which is critical for controlling infiltration, convection, radiation, and conduction (Figure E–1). Windows that do not close tightly, have cracks, or are not weatherized, allow conditioned air to escape and extra air to enter that needs to be conditioned, thus increasing the demand on the heating and cooling systems. Water leaks through windows are also a concern in hospitals because of the potential for mold growth and compromising IAQ. Leaky windows should be repaired with caulking and weather-stripping, and cracked glass should be replaced. Caulking and weather-stripping are lower cost measures that can have a short payback from savings associated with the decreased demand on the HVAC system.

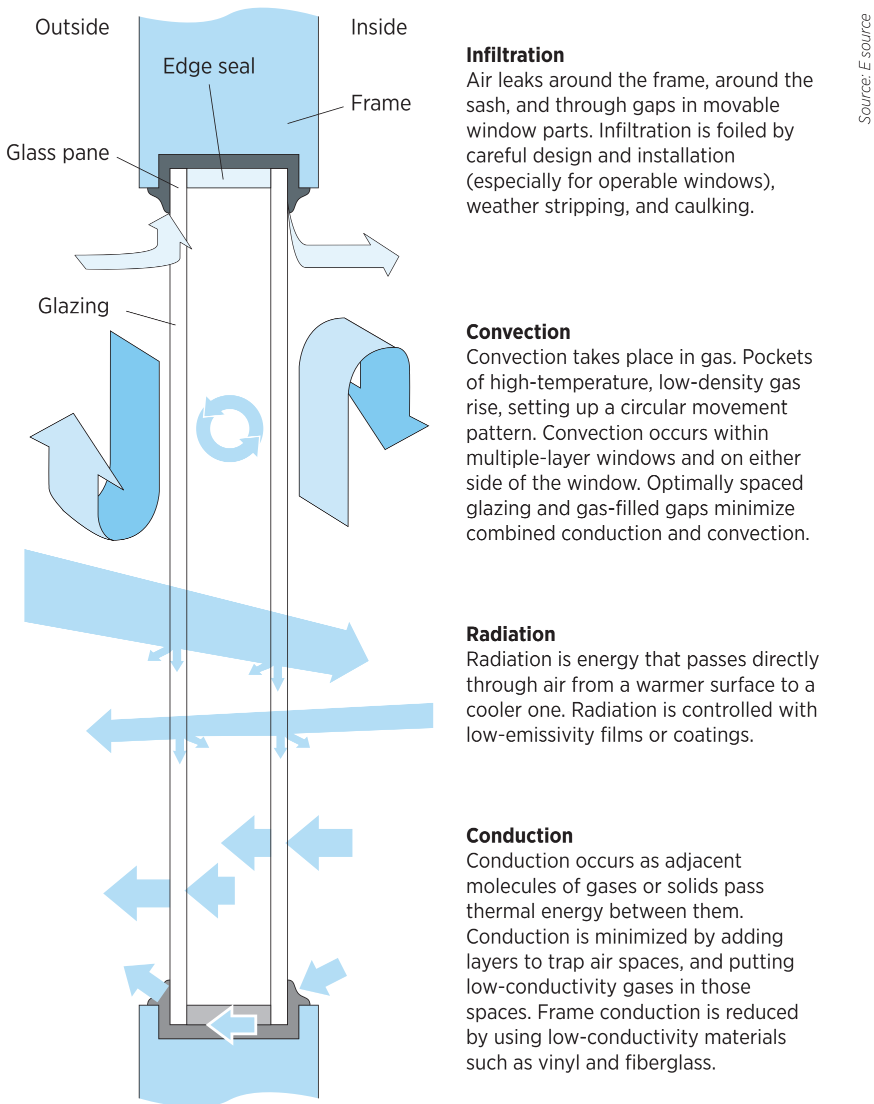

Figure E–1 Windows exchange energy with the environment through a combination of convection, conduction, radiation, and air infiltration

E.4 Service Water Heating

E.4.1 Install low-flow faucets and shower heads

Low-flow aerators save energy as well as water—less water used means less water has to be heated, and less has to be pumped to the faucets. Although there is no standard value for typical "low-flow" rates, most defer to values from the EPA *Water Sense (www.epa.gov/WaterSense/index.html)* program, designed to improve water efficiency and protect the U.S. water supply. Part of the program includes the Water Sense label, awarded to products that "use less water while performing as well as or better than conventional models." Water Sense faucets must have a flow rate of less than 1.5 gallons per minute (gpm). In comparison, federal regulations mandate that new faucet flow rates use less than 2.5 gpm at 80 pounds per square inch (psi) of water pressure and less than 2.2 gpm at 60 psi.

To calculate energy savings from low-flow faucets, FEMP offers an *online energy cost calculator* (*www1.eere.energy.gov/femp/technologies/eep_faucets_showerheads_calc.html*). The calculator allows a comparison of a specific product to baseline models as well as other more efficient products. The calculator uses the following values for energy use per gallon of water: 0.05 kWh/gallon and 0.003 therms/gallon. Actual energy savings will vary depending on usage and local utility rates, which can be entered into the FEMP calculator.

E.5 HVAC: Heating and Cooling

E.5.1 TAB AHUs, flow modulation devices, chilled-water pumps and valves, and refrigerant lines to ensure that flow rates and supply air temperatures meet cooling loads and no unnecessary flow restrictions are present

As buildings age, so do their internal systems. Equipment slowly degrades, occupants alter system set points away from ideal settings, and cooling loads fluctuate as occupancy levels vary and space usage within a healthcare facility changes. This aging process can lead to inadequate cooling in occupied spaces, hot and cold spots, and equipment overloading. TAB brings the cooling system back into balance, maximizes equipment life and occupant comfort, and minimizes wasted energy.

The TAB process involves testing equipment functionality and making improvements and repairs as needed, adjusting system parameters, and balancing them to efficiently meet building loads and satisfy local ordinances. Typical cooling system values such as water flow rates, fan speeds and pump pressures, and temperature set points are investigated during a TAB analysis. Other equipment problems such as chipped fan blades, improper refrigerant charge, and overheated water pumps are also revealed through TAB.

TAB may be needed if building staff are constantly adjusting HVAC components to maintain comfort, occupants are frequently submitting complaints about indoor comfort issues, or spaces within the building have been repurposed. TAB analysis should also be conducted as part of any major renovation and recommissioning efforts. A balanced system can fall out of "tune" in a year or two with constant use, so rebalancing every few years keeps HVAC systems operating efficiently. Although savings through TAB are hard to generalize because they depend heavily on building conditions, improper operations from the cooling system will eventually lead to occupant discomfort and wasted energy.

E.5.2 Verify or establish a comprehensive maintenance protocol for HVAC equipment, including cleaning cooling and heating coils, chiller tubes, burners, and radiators

RCx will identify major HVAC equipment problems and necessary repairs; however, establishing maintenance schedules and procedures ensures that efficient operations of the HVAC system will continue, and will lengthen the useful life of the system and its individual components.

An important step in this process is acquiring or creating reference maintenance materials for all HVAC equipment and systems. These include product literature and service manuals from the manufacturer as well as maintenance logs to record all maintenance activities. With these documents in place, you can establish preventive maintenance schedules for each component of the HVAC system. Each element within the HVAC system will have its own list of scheduled maintenance items to be carried out by building staff.

The idea behind scheduling preventive maintenance measures is to avoid major system failures. The preventive method gives building staff an opportunity to evaluate HVAC systems regularly and identify potential problems before they become major operational problems. These schedules will also drive procurement schedules, ensuring that replacement parts are available when they are needed.

Important elements in the process include condenser and evaporator coils, cooling towers, burners, and radiators.

Coils. To maintain efficiency in a vapor compression cooling system, condenser and evaporator coils must be kept clean. Dirt on the evaporator coil reduces system airflow and degrades the coil's heat transfer efficiency, which in turn cuts cooling capacity. Inspect the evaporator coil at least annually to ensure that the filters are doing their job. Shining a light through the coil is one way to inspect it, although enhanced fin designs, with their wavy patterns, can make this difficult. An alternative is to measure supply fan current and filter/coil pressure drop with clean filters in place. If the pressure drop is higher than last year's measurement, the coil is dirty and needs to be cleaned. For single-speed fans with PSC motors, the current will drop when the coil is dirty. For variable-speed fans, the current will go up.

Unlike the evaporator coil, the condenser coil sees unfiltered OA, and therefore degrades more rapidly. A dirty coil reduces the cooling capacity of the air blowing across the condenser coils. For example, if the dirty coil results in an increase in the condensing temperature from 95°F to 105°F, cooling capacity will decrease by 7% and power draw will increase by 10%.

The best tool for cleaning the coils is a power washer that feeds cleaning solution into a high-pressure water flow. Some companies specialize in performing this type of cleaning at a competitive price. They typically use tank trucks and custom self-contained equipment. Spray-on cleaning solutions that are intended to be used with a brush and a hose will not do a good enough job of cleaning the coils, even though they may brighten the outer surface.

Before-and-after measurements of the temperature difference across the coil will verify the effectiveness of the cleaning. These measurements should be included in a report to the owner or supervisor. Power washing, if done improperly—for example, using the wrong spray angle or excessive pressure—can damage coils by bending the fins, or even breaking them off if the coil is old.

Cooling towers. In healthcare facilities cooled with water-cooled chillers, cooling tower maintenance is critical. Scaling, corrosion, and biological growth all reduce efficiency and raise maintenance costs because of the resultant condenser fouling and loss of heat transfer capability. Water with high concentrations of dissolved minerals, which become increasingly concentrated during the evaporation process, accelerates the problem. In addition, *Legionella pneumophila* and other pathogens that can create health problems can grow in cooling tower water. Placing cooling towers away from air intake vents can cut the risk of transmitting pathogens into the building. The typical solution to this and the other cooling tower water problems is to treat the water. Biocides can inhibit biological growth, corrosion inhibitors can maintain equipment surfaces, and other chemicals can maintain proper pH. Finally, a significant amount of "blowdown" (deliberate water overflow) is typically used so that fresh makeup water reduces the buildup of salts and pollutants.

Although treatment chemicals are necessary for maintaining cooling towers, they can be hazardous to handle and dispose. Chemicals also increase operating costs. To reduce these problems, one company offers a system that uses electrolysis to automatically add the biocide bromine to the tower water as needed. This approach eliminates the need for maintenance staff to manually perform the task—reducing the risk of exposure—and could reduce the amount of chemicals used that must later be disposed.

Some companies have attempted to develop nonchemical treatments, with mixed results. Magnetic field treatments, in particular, have yet to conclusively demonstrate their value. Although some reports indicate that such systems have been used successfully, many failures have been observed. There is no scientific explanation for how magnetic fields could influence particles and microorganisms in water to prevent fouling, so predicting whether such treatment would work for any given condensing-water system is impossible.

Another nonchemical treatment is ozone. It is an effective biocide, but the circumstances under which it works well for cooling towers are unclear. In addition, it is still debated as to how—or even if—it can prevent scale buildup or corrosion. Some ozone system manufacturers recommend using chemicals in addition to the ozone.

Burners. Over time, burners can become fouled from mineral buildup, corrosion, or soot, reducing the efficiency of the combustion process. Burners should be checked regularly for cleanliness and proper flame control. There are several indicators that a burner needs cleaning. Burners may be overfiring, indicated by a large flame blowing past the thermocouple that measures the temperature of the flames. An underfired burner will have a small flame that does not engulf the thermocouple. A flame with a yellow tip suggests a lack of primary air. Yellow or orange streaks indicate the presence of dust or other particles, which will lead to soot buildup. Perform regular maintenance to keep burners clean by removing burners and brushing and vacuuming thoroughly. Check to ensure that all ports are free of debris before placing them back in their original positions. This will help the heating system achieve peak combustion efficiencies.

Radiators. Radiators, which transfer heat to conditioned spaces, gained popularity because of their reliability and low maintenance requirements, but they still require regular checking for leaks and loose fittings, and require annual air bleeding. The pipes in these systems will expand and contract many times during their lives, so connections will eventually loosen. Valves can loosen or deteriorate over time, causing leaks, and air will likely infiltrate the system during the cooling season. This air takes away from system efficiency by preventing the water from circulating as designed. To bleed out the air, turn all the water supply valves on, then turn the heating system on and wait for it to warm up. Then starting with the radiator at the highest point or furthest away from the boiler, open the bleed valve on each radiator. Any trapped air will exhaust through the valve. Once hot water starts coming out, the bleeding is complete. Close the bleed valve and move to the next radiator in the system, repeating the actions, and continuing with each radiator until you reach the boiler.

E.5.3 Clean and/or replace air, water, and lubricant filters

Air filters are especially important in hospitals, where superior IAQ is critical for patient care. Filters help maintain IAQ and protect the downstream components of an air handling system (the evaporator coil and fan) from accumulating dirt. Filter-changing intervals are typically determined by calendar scheduling or visual inspection, but can also be based on the measured pressure drop across the filter. Scheduled intervals are usually 1–6 months, depending on the local air quality, both indoors and out. More frequent changes may be needed during the economizer season, because OA is usually dirtier than indoor air.

Measuring pressure drop is the most reliable way to determine if filters need cleaning, but requires some effort because most RTUs do not have built-in pressure taps. Taps can be made by drilling into the cabinet wall and installing ¼-in. tubing with removable caps. A technician can then use a handheld pressure meter or manometer to check filter status. Accurate readings require cabinet access panels to be shut tightly, with all screws replaced. In facilities with predictable and regular filter loading, pressure measurements can be used to establish the proper filter change interval; thereafter, filter changes can simply be scheduled.

E.5.4 Ensure that steam traps are operating and free of leaks

Many large hospitals produce and use steam for heating and sterilization. Steam traps are automatic valves that are installed on the pipes throughout the distribution system to remove condensate from the steam flow and maintain the proper operation of the steam distribution system. Because of the exposure to harsh conditions, steam traps will eventually leak or fail. When they leak or fail in the open position, energy is wasted from the loss of steam heat. One malfunctioning trap can cost thousands of dollars in wasted steam annually. Traps that fail closed do not cause energy or water losses, but can cause significant capacity reduction and damage to the system. On average 15%–25% of steam traps in existing buildings leak, which can waste hundreds of thousands of energy dollars annually. When not regularly maintained, as many as 25%–50% of steam traps will have failed in a facility (DOE 2005).

Conduct a steam trap audit to assess the working condition of every steam trap. In the audit, a visual inspection is conducted and a trained technician uses diagnostic tools such as thermography and ultrasonic analyzers to detect leaks and other problems. DOE provides a maintenance checklist, with different maintenance frequencies for different steam pressure ratings (Table E–1) (PNNL 2010). Hospitals, which use lower pressure steam traps, should be inspected at least once each year—more often if there is a history of problems with existing steam traps.

Table E–1 Steam Trap Maintenance Checklist

Description	Comments	Maintenance Frequency			
		Daily	Weekly	Monthly	Annually
Test steam traps	Daily/weekly test recommended for high-pressure traps (250 psig or more)	✓			
Test steam traps	Weekly/monthly test recommended for medium-pressure traps (30–250 psig)		✓		
Test/repair steam traps	Monthly/annual test recommended for low-pressure traps. Repair or replace when testing shows problems.			✓	
Replace steam traps	When replacing, take the time to make sure traps are sized properly. Typically, traps should be replaced every 3–4 years.				✓

Audits of a steam trap system can be costly. The traps may be difficult to access, and inspection of each steam trap can be time consuming. However, the energy and cost savings from identifying and replacing or repairing steam traps far outweigh the audit costs. For example, thermography was used to inspect 20% of a 500-trap network in a hospital, and showed that 22 traps had failed. By extrapolating the initial inspection results across the entire steam system, it was estimated that by replacing 75 faulty steam traps, the hospital would reduce its natural gas cost by more than $95,000 annually, resulting in a 3-year payback on the investment (Chicago Healthcare Council 2007).

E.5.5 Check flue gas temperature and concentrations for boilers and furnaces, and adjust combustion airflow if necessary

The flue gas temperature and flue gas oxygen or CO_2 concentrations are primary indicators of combustion efficiency, which is defined as the percentage of heat content in a fuel that is converted to usable heat in a boiler. A precise, theoretical amount of air (called the stoichiometric mixture) is required to completely react with a specific amount of fuel. In practice, incomplete mixing means that a certain amount of excess air must be supplied to completely burn all the fuel. Too much excess air causes heat loss from an increase in the flue gas flow and elevated stack temperatures; too little excess air results in unburned combustibles. The combustion efficiency is highest when excess air and flue gas temperature are at the minimal acceptable levels for a given system. That level can be established by measuring the flue gas oxygen or CO_2 concentrations and working with the boiler manufacturer to determine the appropriate fuel/air mixture. Measurements can be made using inexpensive gas-absorbing test kits or more expensive computer analyzers that display the percent oxygen, gas temperature, and boiler efficiency. Incorporating an automatic excess air trim loop into the boiler controls will minimize excess oxygen and improve efficiency. Table E–2 relates flue gas temperature and flue gas concentrations with combustion efficiency (Chicago Healthcare Council 2007).

Table E–2 Combustion Efficiency for Natural Gas Boiler

Excess (%)		Combustion Efficiency Flue Gas Temperature Minus Combustion Air Temperature (°F)				
Air	Oxygen	200	300	400	500	600
9.5	2.0	85.4	83.1	80.8	78.4	76.0
15.0	3.0	85.2	82.8	80.4	77.9	75.4
28.1	5.0	84.7	82.1	79.5	76.7	74.0
44.9	7.0	84.1	81.2	78.2	75.2	72.1
81.6	10.0	82.8	79.3	75.6	71.9	68.2

E.5.6 Verify correct operation of OA economizer

Economizers provide "free" cooling by drawing in cool OA to offset mechanical cooling when outside temperatures are sufficiently low (Figure E–2). When economizers operate as designed, they can save considerable energy. Simulations for eight cities across the United States show that standard economizers can cut HVAC energy use by 1%–5%; high-performance units can save 8%–20%. Savings are greatest in milder climates (Hart 2011).

