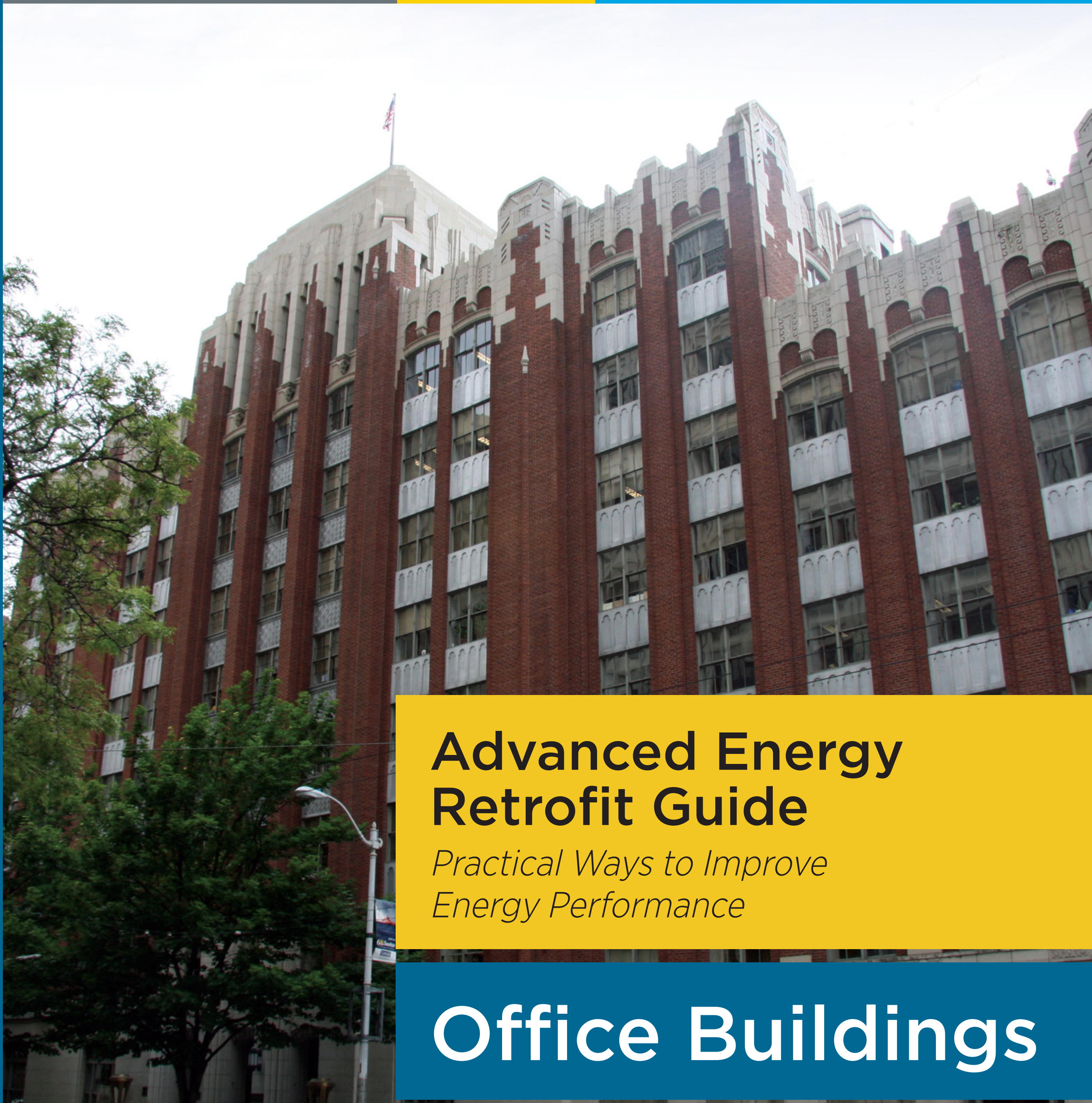
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM



Advanced Energy Retrofit Guide

Practical Ways to Improve Energy Performance

Office Buildings

Pacific Northwest National Laboratory

PECI

U.S. Department of Energy

Prepared for the
U.S. Department of Energy

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BUILDING TECHNOLOGIES PROGRAM

Advanced Energy Retrofit Guides

OFFICE BUILDINGS

PREPARED BY

Pacific Northwest National Laboratory

and

PECI

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We are very proud of the guide that the project team has developed. We hope readers will find it to be a valuable source of practical information for guiding office building energy efficiency retrofit projects.

Guopeng Liu, Project Manager
September 2011

Foreword

How to Use This Guide

The *Advanced Energy Retrofit Guide for Office Buildings* is one of the five retrofit guides DOE commissioned at the beginning of Fiscal Year 2011. By presenting general project planning guidance as well as financial payback metrics for the most common energy efficiency measures, we believe these guides provide a practical roadmap for effectively planning and implementing performance improvements for existing buildings.

The *Advanced Energy Retrofit Guides* (AERGs) are designed to address key segments of the U.S. commercial building stock: office, retail, K-12 schools, grocery, and healthcare buildings. The guides' general project planning considerations are applicable nationwide, while the energy and cost savings estimates for recommended energy efficiency measures have been developed based on energy simulations and cost estimates tailored to five distinct climate zones, detailed in the figure below. The results of these analyses are presented for each individual measure, as well as a package of recommended measures for three project types: operations and maintenance (O&M) measures implemented through the existing building commissioning (EBCx) process, standard retrofits, and deep retrofits. In this guide, standard retrofit measures provide cost-effective and low-risk efficiency upgrade options including equipment, system and assembly retrofits. Deep retrofit measures require a larger upfront investment and may have longer payback periods than O&M or standard retrofit measures.

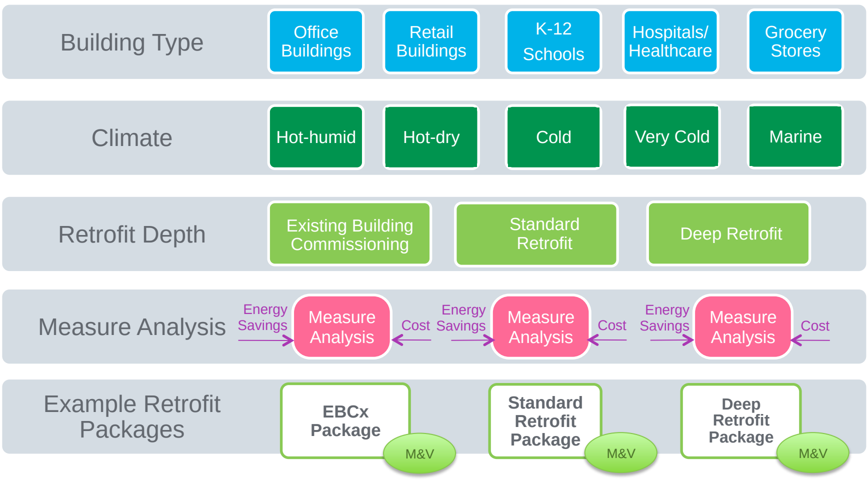

Figure F.1. Scope of AERGs

This guide primarily applies to facility managers and energy managers of large existing office buildings (>100,000 sf), but also includes considerations for small and medium office buildings. Additional parties, outlined in the table below, will also find this guide beneficial.

		Building Owners[1]	Building Operators[2]	Financial Institutions	Government Agencies	Utilities	Energy Auditors	Commissioning Providers	Architects and Engineers	Tenants
		Office								
1.0	Introduction	●	●	●	●	●	●	●	●	●
2.0	Improving Energy Performance	●		●	●				●	
3.0	EBCx	●	●			●	●	●		
4.0	Standard Retrofits	●				●	●	●	●	
5.0	Deep Retrofits	●				●	●	●	●	
6.0	M&V	●					●	●		
7.0	O&M	●	●					●		
8.0	Conclusions	●	●	●	●	●	●	●	●	

1 • Includes facility managers and energy managers
2 • Includes service contractors

Figure F.2. Target Audiences

The significant number of energy efficiency project planning considerations is matched only by the scale of opportunity for energy efficiency improvements in existing office buildings. A typical office building can cut energy use by up to 25% by implementing no and low cost measures and over 45% (including 25% EBCx savings) by pursuing deeper retrofit measures presented in this guide. The impact of such projects will be felt in the form of reduced operating costs, improved occupant comfort, and other related benefits.

Acronyms

AEDG	Advanced Energy Design Guide
AERG	Advanced Energy Retrofit Guide
AIA	American Institute of Architects
AIRR	Adjusted internal rate of return
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BAS	Building automation system
BEEP	BOMA Energy Efficiency Program
BEPC	BOMA Energy Performance Contract
BOC	Building Operator Certification
BOMA	Building Owners and Managers Association
CAV	Constant air volume
COP	Coefficient of performance
DB	Dry bulb
DCV	Demand-controlled ventilation
DDC	Direct digital controls
DOAS	Dedicated outdoor air system
DOE	Department of Energy
DSIRE	Database of State Incentives for Renewables and Efficiency
DX	Direct expansion
EBCx	Existing Building Commissioning
EC	Evaporative cooling
EERE	Office of Energy Efficiency and Renewable Energy (Department of Energy)
EIA	Energy Information Administration
EIS	Energy information system
EPA	Environmental Protection Agency
ESCO	Energy service company
EUI	Energy use intensity (typically described as kBtu/sf)
EUL	Effective useful life

HID	High-intensity discharge
HP	Horsepower
HVAC	Heating, ventilation, and air conditioning
IEA	International Energy Agency
IGV	Inlet guide vanes
IPMVP	International Performance Measurement & Verification Protocol
IRR	Internal rate of return
IT	Information technology
kW	Kilowatt
kWh	Kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LCC	Life cycle cost
LEED	Leadership in Energy and Environmental Design
LPD	Lighting power density
MACRS	Modified Accelerated Cost Recovery System
MCWB	Mean coincident wet bulb
MIRR	Modified internal rate of return
M&V	Measurement and verification
NAESCO	National Association of Energy Service Companies
NBI	New Buildings Institute
NC	New construction
NEEA	Northwest Energy Efficiency Alliance
NIST	National Institute of Standards and Technology
NOI	Net operating income
NPV	Net present value
NREL	National Renewable Energy Laboratory
O&M	Operations and maintenance
OA	Outdoor air
OMETA	Operations, maintenance, engineering, training, and administration

PACE	Property Assessed Clean Energy (financing)
PIER	Public Interest Energy Research
PNNL	Pacific Northwest National Laboratory
RA	Return air
RCx	Retrocommissioning
RFQ	Request for qualifications
RH	Relative humidity
ROI	Return on investment
RP	Recommended package
RTU	Rooftop unit
SF	Square feet
SHGC	Solar heat gain coefficient
SHW	Service hot water
SWH	Service water heating
TAB	Testing, adjusting and balancing
VAV	Variable air volume
VFD	Variable frequency drive
WSDGA	Washington State Department of General Administration

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1

Introduction

ABOUT THIS SECTION

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

The *Advanced Energy Retrofit Guides* (AERGs) for Existing Buildings have been developed by the U.S. Department of Energy (DOE) to help building owners, facility managers and energy managers select the energy efficiency improvements that best suit their building type and location, and successfully execute those improvements. The full series of guides will address key segments of the commercial building stock. Emphasis is put on actionable information, practical methodologies, diverse case studies, and objective evaluations of the most promising retrofit measures for each building type.

This guide addresses office buildings, which represent approximately 17% of energy use in commercial buildings nationwide (Figure 1.1). Office buildings in the U.S. consume more energy than any other building type (U.S. Energy Information Administration, 2006). And with almost 60% of existing office buildings built before 1980, many are past due for upgrades to aging building equipment, systems, and assemblies. Office buildings offer significant opportunities for deep, cost-effective energy efficiency improvements, and this guide provides practical and specific guidance for realizing these opportunities.

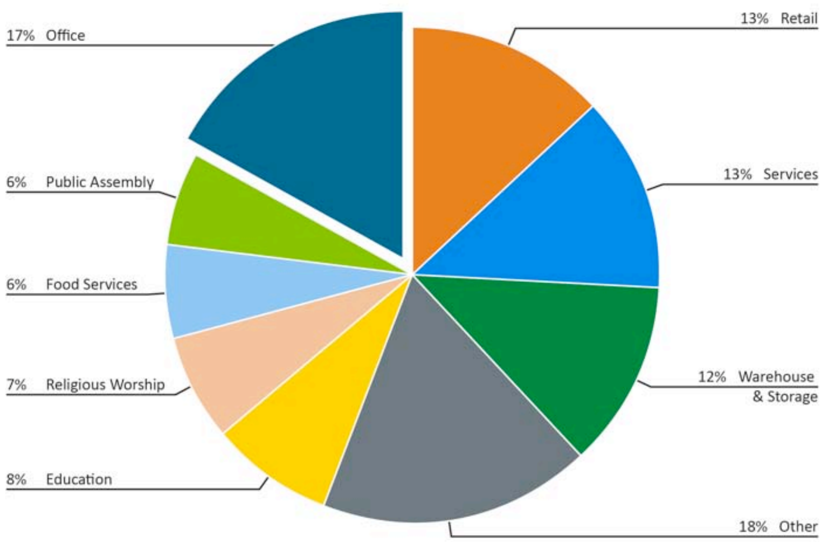

Figure 1.1. Distribution of Commercial Building Energy Use (U.S. Energy Information Administration, 2006)

1.1 Purpose of the Guide

This guide has been created to help building owners, facility managers and energy managers plan, design, and implement energy improvement projects in their facilities. A 2011 survey identified record high interest in energy efficiency projects among building owners and managers, but also noted significant barriers relating to project finance and planning (Institute for Building Efficiency, 2011). This guide provides building owners and managers with insightful information to address those barriers, including robust approaches to project planning, plus data and methods for financial analysis.