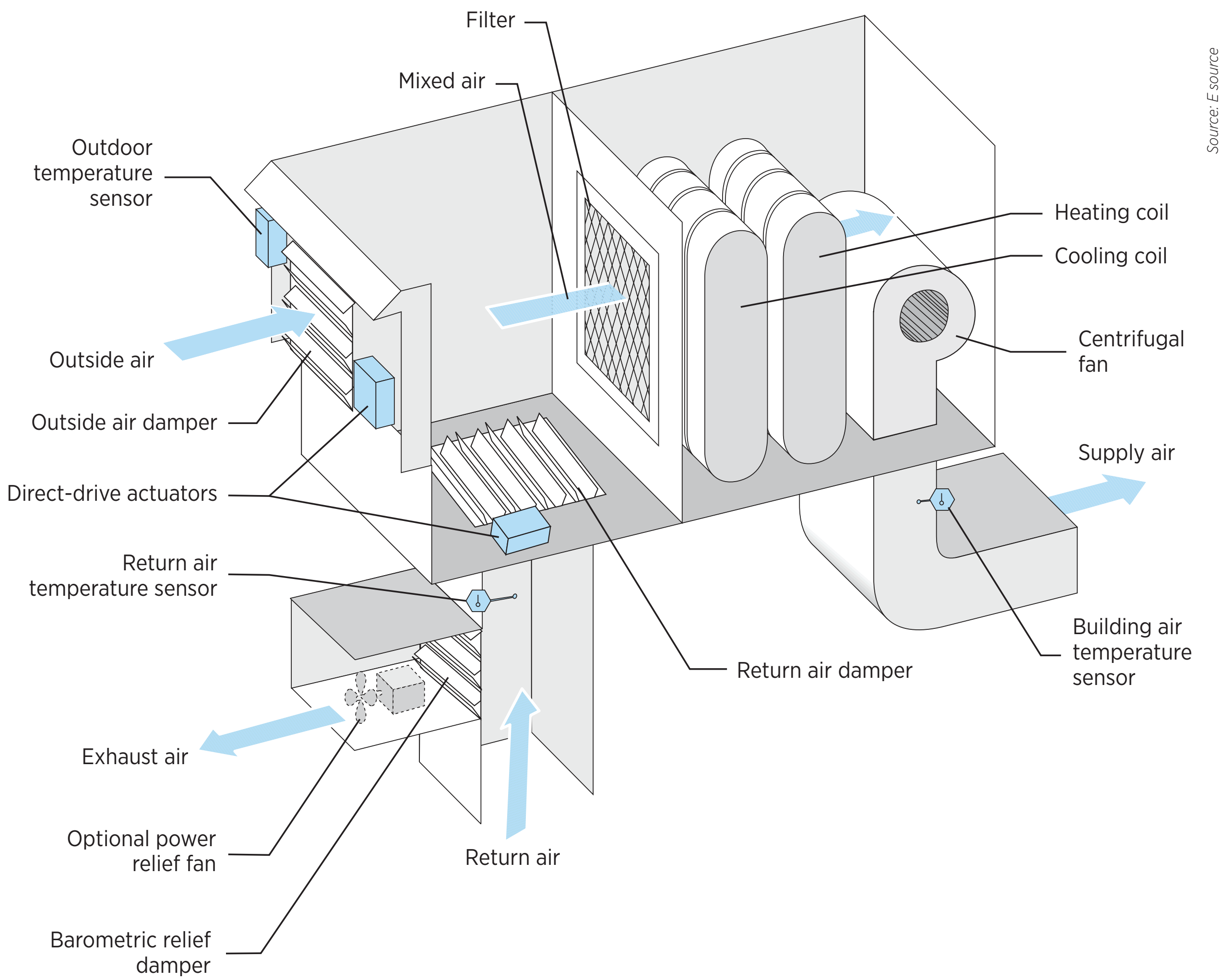

Figure E–2 Economizers include a number of components that must be properly maintained

Economizers often do not operate as designed. Between 2001 and 2004, the New Buildings Institute compiled the results of several field studies conducted in the western United States. Inspectors found that of 503 economizers on HVAC RTUs, 64% had failed or required adjustment (Cowan 2004). Common problems included corrosion-frozen dampers, broken linkages between the actuator and damper, malfunctioning outdoor temperature sensors, and improperly set controls.

Because economizers are exposed to unfiltered OA, the pivot points and actuators can easily become dirty and bind, resulting in serious energy waste. Economizers stuck in the open position risk overloading the cooling coil with warm OA; economizers stuck in the closed position eliminate the free cooling potential. One study estimated that economizer malfunctions waste 20%–30% of all HVAC energy consumed (Roth et al. 2002). One simulation showed that in hot-humid locations, if an economizer damper is stuck in the open position, it can increase energy use by as much as 50% (E Source 2009).

To ensure that economizers provide energy savings, conduct an annual maintenance program that includes functional testing, which can identify failed actuators, linkages, and stuck dampers. PECI provides a free checklist for economizers: *Functional Performance Test, Air-Side Economizer* (*http://www.peci.org/ftguide/ftg/SystemModules/AirHandlers/AHU_ReferenceGuide/CxTestProtocolLib/Documents/econtest.doc*) and Pacific Gas and Electric offers a *General Commissioning Procedure for Economizers* (*http://www.peci.org/ftguide/ftg/SystemModules/AirHandlers/AHU_ReferenceGuide/CxTestProtocolLib/Documents/EconomizerProcedure.doc*). Portable data loggers can also help identify problem areas, as described in this *application note* (*www.pge.com/includes/docs/pdfs/about/edusafety/training/pec/toolbox/tll/appnotes/assessing_economizer_performance.pdf*) from Pacific Gas and Electric's Pacific Energy Center. Building automation systems can also be used to monitor economizer performance if they are equipped with the right sensors and diagnostic software.

Regular maintenance should also include regular cleaning, lubricating, and inspecting dampers—up to three or four times per year. Cleaning can be performed with a power washer or with soapy water and a brush. Once the dampers are cleaned, they should be run through their full range of motion. Lastly, the economizer set point should be checked and damper response confirmed.

Economizer maintenance costs are hard to pin down because service contracts usually cover the air-conditioning system rather than specific components. A survey of HVAC contractors across the United States found that the cost of a service contract for a 10-ton unit to be $1,000–$1,200, but coverage varied: some may provide only visual inspections of economizers; others perform functional testing (E Source 2009).

E.5.7 Ensure correct refrigerant charge in cooling systems and heat pumps, and repair any refrigerant leaks

Refrigerant system charge should be checked, and the system inspected for leaks, at least annually, but seasonal checkups may be more valuable if this is a new task for maintenance or the system is frequently leaking. Inspecting charge levels can be completed as part of a TAB analysis or as a stand-alone maintenance task for the cooling system. An improperly charged refrigerant system reduces system efficiency by as much as 50% (Criscione 2004) and can damage cooling equipment. An undercharged system leads to increased loads on the compressor, causing it to run continuously; low suction and head pressures; and an inability to maintain temperature set points within designated ranges. An overcharged system results in high head pressure, increasing the compressor load; and may also flood the condenser, reducing its capacity. If the cooling system has any components that are susceptible to leaking, an overcharged system will increase the risk of refrigerant leaks.

E.5.8 Turn off or set back HVAC equipment overnight in areas that are not being used (cafeterias, educational areas, office space)

Areas such as cafeterias, educational spaces, and medical office spaces are not occupied 24 hours per day. Programmable thermostats in these areas can automatically shut off HVAC systems or set back temperatures at night during the heating season and turn off or set temperatures up during the cooling season. See the next section for more discussion on temperature setbacks.

E.5.9 Increase thermostat setback/setup when building is unoccupied

Heating and cooling account for 48% of a typical outpatient facility's energy consumption (DOE 2003), so setting thermostat setback and setup procedures for unoccupied hours can save significant energy. During occupied hours, temperature settings should follow ASHRAE Standard 170-2008 (ASHRAE 2008) guidelines—typically 70°F during the heating season and 75°F during the cooling season (VA 2011). During unoccupied periods such as nights, weekends, and holidays, set temperatures according to climate, season, and length of time the space is unoccupied. For example, during the heating season, for long breaks over the weekend, or a holiday, the temperature can be set back to 55°F, but 60°–63°F may be more appropriate for a shorter break. For every degree of change in temperature, energy costs increase or decrease 2%–3%. The optimal temperature setbacks will vary depending on the specific systems and features of the building and climate. In general, energy savings from thermostat setbacks are greater for facilities in milder climates than those in more severe climates.

Changing temperature settings for different times or situations is easiest with an EMS or a BAS. If those systems are not in use, programmable thermostats can accomplish the same thing. With either approach, be sure to allow enough time in the morning to bring the facility back to a comfortable temperature before patients arrive. Hospital staff need to be trained to ensure proper programming and maintenance.

E.5.10 Turn off unneeded heating and cooling equipment during off seasons

During off seasons, unnecessary heating or cooling equipment should be completely shut off in outpatient healthcare facilities. When a heating system is left on during the cooling season, hot water or steam can leak through control valves, wasting heat energy and increasing the loads on cooling demands. Likewise, during the winter heating season, ensure the air cooling equipment has been completely powered down. Even when turned off but still connected to power, cooling equipment will consume a small amount of energy.

In areas with very hot, cold, or humid climates, it may not be appropriate to turn off the heating or cooling systems because of the large amount of time it will take to recondition the building back to a comfortable temperature or the need to control humidity. In these cases, thermostat setback and setup protocols should be implemented. See Section E.5.9 for more information on thermostat setbacks and setups.

Turning cooling systems off may be preferable to using an air- or water-side economizer in hot-humid climates. The decision depends on the number and sizes of control valves and the presence of VSDs, but shutting down equipment can be much more efficient than using a bypass.

E.5.11 Precool spaces to reduce peak demand charges

In many climates, temperatures at night are cool during periods when daytime temperatures do not allow for economizer operation, making them amenable to the practice of precooling. With precooling, the AHU and economizer flush the building with night air to cool the building mass. The cool mass then acts as a heat sink the following day, absorbing heat from internal gains and reducing the amount of energy needed for cooling. Mechanical precooling can also be used to cool the building during periods of lower electricity charges (Figure E–3).

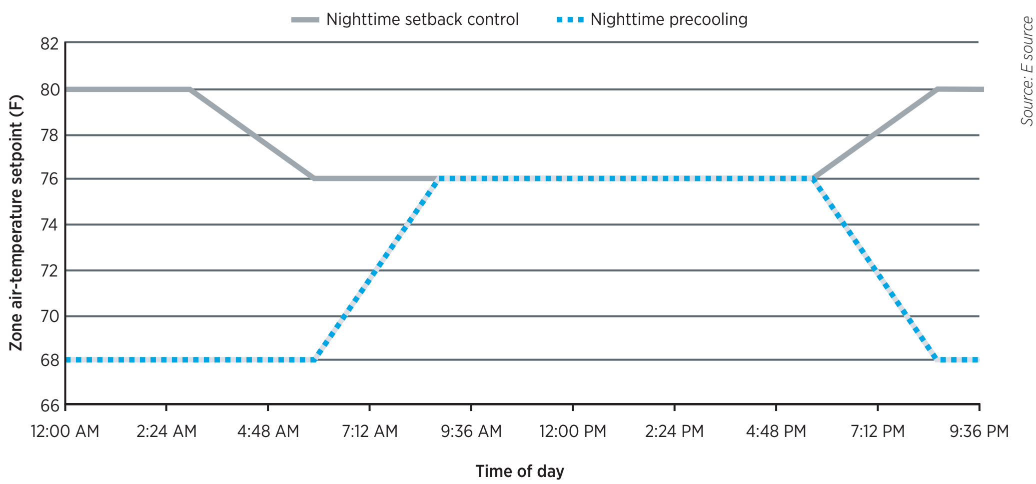

Figure E–3 Comparing nighttime precooling and nighttime setback

Most buildings use nighttime setbacks and allow inside air temperatures to rise at night, then cool things in the morning immediately before occupants arrive. Nighttime precooling is nearly the opposite—the nighttime temperature set point is about 68°F, but the building air temperature is warmed in time for the occupants' morning arrival. In the example shown here, the desired occupied temperature is 76°F for both strategies.

Recent modeling suggests that precooling can reduce peak demand by up to 30% in commercial buildings (Lee and Braun 2008). In another study, tests were performed comparing a conventional night setup and a simple precooling control strategy and found that the precooling strategy reduced peak demand loads 9%–31%, depending on the location of the specific zone in a building (Braun and Lawrence 2002).

Night precooling has the potential to be more cost effective than mechanical thermal storage because it eliminates the need to install pumps and tanks. However, it does require special control hardware and software. This technique has the additional benefit of introducing extra fresh air to a building, which can improve air quality.

Building simulations and field studies have demonstrated that precooling can be very effective in cool and moderately warm climates and that peak demand savings rise with increased building thermal mass. Recent studies by LBNL also suggest that precooling in hotter climates has similar potential to that seen previously in cool and moderate climates (Xu et al. 2009). For a concrete building with medium thermal mass, the whole-building electricity peak demand can be reduced by up to 15.2% and 21.0% during peak hours in warm and extremely hot climate zones, respectively (Yin et al. 2010). In the same study, a control strategy that combines precooling with exponential temperature setup achieved the greatest peak demand savings and the flattest afternoon electric load shape. In this approach, the building is precooled during the early morning hours, and then the zone temperature reset set points are allowed to exponentially increase during the afternoon until after hours when the temperature is allowed to float.

E.5.12 Reoptimize supply air temperature reset based on current building loads and usage patterns.

If the right controls are in place, the supply air temperature can be reset to reduce energy. In typical CV HVAC systems, the supply air temperature for the building is set at a constant set point, typically 50°–55°F, to satisfy cooling demands on the hottest day of the year, and is designed to provide cooling to the zone with the highest demand. To maintain comfortable conditions in zones with lower cooling loads, air will be reheated as it enters the zone. To minimize this simultaneous cooling and heating, the supply air temperature can be reset. In this approach, cooled water flow is reduced to create warmer supply air (reset) in response to a decrease in cooling demand. This reset is controlled by measuring OA temperatures (OA reset) or by measuring the warmest area (warmest zone reset). The warmest zone reset approach is more accurate because control is based on measured indoor air temperatures. However, OA reset uses much simpler controls.

If the existing system is a VAV system, the optimal supply air temperature, which depends on local conditions, minimizes the combined energy consumption for fan, cooling, and heating. For example, low supply air temperature can be a better choice in warm and humid climates where there are fewer potential economizer hours and dehumidification is important, unless humidity measurement and control are included in the control algorithm. Based on simulations of VAVs in various climates, the *Advanced Variable Air Volume System Design Guide* from the California Energy Commission provides general guidelines for optimizing systems (CEC 2005a).

E.5.13 Reoptimize boiler temperature reset based on current building loads and usage patterns.

OA reset controls monitor outdoor temperatures and use that information, plus a building-specific heat loss coefficient, to match boiler output to heating demands. This approach leads to savings that result from fewer on/off cycles, increased burner efficiency, and lower average water temperatures.

These control systems have been implemented for many years, with studies as far back as the 1980s claiming savings from OA reset controls. In fact, most new boilers sold today have an OA reset strategy built into their onboard electronic control systems. For boilers without these controls, modern electronic controllers can be retrofit onto existing boilers to perform OA reset functions along with a number of other options, such as advanced control interfaces that can communicate with BAS controls to coordinate boiler sequencing and shut systems down during periods of warm weather. Savings estimates typically run 10%–15% (Siegenthaler 2001), with the most savings available from older and less efficient units.

Other benefits to OA reset controls include a reduction in on/off heating cycles that improves temperature stability, resulting in improved occupant comfort, and less on/off cycling that increases the life of the boiler.

E.5.14 Reoptimize chilled water temperature reset based on current building loads and usage patterns.

When loads decrease, chilled water temperatures can be reset to higher values, enabling the chiller to operate more efficiently. The temperature can be changed based on chiller loads or outdoor conditions; however, this measure has to be implemented carefully to avoid excessive increases in pumping power and indoor humidity levels.

On average, a 1°F increase in supply temperature corresponds to a decrease in compressor electricity consumption of 1.7% (DOE 2002b). FEMP's *Continuous Commissioning Guide* (*www1.eere.energy.gov/femp/pdfs/ccg02_introductory.pdf*) provides the following recommendations for resetting the chilled water supply temperatures:

- Increase the chilled water temperature linearly from the design value up to 5°F higher than the design value as the chiller plant load decreases from 100% to 40%.
- Increase the chilled water temperature from the design value up to 5°F higher than the design value as the ambient temperature decreases from the design value to 60°F.
- Adjust the chilled water temperature within a range of 45°–50°F using the valve position. If the maximum open valve in the primary chilled water loop is less than 90%–95% open, increase the chilled water supply temperature. If more than one valve is 100% open, decrease the chilled water supply temperature.

This strategy may have pitfalls. Pump energy use may increase when increasing the chilled water temperature. To minimize this effect, make sure that the secondary chilled water flow is less than 60% of the design flow rate before initiating the temperature reset. The supply temperature reset should not increase it above this level. In addition, the temperature reset can affect dehumidification. In humid climates, warmer supply air results in less dehumidification and higher humidity levels. Humidity sensors can be installed to override the reset function if humidity levels exceed a specified maximum level. In general, the water temperature should not be reset to a higher temperature unless the dew point temperature is lower than 57°F (DOE 2002b).

E.5.15 Reoptimize condenser temperature reset based on current building loads and usage patterns.

Colder condenser water temperatures reduce chiller energy consumption but increase cooling tower fan power. As shown in Figure E–4, the optimum operating temperature occurs at the point where these opposing trends produce the lowest total power use. However, this point changes with outdoor conditions, so the set point needs to be adjusted continuously to maintain efficiency.

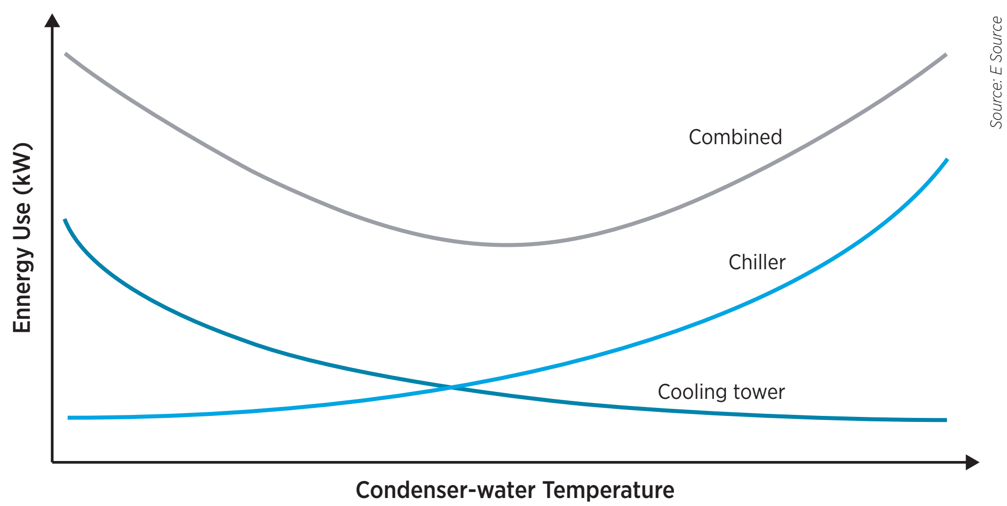

Figure E–4 Finding the optimum condenser-water temperature

FEMP's *Continuous Commissioning Guide* (*www1.eere.energy.gov/femp/pdfs/ccg02_introductory.pdf*) provides the following general guidelines for condenser return water temperature reset (DOE 2002b):

- The cooling tower return water temperature set point should be at least 5°F (adjustable according to design) higher than the ambient wet-bulb temperature. This approach prevents excessive power consumption by the fan.
- The cooling tower water return temperature should not be lower than 65°F for chillers made before 1999 and should not be lower than 55°F for newer chillers. The chiller manufacturer's manual should be referenced for more information.

The condenser temperature can be reset manually with a BAS or other controls that automatically optimize the condenser water temperature based on outside temperatures and energy use data from the cooling tower and condensers. Operators can manually reset the set point daily using the daily maximum wet-bulb or dry-bulb temperature, but should do so carefully to avoid an increase in overall energy consumption.

E.5.16 Seal leaky ducts

Reducing duct leakage can have a significant impact on energy consumption and electricity demand. The energy savings depend on the initial duct leakage level and type of building. In general, buildings with 15% duct leakage must use 25%–35% more fan power to distribute air than if there were no leakage (CEC 2005c).

Metal-reinforced tapes and mastic are the conventional method for sealing ducts. Mastic is a rubbery, fiber-reinforced goo applied with a brush. Holes can be patched with sheet metal and then sealed with a layer of mastic. Duct tape is a poor material for duct sealing, but is still commonly used. For leaks in hard-to-reach or inaccessible ducts, a technique is available for diffusing an adhesive aerosol spray throughout the duct system, building up into a flexible seal at holes and cracks (Aeroseal 2011).

E.6 HVAC: Ventilation

E.6.1 Reduce ventilation levels when building is unoccupied

Most buildings base their ventilation rates on ASHRAE Standard 62, which specifies the minimum amount of OA that needs to be brought into the building, depending on its type and use. This approach usually leads to a fixed ventilation rate based on assumed occupancy. However, in outpatient facilities occupancy varies during the day and the building may be unoccupied during evening and weekend hours. If ventilation systems are still operating at full capacity during these unoccupied periods, significant energy savings are available. Suspending ventilation during unoccupied periods also reduces wear and tear on ventilation equipment, extending system life and lowering maintenance costs. In addition, in humid climates, unnecessary ventilation during unoccupied periods can lead to elevated humidity levels. This increase leads to occupant discomfort and increased demand on the HVAC system to lower humidity to acceptable levels. One field study by the CEC found that 30% of observed systems were operating ventilation fans during unoccupied periods (CEC 2005b).

In some outpatient healthcare facilities, ventilation can be completely shut down at night and on weekends, when the building is unoccupied. A flushing cycle may be used to re-establish air quality before the building is occupied again. This process involves increasing ventilation above occupancy levels for a short period of time. However, in humid climates, it may not be acceptable to turn off ventilation during the cooling season because of its effect on humidity control.

E.6.2 Reduce ventilation levels in operating rooms, delivery rooms, and other intermittently used spaces when unoccupied, while maintaining pressurization

In hospitals, ventilation systems maintain a comfortable indoor air environment, control odors, remove contaminants, and minimize the risk of transmitting airborne diseases. Reducing the number of air changes per hour in intermittently used areas during unoccupied periods can save significant energy. For example, a hospital design review study found that 5 of 10 operating rooms examined could reduce supply air flows by 20%–56% of the occupied flows to conserve energy and still maintain the desired room pressurization (Hermans et al. 2006). St. Joseph Medical Center in Bellingham, Washington, cut ventilation rates in half during unoccupied periods (Dorough 2011).

According to ASHRAE HVAC Applications Handbook, the number of air changes may be reduced to 25% of the indicated value when the room is unoccupied, as long as the required number of air changes is re-established whenever the space is occupied, and the pressure relationship with the surrounding rooms is maintained when the air changes are reduced (ASHRAE 2003).

E.7 Additional Measures for Consideration

Several of the most important and frequently occurring EBCx measures have been discussed in the preceding paragraphs. Many additional low-cost measures can be worth exploring, depending on the condition of the healthcare facility. A number of these measures are listed in Table E–3, and further possibilities can be found in the reference documents listed in Section 3.4.

Table E–3 Additional EBCx Measures That Should Be Considered

System	EEM Description
Lighting	Clean lamps, fixtures, and diffusers
	Improve occupancy and daylight sensor locations, and move line-of-sight obstacles
Plug and process loads	Calibrate cooking equipment temperature settings, repair broken knobs, and ensure pilot lights are not overlit
	Schedule cooking activities to use equipment at full capacity
	Check electrical connections and clean terminals
	Verify that airflow paths around transformers are not blocked
Building enclosure	Cap unused air chases
	Repair any broken or cracked windows
Service water heating	Repair any leaky pipes and fixtures
	Reduce set point to 120°F, with boost heating for dishwashers
	Repair any damaged or missing pipe and tank insulation
HVAC	Align/tighten belts and pulleys
	Repair leaky pipes, valves, and fittings
	Move improperly located thermostats to prevent over- or undercooling

Appendix F

Detailed Retrofit Energy Efficiency Measure Descriptions

The following sections provide general overviews of the retrofit measures that are most likely to be effective in typical healthcare facilities. Each section includes a technical overview, strengths and weaknesses, and special considerations to help energy managers select the EEMs that best meet their needs.

F.1 Lighting

Lighting represents about 42% of electricity consumption in hospitals, not including its impact on cooling loads (E Source 2010a). Lighting retrofits can save as much as 30%–50% of lighting energy, plus 10%–20% of cooling energy, and generally have shorter payback times than other building system retrofits (EPA 2008).

F.1.1 Replace exit signs using incandescent lamps with LED exit signs

Inefficient exit signs can consume a large amount of energy use in a hospital because they remain lit 24 hours per day, 7 days per week. Most exit signs have been converted to efficient fixtures using LED technology (see Figure F–1). If you think some or all of the exit signs in your hospital have not been converted, this should be your first priority. LEDs can be produced in various colors, and have been used for many years in the consumer electronics industry. They are now making headway in many commercial lighting systems, but exit signs remain the most common application.

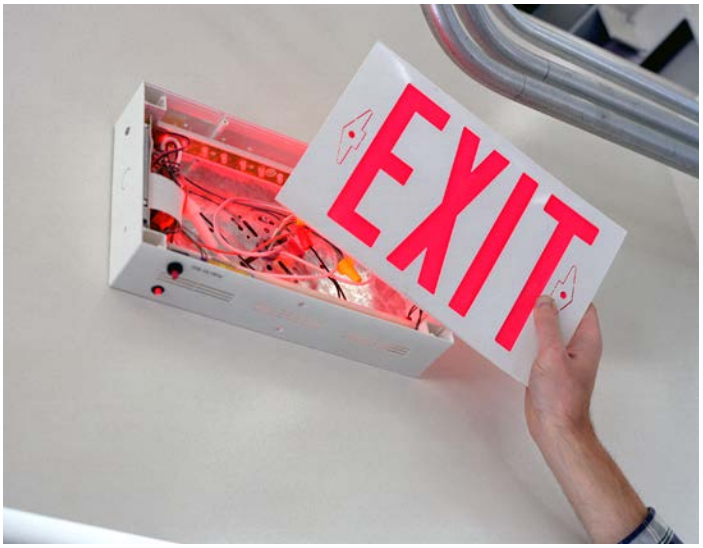

Photo from Chevron Energy Solutions, NREL 07071

Figure F–1 Exit sign illuminated with LED lamp

LED exit signs offer several advantages when installed in hospitals (EPA 2003b):

- **Lower energy costs.** An LED exit sign typically uses less than 44 kWh/year, and costs about $4 each year to operate. This represents about 5% of the annual energy cost for an exit sign using incandescent lamps.
- **Reduced maintenance costs.** LEDs used in exit signs typically maintain their rated illumination levels for 10–25 years, compared to incandescent lamps, which must be replaced several times each year. This greatly reduces the relamping costs associated with exit signs.
- **Improved safety.** LEDs typically provide better visibility than incandescent exit signs because the lamps are brighter and result in greater color contrast. In the event of an emergency, this can help the hospital staff organize the evacuation of the building quickly and safely.

The major disadvantage of LED exit signs is their initial cost. However, in a typical application, the higher first cost is repaid within the first year. ENERGY STAR has developed the *Exit Sign Specification* (*www.energystar.gov/index.cfm?c=archives.exit_signs_spec*), a free analysis tool to help building owners evaluate the economics of LED exit signs (EPA 2013b).

F.1.2 Replace T12 fluorescent lamps and older T8 lamps and magnetic ballasts with high-efficiency T8 lamps and instant-start electronic ballasts

Fluorescent lighting is used in many applications in hospitals and healthcare facilities, many of which today still have fluorescent lighting systems that use decades-old technology that is much less efficient than today's systems. These old systems typically contain:

- **T12 fluorescent lamps.** T12 systems are characterized by "fat" bulbs that are 1.5-in. diameter. T12 systems are common, but can use twice as much energy as modern T8 systems.
- **Magnetic ballasts.** Magnetic ballasts were usually paired with T12 bulbs because their initial cost was low. Magnetic ballasts are characterized by the flicker and hum that many people find objectionable in fluorescent lighting. Magnetic ballasts may also contain polychlorinated biphenyls (PCBs), a hazardous chemical that can be dispersed into the room under certain circumstances.

Energy-efficient fluorescent lighting systems using T8 (1-in. diameter) lamps offer improved efficiency, better light quality, and potentially longer life because of their reduced degradation in light output over time. T8 lighting systems have been in widespread use since the mid-1990s, are commonly available, and can be installed by any electrician or lighting company. The capabilities of T8 systems are constantly evolving to meet market needs, and many now offer dimming capabilities (see Section F.1.8).

A fluorescent lighting fixture requires a ballast, which is a special kind of transformer. For T8 systems, the two main types are instant-start and rapid-start electronic ballasts. Instant-start ballasts generally provide more energy savings than rapid-start systems, but specifying the optimal system in situations where building owners are trying to maximize either energy savings or light output usually requires consultation with a lighting design professional.

If you have not already upgraded to T8 lamps with electronic ballasts, or if you upgraded to T8s, but not the most efficient models, you can save significant energy with a lighting retrofit. The newest high-performance T8 lamps and NEMA premium ballasts boost efficiency and offer improved color quality and longer lamp life. All upgrades to more efficient lighting also reduce the cooling loads on air-conditioning equipment. A new T8 system should also effectively eliminate lighting maintenance costs for a number of years. T8 system lamps and ballasts are manufactured by major companies and typically carry warranties of 3–5 years.

The principal disadvantage of retrofitting a T12 system to T8 is the first cost of the retrofit and a modest heating cost increase. However, because this lighting retrofit saves so much energy, it may have a payback of less than 2 years in areas that are always lit (e.g., hallways and nurses' stations on patient floors).

F.1.3 Replace incandescent lamps with CFLs

Use CFLs to replace incandescent lamps in fixtures where existing fixtures are in good condition and maintenance personnel can replace bulbs with no more equipment than a stepladder. For applications that require fixture replacement, or in which bulb replacement requires either an electrician or specialized equipment (e.g., a mechanical lift to reach a fixture in a high-ceilinged lobby), LEDs are often the more economical choice (see Section F.1.9). CFLs cost more initially than incandescent lamps, but quickly pay for themselves through energy and maintenance savings. The longer the annual operating hours, the more attractive the economics of CFLs become, because a larger incandescent relamping cost is being avoided each year. The ENERGY STAR program offers a free calculator to help building owners estimate the economics of CFL bulb replacement programs (EPA 2011h).

CFLs come in two general forms—self-ballasted or pin-base. Self-ballasted CFLs—also known as screw-base, screw-in, or integrally ballasted CFLs—can replace incandescent lamps without modifying the existing fixtures. They combine a lamp, ballast, and base in a single sealed assembly that is discarded when the lamp or ballast burns out. Make sure that burned-out bulbs are properly recycled, as they contain mercury.

Pin-base CFLs, the type most commonly employed in commercial buildings, are used with separate ballasts. They are available in lower power versions, which can replace incandescent lamps, and in higher power versions, which can replace linear fluorescent lamps or high-intensity discharge lamps. Pin-base systems feature a ballast and pin-base fluorescent lamp socket that is wired into a fixture by the manufacturer or as part of a retrofit kit. Because they are hardwired, dedicated systems, they eliminate the possibility that a user will return to using an inefficient incandescent bulb.

One of the most common uses of CFLs in hospitals is in recessed downlight cans. A wide range of fixtures are now available for this fixture class, some with very good reflector designs, good optical control, and dimming capabilities. Care must be taken in this application to ensure that excess heat buildup does not shorten the lamp life.

When using CFLs, remember these key points:

- **Go for a 3:1 ratio.** Lamp manufacturers often publish a 4:1 ratio for replacing incandescent bulbs with CFLs (that is, a 25-W CFL can replace a 100-W incandescent lamp). A 3:1 ratio is more appropriate (a 25-W CFL can replace a 75-W incandescent lamp)—in practice, CFL output is lower than the nominal rating because of lumen degradation and the effects of temperature and position on lamp output.
- **Limit the number of CFL types.** CFLs are available in a wide variety of sizes and shapes—it is useful to standardize on just a few types to reduce stocking requirements and confusion at relamping time.
- **Use dedicated fixtures.** To prevent the replacement of CFLs with incandescent bulbs when it is time to relamp, use dedicated fixtures that will accept only pin-base CFLs.
- **Choose CFLs that have earned the ENERGY STAR rating.** This rating from the EPA ensures reliability as well as efficiency in self-ballasted CFLs.

F.1.4 Install more efficient exterior lighting for façades and parking lots

Careful attention to parking lot and exterior lighting systems can save significant energy, make the healthcare facility grounds safer and more attractive, and minimize the annoyance that exterior lighting often causes neighbors. Designing and implementing an optimal exterior lighting system, however, requires the expertise of a lighting design professional.

Several types of lighting systems—high-intensity discharge, T5 and T8 fluorescent, and LED—are suitable for outdoor lighting systems. Mercury vapor lights, which are common, are considered obsolete.

Many healthcare facilities were either built before the modern set of lighting technologies were available, or did not use optimal lighting design. Parking lots and exterior façades were flooded with light on the theory that more light makes the facility grounds safer. Modern design standards take into account a range of factors, including:

- **Nighttime visibility.** Parking lot lighting design should minimize glare for drivers and pedestrians, focusing more light on the driving lanes and less on the parking areas. Also, a good parking lot lighting design focuses on the vertical plane, which facilitates object recognition and promotes a safer environment. The color of the light can also be a safety factor, as evidence shows that the whiter light from LEDs, T5s, and T8s provides more visibility than the yellowish light from high-pressure sodium lamps.
- **Safety.** Safety is a paramount concern in hospital patient and emergency room entrances. Lighting must be sufficient to ensure that mobile patients and visitors can enter and leave safely; that patients and visitors with limited vision or mobility can clearly see potential obstacles, steps, and slopes; and that ambulance and emergency room personnel are not handicapped by poor lighting quality and bad color rendering. The answer is not simply more wattage, because glare can be as dangerous as dim lighting. Careful design of fixture type and placement by a lighting professional are required.
- **Aesthetics.** Façade lighting should accentuate the attractive architectural aspects of the facility, which is best accomplished by a lighting design professional. Illumination should be sufficient for visitors to have the impression of safety and to make the exterior façade of the facility welcoming rather than forbidding.
- **Light trespass and pollution.** Using fixtures with appropriate hooding, or LED fixtures that can achieve full cutoff at property lines, can minimize the trespass of light onto neighboring properties. Lowering the overall wattage of exterior systems and focusing the light where it is needed on the ground can limit the dome of light pollution that characterizes many public facilities. For more detailed information on this subject, consult the IESNA *Lighting Handbook* and the DOE publication "*Technology Specification Project: LED Site (Parking Lot) Lighting*" (*http://apps1.eere.energy.gov/buildings/publications/pdfs/alliances/techspec_ledparkinglot.pdf*).
- **Controls.** Computerized control systems and motion sensors can limit the run hours of exterior lighting systems and enhance security.

The major disadvantage is the capital cost of a new lighting system, and exterior lighting redesign is often postponed and made a component of a major facility renovation. However, a stand-alone exterior lighting retrofit project may have a surprisingly short payback, depending on the amount of overlighting, the lack of control in the current system, and local utility prices. Many times parking lights come on during peak demand periods. Peak demand reduction can have a large impact when demand charges are high.

F.1.5 Install wireless motion sensors for lighting in rooms that are used intermittently

The easiest and cheapest way to save energy on lighting is to turn lights off in rooms that are not occupied. Unfortunately, doctors, nurses, technicians, and maintenance personnel often forget this simple energy-saving technique. Many hospitals employ occupancy sensors (infrared or acoustic or both) to control electric lighting in rooms that are used intermittently, such as offices, supply rooms, or exam rooms. If the sensors detect that a room is unoccupied, they signal a lighting control system to turn off the lighting, which can save significant energy in rooms that are frequently empty.

To avoid problematic lighting shutoffs, occupancy sensor systems typically do not shut off lights for several minutes. This "delay time" is user set, and usually ranges from 5–15 minutes, depending on the use of the room. Most systems shut the power off completely at the end of the delay time. More sophisticated control systems on lights with dimmable ballasts can be set to gradually turn down the light level, in case someone is in the room.

Vacancy sensor systems may also require that the lights be manually switched on when the room is reoccupied, rather than turned on automatically when the sensors recognize occupancy. Because vacancy sensors are do not turn lights on automatically, they tend to save more energy than occupancy sensors.

The principal advantages of using motion sensors in hospitals and healthcare facilities are reduced lighting energy costs and reduced lighting systems maintenance due to decreased run hours.

The disadvantages of motion sensors are the installation costs, a modest increase in heating costs, and the need for proper system installation, calibration, and maintenance. If first cost is a major issue, you might want to consider the new wireless sensor systems, which are easier to install. The field of view of the sensor must be carefully selected and adjusted so that it responds only to motion in the space served by the controlled lighting. For example, an occupancy sensor controlling lights in an office should not detect motion in the corridor outside the office.