The primary audience for this guide is facility managers and energy managers who wish to improve the energy performance of their buildings, generate strong financial returns, and simultaneously achieve non-energy benefits, such as improved occupant comfort. An owner who is new to energy efficiency projects will find a primer on the key concepts in Chapter 2, and guidance on implementing operations and maintenance measures to reap up to 25% savings in Chapter 3. A facility manager who has optimized existing operations can find recommendations on energy efficient retrofits in Chapter 4. Chapter 5 is for those who are looking to distinguish their facilities through deep, integrated retrofits, perhaps as part of a major renovation.

The following additional audiences are expected to benefit from much or all of the content in this guide:

- Financial institutions seeking objective analysis of the cost savings and performance risks associated with specific building improvements
- Government agencies considering the feasibility and cost-effectiveness of regulations or financial incentives for energy efficiency improvements in existing office buildings
- Utilities operating energy efficiency programs
- Architects, design engineers, and consultants responsible for a major renovation
- Commissioning agents evaluating the cost-effectiveness of energy efficiency improvements
- Building operators interested in cost-effective operational strategies

BARRIERS ADDRESSED

- Difficulty getting started
- Limited capital and competition for resources
- Shortage of actionable cost and energy savings
- Failure to consider all benefits over project life
- Lack of specific methods to achieve deep retrofits

This guide targets one of the key barriers to implementing energy saving projects: the lack of actionable cost and energy savings data and analysis for energy efficiency improvements (Institute for Building Efficiency, 2011). This guide addresses that gap by providing practical analytical methods for evaluating the cost-effectiveness of potential building upgrades, tailored to office buildings in multiple locations. These methods are then applied to produce a series of recommended measures and packages of measures that are tailored to five U.S. climates.

Detailed tables are included to illustrate the energy impact of implementing the recommended packages of measures on a typical building. Case studies are also included, to demonstrate how office building owners have successfully implemented similar energy efficiency projects.

1.2 Approach of the Guide

Office buildings have widely varying designs and uses, and building owners and facility managers face a variety of financial constraints. To address the diversity, this guide presents three levels of upgrade options: (1) Implementing operations and maintenance (O&M) improvements through Existing Building Commissioning (EBCx), (2) standard retrofits, and (3) deep retrofits. In this guide, standard retrofit measures provide cost-effective and low-risk efficiency upgrade options including equipment, system and assembly retrofits. Deep retrofit measures require a larger upfront investment and may have longer payback periods than O&M or standard retrofit measures. Another layer of diversity is created by the dependence of retrofit options on climate, so the upgrade options for standard and deep retrofits are customized for five different climates. This multi-level and multi-climate approach broadens the applicability of the guides to a wide range of situations.

The flow chart in Figure 1.2 provides one example of how the main sections of the guide correspond to key project planning and implementation phases.

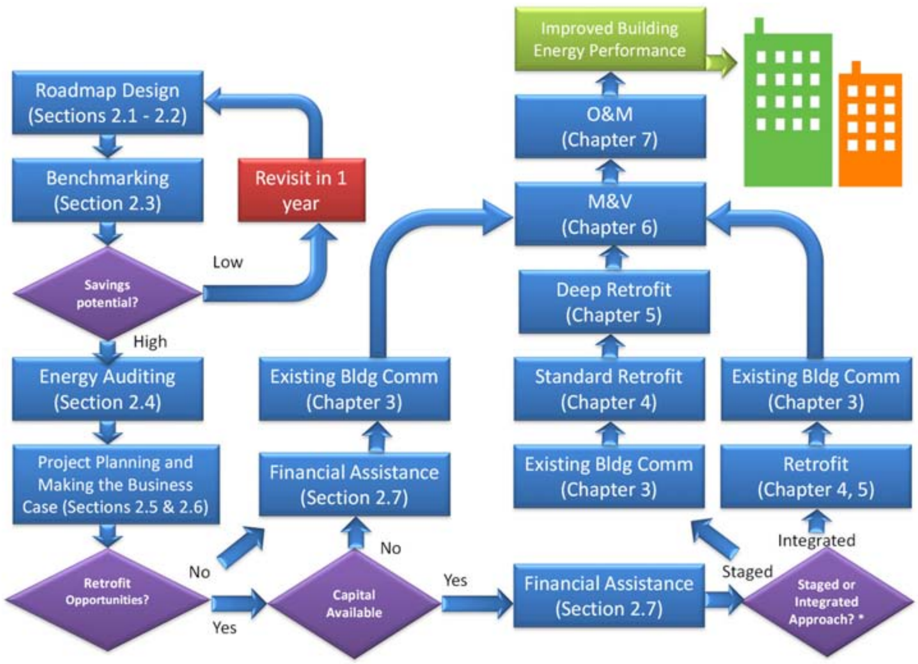

Figure 1.2. Example of AERG Project Planning Flow Chart
* Integrated Approach: Simultaneous retrofit of multiple building systems, EBCx after the system/equipment upgrade
Staged Approach: Retrofit of building systems sequentially

The guide begins in Chapter 2 with an introduction to key concepts underpinning energy efficiency projects; discussions of goal setting, project planning, and performance tracking illustrate the process for initiating energy efficiency projects. Chapter 2 also explains energy audits, financial analysis, and financing options, to provide the remaining elements needed for a strong business case. This chapter lays the foundation upon which energy efficiency project options are built in the subsequent sections.

Chapters 3 through 5 provide sample upgrade packages for three levels of project: EBCx, standard retrofits, and deep retrofits. Each package has been modeled based on a typical large office building (200,000 square feet), to give robust and consistent estimates of implementation costs and energy savings. Considerations for small and medium office buildings are presented in each discussion of retrofit measures packages as well.

In reality, all buildings are unique, so the recommended packages presented in this guide are intended as an intelligent starting point. The costs and savings values included in this guide for the recommended packages and the individual measures are estimated values. A brief description of the sample recommended package of measures presented in Chapters 3 through 5 is provided in Table 1.1. The savings ranges for all three project types presented in the table assume a common baseline building condition.

Table 1.1. Energy Upgrade Project Type Descriptions for Office Buildings

Existing Building Commissioning (EBCx)	Up to 25% Energy Savings
Significant savings can often be achieved with minimal risk and capital outlay by improving building operations and restructuring maintenance procedures. This process, commonly known as existing building commissioning, or EBCx, is generally recommended even when deeper retrofits are being considered. A nationwide study of commissioning projects by Lawrence Berkeley National Laboratory found that office buildings typically realized 22% energy savings through EBCx, with an average simple payback period of 1.1 years (Mills, 2009).	
Standard retrofit	**25-45% Energy Savings**
This type of project includes the system retrofits that are most cost-effective and lowest risk. These standard retrofit measures are typically component-level replacements of existing equipment for improved energy efficiency. Typically, no one standard retrofit measure will achieve 25-45% site energy savings, but as a package of measures, this range is easily achievable.	
Deep retrofit	**45% Energy Savings**
Deep retrofits go beyond component level replacements and take an integrated whole-building approach to energy savings projects. Savings beyond 45% are achievable when upgrades to the building envelope are combined with retrofits of lighting and mechanical systems.	

The recommended retrofit packages presented in this guide are built on an analysis of almost 60 promising energy efficiency measures. Chapters 3 and 4 describe each of these measures in brief, and additional detail is provided in the appendices. The process for developing the recommended packages of measures was done by first brainstorming all potential measure options, then prioritizing measures based on technical feasibility and appropriateness, and finally finalizing measure packages based on cost-effectiveness. This process, simplified in the Figure 1.3, can be mirrored by building owners to determine the energy efficiency measures best suited to their building's needs and energy performance improvement strategy.

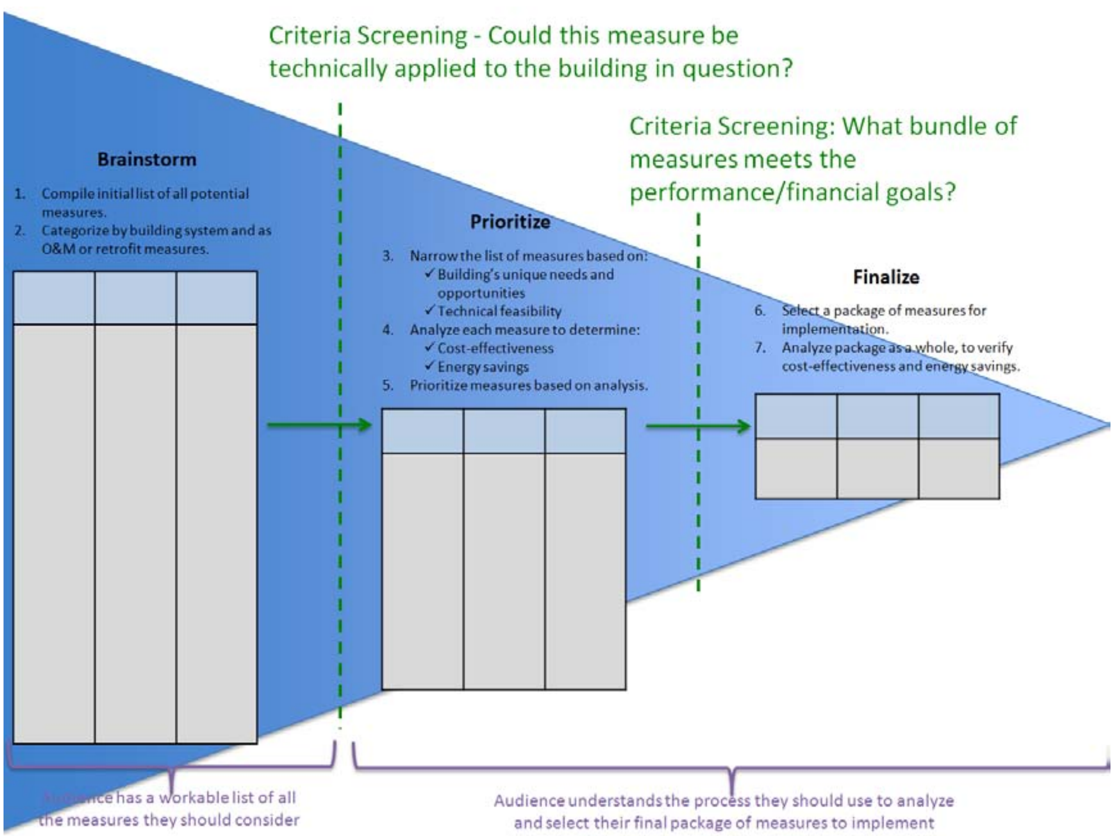

Figure 1.3. Measure Prioritization Process

Many of the measures presented in this guide are climate-dependent; for example, improvements in cooling efficiency will have a greater impact in hotter climate regions. For this reason, each package of measures is analyzed for five different climate zones shown in Table 1.2. The cost/savings data are based on the regional utility rates and labor rates.

Table 1.2. AERG Climate Zones and Reference Cities

Zone	Represented By
Hot & Humid	Miami, FL
Hot & Dry	Las Vegas, NV
Cold	Chicago, IL
Very Cold	Duluth, MN
Marine	Seattle, WA

Throughout the guide, a diverse set of case studies provides examples of how the approaches described in this guide have been successfully implemented by building owners and managers. The case studies are accessible and objective, offering insights into the opportunities, trade-offs, and potential pitfalls that may be encountered in a retrofit project.

The guide concludes with a discussion of strategies to ensure that the energy savings expected from the upgrades are achieved and persist over time. The first of these strategies, described in Chapter 6, is to implement a measurement and verification (M&V) program, together with the upgrades, to ensure that improvements are operating as intended. The second key strategy, covered by Chapter 7, is to optimize O&M activities to maintain and continually improve building performance.

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2

Improving Energy Performance in Existing Office Buildings

Industry leaders have long recognized the role that energy efficiency can play in reducing operating costs and increasing asset value, while also improving occupant comfort. Opportunities for improved energy performance exist in nearly every office building. These opportunities come in many forms, including improved operational and maintenance practices, equipment retrofits, occupant behavioral changes, and building envelope modifications, to name just a few. Over the life of a building, different opportunities will be available at different times, depending on the changing usage of a building, remaining life of the equipment and assemblies, and availability of improved technologies in the market.

While the opportunities for energy efficiency improvements in existing office buildings are significant, the process of identifying, analyzing, and implementing those improvements is not always straightforward. This chapter of the guide provides an overview of the steps necessary to identify energy efficiency improvement opportunities and plan their implementation. It addresses plotting an energy efficiency roadmap, available financing mechanisms, performance assessment through benchmarking, and identifying cost-effective measures through energy auditing. Each section includes references to the extensive body of literature that exists on these topics to provide more details.