Various sensor types are available on the market, including passive infrared, acoustic, and ultrasonic. Information about the characteristics of sensor types can be found on the *E Source Advisor website* (*www.esource.com/escrc/0013000000DP22YAAT/BEA1/PA/PA_Lighting/PA-10*).

F.1.6 Install lighting timers in rooms that are used intermittently and for very short intervals

Some rooms that are used intermittently, such as supply closets or maintenance closets, need lighting controls to ensure that the lights are off when the room is unoccupied, but do not need controls with dimming capabilities or delay timing functions. A motion sensor that turns on the lights when it senses occupancy and shuts off after a timed interval (e.g., 5 minutes) is sufficient. Alternatively, a simple door switch system that turns on the lights only when the closet door is open, may be all that is required.

F.1.7 Install tubular daylighting devices or light shelves

Hospitals and healthcare facilities that are in competitive markets often look for ways to make their facilities more inviting and nurturing for patients. One way to do that, and to save money, is to incorporate more daylighting into spaces such as emergency rooms, waiting rooms, cafeterias, patient rooms, common rooms, and staff break rooms. Shallow perimeter rooms such as offices can incorporate daylighting with methods as simple as opening window shades, turning off or dimming fluorescent lights, and covering windows, if necessary with appropriate films or translucent solar screening.

Perimeter rooms that are too deep to be daylit solely from the windows can use two simple, nonmechanical retrofits to move daylight further into the room:

- Install light shelves into the upper third of window frames to reflect light off the ceiling into the back of the room.
- Install tubular daylighting devices to transmit daylight through reflective tubes from the roof into the back of the room.

The application of these devices is generally restricted to top-floor or one-story rooms, or two-story spaces in which there are existing chases, or in which chases can be easily unobtrusively constructed, through which to run the reflective tubes.

The primary advantage of daylighting is the reduction in electric lighting energy use. Daylighting also makes patients feel better than artificial lighting, especially fluorescent lighting, resulting in faster recovery times.

Disadvantages of daylighting strategies are the costs associated with the design and installation of the light shelves or tubular reflective devices. These costs can be substantial, and in many cases daylighting retrofits are most economical when done as part of a renovation project, which need not be a gut rehab, but only a modest modernization of décor, fixtures, and equipment. The cost/benefit of daylighting strategies should be carefully calculated, to ensure that the energy savings and nonenergy benefits of natural lighting are properly valued against the installation costs of the measures. Daylighting systems can also be complex, and may be ineffective when not designed or implemented correctly.

F.1.8 Install photosensors and dimming ballasts to dim lights when daylighting is sufficient

On bright, sunny days, the natural light available in visiting areas, offices, and waiting rooms on the perimeters of hospitals and healthcare facilities can make the use of electric lighting systems superfluous. A photosensor that senses the light in a room and signals dimmable ballasts to lower lighting levels, or signals nondimming ballasts to shut off, can save significant energy costs with no degradation of light levels. Making use of daylight saves energy and makes a space more comfortable. Controls can be expensive and disruptive to retrofit, but wireless control systems, which are easier to install and adjust, are becoming available. Daylighting systems need to be designed and commissioned carefully to avoid glare, overheating, and distracting changes in light levels (E Source 2005).

A photosensor/daylighting system provides several types of energy savings (U.S. Army 2010):

- **Lighting energy.** Dimmable lighting systems can save 25%–50% of the energy used by systems with non-dimming electronic ballasts. Hospitals and healthcare facilities in areas that have frequent overcast days will experience lower savings.
- **Cooling energy.** Dimmable lighting systems reduce the energy required to air condition healthcare facilities by reducing the runtime of fixtures. Even efficient lighting systems produce heat when they are operating, so a shorter runtime reduces the heat that must be removed by the air conditioning.
- **Demand charges.** Dimmable lighting systems reduce peak electricity demand and associated demand charges. This may be especially significant in facilities that are subject to demand-ratchet billing, in which the highest demand for a single hour sets the demand charge for a season or even a full year.

As with motion sensors, the disadvantages of photosensors are the installation costs, a small increase in heating costs, and the need for proper system installation, calibration, and maintenance. Also, rooms on the south sides of buildings may experience excessive heat gains in hot weather if the blinds or shades are opened and the lights dimmed or turned off. When the sun is low on the horizon, some rooms may experience excessive glare from direct sunlight, which can be mitigated with retrofitted light shelves or window films.

F.1.9 Install LED fixtures in operating rooms, patient rooms, and exam rooms

LED fixtures use far less energy than either incandescent or fluorescent systems, and can last up to 100,000 hours, so they are expected to gradually replace these older lighting technologies over the next decade. Many applications of LED systems are economical today, especially when the healthcare facility is planning to implement fixture replacement rather than just bulb replacement.

A lighting design professional can identify the best LED applications for your facility, and calculate the economics of the replacements based on criteria such as:

- **Run hours.** Operating room lighting systems are an example of a good LED application, because hospitals are constantly working to increase operating room utilization by consolidating procedures into some rooms and decommissioning underutilized rooms, increasing the run hours of the average operating room.
- **Light quality and focus.** Correctly implemented LED fixtures can provide more focused light with better color rendering than CFL fixtures. These are important characteristics in diagnostic settings, such as exam rooms, or in patient rooms, when a doctor or nurse is using bedside task lighting (as opposed to ambient room lighting) to monitor a patient's skin color or the condition of a wound.

F.2 Plug and Process Loads

Plug and process loads are important contributors to energy consumption in hospitals and healthcare facilities—they include electricity and gas loads such as computers, printers, laboratory equipment, refrigerators, and cooking appliances. Measures can be taken to reduce supplemental loads, which in turn can reduce the operating time and energy consumption of HVAC systems.

F.2.1 Consolidate equipment and improve cooling air movement in hospital data centers

Many hospitals have an IT infrastructure composed of a variety of hardware systems—some of which are obsolete—that have accumulated over time. Cooling equipment and the design of airflow for these IT equipment loads are not usually optimally designed and waste electricity used to provide cooling. One solution is to consolidate the computing hardware and applications onto blade servers. The blade servers provide a denser computing platform, which requires a much smaller footprint. This strategy reduces the energy consumption of the computing equipment and the cooling load of the data center because blade servers generate less waste heat.

There are basically three strategies for cooling the IT equipment. A common but inefficient strategy is to try to cool the entire room and the IT equipment in it with a room-level cooling system. Room-oriented cooling does not provide for flexibility in cooling air movement and performs poorly in high-density data centers.

A more efficient strategy is to design cooling air movement so that it cools the individual rows of IT equipment. Locating server equipment close to the cooling supply air, and making sure that hot exhaust air from the racks does not mix with the cooling supply air, increases the efficiency of cooling air movement. This strategy of row-oriented cooling is especially efficient for high-density designs. Designing the system for shorter air paths requires less fan power and saves energy. It also allows cooling capacity to be targeted to the needs of specific rows. Row-oriented cooling air movement is fairly unaffected by room geometry or layout.

The third approach is to use modular cooling equipment deployed at the level of individual racks. Rack-oriented airflow paths are even shorter than row-oriented cooling designs; however, cooling capacity cannot be shared among racks. For more information on cooling control strategies, see LBNL's "*Control of Computer Room Air Conditioning Using IT Equipment Sensors*" (*http://hightech.lbl.gov/documents/data_centers/lbnl-3137e.pdf*).

The power usage effectiveness (PUE) of a data center is a convenient relative measure of data center efficiency. PUE is defined as the ratio of total data center load (both electrical and thermal) to the electrical load of the information technology equipment. For example, if the total load of a data center is 400 kW but the servers use only 200 kW, the PUE is equal to 2. A typical PUE value for a small, air-cooled data center is about 2.0. In a retrofit scenario, a reasonable target value would be 1.4 (Mathew et al. 2010). Comparing the PUE of your data center to these reference values provides a benchmark for estimating potential efficiency improvements.

F.2.2 Replace cafeteria appliances with ENERGY STAR models

Replacing old appliances with new ENERGY STAR models can save significant energy in hospital kitchens. A wide range of appliances are used in a typical hospital kitchen, including ovens, fryers, griddles, steamers, dishwashers, refrigerators, freezers, and hot and cold holding cabinets.

Outdated refrigerators and freezers (walk-in or freestanding) may be inefficient if they have old compressors, primitive controls, failed door gaskets, poor maintenance, or improper location. Consider these factors when buying new refrigerators and freezers:

- It is important to purchase the right size for the hospital's needs and to compare models on the basis of energy efficiency. Installing a larger unit than needed will waste energy.
- The higher the energy efficiency ratio for the compressor, the less energy it uses.
- The units should be located so that the ventilation system can remove the rejected heat.
- Units should not be located in close proximity to other equipment such as stoves that leak heat.

Inefficient cooking equipment wastes energy dollars directly and generates excess heat that adds to the load on the hospital's HVAC and refrigeration equipment and can increase worker fatigue. The cost effectiveness of replacing cooking equipment will depend on the age and condition of the old equipment, the price of the replacement equipment, and the amount of energy savings and utility rates. ENERGY STAR-rated cooking equipment comes with a wide variety of energy-efficient features, including computerized controls to automatically control the time to cook certain foods.

Convection and microwave ovens have become very energy efficient and have the advantage of not requiring outside ventilation. The more efficiently these ovens cook the food, the greater the reduction in waste heat, smoke, odors, and grease vapors. By reducing these byproducts of the cooking process, the need for ventilation to remove these emissions is reduced and energy is saved. Excessive ventilation wastes energy from running the ventilation equipment and conditioning the air that must replace the exhaust air.

ENERGY STAR-rated cooking equipment typically requires less O&M than older cooking systems.

Antiquated dishwashing systems use large volumes of heated water and air. ENERGY STAR dishwashing systems reduce temperatures and pressures to the minimum required by health codes for cleaning and drying dishes. This equipment typically requires very little maintenance. Even with efficient equipment, it is important to run full rather than partial loads to avoid wasting energy and water. Depending on the size of the system, a wastewater heat recovery system may be a cost-effective addition to the dishwashing equipment.

F.2.3 Install VSDs for demand control of kitchen hood exhaust fans

One of the most effective energy-efficient kitchen upgrades is improving the ventilation system. Installing VSDs on kitchen exhaust fans allows the ventilation system to respond to the actual load on the system in contrast to the CV exhaust fans typically found in hospital kitchens. VSDs on exhaust fans are probably the most common energy improvements installed in hospital kitchens because they save significant energy. Most of the energy savings are likely to be fan energy and cooling energy. These systems are often sold with a controls package and tend to require only a moderate level of cleaning and maintenance similar to that of other fan control systems. Sensors can also be installed that measure the smoke and particulates from cooking and modulate the speed of the exhaust fan to match the amount of emissions produced. The ideal control system monitors both the exhaust and makeup air fans associated with the kitchen hoods so that proper air balance is maintained. In most cases kitchen exhaust hood systems are equipped with a local override button. If the override button is used to return fans to full speed, a trouble alarm should be activated and sent to the appropriate hospital staff so the problem can be addressed. In most cases VSDs can improve the control of kitchen temperature conditions and can be integrated into the hospital's EMS, which constantly monitors the VSD and increases energy savings.

F.3 Building Enclosure

The building envelope includes windows, doors, walls, the roof, and the foundation and is important for controlling the movement of heat and airflow in and out of a healthcare facility. OA can infiltrate a building through a variety of places, but can be controlled through proper insulation and weatherization. Problems with the building envelope, such as insufficient insulation and air sealing, result in uncontrolled air and heat movement in and out of the building.

F.3.1 Add continuous roof insulation

Hospital roofs that leak or have damaged or inadequate insulation present an energy efficiency improvement opportunity when combined with a roof replacement project. For example, by attaching an additional 3–6 in. of EPS insulation over existing insulation, a minimum of R-25 can be achieved. New roofing material that will be used to cover the insulation may be a rubber or reflective membrane, or both, if climate appropriate. It is critical for the new roof to be properly sealed with flashing around the HVAC unit curbs, plumbing vent stack, and other roof penetrations. The edge of the roof must be properly flashed and finished to provide a watertight seal.

F.3.2 Install low solar gain window films

Window film retrofits are the most cost-effective approach for healthcare facilities, which have a high window-to-wall ratio, to improve the thermal performance of windows. Because hospitals cannot be evacuated, it is necessary to apply window film to the outside surface of the glass, which requires occupant notification but not evacuation. For some healthcare facilities, it may be possible to install interior window film that will significantly reduce the installation costs. The solar heat gain characteristics of the window film can be selected that allow tuned solar control, based on the building's location and orientation. Because natural daylight is therapeutic, it is important to select window films for hospitals that are virtually clear. Window films effectively block UV radiation, which reduces damage to interior furnishings. Window films can also improve glass safety by reducing the breakage hazard from storms and reduce glare. Window films improve interior glass surface temperatures, which increases comfort for patients and staff. Warmer glass temperatures in winter and cooler glass temperatures in summer reduce the need to adjust HVAC temperature controls. Modern window films use customized low-e coatings and suspended film technology. The most economical locations for window films in hospitals are on windows that face south, east, and sometimes west.

F.3.3 Add a reflective roof covering

Adding a reflective roof coating or installing a reflective roof membrane to a hospital or healthcare building can minimize its heat gain and reduce its cooling loads. Reducing the temperature on the roof reduces the building's interior temperature, which saves cooling energy. Larger single-story healthcare buildings in warmer climates, with high ratios of roof area to total facility square footage, will achieve the most energy savings if they operate during the summer months. Cool roofs are not cost effective in all situations, but are most likely to pay off under one or more of the following conditions: the hospital has high air-conditioning use, the cooling season dominates energy consumption, the climate is hot and sunny, or the building is scheduled for reroofing. Use the *ENERGY STAR Roofing Comparison Calculator* (*www.roofcalc.com/*) to help evaluate cool roofs for your healthcare facility.

Solar reflectance is the most important characteristic of a roof coating product in terms of producing energy savings. Another significant factor in the performance of "cool roofs" is the amount of energy that is released based on the heat that has been absorbed from the sun. In warmer climates where the cooling load is dominant, high emissivity helps reduce cooling loads. However, lower emissivity is preferable for buildings located in colder climates, because it will reduce the heating load.

An additional benefit of reflective roofing treatments is that the life of the roof may be prolonged by reducing the temperature of its components. To maintain reflectivity over time, the roof may need to be cleaned or washed occasionally. Otherwise, the roof maintenance should be similar to the maintenance of other roofs.

F.4 Service Hot Water

F.4.1 Install low-flow hot water fixtures

Hospital and healthcare facilities contain both domestic and process water equipment (e.g., cooling systems). Typically the economics of efficiency improvements to process water equipment are better than domestic water equipment improvements. The primary retrofits for domestic water equipment are low-flow toilets and urinals, faucet aerators or controls, and low-flow showerheads. Ultra low-flow urinal systems only use 0.125 gallons per flush and ultra-low flow toilets use 1.28 gallons per flush. Waterless toilets have been heavily promoted; however, maintenance failures can lead to significant odor problems and the lack of dilution of liquid waste from these urinals can result in clogged lines.

Toilets, which use piston valves, have more reliable water-savings performance than diaphragm valves that require more maintenance and tend to leak. Faucet aerators spread the distribution of the water, providing satisfactory rinsing even with a lower flow of water from the tap. For most bathroom faucets, aerators can be installed that are 0.5–1.0 gpm. In locations such as kitchens or janitors' sinks, where a higher flow rate in gpm is usually required, an aerator of 1.5–2.0 gpm may be more practical.

Just as occupancy sensors are used to control lighting based on need, automatic sensors are used for public restrooms. These are typically photocells, which are used to turn on tap water for fixed intervals and to control the flushing of urinals and toilets. Automatic flush controls may be especially valuable in preventing "kick flushing" of toilets, which tends to result in premature failure of manual flush valves. By reducing the rate and duration of water flow, substantial water and some energy associated with hot water can be saved.

An attractive opportunity to reduce the amount of hot water used in hospitals is to install water-conserving, low-flow showerheads. Experience has shown that user acceptance of high-quality replacement showerheads is very high and is a common EEM for reducing the amount of energy used to heat the water. Many older showerheads may use as much as 5 gpm of hot water. Current federal standards require that showerheads use no more than 2.5 gpm and some low-flow showerheads work effectively at a 1.75-gpm flow rate.

The following considerations are important in selecting a low-flow showerhead:

- It should deliver sufficient pressure with a nonaerating spray to properly rinse long hair. Nonaerating spray reduces heat loss and increases shower comfort. If the flow rate is too low, the length of a shower might be extended, which defeats the purpose of the lower flow rate.
- It should compensate for fluctuations in water pressure so it conveys a consistent spray velocity over a wide range of water pressures for effective performance.
- It should have a sediment filter that prevents line debris from clogging the showerhead. Ideally, the showerhead should have a self-cleaning spray adjustment that helps maintain performance over time.

The cost effectiveness of showerhead replacement depends on the cost of the showerheads and amount of water and energy savings resulting from the installation. For hospitals that have hard water, a water softening system should be installed to reduce mineral buildup in the plumbing that could decrease the performance of the showerheads and to reduce the run time of showers (hard water requires a longer rinse time). Properly installed showerheads with a well-maintained plumbing system should require very little maintenance.

F.4.2 Add insulation to steam/hot water pipes

Uninsulated hot steam and hot water pipes are an obvious source of wasted energy, which also can increase the load on the hospital's cooling system depending on the location of the pipes. In many cases, pipes that were originally insulated may have had the insulation deteriorate or be damaged so that it does not provide an effective thermal barrier. Replacing damaged or missing insulation can reduce the heat loss from hot pipes. The higher the temperature of these uninsulated pipes, the greater the heat loss. Bare metal hot pipe surfaces may also pose a safety hazard. Some sections of pipe (e.g., valves) may require removable insulation jackets for maintenance purposes. Removable insulation jackets may be made of silicone-impregnated fiberglass cloth as the outer jacket with a 1-in. thick density "E" type material. The type of insulation required will depend on the size and temperature of the pipe being insulated. The materials used for pipe insulation must be resistant to degradation based on exposure to high temperatures and moisture.

F.5 HVAC: Heating and Cooling

Heating and cooling systems account for 45% of a typical healthcare facility's energy consumption, making them a major target for substantial energy savings (DOE 2003). When systems are approaching the end of their useful life, consider replacing them with high-efficiency systems. For example, replace a standard furnace with a high-efficiency condensing furnace. Upgrades to heating and cooling systems are best implemented after other steps have been taken to reduce loads. New equipment sized to meet the new loads can be smaller and less costly, and will operate more efficiently. However, numerous measures can be very cost effective even before the existing heating and cooling equipment reaches the end of its useful life. Some of these are discussed in the following sections.

F.5.1 Improve hospital chiller and cooling tower design and controls

For large cooling towers, hospitals can optimize tower capacity by plumbing them in parallel fashion and installing VSDs for the cooling tower fans. Reducing the condenser water temperature can maximize chiller savings, but the tradeoff between cooling tower fan energy and chiller enegy must be considered (see Section E.5.15). VSDs can also be used to control the chiller's compressor pumps to reduce energy consumption. Proper sequencing of the VSDs to minimize ramping speeds maximizes the energy savings. Hydeman and Zhou (2007) published an article in the *ASHRAE Journal* titled "*Optimized Chilled Water Plant Control*" (*www.taylor-engineering.com/downloads/articles/ASHRAE Journal - Optimizing Chilled Water Plant Controls.pdf*).

Another improvement is to install velocity regain fan cylinders, which will generate about 7% more airflow because they relieve the exit pressure that the fan works against. Higher performance can also be obtained by removing the splash deck and replacing it with an efficient redistribution deck or target orifice nozzles. These investments are justified only if the cooling tower has a long remaining useful life. Both procedures provide a more uniform distribution at the top of the tower and use the entire height for cooling, rather than a portion of it for water breakup. The result is a lower net temperature. Increasing surface area and reducing fan horsepower reduce chiller operating costs. Using larger cooling towers and operating them to achieve the lowest acceptable leaving-water temperature decrease the chiller's condensing temperature, thereby reducing its operating pressure. Cooling tower maintenance should be optimized before hardware improvements are installed. Scaling, corrosion, or biological growth may reduce power efficiency and increase maintenance costs because the condenser is fouled and heat transfer is lost. Spray systems in counterflow cooling towers are greatly improved by installing noncorroding polyvinyl chloride (PVC) piping in conjunction with nonclogging, nonorroding square spray acrylonitrile butadiene styrene (ABS) plastic nozzles. The most dramatic performance improvement is obtained by changing to a high-efficiency dense film fill, also known as cellular fill, which results in 5°–10°F colder water, which can provide up to a 50% increase in tower capacity. Water quality analysis is required to select the proper configuration of cellular film fill and strict attention to chemical water treatment is needed for optimum performance.

F.5.2 Install a coil bypass to reduce pressure drop when there is no need for heating and cooling

Install a coil bypass so that when the heating or cooling coils are not in operation, a bypass damper can open and air flows have a lower pressure drop, which will reduce fan energy. Installing a coil bypass damper and controls is expensive, and unless the local climate presents frequent opportunities for coil bypass, this measure is not likely to be cost effective.

F.5.3 Install a stack economizer to recover waste heat

Installing an economizer in a healthcare facility boiler stack will recover heat from the boiler flue gas to preheat feed water before it enters the boiler. Preheating the boiler feed water will typically improve boiler efficiency by a few percentage points. A boiler control package, properly implemented, may reduce stack gas temperatures to the point where a stack economizer is no longer worthwhile. Critical operating variables are the temperature of the flue gas and the degree to which that temperature will be reduced by the heat recovered by the stack economizer. It is critical to prevent the condensation of combustion gases, because this condensate is acidic and can damage the flue. One alternative is to use a recirculation loop to limit the amount of heat recovered by the stack economizer. Proper design and materials must be used in stack economizers to prevent corrosion, which would otherwise shorten the life of stack economizer equipment. For gas-fired boilers, maintenance of stack economizers is not a major concern, but for oil and coal boilers the maintenance costs are a major disadvantage. Also, the impact of economizers on the draft of combustion gases must be evaluated to guarantee that sufficient draft is maintained over the complete boiler load range.

F.5.4 Install boiler controls to allow reset of hot water temperature or steam pressure, reduce excess combustion air, and provide oxygen trim control

For large boilers, dedicated boiler control systems can be used to optimize boiler operating efficiencies in hospitals and health care facilities. A typical boiler combustion control and instrumentation panel will provide a liquid crystal display touch-screen and data modules. Typical inputs for the panel include the percentage of excess oxygen, VFD speed, boiler steam flow, boiler steam pressure, boiler flue gas temperature, boiler feed water temperature sensor, feed water valve position, and boiler gas flow rate. Analog outputs for the control may include a forced draft damper actuator, VFD, feed water valve, and outlet (draft) damper actuator. These new controls save energy and improve safety by shutting down the boilers in case of unsafe conditions. By monitoring and reducing the oxygen levels in the flue gas to 5% or less, the amount of excess combustion air can be limited. Draft control and VFD control can also be used to optimize airflow for fuel combustion.

Control loops may include feed water, draft, parallel positioning with oxygen trim, gas and oil valves, forced draft damper, and VFD control. The trim control package typically includes a boiler stack oxygen sensor, connecting cables, and a fuel/air ratio controller that monitors stack oxygen levels, interfaces with the temperature controls, and adjusts the combustion airflow in coordination with the fuel valve to optimize the mix of fuel and air. In some cases the forced draft fan motor and VFD may need to be replaced to effectively interface them with the control system for the boiler.

Some control packages allow for resetting water temperature based on variations in the heat load, depending on the outdoor temperature. For steam boilers, a similar strategy can be used to reset steam pressure when higher outdoor temperatures reduce the heat load. When resetting water temperature or steam pressure, it is important to consider the potential for thermal shock caused by large variations in heat transfer rates.

F.5.5 Add controls to stage chillers

Multiple chillers typically run at different efficiencies based on load factor. Adding controls to regulate chillers to operate at their best points on the efficiency curve, which is usually closer to full load capacity, reduces energy consumption. If the hospital has both a larger and a smaller chiller, the smaller chiller may be able to handle the lower nighttime cooling load and the larger chiller would not be started until the building cooling load exceeds the capacity of the smaller chiller. In addition to controlling the loading sequence, the controls may also distribute the run-hours between multiple similarly sized chillers to maximize equipment life. The greatest savings may come from optimizing chiller schedules. This measure may not always produce the expected savings, often because operators do not understand the control strategy and may override it. For control persistence monitoring, EMS trending is not ideal because trends may be wiped out, data collections may be canceled, or data archives may be deleted. It is important to archive trend data (chiller sequences, chilled water valve cycling, air and water temperatures, etc.) at a location that is remote from the building server. A daily download of data to these archives, which are completely independent of the EMS, is ideal. This can be a fairly simple passive monitoring system that continuously collects 5-minute interval data. The O&M manual for the chillers should include a comprehensive list of optimal system control set points. A comprehensive approach to chiller controls automates operation of the chillers and related systems such as pumps and fans to optimize system efficiency.

F.5.6 Install a water-side economizer to bypass the chiller

Under the right conditions a water-side economizer system can provide significant energy savings for hospitals. The most common method is a type of indirect free cooling that uses a separate heat exchanger, typically of the plate and frame type, and allows for a total bypass of the chiller, transferring heat directly from the chilled water circuit to the condenser water loop. As long as there is a sufficient difference in water temperatures, this strategy can reduce cooling costs. A less common method is direct free cooling, in which the condenser and chilled water circuits are linked directly together without the use of a separate heat exchanger. This avoids the pressure drop caused by using a heat exchanger, but is seldom done for other reasons. Filtration systems or strainers are required to minimize the possible contamination of the chilled water circuit with contaminants present in the cooling tower. Hospitals that have large year-round cooling because of high sensible heat gains may benefit the most from direct free cooling. For either approach, proper sizing is critical.

F.5.7 Install an air-side economizer

Economizers are one of the simplest devices to install in hospital HVAC systems. When the OA is cool enough and there is a demand for cooling, economizers can use the OA to cool the space by opening and closing dampers installed in the air handling equipment. One damper opens up to the outside and the other reduces the return air to the unit, which makes the unit draw in more OA. Most of the savings from an economizer system occur during the shoulder months when there is a cooling load and outdoor temperatures and humidity levels are low enough to provide free cooling.

To determine whether the OA is cool enough for economizer operation, the most common method is to install an outdoor dry-bulb temperature sensor to control the changeover to economizer operation. This approach works most effectively in areas that have low outdoor humidity. The more humid regions of the country must adjust the dry-bulb temperature setting to a lower level for effective economizer operation, because a wet-bulb system, which senses both temperature and humidity, is generally too expensive.

The proper location of the OA sensor is very important for optimal performance of the economizer. When the system enters economizer mode, dampers adjust based on sensors mounted in the mixed air stream to modulate the return and outdoor air dampers, mixing the two air streams to supply air at about 50°F.

The more OA that can be used for cooling, the longer the cooling compressor can remain off, which saves energy. Another benefit is the economizer can actually extend the life of the cooling system, provided it is maintained properly.

The primary limitation of using the economizer strategy is the humidity level of the OA. When relative humidity is too high, excess moisture can be brought into the building, resulting in uncomfortable conditions or an increased load on the cooling system. Savings achieved vary by climate with higher savings in moderate climates and significantly lower savings in hot or humid areas.

Proper maintenance is essential for ensuring that economizers perform as expected (see Section E.5.6).

F.5.8 Add evaporative cooling to improve condenser performance

Cooling systems for smaller healthcare facilities often include a rooftop condenser unit. Condenser coils can be evaporatively cooled in dry climates by spraying them with water. The water evaporates and lowers the temperature of the condensing coil, which increases the efficiency of the cooling system. Evaporative cooling works best during hot days with low humidity, usually found in very dry climates because the higher the humidity level the less evaporation takes place and the less cooling can be provided to the condenser coil.

An alternative approach is to install an evaporative coil in the condenser supply airflow upstream of the condenser coil. This lowers the temperature of the air and increases the heat transfer from the condenser coil.

Evaporative cooling systems can also save significant energy compared to a cooling system that is completely refrigerant based. Water costs and mineral buildup on condenser coils are maintenance concerns with evaporative cooling systems. The LCC of evaporative cooling equipment must be carefully evaluated relative to the predicted energy savings.

F.5.9 Add a small condensing boiler to handle the base load and summer load, with current inefficient boiler operating only when heating loads are highest

Operating old oversized boilers, which most of the time run at 70% of design capacity, is an inefficient method for hospitals to produce heat. Adding a small condensing boiler for base heating loads (hot water and reheat), or replacing these boilers with multiple, cascading, high-efficiency near-condensing and/or condensing boilers can be very cost effective.

Staged, energy-efficient boilers offer several advantages:

- The combustion efficiency of modular boilers is 88%–94%, compared to the 70%–80% of a large boiler.
- A modular boiler system allows for staging the system to fire only the number of boilers required to meet the heat load at a particular time, eliminating the inefficiency of firing a large oversized boiler for small or medium heating loads.
- A modular boiler system has built-in redundancy with excess capacity in the event one of the small boilers fails.
- A modular boiler system increases the efficiency and flexibility of the heating system. If additions are built on to the hospital, additional boilers can be added with minimal changes to the heating plant.
- Modular boilers can also be used to make domestic hot water with the addition of a storage tank. Although more pieces of equipment must be maintained with this strategy, most of the small units will be identical.

Some disadvantages of modular boiler systems must be considered:

- The scheduling and sequencing of modular boiler operation should be rotated so that the number of operating hours on each unit can be equalized to reduce maintenance costs. This requires detailed operating control of the system, which can be done by an automated boiler control system.
- High-efficiency condensing boilers require proper water treatment and maintenance to maintain performance. They may require more frequent replacement of breeching from condensation. Because they cannot operate in the condensing mode much of the time when return water temperatures are too high, near condensing small package boilers (88% efficiency) may provide most of the energy savings with lower maintenance costs. Sometimes a combination of condensing and near condensing boilers may be the optimum combination.

- Small boilers cannot accept variable water flow, but a primary-secondary pumping system can be used to maximize energy savings. Installing a VSD on the secondary building loop pump (which is connected by a hydronic bridge to the primary boiler pumping system) allows the building loop pump to vary pumping speed according to heat load requirements. Energy savings result from lower pumping horsepower, lower water temperatures, and higher combustion efficiency.
- The condensate from condensing boilers is acidic and may require water treatment for proper maintenance to protect the plumbing drain that collects the condensate. It is a good strategy to obtain an outside contract for water treatment, unless your staff can be trained to provide the treatment protocol required by the manufacturer.

F.5.10 Install VSDs on chilled-water and hot water pumps

CV pumping circulates the same amount of chilled or heated water through the system, even when the load requires less water. A VSD allows the building to vary the volume of circulating chilled water as the cooling load varies. Converting to VSD to modulate the speed of the pumps, combined with a NEMA premium efficiency motor and two-way valves at each coil, can dramatically reduce both pumping costs and the energy costs to make chilled water, as well as improve temperature control in the conditioned space. Similar benefits accrue for hot water pumps used for space heating. VSDs with soft-start will also reduce starting current, which could help if there are issues with starting noise, mechanical system startup stresses, or voltage sags that cause lights to dim.

As with other HVAC modifications, an engineer should quantify the cooling load to correctly design and size these modifications to the cooling system. The level of maintenance on these VSDs is similar to that of a VAV air handling system (see Section F.5.14). The economics of this measure will depend on the magnitude and variability of annual cooling and heating loads, and local electricity costs.

F.5.11 Replace standard furnace with a high-efficiency condensing furnace

Fuel burning furnaces are rated in terms of annual fuel utilization efficiency (AFUE), a percentage rating of expected performance equal to the Btus of heating output divided by the Btus of fuel input during a representative heating season. The AFUE takes into account heat losses up the chimney, the effects of cycling the unit on and off, and losses through the furnace housing.

In addition to selecting a condensing unit with a high AFUE, it is critical to correctly size the unit so that it delivers the proper amount of heating and ventilation for the space it serves. Too large a unit will waste energy and too small a unit will not be able to maintain comfortable temperatures. An engineer should calculate the heat load of the building to ensure that the furnace is properly sized. A high-efficiency condensing furnace may exhaust flue gas at a temperature sufficiently low that it can be vented through a wall rather than a chimney.

As with a condensing boiler, the condensate generated by a condensing furnace is acidic and may require water treatment. Condensing furnaces may also be noisier than conventional furnaces, so it is important to consider the acoustics of their location, because they are only likely to be used in smaller healthcare facilities.

F.5.12 Install an EMS and replace pneumatic controls with DDC

An EMS provides hospitals with automatic programmed controls, which can manage temperature and equipment operating schedules. An EMS consists of a computer, software to monitor and manage equipment performance and equipment schedules, sensors and controls, and a communications network for larger systems.

There are two general types of EMS systems: pneumatic and DDC. Pneumatic controls found in older systems do not supply the level of reliability and accuracy that DDC provides. Pneumatic controls depend on a properly functioning air compressor and clear air lines (rather than electronic signals), which require continuous maintenance. Using DDC instead of pneumatics reduces long-term controls maintenance costs. There is a cost premium to replace all the pneumatic controls with DDC, which should be compared to the expected energy and maintenance savings from a new DDC system. Sometimes a hybrid system is the best choice from an economic standpoint.

Advances in EMS technology have reduced costs and increased system capabilities. A significant advantage for a hospital EMS is that the system can control equipment and scheduling more reliably and precisely than manual controls. An EMS also can provide equipment monitoring data and track indoor and outdoor temperatures, which allow the operating schedules of HVAC equipment to be optimized. These capabilities save energy, improve comfort conditions, and trigger automatic diagnostic alarms when equipment is operating outside its correct schedule or temperature set points. Proper EMS programming that is checked to verify functional control of the equipment and energy management strategies is necessary for effective system performance.

An EMS is most effective when the hospital's building operating staff is properly trained in how to use the capabilities of the system. It must be monitored regularly to make sure the programmed schedules and settings are up to date and that the energy management strategies are working. Be sure to select a system that hospital building staff can be effectively trained to operate or obtain a service contract to support system operation. One weakness of an EMS is that it requires appropriate operator action in response to some of the data on equipment performance. Operator indifference to, or lack of awareness and response to, significant data provided by the EMS reduces its value as an energy savings strategy. Operator interference or error can compromise system schedules or set points. For example, a temporary change to accommodate a schedule variation that is not reset to its proper settings can result in lost energy savings.

The energy savings available from an EMS in a hospital is usually less than 15% of total building energy consumption. The energy savings an EMS delivers will depend on the operational status and manual control of the equipment before the EMS is installed. For example, a small hospital building with a rigorous manual control system may not realize significant savings from a new EMS. An EMS may, however, provide significant O&M savings for a hospital campus that has many buildings spread over a large area. Multiple buildings can be operated by a single integrated EMS. This allows maintenance staff to remotely monitor the operation of equipment from a centralized location and to make adjustments to control settings without having to physically visit the buildings linked to the system.

F.5.13 Replace oversized, inefficient fans and motors with right-sized NEMA premium efficiency motors

Motor efficiency is the ratio of mechanical power output to the electrical power input and is usually expressed as a percentage. Improvements in the design and the use of higher quality materials enable premium efficiency motors to accomplish more work per unit of electricity used. Additionally, premium efficiency motors have longer service lives, longer insulation and bearing lives, lower waste heat output, and less vibration, which are features that increase the reliability of motor performance. Many motor manufacturers also offer longer warranties for energy-efficient models.

In most hospitals, new premium efficiency motors are selected to replace older motors of 5 horsepower and higher. It is usually a good idea to retain a professional engineer to assist in a motor replacement project, because projects usually involve more than just a one-for-one swap of old motors for efficient motors. For example, the most common reason for motor replacement is that the existing motor will not accept VSD control. Although it is important to use a premium efficiency motor in a VSD system, it is even more critical to appropriately size the motor to the load. In many hospitals, old motors were oversized in the hospital's original design and therefore can be replaced by motors with lower horsepower ratings.

High-efficiency motors also run slightly faster than standard motors with an equivalent nominal speed. When loads such as fans or pumps are powered, the higher speeds can result in an increase in energy use. To avoid this, when replacing a standard motor with a high-efficiency one, the engineer will match the full-load revolutions per minute rating to be equal to or less than that of the existing motor, or compensate for the increased speed by adjusting fan sheaves or trimming pump impellers.

The economics of motor replacement depend on the age, condition, operating hours, and size of the existing motors and the electricity cost for motor operation. In general, it is cost effective only when an old motor fails or if the motor being replaced is very large. To be considered a *Premium Efficiency Motor* (*www.nema.org/Policy/Energy/Efficiency/Pages/NEMA-Premium-Motors*), its performance must equal or exceed nominal full load efficiency values established by NEMA.

F.5.14 Convert CV air handling system to VAV

CV fan systems waste energy by moving excessive hot or cold air to maintain zone set point temperatures. By installing VSDs on fan motors, the speed of the motors can be controlled so that the system provides only the appropriate amount of air and heat to meet the space temperature and ventilation needs. As the amount of air volume moved by the fan system decreases, the amount of electrical energy required decreases dramatically. Fan energy is reduced, and the energy needed to heat or cool the air is decreased.