2.1 The Office Energy Picture

Before addressing how to implement energy efficiency improvements, it is valuable to first investigate how energy usage is spread across building systems in a typical office building. Figure 2.1 demonstrates the percent breakdown of energy consumption by end-use for office buildings in the U.S.

As indicated in the figure, end-uses related to the HVAC system (heating, cooling, and ventilation) make up 51% of total energy use, and lighting represents 25% of total use (U.S. Energy Information Administration, 2006). As these two end-uses combined typically make up three quarters of an office building's energy use, it's usually best to focus on energy retrofits related to these end-uses first. The quantity of measures presented in this guide for each building system is reflective of the relative energy use of that system and the scale of opportunity for energy savings.

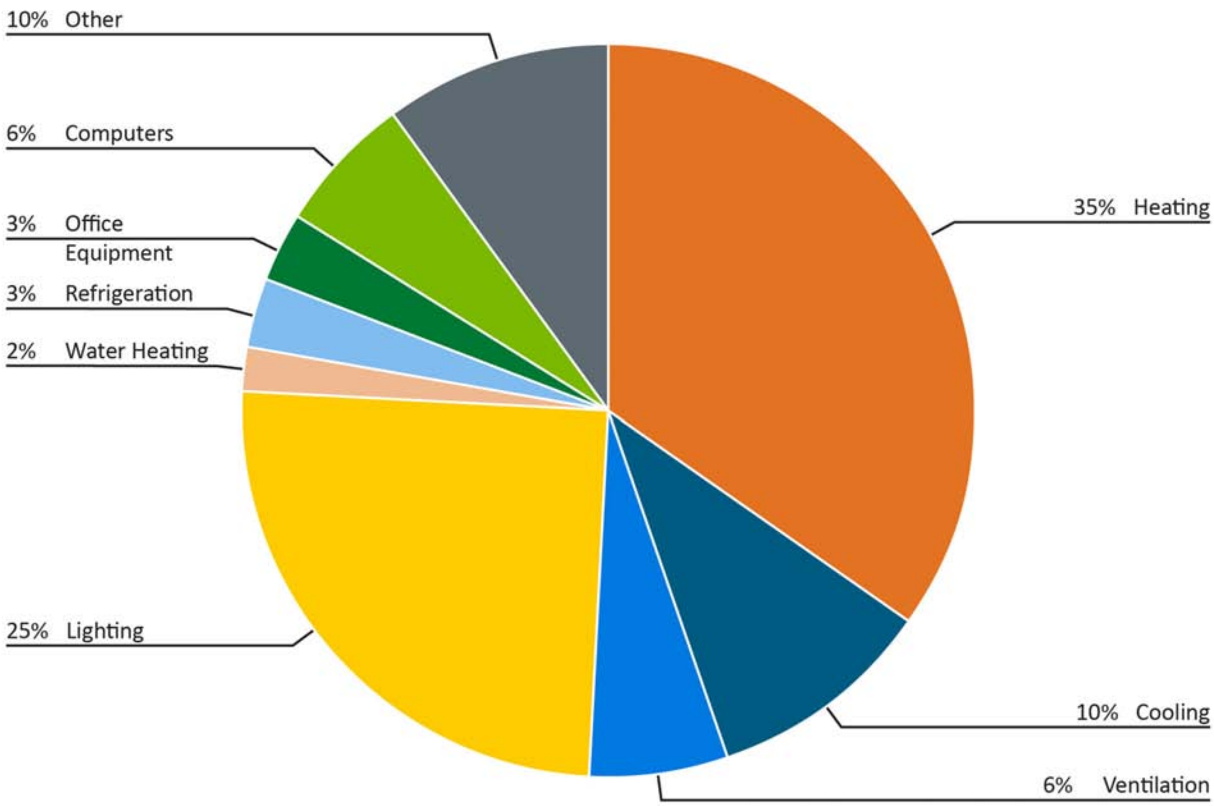


Figure 2.1. Percent Energy Use by Building System (U.S. Energy Information Administration, 2006)

2.2 A Roadmap for Building Performance

All office buildings present some opportunity for energy efficiency improvements. As more efficient technologies and practices emerge, even relatively new buildings can reap savings. Successful continuous improvement of building performance requires more than opportunities, however; industry leaders often talk about energy efficiency becoming part of the company culture. This section discusses how an organization can find and deliver on energy-saving opportunities. It begins with a commitment and goal setting, and then moves to implementing upgrades and measuring progress.

2.2 TOPICS COVERED

- Making the commitment
- Setting goals for energy performance
- Creating an action plan
- Evaluating financing options and incentives
- Implementation approach
- Project completion

Making the Commitment

This guide provides numerous examples where implementing an energy efficiency upgrade makes good business sense. But the fact remains that many building owners and operators are missing out on these opportunities to cut expenses and strengthen revenues. In many organizations, this gap exists because internal infrastructure operations are not linked to business strategy discussions. One way to create this linkage is through a high-level commitment to reducing energy use. Today's business environment provides numerous financial, policy, and market drivers that can support such a commitment, including:

- Tenant recognition of energy efficiency value, leading to higher occupancy rates and pricing
- Industry initiatives, such as LEED and Architecture 2030®, providing a competitive edge in the marketplace
- Energy and environmental regulations and codes
- Aging infrastructure leading to declining economic value
- Utility, state, and federal energy efficiency and financing programs

Combining these motivations with the promise of attractive investment opportunities can put energy efficiency on the agenda of any organization. The commitment to find and implement energy efficiency upgrades can be effectively communicated with the establishment of an internal goal for building energy performance.

Setting Goals for Energy Performance

An energy performance goal expresses an aspiration for achieving an improvement on a building's baseline energy performance through efficiency upgrades. Such a goal can serve as a strong motivator to drive projects from inception through completion. To be effective, an energy performance goal should:

- Express the building owner's motivations for the project
- Be achievable, based on industry best practice
- Function as a basis for tracking progress

Energy performance can be assessed at the building portfolio, building, and system level. Procedures for assessing energy performance include benchmarking and energy audits, which are discussed in detail in sections 2.3 "Benchmarking Current Energy Performance" and 2.4 "Energy Audits." Both of the procedures provide an understanding of baseline performance and some idea of the potential for improving performance. This information can be used to set the performance goal.

An energy performance goal is often expressed as a percentage reduction relative to the existing energy use intensity of the building. As such, it can be aligned with one of the three levels of energy efficiency upgrades defined within this guide. An alternative approach is to call for implementation of all projects that feature a return on investment better than a defined threshold. This latter approach has the benefit of aligning with many organizations' standard financial evaluation process, but it may be less effective at encouraging creative, integrated approaches inspired by an energy performance goal. When a percentage reduction is targeted, specific project proposals can still be subjected to an organization's standard financial evaluation.

Creating an Action Plan

An organizational goal for building performance improvement must be supported by an action plan that shows how the goal will be achieved through implementation of specific projects. If the goal-setting process utilized a detailed energy audit, then this audit will have identified specific projects that can form the basis of the plan. If another approach was used to set the goal, then an energy audit can be conducted next with the explicit purpose of developing a plan to achieve the goal. When the goal targets energy savings of greater than 45% (deep retrofit territory), the plan will most likely call for an integrated design process to precede a major renovation.

A deep retrofit project requires simultaneous evaluation of opportunities across multiple building systems. It thus lends itself to an integrated design process and concurrent implementation of upgrades to many systems. In contrast, a plan calling for a standard energy efficiency retrofit may elect to implement measures in stages. Often, a staged approach is chosen because of budget constraints. When using the staged approach, it is important to consider the ordering of projects to ensure that maximum performance is ultimately achieved. The integrated and staged approaches to energy efficiency upgrades are discussed in Section 2.5 “Planning for Energy Performance Improvements.”

Evaluating Financing Options and Incentives

Energy savings are valuable. They offer building owners and renters a low risk investment that will reduce operating and maintenance expenditures. They allow electric and gas utilities to avoid costly infrastructure investments. And they contribute to healthier environments and more competitive industries, which benefit the entire economy. Because of this wide valuation by various stakeholders, many options exist for financing energy efficiency upgrades.

Conventional project finance options, such as commercial loans, can be used for energy performance upgrades. In addition, there is a suite of finance options available only to energy efficiency projects. These additional options include energy performance contracts, utility rebate and on-bill finance programs, and government-supported low interest loans. A variety of tax incentives further improve the economics of energy efficiency upgrades.

The energy performance goal and action plan must align with the financing options available to an organization. Stating the anticipated funding sources in planning documents is important, as is a formal planned task to validate the anticipated funding assumptions. Key planning considerations and questions include:

- What is the preferred approach to economic analysis and decision-making?
- What are the economic criteria that the project needs to satisfy?
- Who are the external project partners that can offer financial incentives?
- What level of funding can potentially be acquired?
- What is the preferred source of funding, and is performance contracting an option?

These questions do not necessarily need to be answered within a planning document, although this can be highly beneficial. At a minimum, a plan needs to identify when these questions will be answered and who will be responsible for answering them. Sections 2.6 “Business Case for Upgrading Building Performance” and 2.7 “Financial Assistance for Energy Efficiency Projects” of this guide provide further discussion of the issues involved in developing a business case, including financing options.

Implementation Approach

Identifying the likely implementation approach is another important part of an energy efficiency planning effort. Each approach has implications for the project as a whole. Energy efficiency projects can be implemented using one or a combination of three key approaches: in-house implementation, design-build contracts, and design-bid-build construction. To this list we can also add energy performance contracting, which is a financing and management tool that can be applied to the design-build approach.

In-house implementation is typically the lowest out-of-pocket cost for an energy project. It assumes that a building owner’s facilities maintenance personnel will actually execute and install the identified building energy efficiency improvements. This implies that these individuals can integrate this additional work with their ongoing work tasks, or that the building owner can temporarily hire additional personnel.

Design-build contracts imply turnkey project delivery with the design and construction activities integrated into a single team.

Design-bid-build construction approaches are conventional in the new construction market for office buildings and can be applied to complex, deep retrofits of existing office buildings. Under this approach a design firm delivers bidding documents, which the owner then uses to solicit bids for the construction phase of the work.

Energy performance contracting is a special case of design-build construction, where the same contractor (the Energy Service Company, or ESCO) is involved from initial performance assessment through final monitoring and verification, and generally will offer some level of guarantee that savings will be achieved. An energy performance contract may be the lowest out of pocket cost, when the project cost is arranged to be paid from the energy savings. Section 2.7 "Financial Assistance for Energy Efficiency Projects" provides more information on energy performance contracting.

With any approach, a major challenge is to maintain the same level of energy efficiency awareness in the design and construction team as was present in the planning team. If an information disconnect occurs between these teams, the project can fall short of its savings goals.

Regardless of the approach chosen, there are other implementation considerations that must be addressed as a retrofit project is defined. Most important among these is the project's impact on building occupants. Scheduling construction work after normal building operating hours or temporarily vacating portions of the building may be necessary for some retrofits, which can impact project timeline and cost.

Project Completion

Close-out of an energy efficiency retrofit project is often more complex than that of a typical construction project. Not only do all of the installed elements need to work upon completion, the energy use reduction goals need to be achieved for the project to be deemed successful. Generally, project close-out will involve: (1) Standard inspections, (2) Performance testing to ensure measures function as intended, (3) Delivery of project close-out documents and owner training, and (4) Measurement and verification (M&V) of energy savings.

Using M&V to quantify the energy savings results of a project is critical to validating a project's investment, showing progress toward goals, and building the business case for subsequent retrofit projects. For a detailed discussion of M&V best practices, see Chapter 6.

2.2 KEY POINTS

- A roadmap for building performance improvement incorporates elements of commitment, planning, and execution.
- Setting an energy savings performance goal that addresses the "before and after" energy use of the building is a strong first step toward completing an energy improvement plan.
- An energy audit assesses current building performance and identifies opportunities for energy efficiency improvement.
- Many options exist for financing energy efficiency upgrades, ranging from commercial loans to utility incentives. You can select from these options to match your organization's needs and upgrade opportunities.
- The three most common approaches to project implementation are in-house, design-build, and design-bid-build.
- M&V of project savings is critical to validating a project's investment and building the business case for subsequent retrofit projects.

Additional Resources

Use these resources for more detailed information on planning and procedural aspects of energy efficiency project implementation.

- Environmental Protection Agency, *"Building Upgrade Manual"*, 2008: A strategic guide for planning and implementing a profitable energy saving building upgrade following a five-stage process. Chapter 1 discusses Investment Analysis. Available for free download online; www.energystar.gov.
- ASHRAE, *"Energy Efficiency Guide for Existing Commercial Buildings: The Business Case for Building Owners & Managers"*, 2009: A guide to making the business case for efficiency upgrades; includes discussion of cash flow analysis methods. Available for purchase; www.techstreet.com
- BetterBricks, *"The High Performance Portfolio Framework"*: A strategic guide to improving building performance that addresses organizational best practice procedures. Available for free download online; www.betterbricks.com.
- Rocky Mountain Institute, *Retrofit Depot*: A website that provides a wealth of information and tools for planning and designing commercial building retrofits; www.retrofitdepot.org.