Some advantages for hospitals to use the VAV approach are individual room temperature controls, proper OA ventilation, better temperature control, quiet operation, reduced stresses on mechanical equipment, and greater energy efficiency. VAV systems are very robust and flexible, and with appropriate dampers will adjust to the room conditions to provide the proper volume and temperature of air to satisfy the heating or cooling load in the space. As the temperature reaches room set point, the air volume adjusts to its preset minimum flow to provide the necessary ventilation.

Some potential disadvantages of VAV systems include inadequate air circulation at low loads and poor reliability caused by inadequate maintenance and increased complexity of controls. These systems are most economical when the system that was replaced was an oversized CV system with excessive runtimes.

F.6 HVAC: Ventilation

F.6.1 Upgrade to demand controlled ventilation to reduce OA flow during partial occupancy

In many large spaces in healthcare facilities, the occupancy is highly variable, which results in a very large range in the required ventilation rate. Much less fresh air is required when two or three people are in a large space than when 200–300 people are in that space. A system that varies the ventilation based on occupancy can be a substantial energy saver because the amount of OA that must be heated or cooled is reduced during hours of low occupancy. It also reduces the need to manage the humidity impacts of excessive OA. As more people occupy the space, the OA increases to provide the appropriate ventilation required by code.

CO_2 provides a reasonably good indicator of the number of people in a space. Measurement of CO_2 levels by sensors can be used to regulate the OA ventilation that is needed in a space. One strategy is to locate CO_2 sensors in the return duct for the AHUs that serve those spaces. More sophisticated systems can sample from several locations and calculate a weighted average of the CO_2 concentration in each zone. It may be useful to install one ambient CO_2 sensor, because knowing ambient CO_2 levels can be important in setting the control and alarm thresholds properly and may help to verify calibration. Some sensors incorporate a self-calibrating feature and offer a lifetime calibration guarantee. The CO_2 sensors should be self-calibrating so they maintain accuracy over time. The readings of CO_2 levels can also be integrated into an EMS, which provides control signals to the ventilation equipment. Whenever the sensors indicate higher levels of CO_2, ventilation rates are increased to reduce the levels of CO_2. This provides a very flexible control strategy, which is based on occupant comfort and health.

Today's high-quality CO_2 sensors are very durable and require little maintenance. However, periodic testing to verify their calibration is advisable. The primary variables that determine cost effectiveness are the relative costs of heating and cooling and the amount by which OA ventilation can be reduced in the controlled zones.

F.6.2 Add energy recovery to ventilation system

ERV exchanges energy and moisture between OA and exhaust air, so less energy is required to heat or cool the building. ERV is typically done with a rotating energy recovery wheel, which rotates between the exhaust air and supply air within an ERV cabinet. Energy may also be recovered using a liquid desiccant, which may provide cleaner air for a hospital environment. Installing ERV equipment can reduce infiltration of air contaminants from the outdoors and significantly reduce HVAC energy loads (EPA 2003a).

In winter, as exhaust air passes through the ERV, its energy is captured and transferred into the incoming air stream to heat and humidify the incoming air closer to required indoor air conditions. This generally reduces the load on the heating system. However, when a reheat system is used, there is less energy savings for space heating, because OA is mixed with recirculated air, and cooled to a fixed temperature (typically about 50°–52°F) regardless of the OA temperature. When cooling is required, heat and humidity are captured from the OA and transferred to the cooler and drier exhaust air as it passes through the ERV. This reduces the energy consumed by the cooling system. Using an ERV to reduce the load on the HVAC system also reduces the required heating and cooling capacity, allowing the purchase of smaller units when it is time to replace the boiler, furnace, or chiller. An ERV can also improve IAQ, especially through humidity control.

The economics of ERV depend on how much energy can be saved in both the cooling and heating modes. Energy recovery wheels are designed to last for the life of an HVAC system with minimal maintenance. ERVs should not be installed in proximity to any rooftop sources of pollution (plumbing vents, exhaust fans, etc.).

F.7 Additional Measures for Consideration

Industry experts have identified the preceding measures as the most likely to be significant energy savers, cost effective in a variety of situations. But many other retrofit measures have the potential to provide strong financial returns under the right circumstances. Every healthcare facility has its own unique opportunities, and users of this guide are advised to keep an open mind about specific building improvements to consider. Several additional ideas for standard retrofit projects are listed in Table F–1. Many other possibilities can be found in the various guides and handbooks listed in Section 4.4.

Table F–1 Additional EEMs That Should Be Considered

System	EEM Description
Lighting	Replace lighting system with a more efficient approach (reduced ambient light, greater use of task lighting, indirect T5 fixtures in place of direct T12 fixtures)
	Install dimming control for nighttime setback in corridors and at nurses' stations, with upgraded task lighting
	Use lighting controls that first switch power to 80%, with 100% requiring manual up-switching for examination rooms, nurses' stations, and other areas
	Install LED lighting for all patient rooms, examination rooms, and operating rooms
Plug and process Loads	Recover direct heat off all large radiology equipment
	Specify medical equipment that has low standby mode electrical use, and equipment that can be powered down or off when not in use
	Provide red plug and green plug systems for workstations, patient rooms, and work rooms. Red outlets never turn off; the rest of the equipment can all be switched off together to create a "room off" mode when not in use
	Replace electrical transformers with right-sized, higher efficiency models
Building enclosure	Replace windows and frames with double-paned low-e, thermally broken, vinyl-framed windows, with high visible light transmittance
	Modify window areas and locations to optimize daylighting
	Add skylights to increase daylighting
	Install vestibules with inner and outer doors
	Add interior rigid insulation and a continuous air barrier to exterior walls
	Install automated louver shading systems on all sun-exposed windows
Service water heating	Install solar hot water pre-heat
HVAC: Heating and cooling	Use localized/de-centralized boilers at point of use rather than one centralized boiler
	Replace air-cooled chiller with high efficiency, right-sized water- or air-cooled chiller
	Replace air-cooled or water-cooled heat pump with a right-sized ground source heat pump
	Replace standard boilers with right-sized high-efficiency condensing boilers
	Replace single large boiler with several smaller, staged boilers
	Replace DX cooling system with more efficient right-sized model with evaporative condenser
	Decouple heating and cooling from ventilation and use radiant heating and point of use cooling
	Install a point-of-use steam system with hot water boiler (hospitals only)
	Install a heat recovery chiller for process heating or reheat loads
	Install chilled beam cooling system for patient rooms (if codes allow)
Ventilation	Install a dedicated outdoor air system with high-efficiency heat recovery to reduce the heating, cooling, and dehumidification loads
	Convert to displacement ventilation system (where ceilings are higher than 9 feet)

Appendix G

Integrated Design Principles for Retrofit Projects

This appendix provides principles of integrated design for more aggressive healthcare facility retrofits in combination with a comprehensive renovation, allowing a much wider range of opportunities and higher potential energy savings than a typical retrofit project. Recommendations are presented for the entire facility and for individual subsystems. Integrated design is essential when pursuing an aggressive energy savings target using a whole-building approach. Much of the material in the following sections was developed for this AERG by Rocky Mountain Institute as part of its *RetroFit Depot initiative* (*www.rmi.org/retrofit_depot*).

G.1 Overview: The Right Steps in the Right Order

A major obstacle to achieving deep energy savings in healthcare facilities is that energy and maintenance cost savings alone do not always justify the investment. However, the economics become much better when you take into account the avoided costs of replacements and upgrades that must occur anyway as part of ongoing capital improvements. Moreover, considering only the economics of a retrofit project potentially misses an enormous amount of value beyond the cost savings. In healthcare facilities, this value can be an improved healing and working environment, and better community stature. Multiple studies have shown that providing good outdoor views and daylighting in a patient room reduces stress and anxiety, lowers blood pressure, improves postoperative recovery, reduces the need for pain medication, and shortens hospital stays (BetterBricks 2010, Ulrich 1992). Moreover, a bright, efficient, clean, and healthy place to work and treat patients will attract the best doctors, nurses, and other skilled personnel. Finally, such space improvements and environmental stewardship can be used to create excellent promotional materials for the hospital (Green Guide for Health Care 2009, ASHRAE 2009b).

Facility managers are often tasked with improving the healing and working environment or at least preventing hospital equipment and spaces from falling into obsolescence. More than 50 healthcare facilities have earned the ENERGY STAR label, totaling more than 43 million ft^2 (EPA 2003), and more than 200 healthcare construction projects have registered with the Green Guide for Healthcare to inform their sustainability strategies.

Investing in greater efficiency and load reduction can actually eliminate significant costs through downsizing, or even eliminating, mechanical systems—an occurrence known as "tunneling through the cost barrier" (Lovins et al. 1999). Take these general steps to reap the greatest energy savings and to realize multiple benefits from single expenditures:

1. **Define the specific end-user needs.** What needs and services do the occupants require? Start from the desired outcome(s): think of purpose and application before equipment. Think of cooling, not chillers; a hole, not a drill; then ask why you wanted the cooling or the hole. How much energy (or other resource), of what quality, at what scale, from what source, can do the task in the safest and most cost-effective way?
2. **Understand the existing building structure and systems.** Understand and assess the current state of the hospital. What needs are not being met? Why not?
3. **Understand the scope and costs of planned or needed renovations.** What systems or components require replacement or renovation for nonenergy reasons? What are the costs of interruptions to service or occupancy?
4. **Reduce loads.** Select measures to reduce loads:
   a. First, through passive means (such as increased insulation)
   b. Then, by specifying the most efficient non-HVAC equipment and fixtures

5. **Select appropriate and efficient HVAC systems.** After reducing loads as much as possible, consider what HVAC system types and sizes are most appropriate to handle these drastically reduced loads.
6. **Find synergies between systems and measures.** Seek synergies across disciplines and find opportunities to recover and reuse waste streams. Through this exercise, you can often realize multiple benefits from a single expenditure.
7. **Optimize controls.** After selecting the most appropriate and efficient technologies, focus on optimizing the control strategies.
8. **Realize the intended design.** Tune the OPR and implement M&V and ongoing commissioning to ensure the intended design is realized. M&V will also help staff prevent problems, ensure correct diagnosis, and permit monitoring to improve operation and future retrofit work.

G.2 Lighting (Daylight and Electric)

Lighting accounts for the largest individual end use (42%) of electricity in healthcare facilities and represents a great opportunity for energy savings (DOE 2003). But in a building sector with specialized medical equipment and building systems, it may seem difficult to address lighting energy use without interfering with higher priority health and safety demands.

Lighting impacts patient comfort and health, and plays a significant role in caregiver well-being and performance. A major lighting retrofit can address any deficits in lighting and daylighting that staff or patients have identified. If historical lighting updates in your facility have been few and far between, this can be the opportunity to ensure that lighting systems are more energy efficient and more effective in illuminating the many medical procedures and supporting activities that take place in a healthcare facility. A lighting retrofit should go beyond changing out lamps, and explore options for improved daylighting and electric lighting system design to reduce loads on HVAC systems and improve indoor environment for patient care and convalescence.

G.2.1 Define Needs—Identify Visual Task Requirements

The basic lighting objectives in healthcare facilities are to:

- Provide the requisite visual environment needed for caregivers to accomplish visual tasks at hand.
- Provide visual comfort and control to patients in support of a healing environment.

In practice, meeting these objectives requires a clear understanding of the specialized tasks that are to be conducted in each space, and an understanding of the diverse range of visual needs that can be required.

In healthcare facilities, errors in simple visual tasks can have serious consequences, and it is important to eliminate any conditions with inadequate light levels. But more light does not always equate to better vision. Providing a comfortable and effective visual environment is about tuning that environment to specific tasks at hand and addressing the visual needs of a potentially diverse occupant population. The following criteria are just as critical as providing adequate light levels:

- **Light distribution.** Are ambient light levels pleasantly and evenly distributed throughout spaces, or are there uncomfortable shadows cast or high contrast areas? Uniformity of lighting improves caretakers' ability to perform their jobs.
- **Glare and distraction.** Is it easy for caregivers to view medications, equipment, and equipment monitors and to assess patients? Is it easy for the patients to rest comfortably without intrusive glare in their field of vision? Do specific light fixtures cause distracting or competing brightness and reflections?

- **Color temperature and color rendering.** Is the lighting effective for properly assessing patient condition, especially in the operating rooms? Can caretakers and patients clearly distinguish between colors? Does the color temperature provide a warm, comfortable, and aesthetically pleasant environment in patient rooms?
- **Utility and controls.** Do controls allow caregivers and patients to easily tailor lighting to accommodate different visual tasks in a given space? The lighting required for examinations is not necessarily the lighting most conducive to resting and relaxation.
- **Access to daylight.** Studies show that access to daylight improves overall performance and well-being of building occupants. How does your healthcare facility address this opportunity?

Refer to the IES *Lighting Handbook*, which provides detailed guidelines for addressing specific visual tasks and priorities in different space types (DiLaura et al. 2011). Take a light meter into several rooms to get a feel for whether the current lighting system is meeting guidelines for illumination levels and uniformity. In addition to strict visual needs, there are high demands for daylight and electric lighting systems to meet practical requirements, including the following, as identified by the *Lighting Handbook*:

- Avoiding interference with medical equipment operation and placement
- Avoiding interference with air ducts and other high-priority building systems
- Ease of germ and dust management
- Accommodating the requirements of hazardous material storage and handling.

Talk to staff to find out how well visual and practical needs are being met in the facility to identify major deficiencies that should be addressed along with energy efficiency.

G.2.2 Design Strategies and Energy Efficiency Measures To Reduce Loads

Because lighting needs in a given space type can be very diverse, no single fixture type will be universally applicable. Use your retrofit as an opportunity to ensure a *hierarchical* approach to meeting lighting needs in your facility. First, use daylight and design the ambient electric lighting layout by selecting fixtures that provide pleasant and adequate ambient lighting. Then, design strategic supplemental task and accent lighting as needed to accommodate the task at hand in different spaces.

Optimize Passive Daylighting

Improving facility access to daylight and views can be extremely beneficial from an energy perspective and from a staff and patient performance perspective. A growing body of literature supports the positive role of daylighting and views in patient outlook and recovery times (Devlin and Arrneill 2003). Daylight can provide welcome fluctuations in light level and color throughout the day, introducing "cheeriness" and a connection to the outdoors, and providing important wayfinding cues in uniform, dreary spaces. It can also improve color rendering and add interest and delight to aesthetically challenged waiting rooms and other areas. Access to daylight can also improve staff alertness and well-being, serving as a welcome respite in otherwise uniform lighting conditions.

In retrofits, the pros and cons of the existing building massing, ceiling plenum design and equipment configuration, ceiling height, and window count and placement are inherited. Although many space types could benefit from daylight and windows, most healthcare facilities are large, multifloor, massive structures. In most retrofits, the massing of the building cannot be altered (e.g., provide new atriums), so it is critical to prioritize which space types get access to perimeter daylit zones. High-priority spaces include patient rooms and family and patient community spaces. Wherever possible, natural light should be the primary source of ambient light during daylight hours. The first step is to consider the geometric proportions of the spaces in relation to the existing windows and skylights. Then, search for opportunities to improve daylight penetration and distribution throughout regularly occupied areas despite those limitations.

For detailed practical guidance on daylight design in hospitals, refer to the IES *Lighting Handbook* (DiLaura et al. 2011) and Architectural Lighting (Egan and Olgyay 2002).

To use daylight, it must first be let it into the building through openings in the envelope such as windows, skylights, or tubular daylighting devices. If you are already considering a retrofit to sections of the envelope (for example, to add insulation on the roof or exterior walls, or to reconfigure RTUs and equipment) it could be a good opportunity to piggyback off required service interruptions or construction to add, resize, or reconfigure envelope apertures. Even if you are not considering a roof or envelope overhaul, daylighting could provide significant enough visual benefits and reductions in lighting energy use to warrant consideration.

In most hospitals, sidelighting is the primary type of daylighting aperture available in patient rooms. Consider that access to daylight and access to views are two different things, and can be provided through different apertures, or enhanced through different ameliorations to existing windows. Clerestories can be a very strategic way to leverage a small amount of glazing to do a lot of work in providing daylight; the higher the clerestories, the deeper the daylight will penetrate into the building. Vision glazing should be sized and located to allow views from the patient's bed. Balance lighting with thermal performance when sizing and placing windows. Remember, bigger and more are not always better.

Toplighting can be a great way to bring daylight into the top floors. In buildings with disadvantaged orientation, toplighting can provide a second chance to "get orientation right." Unlike sidelight glazing, which is limited by the façade orientations, toplight glazing can often be oriented as desired to take advantage of the various thermal or visual properties of directional sunlight throughout the day.

Consider that, properly designed, only 3%–5% of roof area need be dedicated to toplighting to daylight 100% of the adjacent space below. Toplighting devices come in many shapes and sizes, ranging from custom monitors to manufactured light tubes and skylights (domed and flat), some available with tracking devices to track the course of the sun. Factors that can affect your toplighting device selection include budget, architectural and aesthetic needs, available roof area, ceiling plenum depth and construction, ceiling height, and impacts to envelope performance (solar heat gain and insulation). For spaces/ceiling plenums that cannot incorporate skylights at a reasonable cost, consider light tubes to bring daylight into the top two or three floors of your facility. When bringing daylight to multiple floors below, minimize roof penetrations by bundling light tubes with existing or new vertical shafts, columns, or other multifloor penetrations.

Adding or retrofitting exterior shading devices. Exterior shading devices can help control solar heat gain and glare, and intentionally redirect light to ceilings and other interior surfaces for improved distribution. Adding or retrofitting exterior shading devices can help "fix" existing skylights or windows that let in either too much or too little solar heat, or compromise visual comfort with excessive glare. Consider structural requirements and limitations of the envelope when selecting and detailing exterior shading devices.

Replacing or retrofitting glazing in existing windows. Careful glazing selection can also help balance the visual and thermal properties of sunlight entering the building. Glazing measures to consider include (1) switching out existing glazing for glass with an improved solar heat gain coefficient (SHGC) and visible light transmittance; (2) improving glazing performance by adding a second or third pane or gas fill; or (3) adding a film to the existing window.

Relocating or reconfiguring program spaces. Interior spaces can be shaped and configured to help redirect light, optimize light distribution and illuminance levels, and reduce glare. When changes can be made to skylights and windows, relatively inexpensive interior improvements can help make the most of your envelope investments. Even exclusive of aperture improvements, changes to interior reconfiguration and design can make a big difference in perceived light quality. In patient rooms, consider relocating toilet rooms situated at the window wall closer to the interior to allow maximum patient access to views and daylight.

Raising ceiling heights and improving ceiling profiles. Higher ceilings can help redirect and distribute daylight deeper into interior spaces. If you are already planning to reconfigure ceiling ducts, HVAC equipment, or other large equipment, it could be a good opportunity to eliminate all or portions of dropped ceilings in some areas. In patient rooms, retrofitting glazing with high-performance glazing can help reduce the need for perimeter heating and cooling. Moving existing ductwork away from windows can increase ceiling heights at the window where they are most impactful. Consider splaying ceiling profiles (down and away from skylights) to reduce contrast and improve daylight distribution from those apertures.

Adding or retrofitting interior light shelves and baffles. Interior light shelves and baffles can make the most of skylights and windows by controlling glare and redirecting daylight toward the ceiling and further into interior spaces. They can be part of the "fix" for skylights and windows that interfere with patient comfort or caregiver tasks. Operable blinds (blackout in some instances) can provide desirable full control over daylight conditions. Consider controls that are easily operable from patient beds.

Adding cutouts or glazing to interior partition walls. Openings or glazing in partition walls can help perimeter and toplit areas share daylight with adjacent spaces. Interior glazing placement should be used judiciously to make the most of your investment and to preserve visual privacy where appropriate. Prefer clerestory glazing to light the ceiling surface of adjacent spaces. Where audio privacy and physical separation are not issues (e.g., general office areas), leave cutouts unglazed.

Reconfiguring furniture. Optimize the location and orientation of furniture to improve daylight distribution. In offices and reception areas, reconfigure desks so they sit perpendicular to vision glazing. Likewise, relocate equipment and computer monitors where feasible to sit perpendicular to vision glazing to minimize glare for caregivers.

Improving surface reflectances. Light-colored ceilings, walls, and floors can aid significantly in perceived light distribution.

These EEMs should not be considered in isolation. They work together to optimize lighting conditions; in some cases, it will not make sense to pursue one measure without pursuing others as well.

Efficient Electric Lighting

An electric lighting system should be functionally capable of meeting all the facility's lighting needs. In practice, controls (discussed in the next section) should be deployed to dim electric lights as needed for specific tasks, and to take advantage of daylight where possible.

Provide a hierarchical electric lighting strategy to provide ambient light first, and then task lighting to illuminate specific tasks as desired.

An important metric to track when assessing electric lighting efficiency is your LPD, or Watts per square foot (W/ft^2). Refer to the local energy codes for LPD requirements for specific interior and exterior spaces.

To quickly determine where your LPD currently stands for different space types, calculate:

[Watts per lamp] × [# of lamps in room] ÷ [total square feet area in room] = W/ft^2 in space type

Interior lamp efficiency. Two effective ways to quickly and cost-effectively increase electric lighting efficiency are to replace incandescent bulbs with higher efficiency CFLs or LEDs, and to delamp fixtures in areas that are overlit (e.g., remove one fluorescent lamp in a fixture that has three fluorescent lamps). Detailed discussion of lamp replacements can be found in Section F.1.

In many instances, you can improve light distribution by relocating light fixtures. How many light fixtures can you eliminate through efficient delamping and relocation alone, while still providing sufficient illumination? There is likely an especially large opportunity for ambient lighting. Consider increasing the mounting height of light fixtures to reduce required quantity, thus decreasing the LPD and improving uniformity. In areas with dropped grid ceilings or exposed ceilings, moving fixtures around is no cost or low cost. In situations where moving fixtures around requires the demolition of parts or all of the existing ceiling, it could make sense to bundle fixture reconfiguration with an upgrade to entirely new light fixtures, and simultaneous improvements to ceiling equipment layout and to ceiling height to optimize for daylighting.

Interior fixture efficiency. For ambient lighting, you can get to significantly deeper efficiency by upgrading T12 fixtures to high-performance T8 or T5 fixtures, or to LEDs. In fluorescent light fixtures, be sure to replace all magnetic ballasts with electronic dimming ballasts. For LED light fixtures, provide a driver (required for proper operation of LEDs) that allows the LEDs to dim.

Consider efficient upgrades for specialized light fixtures as well. For example, remove any remaining inefficient exit signs and replace with LED exit signs that consume 5 Watts or less. LED lighting can be especially useful to reduce heat gain loads, and they are a viable solution when it is important to reduce or eliminate ferrous lamps or mercury content. Further information about LED exit signs can be found in Section F.1.1.

Interior reconfiguration and design. Interior design can go a long way to complement electric lighting design, just as it can with daylighting design. Consider reflectances of all interior finishes, ceiling height, furniture height and configuration, and location and height of interior partitions to ensure they work well with the electric lighting design to optimize lighting distribution and minimize contrast.

Exterior lighting. Evaluate the illumination levels in your exterior space. They are probably higher than what is required or recommended. Consider improving the quality and efficiency of exterior lighting by using a lower wattage lamp that provides a full-spectrum white light (MH or LED). Look for light fixtures that provide a wide, uniform distribution to improve uniformity. Improved color and uniformity improves the overall perception of safety and security, and can often be achieved with 50% less wattage.

Install full cutoff exterior lighting at building façades and parking lots, with photocell controls. Full cutoff light fixtures mitigate light pollution onto surrounding areas and into the sky, and save energy by directing light toward the ground where it is needed (allowing you to use lower wattage lamps). The IES and International Dark-Sky Association have jointly introduced a new rating system through the Model Lighting Ordinance that goes beyond addressing cutoff alone, and assesses luminaires based on the amount of light they emit in backlight, upward, and glare zones (called the "BUG rating system"). Consider voluntary adoption of the rating system requirements as part of your retrofit, to limit expenses that may be required should your jurisdiction require mandatory compliance in the near future. Refer to the Model Lighting Ordinance user guide for more information (Benya et al. 2011).

Additional information about specific exterior lighting retrofits for parking lots and façades is provided in Section F.1.6.

Efficient Controls

Proper controls are essential to ensure that electric lighting is (1) activated for specific visual tasks; (2) minimized during unoccupied periods; and (3) integrated with daylighting to eliminate unnecessary use when and where appropriate. Controls should be easily operated by staff in all areas, and by patients as appropriate in patient rooms. Consider controlling ambient light fixtures separately from task light fixtures or accent light fixtures. Enable bilevel switching to control light fixtures in daylit and perimeter zones separately from nondaylit spaces. In transient spaces such as restrooms, break rooms, supply closets, and stairwells, control light fixtures with occupancy sensors. For further energy savings, wire the occupancy sensor as a vacancy sensor (same device, different wiring), which requires a person to manually turn the lights on in a space, but automatically turns the lights off when the space is vacant. At night, people perceive brightness at lower light levels. Enable automated dimming of ambient light fixtures to a level that still provides appropriate light level requirements for staff members to comfortably complete their tasks. Doing so will improve visual comfort and decrease the fatigue of nighttime workers. Additional control strategies are described in Section F.1.4 and F.1.5.

G.2.3 Climate Considerations

Thermal risks and opportunities

When making changes to apertures, glazing, and shading, take into account impacts to (1) solar heat gain; and (2) insulation performance of the envelope. Understand the needs in your local climate and strategize size, type, and location of glazing and shading devices accordingly to reap the benefits. Balance the SHGC and U-value of skylights with visual transmission needs to discourage unwanted energy losses. Minimize sidelighting on west- and east-facing façades where solar heat (and glare) are hardest to control.

Façade-specific approach to window and daylight design

Local impacts from climate change are hard to predict, but sun path is not. Daylight color temperature, height, and controllability vary throughout the course of the day, and even between seasons. Develop a tailored approach to daylight design that responds to distinct concerns at each glazing façade.

Overcast versus sunny skies

Consider whether your climate is dominated by sunny or cloudy skies. Even cloudy sky climates can provide welcome daylight to patient rooms, waiting areas, and other spaces—but glazing selection, placement, orientation, and shading design could differ to meet your goals.

Exterior lighting functionality

Select exterior lighting fixtures and lamps that can function well in your climate type. As a simple rule of thumb: Exterior fluorescents perform best in warmer climates. LEDs generally outperform fluorescents in most climates, and excel in colder climates.

G.3 Plug Loads, Miscellaneous Loads, and Occupant Behavior

Plug and miscellaneous loads represent about 23% of total electricity use in healthcare facilities (DOE 2003), and are typically subject to occupant behavior. There are numerous low- and no-cost solutions, as well as solutions that require significant capital expenditures. A comprehensive retrofit provides an opportunity to consider all measures and perhaps integrate them with other upgrades (for efficiency or otherwise) for greater cost effectiveness and convenience.

G.3.1 Define needs—What services do the loads provide?

The end uses of plug and miscellaneous loads generally fall into three categories:

1. All the electrical devices that are needed for effective healthcare. These include patient monitoring, analysis, and operating equipment—everything from a computed tomography scanner to an electric blanket used in surgery—as well as sterilizing equipment.
2. All the appliances in the offices, break rooms, and cafeteria, such as printers, computers, coffee makers, vending machines, and refrigerators.
3. "Other," which includes electrical transformers (the devices that take high-voltage electricity from the grid and convert it to voltages appropriate for plug loads and some lighting systems) and any other device not captured in the first two categories.

G.3.2 Design strategy and energy efficiency measures to reduce loads

The approach to addressing plug and miscellaneous loads can be summarized by three steps:

1. Replace or decommission existing equipment.
2. Add plug load controls.
3. Educate patients and staff.

The cost effectiveness of these steps can vary greatly. For the more cost-effective measures, see the EBCx and retrofit discussions in Sections 3 and 4. This section will describe some strategies for selecting measures for whole-building retrofit projects that may not be so cut and dried.

Replace or decommission existing equipment

Many pieces of equipment in healthcare facilities are unneeded, obsolete, or inefficient. If the equipment is not needed or is obsolete, the answer is simple: decommission it, dispose of it, or replace with something more efficient, preferably ENERGY STAR certified. If the equipment is inefficient—likely the case if it is more than a few years old—it can often be replaced.

Many facility managers wish to wait until equipment has neared the end of its useful life before replacing it with something more efficient. Understandably, they believe that sending a completely good piece of equipment to the landfill is wasteful. This is certainly true, but waste is also associated with unnecessary energy use. Moreover, a local recycling company may be willing to pick up the equipment and salvage all the materials, which can then become feedstock for new manufacturing, effectively keeping the materials out of the landfill.

Aside from a concern about sending materials to the landfill, energy managers may find that the energy cost savings alone do not justify replacing the equipment. However, it is important to consider the other benefits associated with the new equipment. For example, an energy-efficient combined copier/scanner/printer may free up enough space in the offices for some new greenery, which contributes to a friendlier and more pleasant environment for patients and staff.

Add plug load controls

The purpose of plug load controls is to reduce or completely eliminate energy use when equipment is not being used. Most equipment (even small items such as cell phone chargers) still uses energy when it is plugged in but not serving a useful purpose—a phenomenon known as *phantom energy use*. These nonessential items can be wired into an EMS that turns them off (a more elegant and reliable solution than power strips with timers). Computer monitors can be tied to a network control.

Some plug load control strategies can also be very visible aspects of sustainability in healthcare facilities. For example, vending machine lighting can be controlled to switch on only when someone approaches. See Section E.2 for further information about plug load reduction strategies.

Educate patients and staff

Addressing plug and miscellaneous loads offers a great opportunity to engage patients and staff in the process of reducing energy consumption. For example, small stickers may be applied next to light switches as a reminder to turn off lights that are not in use. An effective way to engage staff is through a short educational workshop on ways they can reduce energy use.

G.3.3 Climate Considerations

Strategies to reduce energy consumption from plug and miscellaneous loads do not vary by climate. However, the effects of reducing plug and miscellaneous energy consumption on other building systems may change by climate, ultimately leading to a different decision about whether to implement the load-reducing measures. Energy use in healthcare facilities in temperate climates is much more sensitive to internal gains, and heat gain from plug loads therefore has a much larger impact on peak cooling loads. In these climates, a reduction in plug load power (and therefore internal heat gains) could be significant in terms of downsizing the cooling system, especially if these load reductions can be achieved during peak cooling hours in the late afternoon.

G.3.4 Leverage a Planned Facility Improvement

It is clearly most advantageous to replace equipment when it is already due for replacement. However, other instances may be less obvious. Do you plan to significantly reduce your electricity consumption? Consider decommissioning a transformer or two. Are you rewiring an older healthcare facility? Consider creating “essential” and “nonessential” circuits that are separately controlled by an EMS and turned off at programmed times.

G.4 Building Envelope

The building envelope serves as a first line of defense against the elements and as a blanket of comfort for those inside, with windows and doors an essential link between environments. Common energy retrofits rarely touch the envelope, but a comprehensive whole-building energy retrofit should always address the envelope, and healthcare buildings need not be poorly performing or poorly constructed. A whole-building retrofit is an ideal time to address many façade and roof issues and correct original construction defects, often resulting in an ability to downsize mechanical equipment slated for replacement and save capital cost. The high performance envelope improvements also contribute to higher morale, faster recovery rates, and increased facility preference by doctors and patients. Envelope technology and products have evolved significantly since the 1990s, so any healthcare facility constructed before that period may well be primed for major envelope retrofits.

G.4.1 Define End-Use Priorities

When it comes to the enclosure, address infiltration first and then thermal performance. Basic maintenance assumes ensuring a functionally sealed building against water infiltration, but too often, air infiltration is allowed free rein after a building reaches a certain age, and sometimes construction defects were present from the beginning. During a whole-building retrofit, it is recommended, at a minimum, that contemporary performance requirements are targeted for reducing air infiltration to comprehensively mitigate this common condition. When possible, consider targeting the very high performance *Passivhaus guidelines* (0.6 ACH at 50 Pascals) (*www.passivhaus.org.uk/standard.jsp?id=122*).

Once infiltration is addressed, the next priority is to improve thermal performance by adding insulation to walls. Higher insulation levels should not come at a cost of creating moisture problems, so approach envelope measures with care. Done correctly, improving thermal performance can be quite effective; done wrong, it can cost a lot of money later (Rose 2005). In a healthcare facility, the last thing you want is mold and bacteria growth in the walls. Hygrothermal modeling tools such as THERM, HEAT2D, and WUFI can inform the decision of when and where to place additional insulation during a retrofit.

G.4.2 Design Strategy and Energy Efficiency Measures To Reduce Loads

In whole-building retrofits, the design strategy for building envelopes should be one of integrative design processes and solutions. Healthcare building envelope retrofits can have a number of benefits from single expenditures. However, the first step in addressing envelope condition in a whole-building retrofit should always be investigation and building enclosure commissioning:

- Where are the weak points in the system?
- Is there significant room for improvement?
- Are envelope conditions affecting more than just energy consumption?
- Is the condition of the envelope affecting IAQ or patient comfort?

This most often includes occupant surveys, monitoring, infrared thermal imaging, and blower door testing, which can reveal all the inefficiencies in the system.

Walls

The walls serve as the face of the building and are vital in establishing a first impression when attracting medical staff and patients. If it needs aesthetic work through a comprehensive retrofit, this is a great time to address performance as well.

Seal the Cracks

Addressing infiltration is the highest priority in the envelope system, especially in healthcare facilities. If air is getting in, so can water, which patients with stressed immune systems may be unable to tolerate. Infrared thermal images will point to areas where air is clearly passing through the walls unintentionally. Most often, these are at joints between walls and the roof and floor, where materials change, and at penetrations such as vents. If accessible, seal the joint areas from the interior of the building with an expandable sealant appropriate for the adhering material. Seal material transitions and penetrations from the exterior and interior. If the building is constructed of masonry, check mortar and expansion joints for infiltration issues. Extensive repointing, which can significantly extend the life of a building and reduce energy consumption, may be in order.

Insulate

Thermal performance is largely affected by conduction—the movement of heat through material. Adding insulation adds resistance to the movement of heat. To create continuous insulation spanning the enclosure, which is highly desirable, installation on the outside of the wall assembly is the most effective. However, this can change the character of the building significantly, and interior options are entirely viable, although they provide slightly lower energy savings. For buildings that need a facelift, consider some of the new high-performance insulated façade systems as an alternative to the overused and occasionally problematic synthetic stucco exterior insulation and finish system products, although even these may be appropriate in some instances. Again, carefully assess the impacts of adding insulation.

Shade and Reflect

Radiation is the most obvious source of heat gain when assessing thermal performance and one of the easiest to mitigate while adding value to the building. There are two approaches to mitigating radiative effects—shade the building and/or reflect the radiation back into the atmosphere. If you can shade any part of the wall during hot months, do it. If the facility needs a facelift on all or part of the façade, consider adding a rainscreen, vegetated green-screen, or louvered wall assembly tuned to block the summer sun, and include a radiative barrier if possible within the east and west façade assemblies. Pay attention to exterior finish colors, as these can either create a radiative heat sink (good for cold climates) or reflect heat (good for hot climates), depending on the color and reflectivity. In the northern hemisphere, plant deciduous trees on the grounds on the east, south, and west sides to shade the façade and improve the landscape. If possible, calibrate, construct, or extend roof overhangs to perform a useful function and to shade walls during the hotter months.

Reduce Heat Island

Heat convection can impact a building envelope in unforeseen ways and is tied to radiation and infiltration. An adjacent blacktop parking lot may be affecting cooling loads more than you realize. By creating a pocket of warm air over hard surfaces located in close proximity to building openings, it is also radiating heat onto walls and creating a source of warm air for infiltration and penetrating a building you are trying to keep cool. Is it time to replace the parking surface? Consider concrete or other lighter surfaces—even permeable material. Can you shade the parking surface? Add photovoltaic shade structures or landscaped tree islands to reduce the microclimate temperature. Eliminate the hardscape immediately adjacent to the walls and replace with high albedo landscaping to lower the temperature of the wall surfaces.

Roof

At any given time of day, the roof is often the largest area of exposed envelope surface, and certainly experiences the most hours of direct exposure to the sun. A deficient roof can have considerable impact on energy consumption for low-rise healthcare facilities. The roof may actually be the most valuable focus for envelope efficiency in a whole-building retrofit.

Seal the Cracks

Roof EEMs to address infiltration are similar to wall EEMs, but there are usually more equipment penetrations on a roof than the wall, so assess them thoroughly. Seal skylights and light tubes as well. If infiltration is indeed a problem at the roof-wall intersection, consider reroofing during a whole-building retrofit to completely eliminate the gap, especially if rooftop HVAC equipment is being replaced.