2.3 Benchmarking Current Energy Performance

2.3 TOPICS COVERED

- Definition of energy benchmarking
- Approaches to energy benchmarking
- Benchmarking a building

Benchmarking is an essential starting point for understanding a building's energy performance. Calculating an energy performance metric for a building and comparing it with similar buildings provides a hint at the opportunity for upgrades in the building. For a portfolio of buildings, benchmarking will suggest which buildings are in greatest need of upgrades. Moreover, top-performing buildings can provide examples of best practices that may be transferrable to other facilities. Energy benchmarking can also allow top-performing buildings to receive industry recognition with certifications, such as an ENERGY STAR® label.

After project implementation is underway, an ongoing benchmarking program continues to provide value as a good, high-level check that building performance is improving. This section will define energy benchmarking, introduce different approaches, and describe how to benchmark facilities using some helpful tools.

Definition of Energy Benchmarking

Energy benchmarking is a process for describing the energy performance of a building at a point in time and for comparing that performance with similar buildings. As this definition implies, there are two key elements in benchmarking: (1) the description of performance, and (2) the comparison. The description of performance is often accomplished through calculation of a performance metric. Many types of comparison are possible. Several common comparisons are described in Table 2.1.

The appropriate benchmarking metric depends on what type of comparison will be made. Comparisons across building populations require metrics that adjust for dissimilar building characteristics. Comparisons against historical performance of the same building are simpler, but can also include adjustments for changing weather and building use.

Table 2.1. Common Comparisons made when Benchmarking

Comparison	Definition
Best in class	Compare the building to the best performing building in a population of buildings with similar characteristics.
Average	Compare the building to the average performance of buildings in a population with similar characteristics.
Baseline	Compare the building's performance to its historical performance.
Performance standard	Compare the building to a clearly defined performance standard, such as those established in building energy codes.

Approaches to Energy Benchmarking

Energy benchmarking may be internal or external and quantitative or qualitative. Internal benchmarking compares data within a building owner's portfolio of buildings, while external compares against a broader population of buildings. A quantitative approach compares numerical measures of performance to see how building performance changes over time or ranks against that of similar buildings. The qualitative approach analyzes management and operational practices across the entire building portfolio to identify best practices and areas for improvement. These basic approaches are summarized in Table 2.2.

Table 2.2. Approaches to 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.

A combination of qualitative and quantitative measures can be a powerful tool for detecting poor performance and identifying best practices that can be harnessed for improvements. For example, a benchmarking exercise might calculate the energy use intensity for a portfolio of 10 office buildings. If three of the buildings show twice the energy use per square foot as the best performing building, then it's natural to begin to look for an explanation. By comparing qualitative characteristics of the buildings, such as those shown in the Table 2.3, one can begin to understand the reason for the performance discrepancy. It may then be possible to improve performance at the lagging buildings, by looking to the practices at the leading building.

When using quantitative metrics, it is important to make reasonable comparisons. This means that adjustments must be made to account for differences between buildings. Some of the most common adjustments are shown below.

Table 2.3. Sample Measures of Building Performance

Quantitative
Energy cost per square foot
Energy (Btu) per square foot
Energy (Btu) per occupant

Qualitative
Presence of an energy manager
History of retrofit projects
Building envelope characteristics
Type of lighting controls
Type of HVAC controls

Energy type: A typical common energy basis is the Btu (British thermal unit). For example, multiplying electric (kWh) usage by 3,412 will give an equivalent amount of usage in Btus. Usage values for other fuels can also be converted to Btus, and then summed to show the total amount of energy used onsite.

Floor space: Large buildings consume more energy than small buildings. They also have more useful area. Thus, quantitative metrics are commonly normalized to the building's total conditioned floor area.

Climate: A building in Las Vegas has different needs than a building in New York. When comparing buildings in different climates, it is appropriate to include an adjustment factor that suggests how the buildings would rank in a common environment. Similarly, weather can vary considerably from one year to the next, so climate adjustments may also be required when comparisons are made over time.

Benchmarking whole building energy use is the most common and straightforward approach, and sub-metering is an option for building owners who want to dig deeper into benchmarking and optimizing buildings. Sub-metering the consumption of specific end-uses is still relatively rare and can incur extra cost to install, but it is considered a key factor in taking a building to the high end of performance.

Benchmarking a Building

Benchmarking can be challenging, especially the first time. Following the approach described in Table 2.4 will help the process proceed smoothly.

Table 2.4. Steps to the Benchmarking Process

PLAN	**Engage Partners**: include all relevant internal (e.g., facilities staff, building management) and external (e.g., utility representatives) parties.
	Create a Plan: A benchmarking plan defines the goals, scope, and schedule of the effort.
IMPLEMENT	**Collect Data**: Common data needs include energy use and cost, physical building design, operational statistics, and climate variables.
	Calculate Metrics: Determine a building's baseline energy use, rate the building (using a software program such as Portfolio Manager), and document the results of efforts to improve energy performance.
	Compare: Once quantitative metrics are calculated and qualitative measures are tabulated, it is a relatively straightforward process to compare buildings using software programs. Buildings can be ranked, anomalies flagged and high performance recognized.
	Repeat: Ongoing benchmarking will help track progress toward goals.

Benchmarking provides an indication of the opportunity and a basis for tracking progress. The results may be used to set goals and develop action plans targeting poorly performing buildings. Most likely, one outcome of benchmarking will be a motivation to further understand the energy performance of some buildings. The next section of this guide discusses energy audits, which offer a deeper investigation into the energy performance of a building.

2.3 KEY POINTS

- Energy performance benchmarking provides baseline information that will help building owners set energy performance goals, create energy management plans, and prioritize potential upgrade opportunities.
- A benchmarking plan begins by assembling stakeholders, defines the goals for the project, and clarifies the scope of the effort, including the metrics and data needed.
- Implementation of benchmarking includes data collection, calculation of benchmarking metrics, performance comparisons, and ongoing tracking.

Additional Resources

Use these resources for more detailed information on benchmarking building energy use.

- Environmental Protection Agency, *"Building Upgrade Manual"*, 2008: A strategic guide for planning and implementing a profitable energy saving building upgrade following a five-stage process. Chapter 2 focuses on benchmarking. Available for free download online; www.energystar.gov.
- ENERGY STAR, *Portfolio Manager*: A comprehensive, interactive tool that provides a set of benchmarks developed specifically for office buildings that can be used to assess energy performance. Available for free use online; www.energystar.gov.
- ENERGY STAR, *Target Finder*: A no-cost online tool that enables architects and building owners to set energy targets; www.energystar.gov.
- Oak Ridge National Laboratory, *Benchmarking Building Energy Performance* webpage: Includes sections on benchmarking office buildings for a handful of states; http://eber.ed.ornl.gov/benchmark.
- California Commissioning Collaborative, "*The Building Performance Tracking Handbook*", 2008: A guide to various approaches to tracking and analyzing building energy performance. Benchmarking is presented as one approach. Available for free download online; www.cacx.org.

2.4 Energy Audits

The objective of an energy audit is to develop an understanding of a building's energy performance and energy saving opportunities through an investigation of the current equipment, operations, and building energy use patterns. An energy audit provides the project cost and savings information for potential improvement measures, and can be performed with varying levels of rigor and expense.

The following section explores the basic elements of an audit, common types of audits and their characteristics, and considerations for choosing an audit type.

2.4 TOPICS COVERED

- Elements of an audit
- Types of audits
- Audit cost
- Choosing an appropriate audit level
- Selecting a qualified energy auditor

Elements of an Audit

Audits can generally be broken down into three primary steps:

- Pre-site visit analysis
- Site visit data gathering
- Post-site visit analysis and reporting

The pre-site visit analysis involves a review of available data relating to the building's operations and current energy performance. Documents and data reviewed can include building plans and construction documents, historical energy use, and any past audit reports. The energy auditor may also complete a preliminary phone interview with building operations staff to learn as much as possible about building operations before the site visit.

The site visit is the primary opportunity for the auditor to collect current data and observe the building's operations. The auditor will complete a walk-through to inspect all or a subset of the building's energy-consuming systems. By filling out template audit forms, taking photos, and conducting interviews with building operations staff and service contractors, the auditor gathers the necessary information to complete the post-site visit analysis and reporting. The depth of investigation during the site visit is dependent on the audit type (discussed in detail below), and can range from a basic equipment survey to sub-metering of equipment.

Finally, with audit information in hand, the auditor will complete engineering and financial analyses to identify potential building energy efficiency measures. The audit report will detail the building's baseline energy use, the energy savings potential of the identified retrofit and operational improvements, and a rank-ordered list of the measures based on cost-effectiveness and any other priorities set by the building owner.

This final audit report is reviewed by the building owner and used to lay the groundwork to create a roadmap of energy efficiency upgrades in the near, mid, and long-term. See Section 2.5 "Planning Energy Performance Improvements" for more discussion on various energy efficiency implementation strategies.

Types of Audits

There are many approaches a building owner can take to complete an energy audit. The most common and standardized audit approach is offered by ASHRAE. To streamline auditing efforts and provide a common set of standards, ASHRAE has developed three levels of audits that increase in detail, depth of analysis, and cost (Cowan, Pearson and Sud, 2004).

Preliminary Energy Use Analysis

All ASHRAE audits share a common foundation of preliminary energy use analysis. In its simplest form, this analysis involves a review of historical total building energy use and cost, using utility bills from at least the previous two years. The analysis will define the building's Energy Use Intensity (EUI), showing the building's energy use on a per square foot basis. The building's EUI can then be benchmarked against other buildings or industry average. See Section 2.3 "Benchmarking Current Energy Performance" for more detail.

ASHRAE Level I Audit

The ASHRAE Level I audit builds on the preliminary energy use analysis with a brief walk-through of the building and a survey of the building's energy consuming equipment. Given the limited information gathered in a Level I audit, the audit report will be limited to identifying no-cost and low-cost measures and recommending further investigation into measures that would require more significant investment. Estimated energy savings and project costs are based on simple calculations and typically do not account for interactions between systems, such as the reduced cooling load that results from the installation of more efficient lighting. Therefore, the energy saving estimation at this audit level is not highly accurate and is not recommended for financial decision-making on capital-intensive projects.

Consultants can perform a Level I audit, or it can be performed in-house by a building engineer.

ASHRAE Level II Audit

A Level II audit offers a more comprehensive look at building energy use through a survey of all building systems, which is used to compute a breakdown of energy consumption by end-use, including heating, cooling, and interior lighting. A Level II audit builds on a Level I audit by including a more in-depth investigation into the overall performance of the major building systems. Level II audits usually include spot measurements and time-series data logging of equipment to gain an understanding of system performance and to identify potential measures. All practical measures will be analyzed in the audit report, which will provide, at a minimum, estimated energy savings and project costs. For complex and capital-intensive measures, a Level II audit may recommend further data collection and engineering analysis to increase the accuracy of estimated savings and costs. A Level II audit is adequate for many buildings and measures.

ASHRAE Level III Audit

A Level III audit offers the most detailed engineering and financial analysis. The results can be used with a high level of confidence by the building owner to consider complex and significant capital investment decisions. For this reason, Level III audits are often termed "investment grade" audits. A Level III audit builds on a Level II audit by providing a more detailed and accurate analysis of building energy performance and identified measures.

The key feature of an investment grade audit is that it accounts for the interactive effects of all building system improvements, often by using computer models to simulate building and equipment operations. This allows for a rigorous total system engineering analysis that details the estimated cost and savings with a level of confidence sufficient to support large financial decisions. In practice, Level II audits are used as the basis for many decisions where the investment is modest or large returns overshadow any uncertainty. But when a large, expensive project like a deep retrofit is under consideration, a Level III audit reduces the risk that important parameters were assumed or that interactions were overlooked. Taking interactions into account may also lead to opportunities to reduce equipment size. For example, energy efficient lighting and energy efficient windows may reduce cooling loads enough to downsize HVAC equipment.

While a Level III audit provides the most comprehensive estimates of cost and savings for potential measures, these audits are costly and may identify more improvements than can be immediately implemented. When ESCOs perform an investment grade audit as part of a performance contract, they often include financing options to overcome this barrier. Section 2.7 "Financial Assistance for Energy Efficiency Projects" discusses the various financing options.

EBCx Audits

The O&M measures discussed in this guide are low-cost strategies for optimizing existing building operations. While Level I, II, and III audits consider O&M measures, the unique nature of the EBCx process will likely yield the greatest O&M savings. As a result, EBCx is often pursued independently before equipment retrofits. EBCx is introduced here, as it relates to energy audits, and then Chapter 3 provides a detailed discussion of EBCx.

An EBCx provider will often conduct a walk-through audit as part of the early phase of commissioning services. The level of detail of this EBCx walk-through audit is comparable to an ASHRAE Level I audit. The in-depth investigation portion of an EBCx project is comparable to an ASHRAE Level II audit, which results in a report that identifies potential measures and estimates their cost and energy savings potential based on rigorous system data collection.

The key distinction between EBCx and ASHRAE audits is that the EBCx process continues through implementation, measurement and verification of savings, hand off to operations, and in some cases to ongoing commissioning. EBCx typically also addresses non-energy aspects of building performance such as indoor environmental quality, equipment life, maintenance costs, and assembly durability, to name a few.

Audit Cost

For the same building, costs increase from the Level I to Level III audit. However, for the same type of audit, costs may vary dramatically from one building to another, depending upon such factors as location, building size, and complexity of building systems and operation. The audit levels should also be considered as bands of quality; within Level II audits, providers may deliver differing levels of comprehensiveness and detail. It's generally a good idea to check references or review an auditor's sample work products for similar facilities to ensure that the audit quality will support the type of decisions it is meant to support. The range of audit cost and quality is shown in Figure 2.2.

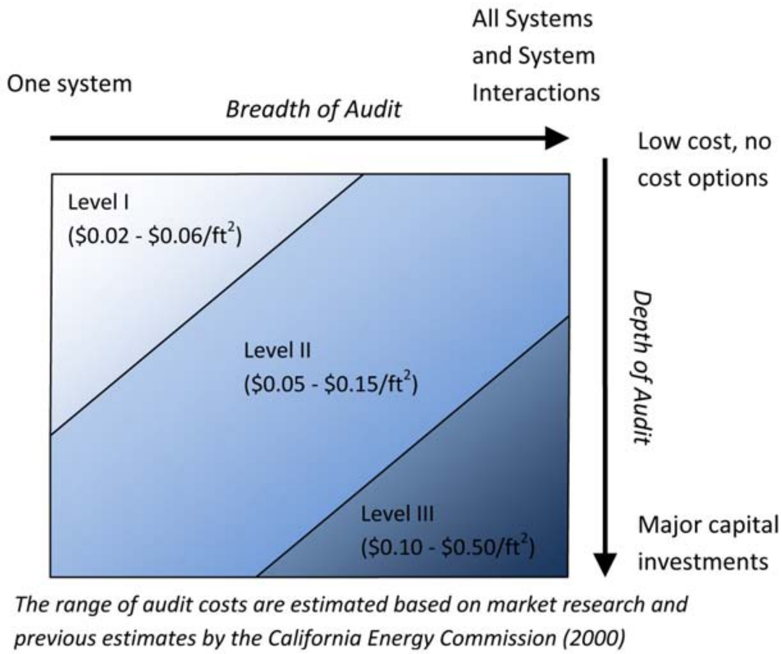


Figure 2.2. Audit Cost and Quality

As shown in Figure 2.2, audit costs span a wide range, particularly for the most complex, Level III audits. Part of this range is due to geographic diversity of provider costs. It is also reasonable to consider that part of an audit cost is fixed (e.g., reviewing utility bills), where another part of it varies with building area (e.g., investigating lighting and HVAC systems). The fixed cost leads to higher per square foot costs for smaller buildings.

EBCx cost is typically towards the top end of the range for a Level II audit costs, or perhaps higher depending on project scope. The higher cost is reflective of the fact that EBCx continues through implementation, hand off, and potentially ongoing commissioning.

Choosing an Appropriate Audit Level

Many factors figure in to the choice of an appropriate audit level, including audit cost, availability of funds for energy efficiency upgrades, and the long-term strategy for the building. If a building owner is interested only in obtaining a rough idea of a building's potential energy savings opportunities, a Level I audit would be sufficient. A Level I audit could, for example, be used to verify that the building portfolio prioritization achieved through benchmarking is indeed reflective of the buildings' energy saving potential.

For the standard energy efficiency retrofits outlined in this guide (e.g., lighting and HVAC upgrades), a Level II audit would typically provide enough detail. For deeper retrofit measures that involve a longer return on investment and more significant capital outlay, a building owner should complete a Level III audit to ensure cost and savings estimates are as accurate as possible.

EBCx may be a standalone project or a complement to a retrofit projects. Standalone EBCx projects are common where capital budgets are low, if there are known operational problems, or if the main focus is on improvements with short payback periods. Availability of rebates from a local utility may also be a motivating factor.

Selecting a Qualified Energy Auditor

As the previous paragraphs have described, audits can be conducted with varying levels of detail and cost. Thus, when selecting an auditor, it is important to clearly specify the scope of the audit and to verify that the auditor is capable of delivering on that scope. For this reason, many building owners decide to select an auditor through a competitive process. An open and competitive process offers insight into the range of qualifications and costs that are available within the field of firms that offer energy audits. An owner's basic process for competitive selection of an energy auditor is as follows: Issue of a Request for Qualifications (RFQ), host site visits, evaluate providers' qualifications, interview top ranked firms, select an auditor, and negotiate a contract.

A competitive process is not always necessary to hire an auditor. It is also possible to take a sole-source approach, particularly where an owner already has an established relationship with a firm that offers energy audits. Directly negotiating a scope and budget with a preferred vendor is likely to be the quickest path to an audit and offers the benefit of selecting a firm that has already proven its abilities. However, even with a preferred vendor, it may be wise to examine examples of their past audit work and contact references.

Once an auditor has been selected, a contract is established to deliver a specified scope of auditing services. The contract with an auditor details the scope of work that they are expected to perform, the specific personnel assigned to the project, the project schedule and budget. It is also a good time to identify any support that the building management team must provide to facilitate the audit. The project description from the RFQ will provide a starting point, but the contracting process represents an opportunity to negotiate a specific scope of work for the selected auditor tied to a maximum price.

2.4 KEY POINTS

- An energy audit involves pre-site visit analysis, on-site data gathering, and post-site visit analysis and reporting.
- Energy audits detail current building energy performance and identify measure opportunities based on energy savings and project cost estimates.
- ASHRAE's three levels of audits provide varying degrees of analysis and detail that are suitable to diverse scenarios depending on the building owner's needs.
- EBCx audits are similar to ASHRAE Level II audits, but focus on operational measures and follow the project through implementation, hand-off, and potentially ongoing commissioning.

Additional Resources

Use these resources for more detailed information on energy audits.

- ASHRAE, *"Procedures for Commercial Building Energy Audits"*, 2004: A guide that offers a brief overview of ASHRAE audit levels and template audit forms. Available for purchase; www.techstreet.com.
- Department of Energy, *"Energy Savings Assessment Training Manual"*, 2005: A thorough reference guide to energy audits, including audit types, implementing audits, and diagnostic tools. Available for free download online; www.eere.energy.gov.
- Rocky Mountain Institute, energy audit sample forms through *Retrofit Depot*. Available for free download online; www.retrofitdepot.org.
- Environmental Protection Agency, *"A Retrocommissioning Guide for Building Owners"* 2007: A comprehensive guide to EBCx projects; includes section on EBCx investigation. Available for free download online; www.peci.org.
- California Energy Commission, *"How to Hire an Energy Auditor To Identify Energy Efficiency Projects"*, 2000: A guide that discusses procedures for selecting and contracting an energy auditor. Available for free download online; www.energy.ca.gov.

2.5 Planning Energy Performance Improvements

2.5 TOPICS COVERED

- Project planning approaches
  - Staged approach
  - Integrated approach
- Additional considerations

Once benchmarking and audits have revealed the opportunities for performance improvements, a strategy can be designed for achieving high performance buildings. With many variables at play, such as age and condition of equipment, the timing and coordination of upgrades are important considerations. A long-term and holistic vision for building upgrades offers the best potential to realize the maximize return on investment.

Project Planning Approaches

The measures discussed in this guide are organized into three levels: (1) existing building commissioning (EBCx), (2) standard retrofits, and (3) deep retrofits. Energy savings increase in magnitude as you move from EBCx to deep retrofit, but adopting a plan that steps sequentially through each level is not necessarily the most cost-effective approach. The following section will discuss two primary energy efficiency upgrade strategies, the staged and integrated approaches, and describe considerations for choosing one strategy over the other.

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, inefficient lights add heat to office spaces that must be removed by HVAC equipment during periods of cooling. By first upgrading lights, future HVAC system improvements can be better optimized in a subsequent stage of the project. Under the staged approach, projects are implemented in the order shown by Figure 2.3. Figure 2.4 provides an illustrative example of how the staged approach might look on a project basis.

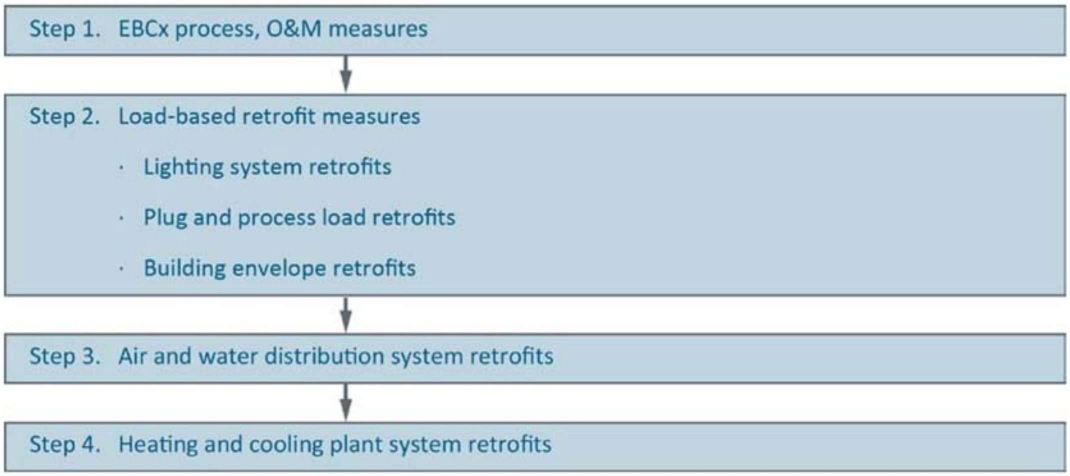


Figure 2.3. Recommended Project Phases for a Staged Approach to Energy Efficiency Upgrades

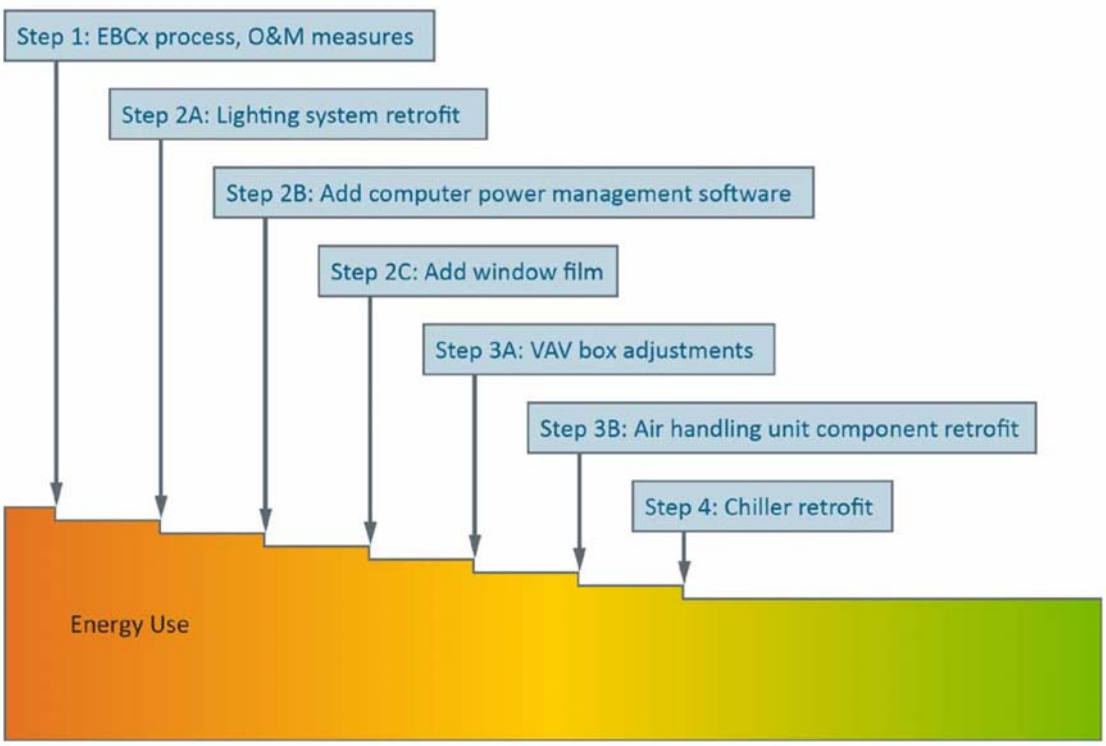


Figure 2.4. Example Project Using a Staged Approach to Energy Efficiency Upgrades

EBCx optimizes the performance of existing equipment, which provides a better baseline for determining which retrofits will be cost-effective. In some cases, EBCx can improve the cost-effectiveness of subsequent measures by showing where systems can be downsized when operated efficiently. In addition, the typically low cost and quick returns of O&M measures makes them an obvious first step for building owners 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.