Insulate

Adding insulation to walls can be problematic, but roof insulation is often much easier to improve. Comprehensive renovations commonly coincide with roof replacement, so take the opportunity to install additional continuous rigid insulation to the exterior of the roof surface and meet roof insulation recommendations stated in ASHRAE Standard 189.1-2011 or the 50% AEDG for Large Hospitals (ASHRAE 2012).

Reduce Radiative Heat Gains

Roofs take the brunt of the sun's radiation. Installing a reflective radiant barrier beneath roof decking can reduce heat gain by 40% in very hot climates. (Fairey 1984) If roofing is indeed being replaced, choose a reflective white or light-colored roof to further mitigate the effect of solar radiation in warmer climates. Additionally, the roof is an ideal location for a vegetated surface. New green roof technology has migrated this design element to the forefront of green building features with limited risk for failure if designed by a professional. Vegetation lowers the roof's surface temperature by as much as 60°F on an average summer day, reducing the interior cooling load by as much as 20% (UT Austin 2008). This also creates an ideal surface for photovoltaics, which operate more efficiently at cooler temperatures.

Doors and Windows

Doors and windows are the most vulnerable parts of the envelope. They require tolerances for movement, feature continuous cracks that are ripe for infiltration, and must be lightweight enough for human control.

Seal the Gaps

Windows and door openings should be weather sealed during basic maintenance, but the units often develop gaps where dissimilar materials join, such as at the connection of glass to frame. In a common example of construction defects, windows and doors are often installed poorly, with unsealed or uninsulated voids within the framing. It may be worthwhile to reinstall good existing windows and doors if the installation is poor. Comprehensive building retrofits are a good time to address all the windows and doors at once to save on costs. Look for component assemblies, which are especially repairable and can be resealed or completely retrofit in 20 years instead of replaced. If the existing units are irreparable, replace with high-performance products that meet ASHRAE Standard 189.1-2011, and choose tilt or casement styles instead of sliding sash units for an optimum seal. In moderate to cold climates, construct vestibules at primary entrances if possible to reduce air infiltration caused by people coming and going.

Reduce Thermal Bridging

In windows and doors especially, thermal bridging within the frame or glazing panel can be particularly detrimental to performance. As stated earlier, some existing units can be retrofitted, and some cannot. Insulated glazing panels can even be retrofitted to mitigate thermal bridging and address radiation (Empire State Building 2011). Older steel windows are particularly challenging. Storm units are effective for older windows; but because most hospitals in operation are less than 20 years old, existing windows can likely be retrofitted quite adequately.

Shade and Filter

Energy managers have addressed excessive window heat gain by applying dark films and installing full height blinds. This leads to cave-like rooms, low patient morale, and dissatisfied staff. Today, spectrally selective window film technology allows a high percentage of heat (with a low SHGC) to be rejected and more visible light to be admitted, and it is available in a retrofit product with good warranties. Simple tinted or low-e films do not necessarily achieve the same results, so choose products wisely. Consider adding shading devices and interior light shelves when assessing windows. Exterior window louvers should be designed with the sun's path in mind for real utility—horizontal slats on the south façade and vertical on the east and west. These simple devices often enhance architectural character and block up to 40% of direct sunlight. They can also dramatically improve the interior environment and reduce energy use. Understand that the solution should differ from the south elevation to the east/west elevations for optimal efficacy.

G.4.3 Climate Considerations

As with any architectural decision, each EEM should be assessed in its appropriate regional and climatic context. Across all climates, reducing infiltration is critical, and in hot and humid climates, moisture barriers become extremely important. Put your money and effort there when prioritizing. If the facility is located in a cold climate, a light-colored roof may not actually save energy. Also, the insulation of the envelope is much more important in heating-dominated climates, but adding insulation to cooling-dominated buildings may not be cost effective. In very hot climates, window shading devices and SHGC should be chosen to block even winter sun.

Shifting climate and weather patterns associated with global warming are wreaking havoc on cities, both in terms of temperature extremes and of high wind speeds. Designing resilient and efficient buildings means that the needs of a 100°F summer day and a –7°F winter day are often being met in one building that until recently experienced a much narrower range of temperatures. Add to that higher wind speeds from increasingly violent storms, and designers are compelled to create tight, well-insulated, durable buildings in an effort to keep hospitals functioning in the event of extreme weather or a natural disaster.

G.4.4 Leverage a Planned Facility Improvement

Whole-building retrofits should be timed with major physical improvements to create an integrative opportunity to address sustainability across all systems. This means that aesthetic improvements should also take into account envelope performance improvements. Landscape projects should also reduce building energy if possible. Major retrofit projects for programming purposes should weave envelope EEMs into the programming. Improving daylighting for accelerating patient recovery? Retrofit the windows for energy efficiency. Rebranding the hospital with a high-tech image? Add contemporary sunshades and a green roof to reduce heat gain.

G.5 Service Water Heating

Healthcare systems are among a community's largest water consumers. Consumption levels, however, vary greatly: per capita water use in a hospital ranges from 40 gpd to 350 gpd, depending on such factors as geographical location; services provided; size, age, and type of buildings; and water use equipment and practices. Regardless of the total usage, service water heating retrofits can often be some of the most cost effective to pursue and should be considered in any comprehensive facility renovation. In most healthcare facilities, service hot water is produced by natural gas boilers within a centralized plant. In large campus-style facilities, steam may be used to produce hot water at distributed buildings.

G.5.1 Define Needs—Specify End Use Temperatures

Service water heating in healthcare facilities provides warm or hot water for the following end uses:

- General cleaning
- Kitchen usage: cleaning, food preparation sink use, cooking
- Medical and laboratory processes
- Laundry (if done on site)
- Restroom hand washing at lavatory faucets
- Showers (patient rooms and locker rooms)
- A comfortable pool or hot tub environment for physical therapy.

First, ask the question: Is warm or hot water really necessary to satisfy this need? In some instances, such as general cleaning, cold water may be sufficient. If heating is required, the incoming water from the utility is typically at about 60°F and energy is used to raise that to the desired end use temperature. Consider the needs that must be met, and re-evaluate the water temperatures required. Changing the temperature set points is the easiest and most cost-effective way to save water heating energy. The set points will often be dictated by the end user's characteristics, such as age, health, and activity level. Evaluate the occupant and end use needs, and specify appropriate temperatures for lavatory faucets, showers, and therapy pools.

G.5.2 Design Strategies and Energy Efficiency Measures To Reduce Loads

Retrofits to a service hot water system present a unique opportunity to conserve not only energy, but also water, which is a rapidly depleting natural resource. Some EEMs reduce only the energy required to heat the service water, but others save energy by simply reducing the amount of water that is being used. The cost effectiveness of these measures is heavily dependent on the water utility rates and their expected escalation in the coming years.

Reduce Hot Water Consumption

The largest opportunity for reducing water consumption in healthcare facilities is for cleaning, kitchen use, and medical and laboratory processes. For janitorial cleaning, use "dry" powder methods instead of "wet" carpet cleaning methods. Switch to microfiber mops from traditional wet mops to realize a 95% reduction in water use for mopping (EPA 2002). In the food preparation areas, specify low-flow spray valves at 1.6 gpm. Also, many food preparation areas have a need for steaming food. Switch to boilerless steamers that use 2 gal/h instead of the typical 20 gal/h. In facilitates with laboratories, replace laboratory aspirators with a central vacuum system.

In restrooms and locker rooms, first fix all faucet and shower leaks. Install aerators to reduce flow in lavatory faucets to as low as 0.5 gpm. If you can replace the faucets, specify sensor or timed electronic faucets with automatic shut-offs. Replace older showerheads with low flow (1.0–1.7 gpm) showerheads. Use this opportunity to ensure that the water pressure is adequate. Further information about low-flow fixtures can be found in Section F.4.1.

Reduce Energy for Water Heating

Once you have reduced the amount of water being used, you can tackle the energy required for heating. Make sure you are covering the basics by addressing heat loss and controls. Minimize the standby heat losses from distribution piping and storage tanks by increasing insulation, and using anti-convection valves and heat traps. For pools and hot tubs, use insulated pool covers whenever the pool is not in use. Use recirculation timers to control the circulation of hot water based on demand and install time switches on water heaters and pool heaters for unoccupied periods.

On the equipment side, consider tankless (instantaneous) water heating at restroom sinks and refrigeration waste preheat for kitchen and cleaning uses. If steam is used to produce hot water, consider whether the savings in pumping energy offset the other energy penalties of heating water via steam. Solar thermal systems are especially appropriate for facilities with high year-round hot water usage, such as those with on-site laundry facilities. Consider heat recovery options with other air or water streams, especially for indoor therapy pools with dehumidification needs. There may also be an opportunity to meet lower temperature water needs (e.g., ~ 120°F) with a heat recovery chiller.

G.5.3 Climate Considerations

In general, most service water heating retrofits are more cost effective in colder climates (with lower incoming water temperatures from the utility), particularly those that minimize distribution heat loss. The cost effectiveness of solar thermal systems is highly dependent on the amount and regularity of solar radiation on site. When considering solar thermal systems, carefully study the minimal daily hot water load, the amount of available solar radiation, and freeze protection requirements.

G.5.4 Leverage a Planned Facility Improvement

Often planned facility improvements can make additional energy retrofits more cost effective. Is the roof being replaced? This is an excellent time to install roof-mounted solar thermal collectors. Is a new cleaning crew coming on board? Institute a new water management program for cleaning, and implement water-efficient cleaning equipment and procedures.

G.6 Heating, Ventilation, and Air-Conditioning

Healthcare facilities provide a comfortable and healthy environment for healing patients and conducting medical research. HVAC systems must support these purposes and be dependable, often with 24–7 operation. During a comprehensive retrofit, it is important to provide reliable systems that meet all the various healthcare-specific criteria and use less energy.

Healthcare facilities, especially hospitals, rarely undergo whole-building retrofits because it is rarely feasible to shut down operation of large portions of the facility. It is far more common to have piecemeal renovations or additions over time. This limits the type of energy retrofits that would otherwise be cost effective in a major renovation.

Although many types of HVAC systems could be used in healthcare facilities, it is common to have central plants (sometimes with purchased steam) serving CV reheat systems. In healthcare facilities, the ventilation air exchange rates often exceed cooling design flow rates. The ventilation air also needs to be dehumidified, which is traditionally accomplished by subcooling. CV reheat systems have been a common approach in healthcare facilities because they can independently control temperature and humidity. Because of the high air change rates and humidity control required in many of the space types found in healthcare facilities, the amount of reheat energy used by these systems is a significant portion of the total energy use.

G.6.1 Define Needs—Specify Temperature, Humidity, and Outside Air

HVAC systems affect thermal comfort by controlling the temperature and humidity of the room air. The most cost-effective way to reduce energy for HVAC systems is to expand the allowable ranges for indoor temperature and humidity. Carefully study and survey the thermal comfort needs of the occupants in each space type, and determine acceptable ranges for temperature and humidity within the space. Next, consider the amount of ventilation air required by the occupants in each space type. Conditioning OA is one of the most energy-intensive jobs that an HVAC system performs in a healthcare facility—the first step is minimizing the amount of OA that needs to be conditioned.

In January 2010, the Facility Guideline Institute released “Guidelines for Design and Construction of Healthcare Facilities – 2010,” which incorporates ASHRAE Standard 170-2008 (Ventilation of Healthcare Facilities) as Chapter 6 (Bartley and Olmsted 2011). As a result there is now a single source of standards governing ventilation and filtration for healthcare facilities. These facilities must also comply with the thermal comfort requirements of ASHRAE Standard 55.

Although most commercial building types have maximum relative humidity requirements (60% for healthcare), some hospital spaces are unique because they also have minimum humidity requirements (20%) per Addendum D to ASHRAE Standard 170-2008 (ASHRAE 2008). Ventilation standards for hospitals are also unique among commercial buildings because their spaces have total airflow requirements as well as ventilation airflow requirements. When calculating the required airflow rates, use the actual design occupancy rates as opposed to default occupancies. The default values tend to be very conservative, and this simple step can sometimes reduce the OA by more than 30%, saving energy and reducing the size of the system required.

G.6.2 Design Strategies and Energy Efficiency Measures To Reduce Loads

As mentioned earlier, healthcare facilities rarely undergo whole-building retrofits because of the disruption to facility operations. With this in mind, the approach to energy retrofits is modified and slightly limited. Rarely does opportunity present to overhaul air and water distribution systems, or to redesign secondary HVAC systems; however, there are many opportunities within controls and central plant design.

Size and Select a System

In the rare case that the mechanical systems can be completely gutted, an ideal system type for healthcare facilities is often water or ground source heat pumps with a dedicated outside air system for ventilation. When most of the facility must remain operational, some retrofits can significantly reduce energy consumption on the air-side systems, including:

- Install high-efficiency fan motors.
- Use runaround coils or heat pipes to minimize the reheat energy.
- Install UV lights on cooling coils.

Evaluate heating and cooling central plant options only after the loads have been drastically reduced from other retrofit measures. These reduced loads can sometimes change the appropriateness of various system options, or significantly downsize equipment. When considering central plant design options, consider the following:

- **Extent of renovation.** Is a new central plant required because the facility has grown significantly? If not, is it possible to make significant changes to the plant without disrupting service? For instance, a new method of heat rejection might be implemented without having to shut down the plant's operation.
- **Climate.** What types of centralized heat rejection can best capitalize on the climate characteristics of your site? Compare traditional cooling towers with ground or water loop heat rejection. With ground source heat rejection, ensure that the loops are sized and spaced to account for unbalanced heating and cooling loads, so that the temperature of the reservoir is not altered over time.
- **Centralized heat recovery.** Are there opportunities for heat recovery at the central plant level? Consider available waste heat streams, such as heat rejection for cooling, and possible uses for cogeneration.
- **Rightsize the chosen systems and account for load diversity.** Accurate sizing of equipment leads to lower equipment costs, lower utility costs, and more comfortable conditions.

Specify Efficient Equipment

Once the systems have been chosen and sized, specify equipment with high peak and part-load efficiencies. Consider condensing boilers, VSD compressors, and high-efficiency fans, motors, and pumps. Part-load performance is just as important as the rated efficiency, so carefully consider performance curves when choosing equipment.

Optimize Distribution Design

Often, the biggest energy savings in healthcare facilities can come from O&M and TAB of the HVAC system. To complete this work, it may be possible to use the maintenance time saved from other retrofits (e.g., installing light fixtures with longer lifetimes). Because renovations and additions often occur in a piecemeal fashion over time, it is common to find that the HVAC controls and zone level airflows are well out of balance, and many spaces are over- or underventilated. Healthcare facilities are notorious for operating under a negative pressure, which results in infiltration and can lead to moisture control problems.

Optimize Controls

Optimizing HVAC controls is a cost-effective energy-saving strategy and is a key component to any comprehensive retrofit. In healthcare facilities, the most important aspect of this is controlling the amount of conditioned OA, as well as the humidity of the air. Use DDC systems for greater accuracy, performance, and energy savings and incorporate these data into a BAS that they facility manager can use to operate the building. Carefully coordinate HVAC and refrigeration control strategies. Some of the most common and profitable control strategies to consider for healthcare include:

- **Off hours controls.** During unoccupied periods, employ temperature setbacks and do not bring in any outside air. While many facilities operate 24/7, the most energy-intensive spaces (such as operating rooms) have regular off hours.
- **Demand control ventilation.** With demand control ventilation, you can control the amount of OA being provided to each zone based on occupancy. CO_2 sensors should be used, because many zones in healthcare facilities can be densely occupied and have highly variable occupancy patterns.
- **Rezoning.** Separate HVAC zones with constant airflow, temperature, and humidity control requirements from those with single- or double-shift occupancy that would allow reductions in air changes or setbacks in temperature and humidity.
- **Economizers.** Consider the use of either an airside or water economizer to capitalize on "free cooling." Depending on the climate, consider whether the economizer should be controlled from air temperatures or enthalpy.

- **Exhaust.** Although the trend is to outsource food service kitchens and laundry functions, many healthcare facilities still have exhaust from these services. Ensure that all exhaust systems have enough makeup air to avoid negative pressures within zones. Consider VAV exhaust with heat recovery.
- **Central plant controls.** Develop an overall control strategy for the entire central plant (if applicable) that includes VSDs, equipment sequencing, water temperature resets, soft-starting of motors, and demand control.

Recover and Reuse Waste Streams

Heat recovery systems are most easily used to capture heat in the form of hot water. It is generally cost effective to preheat a large portion of the service hot water using recovered waste heat from cooling systems. If steam is used within the facility, employ a heat recovery loop on steam condensate for preheating service water.

In some healthcare facilities, refrigeration systems are required for storage of certain materials. These systems create an extraordinary amount of heat, which can easily be recovered for space heating, service water heating, or even for more innovative purposes such as liquid desiccant recharging for dehumidification of ventilation air.

Because conditioning OA for ventilation is such a big contributor to energy use in healthcare facilities, either exhaust air heat or energy recovery is also recommended. Finally, consider ways to recover and reuse condensate for on-site irrigation needs.

Bundle Energy Efficiency Measures to Optimize Synergies

Always consider measures that are interrelated, and which should be implemented together, to maximize savings and return on investment. For example, an overhaul to the centralized control system could be coupled with a real-time educational display of energy usage in the lobby. Daylight dimming controls and shading devices should also be considered along with any lighting retrofit.

G.6.3 Climate Considerations

Climate characteristics should play a role in every decision and strategy within a comprehensive HVAC retrofit. For instance, in hot, dry climates, an airside heat recovery coil for space heating may not be worthwhile because of fan static pressure penalties. In humid climates, desiccant dehumidification can offer a good return when you have a reliable waste heat stream. Generally speaking, it is valuable to:

- Address the thermal risks and opportunities in the climate: Is there an opportunity to eliminate a perimeter heating system with a super insulated envelope?
- Address the solar gain characteristics of the climate to guide passive heating and shading strategies and to evaluate renewable alternatives.
- Evaluate contributions to peak heating and cooling loads. Is this building dominated by heating or cooling loads? Is the climate (envelope loads) a major factor, or are the loads driven by internal gains?

G.6.4 Leverage a Planned Facility Improvement

Planned facility improvements can often make additional energy retrofits more cost effective. If a major addition is planned, it may necessitate relocating the central plant, allowing for new system types and downsizing because of reduced loads. If a complete gut of the central plant or airside systems is not possible, other facility improvements can still trigger cost-effective energy retrofits. Are the parking lots being repaved? This would be an ideal time to install a ground source heat rejection system for the existing central plant. If laundry facilities are being added onsite, consider incorporating cogeneration into the central plant design.

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