After EBCx, completing measures that affect heating and cooling loads is the next step. A variety of measures fall into this category. Some of them directly reduce energy consumption with cooling savings as an indirect benefit, such as replacement of inefficient lighting. Others, such as building envelope improvements, solely reduce energy through indirect means. What they have in common is that all have an impact upon the building's heating and cooling demands. The more efficient lights will emit less wasted energy into the office as heat, and therefore reduce the building's cooling needs and potentially increase its heating needs. The envelope 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 changed heating and cooling demand.

In standard retrofit projects, it is common to progress from the measures affecting heating and cooling loads to a one-to-one replacement of components in the heating and cooling system. A 200-ton chiller is replaced with a more efficient 200-ton chiller. In this standard 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 200-ton chiller could be replaced with an efficient 150-ton chiller. Not only does the smaller chiller cost less, but it also performs better because it is a better match to the optimized building's load.

Building owners must tailor their plan to match the needs of their building, 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 tenant needs. It's a good idea for owners to at least investigate the potential for implementing retrofit measures that will impact heating and cooling loads before embarking on a large scale HVAC system retrofit. That way, the trade-offs that are being made can be clearly examined.

The primary benefit of the staged approach relative to the integrated approach, described below, is that the upfront project costs can be spread over a longer period. Projects with quick paybacks are typically completed first, and it may be possible to use the savings from these early projects to justify the costs of later stages. For this reason, the staged approach may be ideal for organizations unable to justify one large upfront project cost for an integrated retrofit package.

Integrated Approach

In contrast to the staged approach, the integrated approach to energy efficiency upgrades focuses on the simultaneous retrofit of multiple building systems, with a package of measures of varying complexities and financial benefits being installed at the same time. For example, a building owner may complete a lighting system retrofit at the same time as increasing the amount of roof insulation and replacing the HVAC system.

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

- The overall economics of the project are often improved. Cumulative project costs can be reduced compared to the staged approach, due to efficiencies from installing multiple measures at once. Lifecycle benefits may be simultaneously increased, as energy savings begin at a high level, rather than phasing in over time as stages are completed.
- The integrated 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 integrated approach is generally more conducive to identify such opportunities.

The integrated approach typically involves architects, design engineers, and potentially commissioning providers working 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 owner's needs as well as result in minimal energy use (Energy Design Resources, 2002). Retrofit systems are designed in concert, rather than as a sum of individual parts, and the final design is evaluated using lifecycle economics. This process aligns well with the design needs of the deep retrofit projects described later in this guide.

Additional Considerations

When developing a plan for any level of retrofit, it's important to consider the potential need to install complex, deep retrofits in the future. For example, if a building's HVAC system is nearing the end of its useful life, implementing retrofits that reduce cooling demand at the same time as replacing the HVAC system may allow for the installation of a smaller HVAC system. However, if the HVAC system is replaced without first or simultaneously completing the demand reducing retrofits, the HVAC system will be over-sized when those retrofits are eventually completed, resulting in a higher than necessary HVAC system first cost and a lost energy saving opportunity.

If the integrated approach is adopted for a project that includes the retrofit of the building's HVAC system, it is essential to understand the expected performance of the optimized building systems and ensure all of these loads are met by the new HVAC system. For deep retrofits, it's important that the design team consider the building's various systems and components as an integrated system. Members of the project team must coordinate to minimize the expected energy usage of the building and meet the owner's specific design goals. Because of the complex interaction between systems, a whole-building energy modeling software program is often required for the integrated approach.

Retrofits can substantially improve occupant comfort and productivity in a building. However, the process of implementing retrofits may be disruptive to building tenants. Construction dust, noise or use of space may disrupt tenant operations and comfort. Also, working around tenants increases the complexity of a job for the construction crew. Some common strategies for mitigating these impacts are to schedule work outside of the tenants' normal business hours or to provide some form of compensation to tenants for any disruptions that cannot be avoided. Including tenants early on in the discussion of a proposed project will help to provide tenant's with visibility into the long term benefits and to define a mutually satisfactory mitigation strategy.

After implementing retrofits, it's important to verify that the systems are installed properly and operating correctly to achieve the maximum energy savings potential of the retrofit. Appropriate measurement and verification (M&V) approaches are discussed in Chapter 6 of this guide.

2.5 KEY POINTS

- The staged approach to energy efficiency project planning entails sequentially completing projects on building systems. Systems that have a large potential to reduce load requirements of other systems should be replaced first.
- The staged approach allows the savings of each completed project to support the business case of the next project. With careful planning, annual energy savings may reach the same level as in an integrated approach, but cumulative savings will always be less due to the delay in implementing some upgrades.
- The integrated approach focuses on the simultaneous retrofit of multiple building systems, with measures of varying complexity and financial benefits being installed at the same time. Simultaneously considering multiple measures allows the cost-effectiveness and energy savings of the measures to be evaluated as a bundle, rather than individually.
- The integrated approach entails significant upfront project costs, but has the benefit of dramatically reducing energy use over a short period of time, with corresponding benefits for the project's lifecycle cost savings.

- The integrated approach utilizes an integrated design process, where the design team optimizes the energy performance of the building as a whole rather than just the energy performance of individual systems.
- A carefully planned approach will capture opportunities to resize systems to meet the demand of an optimized building. "Right sized" systems typically cost less and perform more efficiently.

Additional Resources

- Environmental Protection Agency, *"Building Upgrade Manual"*, 2008: A strategic guide for planning and implementing a profitable energy saving building upgrade following a five-stage process. Chapter 1 discusses the staged approach to energy efficiency upgrades. Available for free download online; www.energystar.gov.
- *Energy Design Resources*: A website with resources and guidance related to integrating building system design to achieve maximum energy savings. Most content is related to new construction, but the concepts are applicable to deep retrofit projects. www.energydesignresources.com.
- ASHRAE's "50% *Advanced Energy Design Guide for Small to Medium Office Buildings*", 2011: Technical guidance geared towards maximizing energy savings for new construction projects. Chapter 2 discusses the integrated design process in detail. Available for free download online; www.ashrae.org.

2.6 Business Case for Upgrading Building Performance

2.6 TOPICS COVERED

- Energy benefits
- Non-energy benefits
- Impact of lease structures
- Building financial performance
- Risks associated with inaction
- Estimating project value
- Choosing a financial analysis method

Energy efficiency upgrades often provide a generous return on investment. A study that reviewed nearly 200 projects in commercial buildings found the vast majority of those projects achieved an internal rate of return greater than 15% (Goldman, Hopper and Osborn, 2005). The direct cost reductions that upgrades deliver through reduced energy use are complemented by valuable non-energy benefits. This section explores the benefits of energy efficiency and discusses the effect of different lease structures on these benefits. Methods of cash flow analysis are presented to aid in evaluating potential energy efficiency investments.

Energy Benefits

The primary driver for most building owners to invest in energy efficiency is the direct benefit of reduced utility costs. A typical office building's energy costs are as much as 30% of the building's overall operating costs (Flex Your Power, 2011). Thus, reducing utility costs by 30% or more through a deep retrofit would deliver a significant cut in total operating costs and for income-producing properties, a potential increase in net operating income (NOI).

The energy benefit may also be leveraged for public recognition. Programs such as ENERGY STAR and LEED offer buildings a way to receive public recognition for high energy performance. An ENERGY STAR rating is a label of excellence in building energy performance. Buildings that achieve an ENERGY STAR energy performance score of 75 or higher, on a scale of 1 to 100 (with 1 being the worst energy performer and

100 the best), can receive the ENERGY STAR label. For an average performing building, with an ENERGY STAR score of 50, an energy use reduction of approximately 30% will increase the ENERGY STAR score to above 75, making the building eligible for an ENERGY STAR label (see Figure 2.5). This reduction is possible with the implementation of a combination of the energy reduction measures outlined in this guide.

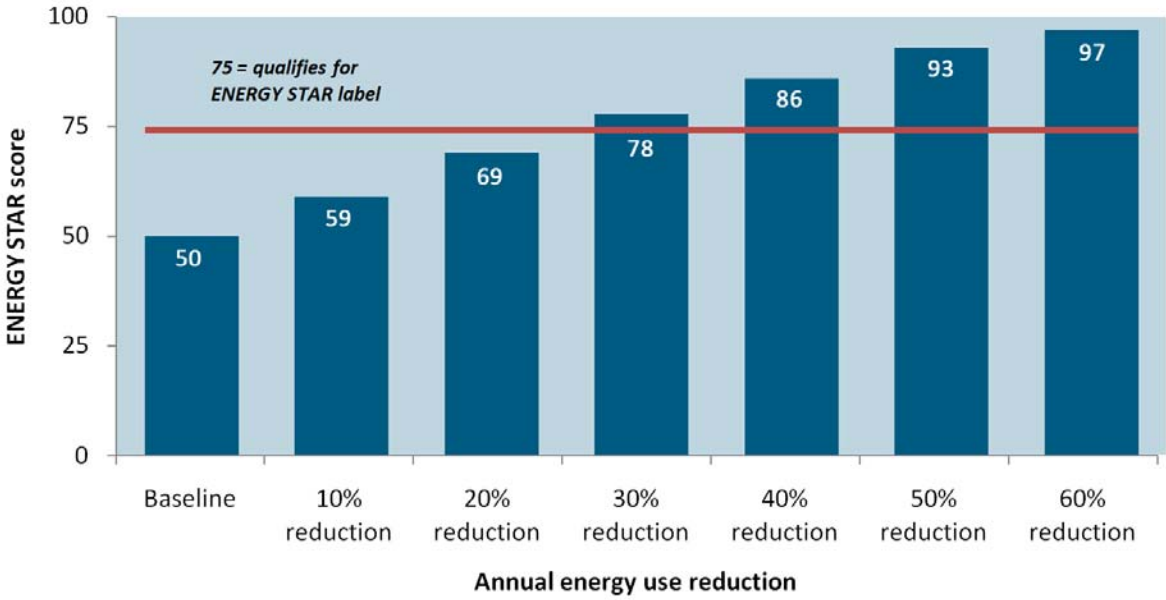


Figure 2.5. Reduction in Energy Usage Leads to Increased ENERGY STAR Scores

To accurately estimate the value of a project's energy savings, many variables need to be considered, including operating schedules, equipment efficiency, interactions with other energy using systems, and energy costs, which vary over time (Landsberg, Lord and Carlson, 2009). There are many approaches to estimating a project's energy savings potential. For simple equipment replacements, the most easily accessible estimate is often the vendor's published energy saving calculation. While this can be a good starting point, it's essential to examine the variables and assumptions used to calculate the savings value; for example, the vendor's claims for cooling savings may be based on a building in a very hot climate. Integrated, deep retrofits typically require savings to be modeled using energy simulation software.

Estimating a project's energy savings potential is challenging, but fortunately a number of tools have been developed to calculate the energy usage of equipment and the potential savings of upgrades. Moreover, energy auditing professionals and other contractors can be hired to complete the calculations. For a list of objective calculator tools available online, see the Additional Resources at the end of this section. An additional calculation resource is utility-sponsored energy efficiency programs, which will often provide calculations of potential energy savings to program participants.

Non-Energy Benefits

While a strong business case can often be formed on energy cost savings alone, there are a number of other benefits that can enter into project economics. These non-energy benefits may in fact be dominant project drivers in situations where energy costs are less important to the bottom line. Non-energy benefits fall into two categories – quantitative and qualitative – with examples provided in the following:

Quantitative Benefits

- Reduced O&M expenditures
- Extended equipment life
- Increased rental value; recent studies have found that office buildings with green certifications command 6 to 16% higher rents than otherwise comparable buildings (Eichholtz et al., 2009; Fuerst and McAllister, 2009)
- Improved occupancy rates; the same studies quoted above observed significantly higher occupancy rates for buildings with green and efficient certifications (Eichholtz et al., 2009; Fuerst and McAllister, 2009)

Increased rents and improved occupancy translate to higher net operating income for a building owner. Using a common calculation method presented later in this section, this equates to higher asset value.

Qualitative Benefits

- Reduced environmental impact of operations and progress towards sustainability-related objectives
- Marketing and PR value for energy saving practices and improved sustainability
- Improved indoor environmental quality (e.g., air quality, noise and lighting levels), which leads to more satisfied building occupants and higher productivity

Impact of Lease Structures

For owner-occupied buildings, the owner bears the cost and enjoys the full financial benefit of energy efficiency improvements, which produces a natural motivation to consider cost-saving upgrades. In income-producing properties, the lease terms, which define how the costs and benefits of energy-saving upgrades would be allocated between landlord and tenants, play a large role in determining each party's motivation to pursue improvements.

There are three primary lease structures in commercial real estate (U.S. Environmental Protection Agency, 2007):

- **Gross lease**: The landlord pays all utility costs, and hence would capture any cost savings that result from an efficiency upgrade. In a gross lease, the landlord's motivation to invest in efficiency should be similar to that of the owner-occupant.
- **Net lease**: The tenants pay all utility costs and are the initial beneficiaries of the cost savings from efficiency upgrades. In a net lease, the landlord may be unmotivated to make upgrades due to an inability to realize the operational cost savings produced by those improvements. Tenants, on the other hand, may be reluctant to invest in upgrades to a building they do not own. Furthermore, in situations where the tenants' share of savings are allocated based on their share of the building's rentable square feet, a tenant that occupies only a portion of the building could find itself in a situation where it funds the entire cost of an upgrade to its own space and receives a fraction of the resulting savings. These so-called "split incentives" can be a barrier to energy efficiency in landlord/tenant settings.
- **Fixed-base lease**: The landlord pays utility costs up to a fixed amount (typically in the context of a "base year" or "expense stop" calculation) with the remainder being borne by the tenant. In a fixed-base lease, the exact terms defining the fixed and variable expense portions, including how annual adjustments are made, determine the extent to which the landlord, the tenant or both enjoy the financial benefits of efficiency upgrades made during the lease term.

Adequate energy metering is also an important requirement for tracking and attributing energy project costs and savings. Sub-building level meters allow energy use to be attributed to specific building systems or spaces. In multi-tenant buildings, such meters interact with lease terms to define how project costs and savings may be passed on to tenants. The building's metering infrastructure has important implications for measurement and verification (M&V) and continuous improvement activities through O&M, which are discussed in Chapter 6 and 7.

Overcoming the Split Incentive

There are several approaches to overcoming the so-called "split incentive" described above. First, lease language could be crafted to ensure that the party that pays for an improvement is the one that receives the financial benefits, enabling that party to recoup the first cost of the said investment. Many leases include language that allows the first cost of an expense-reducing capital improvement to be passed through to the tenants at a pace that is in line with the energy cost savings that are enjoyed by those tenants. This mechanism is particularly helpful in the context of a net or fixed-base lease, where the typical lease structure offers limited means for the landlord to recoup investments in efficiency.

Second, implementing a "green lease" can provide an even greater incentive for owners and tenants to cooperate in the pursuit and realization of energy cost savings. Such leases typically include provisions that make energy efficiency improvement a priority and help ensure that the party that pays for the increased efficiency is the party that primarily benefits from it. Examples of resources for executing green leases include the Building Owners and Managers Association (BOMA) International Commercial Lease and the California Sustainability Alliance's Green Leases Toolkit, both of which are listed in the Additional Resources at the end of this section.

Finally, an increasing number of studies are noting that higher performing buildings appear to enjoy higher asset values, occupancy, and rental rates. These benefits provide strong financial motivation for landlords to invest in efficiency upgrades even if their tenants would see all the direct cost savings initially.

Building Financial Performance

In an income-producing property setting, the energy and non-energy benefits referenced above can result in either cost savings, increased rental income (through higher base rent or lower vacancy), or both. These benefits can drive improved financial performance for an income-producing building in the form of both higher net operating income and higher asset value.

Energy costs can comprise 30% or more of a building's operating expenses. But unlike some operating expenses, such as taxes and insurance, energy should not be considered a fixed cost.

In situations where the leases allow the landlord to capture the financial benefits of an expense-reducing capital project, that project holds the potential to boost the property's net operating income (NOI). NOI may also increase if the project enhances the property's ability to attract or retain tenants. If the property is perceived to have lower operating expenses or a "greener" profile in the wake of the improvement, base rents may increase, which also improves the property's NOI.

EXAMPLE OF ENERGY SAVINGS IMPACT ON ASSET VALUE

Consider a 100,000-ft^2 income-producing property with an annual energy cost of \$1.60/ft^2. Assume that an upgrade costing \$2.00/ft^2 produces persistent energy savings of 25% or \$40,000 annually, and that the lease allows the owner to capture those savings, increasing the property's NOI by the same amount. At a 10% capitalization rate, the property's value could increase by \$400,000, which is twice as much as the project's first cost.

Assuming a stable capitalization rate, incremental NOI has the potential to increase the building's appraised value. A common method for appraising income-producing property is called the "Income Approach" where the

NOI is divided by a "capitalization rate," which can be described as the minimum rate of return required by an investor who purchases the property without the use of leverage.

Asset Value = NOI/Capitalization Rate

Increase in asset value is important whenever a building is sold or refinanced. Valuation increase is also important when an income-property owner needs to demonstrate an increase in equity; for example, in the context of periodic portfolio assessments.

Risks Associated with Inaction

The preceding sections of this guide illustrate how planning and implementing energy-saving upgrades requires proactive decision-making and some level of initial financial outlay. Energy and non-energy benefits will soon pay back the initial investment, but there are definite organizational challenges to overcome when energy efficiency is considered alongside the wide range of other ongoing activities and priorities. Improving energy performance takes effort, and there are some risks to consider. However, there are market-related and regulatory risks associated with *inaction* that building owners should also consider.

Market Risk

In recent years, energy efficient buildings have begun to demand a premium on the commercial real estate market (Eichholtz, Kok and Quigley, 2009). As market awareness of energy issues grows and tenants increasingly demand the disclosure of building energy performance scores (e.g., ENERGY STAR score), the market value gap between high performance and lower performance buildings will continue to widen.

Energy prices represent another source of market risk to building owners. Energy prices have proven to be tremendously volatile in recent years. The potential for future price increases should be considered in long-term financial planning (Landsberg, Lord and Carlson, 2009).

Regulatory Risk

The threat of climate change has put the high energy use of buildings front and center in the efforts to reduce national energy use and carbon emissions (Landsberg, Lord and Carlson, 2009). If policymakers choose to regulate energy and carbon as a way to reduce energy consumption, energy producers will likely pass on the additional costs to energy consumers. An energy efficient building would be less impacted by this cost increase than inefficient buildings.

Estimating Project Value

Understanding the benefits of energy efficiency and the risks of the status quo provides a compelling argument for energy efficiency upgrades. Once motivated, building owners will need to develop a project-specific business case that will ensure that the project meets long-term cost-effectiveness requirements. The following analysis methods quantify a project's overall financial impact in different ways, and summarizes the benefits and drawbacks of each approach.

Simple Payback Method

The most simple and commonly used financial analysis method is simple payback. Simple payback is defined as the time, in years, for a project's cumulative annual savings to equal its upfront cost. For example, if a lighting retrofit costs $100,000 and saves $15,000 in annual energy costs, its simple payback would be 6.7 years.

Simple payback does not take into account any benefits or costs that occur after the initial investment has been recouped. A project can initially appear to be unattractive when viewed through the lens of simple payback period, while a more complete economic analysis reveals it to be a highly profitable investment. Life-cycle cost (LCC) analysis (see below) is more effective at identifying the best project option, once the costs and benefits of each alternative are carefully analyzed and expressed in present value terms.

Net Present Value (NPV)

NPV offers a more rigorous analysis than simple payback by not only extending the analysis to include all cash flows over the useful life of the project, but also accounting for the time value of money. The project's cash flows include the first cost, energy cost savings (which may be assumed to increase with rising energy prices), and all other costs and benefits, such as O&M costs and any salvage value at the end of the analysis term. The calculation of a project's NPV depends on the discount rate selected as well as the length of the analysis term.

Discount rate is often defined as the investor's minimum acceptable rate of return for an investment whose length and risk profile match those of the project being evaluated. In an NPV analysis, the discount rate is used to determine the present value of each cash flow, adjusting all cash outflows and inflows over the life of the project to comparable dollar amounts today. The choice of a discount rate is critical; the chosen rate should reflect the rate of return that could be earned on an investment of similar risk and duration.

A positive NPV indicates that the present value of the cash inflows is greater than the present value of the cash outflows over the analysis term. A negative NPV indicates that the investment required is greater than the project's return, once all of the cash outflows and inflows are reduced to their present values and summed. Using the same lighting retrofit example, the present value of future cash flows, assuming a 6.5% discount rate and a 12-year useful life of the lighting equipment, is calculated as $114,400. Subtracting the upfront project cost of $100,000 produces an NPV of $14,400.

NPV is the primary metric used for economic analysis of the measures presented in this guide. See Appendix 10.4 for a detailed discussion of the NPV methodology as it is applied in this guide. The Additional Resources at the end of this section offers publicly available tools to aid in NPV calculations.

Internal Rate of Return (IRR) and Modified Internal Rate of Return (MIRR)

IRR is related to NPV in that it defines, for a given series of cash flows and a specific analysis term, the discount rate that would result in an NPV of zero. Investors sometimes compare their discount rate (or "hurdle rate") to a project's IRR.

A significant shortcoming of IRR is that it assumes that all cash inflows over the life of the investment can be reinvested at the IRR itself. In most cases, this is an unrealistic assumption. Fortunately, an alternative metric can be calculated: Modified Internal Rate of Return ("MIRR," which is sometimes called, "Adjusted Internal Rate of Return" or "AIRR"). MIRR allows the user to specify the rate at which cash inflows will be reinvested during the analysis term, yielding a financial metric that is more reasonable than IRR.

Life-Cycle Cost (LCC)

As the name implies, life-cycle cost analysis considers all cash inflows and outflows over the useful life of the project, reducing each flow to its present value. When two or more mutually exclusive alternatives are being evaluated, the one with the lowest life-cycle cost should be selected. That alternative will represent the lowest cost when expressed in present value terms. NPV, discussed above, is a form of LCC analysis.

There are many resources available that provide more detail and tools for calculating LCC, including the National Institute of Standard and Technology's Life-Cycle Costing Manual and online Building Life-Cycle

Cost Program tool. The Rocky Mountain Institute also offers a Microsoft Excel®-based LCC calculator called LCCAid. See Additional Resources at the end of this section for a listing of these and other available tools.

Choosing a Financial Analysis Method

The basic characteristics of several commonly used financial analysis methods have been described; however, there are many additional considerations specific to each method and for choosing between methods. Some additional analytical considerations include:

- **Double counting**. Some measures have interrelated energy savings and thus financial impacts. It is important to avoid double-counting savings to avoid skewing the analysis.
- **Assumptions about future values**. Future cash flows are dependent on dynamic variables such as energy prices. A simple sensitivity analysis can reveal how changes in these assumptions would impact project value.
- **The audience for the analysis**. Some decision makers are only comfortable with certain methods of analysis. This human factor is a key consideration when selecting an approach.

Generally, in situations where one needs to decide between mutually exclusive alternatives (e.g., one needs to select a single chiller from a field of many possibilities), LCC methods offer a more realistic portrayal of project economics. LCC is more rigorous because it accounts for all cash outflows and inflows over the analysis term and uses time value of money to adjust each cash flow to its present value.

In situations where one needs to decide the order in which non-mutually exclusive alternatives should be funded (e.g., one needs to choose which of six potential energy-saving projects should be funded given limited capital), one should first calculate the NPV of each alternative (ensuring that no alternative has a negative NPV), and then rank the proposed projects in order of descending MIRR so that they may be approved and funded in that order. Taking this approach ensures the highest and best use of limited capital.

The resources and considerations referenced in this section should be considered a starting point for building a solid business case for energy efficiency projects. While sound engineering and financial analyses are essential to a project's success, equally important is the alignment of all groups within an organization to achieve a common goal. With participation from both the facility team and management team in the creation of the business case, a project will have a much higher likelihood of successful execution.

2.6 KEY POINTS

- Improved building energy efficiency can reduce operational costs, and in the case of income-producing properties, provide incremental net operating income and asset value.
- In addition to energy cost savings, energy efficiency improvements can have significant non-energy benefits, including extended equipment life, increased lease rates, better indoor environmental quality, improved occupant satisfaction, improved sustainability and associated marketing value.
- Improving building performance is a risk management strategy; various market and policy risks can be reduced by improving energy efficiency.
- Simple payback period and internal rate of return are both popular metrics; however, both have their shortcomings. Modified internal rate of return, net present value and life-cycle cost are preferred, and their proper use depends on whether the decision being made involves "mutually exclusive" or "non-mutually exclusive" alternatives.

Additional Resources

- BOMA, "BOMA *International Commercial Lease: Guide to Sustainable and Energy Efficient Leasing for High Performance Buildings*": A guide that helps property professionals execute a lease that addresses building operations and performance. Available for purchase; www.boma.org.
- California Sustainability Alliance, *Green Leases Toolkit*: An online toolkit that provides templates for implementing a green lease. Available for free download online; www.sustainca.org.
- Capital E, *"The Costs and Financial Benefits of Green Buildings"*, 2003: A report that investigates the financial viability of investing in "sustainable" or "green" building practices. Available for free download online; www.cap-e.com.
- Green Building Finance Consortium, *"Value Beyond Cost Savings"*, 2010: A guide to underwriting sustainable properties. Available for free download online; www.greenbuildingfc.com.
- Department of Energy, *Energy Calculators & Software* webpage: A list of resources related to estimating energy use of equipment and potential energy savings of efficiency measures. www.eere.energy.gov/calculators/buildings.html.
- California Commissioning Collaborative, *Retrocommissioning Toolkit*: Retrocommissioning online resources, including spreadsheet tools to perform energy savings calculations. Available for free download online; www.cacx.org.
- Rocky Mountain Institute, *LCCAid*: An Excel-based tool designed to present the results of a LCC analysis in a meaningful and compelling form for key decision makers. Available for free download online; www.retrofitdepot.org.
- Environmental Protection Agency, *Cash Flow Opportunity Calculator*: Excel-based cash flow analysis tool that includes NPV calculation and estimated cost of delaying efficiency upgrades. Available for free download online; www.energystar.gov.
- National Institute of Standard and Technology (NIST), *"Life Cycle Costing Manual"*, 1995: A guide to understanding the LCC methodology and criteria established by the Federal Energy Management Program. Available for free download online; www.nist.gov.
- Department of Energy, *Building Life Cycle Cost* program: An LCC analysis software program designed for government projects but applicable to commercial projects. Available for free download online; www.eere.energy.gov.
- Pacific Northwest National Lab (PNNL), *Facility Energy Decision System*: A software tool that identifies energy efficiency improvement opportunities and completes detailed retrofit project analyses across a wide variety of building types. Available for free download online for federally-funded projects; www.pnl.gov.
- Environmental Protection Agency, *"Building Upgrade Manual"*, 2008: A strategic guide for planning and implementing a profitable energy saving building upgrade following a five-stage process. Chapter 1 discusses Investment Analysis. Available for free download online; www.energystar.gov.
- ASHRAE, *"Energy Efficiency Guide for Existing Commercial Buildings: The Business Case for Building Owners & Managers"*, 2009: A guide to making the business case for efficiency upgrades; includes discussion of cash flow analysis methods. Available for purchase; www.techstreet.com.

- Environmental Protection Agency, *"A Retrocommissioning Guide for Building Owners"*, 2007: A comprehensive guide to EBCx projects; includes sections on lease structures and impacts to building financial metrics. Available for free download; www.peci.org.
- BetterBricks, *"The High Performance Portfolio Framework"*: A strategic guide to improving building performance; The "Commit" chapter includes discussion on developing a business case for efficiency upgrades. Available for free download; www.betterbricks.com.

2.7 Financial Assistance for Energy Efficiency Projects

2.7 TOPICS COVERED

- Purchase options
- Utility and government incentives

Defining an approach for financing is a key step in creating the business case for an energy efficiency project. The approach to financing includes determining the source of funds to pay upfront costs and identifying incentives that may substantially reduce those costs. This section provides an overview of the most common purchase options and some of the incentives available that may improve a project's financial attractiveness.

Purchase Options

A building owner has two primary routes to fund the upfront costs of an energy efficiency project: purchase of equipment and services, or performance contracting. In addition, utility and government incentives can be leveraged to reduce total project costs.

Debt

While an owner may use cash to purchase the services and equipment associated with an energy efficiency project, the most common way to finance a project is through borrowing. When considering this option, it's recommended to research low-interest loans specifically tailored to energy efficiency projects (see "Utility Incentives" below).

Government loans or loan guarantees are often available at multiple levels (local, state, and federal). Many of these loan programs were historically limited to energy retrofits in public buildings, but have recently been extended to commercial buildings.

Performance Contracting

Performance contracting is an alternative to conventional project financing. Under a performance contract, an energy service company (ESCO) delivers turnkey energy efficiency projects, with the project cost recovered over time out of energy savings. The ESCO will typically complete an audit, obtain contractor bids, manage the installation, and finance the project (Landsberg, Lord and Carlson, 2009). Energy cost savings are then shared between the ESCO and the building owner, with the ESCO's share of savings paying for the ESCO's services, including the cost of capital. See Figure 2.6.

Figure 2.6. Distribution of Energy Cost Savings through Performance Contracting

Performance contracting addresses many of the common barriers that delay projects. Some of the key benefits include:

- Building owners avoid upfront project costs because the ESCO finances the project
- ESCOs provide technical expertise for implementing measures
- Risk may be reduced by including a savings guarantee in the project contract.

Performance contracts are complicated by the technical nature of a large energy efficiency project and the complex and nuanced calculations they require. Measurement and verification of savings becomes a critical and sometimes controversial part of the contract and project, especially for larger investments where the contract term may exceed ten years. In response to the complexity of designing and executing performance contracts, several organizations offer detailed guidance on energy performance contracting. These resources are described in the Additional Resources below.

The primary disadvantage of performance contracting is that the owner does not see the full benefit of reduced operating costs during the period of the contract. Further, the ESCO's cost of capital has a significant influence on the project economics. Some building owners may be able to secure financing at better rates than the ESCO, in which case the benefit of a performance contract is reduced. On the other hand, ESCOs have a wealth of knowledge about energy efficiency measures, and they may be a valuable project partner even without a performance contract.

Utility and Government Incentives

Leveraging incentives available through utility programs can be an effective way to reduce a project's total cost. There are numerous programs available offering cash rebates to help make an energy efficiency project more financially attractive. The availability of incentives is highly time and location dependent. To compile an up-to-date list of options, the Database of State Incentives for Renewables and Efficiency (DSIRE) provides a good starting point. Utility representatives are also often able to describe opportunities that relate to your facility. It's worth noting that the incentives usually are issued upon project completion, so the owner will still need to make the full upfront investment.

Utility "On-Bill Finance"

Some utilities have started financing energy efficiency retrofits through On-Bill Finance. On Bill Finance offers utility customers the opportunity to receive a utility payment for a retrofit and then repay the utility through a charge on the utility bill, which is typically offset by project savings. As with performance contracting, this can be a useful way to finance a project, but will result in the owner not seeing the full benefit of the savings until the financing is repaid.

Tax Relief

There are also financial incentives available in the form of tax relief, offered by all levels of government, but are dependent on location. The primary tax relief offered by the federal government is the Commercial Buildings Tax Deduction, which offers up to $1.80/sf for projects that achieve at least 50% energy cost savings (extended through 2013 at time of publication). To demonstrate 50% savings, participating buildings are required to be modeled in a qualifying software program.

An additional tax relief mechanism that has been tested in local government pilot programs throughout the U.S. is Property Assessed Clean Energy (PACE) financing. By allowing building owners to finance retrofit projects as a property tax assessment, PACE financing programs result in more favorable lending rates compared to traditional loans.

2.7 KEY POINTS

- Commercial building owners' two primary options for procuring energy efficiency upgrades are cash or conventional lending, and performance contracting.
- Incentives in the form of special loans tailored to energy efficiency upgrades, tax relief, and utility rebates can be leveraged to reduce a project's total costs.

Additional Resources

- Department of Energy, *Database of State Incentives for Renewables and Efficiency (DSIRE)*: An online database of government and utility incentives available throughout the U.S.; www.dsireusa.org.
- Department of Energy, *Tax Incentives for Commercial Buildings* webpage: Includes information related to the "Commercial Buildings Tax Deduction"; www.eere.energy.gov/buildings/tax_commercial.html.
- Department of Energy, *Energy Savings Performance Contracts* webpage: Extensive documentation of federal experience with performance contracts; www.eere.energy.gov/femp/financing/espcs.html.
- BOMA, *BOMA Energy Performance Contract (BEPC)* model: A performance contracting toolkit that includes boilerplates documents, including RFPs and contracts. Available for free download; www.boma.org.
- Capital E, *"Energy Efficiency Financing: Models and Strategies"*, 2011: A report that maps financing models and strategies that can help accelerate bank and institutional capital participation in scaling energy efficiency financing. Available for free download; www.cap-e.com.
- National Association of Energy Service Companies (NAESCO): Resource for list of qualified ESCOs; www.naesco.org.

3

Existing Building Commissioning (EBCx)

Significant energy savings can often be achieved with minimal risk and capital outlay by improving building operations and restructuring maintenance procedures. Operations and maintenance (O&M) includes two components: "operations" focuses on the control and performance optimization of equipment, systems, and assemblies, while "maintenance" typically refers to routine, periodic physical exercises conducted to prevent the failure or decline of building equipment and assemblies. This process of improving O&M procedures is a key component of existing building commissioning (EBCx), which is a quality-oriented process for investigating and optimizing the performance of a facility and its systems to meet the current needs of the facility.

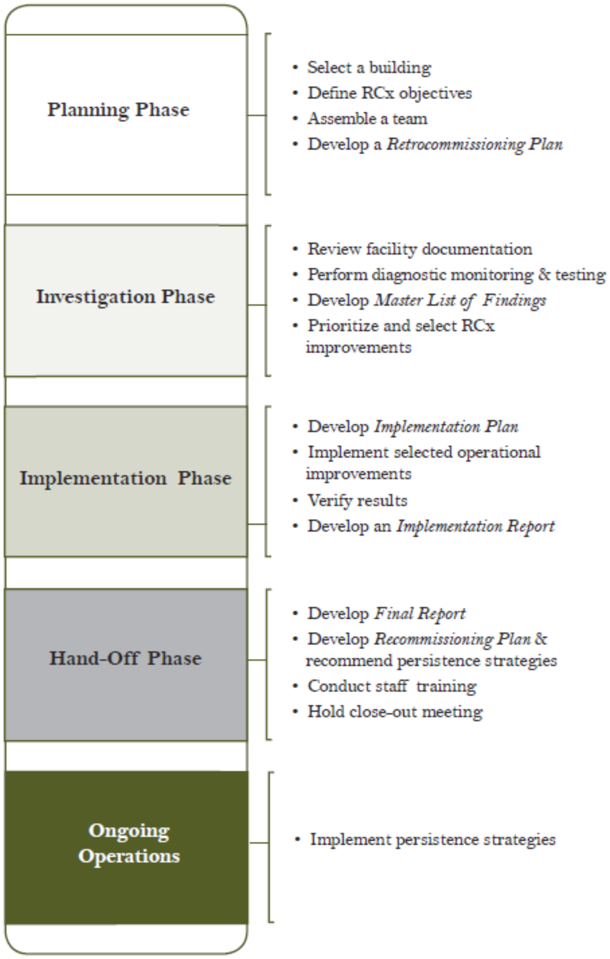


Figure 3.1. EBCx Process

An EBCx process usually consists of four phases: planning, investigation, implementation, and hand-off. The EPA's "A Retrocommissioning Guide for Building Owners" includes a detailed discussion of the activities that take place in each of these phases. Note that the terms "EBCx" and "retrocommissioning" (RCx) are used interchangeably. The EBCx process may vary slightly for specific projects, but most projects follow the process shown in Figure 3.1.

Much of the effort, and cost, of EBCx is applied during the Investigation Phase, where the EBCx provider works with the building operators to conduct an in-depth investigation into building operations, to gain a detailed understanding of the systems and assemblies and to identify operational improvements. About half of the overall project cost is devoted to the EBCx provider's work on the project, which includes this in-depth investigation. The other half is devoted to implementing the measures.

EBCx is generally recommended even when deeper retrofits are being considered, in order to optimize building system operations prior to designing and implementing the retrofits. Besides being a highly cost-effective strategy for reducing energy usage, EBCx can help reduce other O&M costs besides energy, and help ensure the persistence of proper operation. It provides a good first step on the road to increase energy performance, whether using a staged or integrated approach (see Section 2.5 “Planning for Energy Performance Improvements”).

This chapter first discusses O&M measure options that are suitable for most office buildings. The O&M Measure Summary Table (Table 3.1) provides a comprehensive list of O&M measures that could be identified and implemented as part of an EBCx project. The measures included in this list were developed by evaluating the most common and cost-effective measure options being implemented in office buildings. For more detailed information about each O&M measure, refer to Appendix 10.5.

A selection of these measures is then grouped in recommended packages for a representative office building. These packages have been subjected to careful energy and financial analysis. The EnergyPlus modeling results of the EBCx recommended packages of measures resulted in an average energy savings of 23% across the five primary climate zones. As a point of comparison, Mills (2009) found 16% median energy savings among hundreds of EBCx projects across the country.

Next, additional considerations for O&M measures and the EBCx process are offered that address factors that can influence cost-effectiveness, and aspects to consider when evaluating O&M measures. Because all buildings are unique and have particular needs and opportunities for energy upgrades, building owners are encouraged to think about how these aspects will influence their projects.

This chapter concludes with case studies of office buildings that have successfully implemented O&M measures as part of an EBCx project. These case studies offer insight into the process that office building owners went through in completing their EBCx project, and highlight the energy savings and financial results of select real world projects.

3.1 O&M Measure Summary Table

Table 3.1 lists all O&M measure options investigated in this guide. Appendix 10.5 provides a discussion of the technical details of each of these measures.

Table 3.1. O&M Measure Summary Table

System	Measure Number and Description	Applicable To					Stage (see Section 2.5)	Appendix Page # Ref.
		Hot & Humid	Hot & Dry	Marine	Cold	Very Cold		
Lighting	L1. Calibrate exterior lighting photocells	O	O	O	O	O	1	126
Envelope	E1. Replace worn out weather stripping at exterior doors	O	O	O	O	O	1	126
	E2. Reduce envelope leakage	RP	RP	RP	RP	RP	1	126
HVAC Air Side	HA1. Revise air filtration system	RP	RP	RP	RP	RP	1	127
	HA2. Increase duct system efficiency	O	O	O	O	O	1	127
	HA3. Calibrate air sensors	RP	RP	RP	RP	RP	1	128
	HA4. Re-enable supply air temperature setpoint reset	RP	RP	RP	RP	RP	1	128
	HA5. Reduce HVAC equipment runtime, close outside air damper during unoccupied periods	RP	RP	RP	RP	RP	1	129
	HA6. Remove unused inlet guide vanes from supply fan inlet	O	O	O	O	O	1	129
	HA7. Reduce economizer damper leakage	O	RP	RP	RP	RP	1	129
	HA8. Implement a night purge cycle	O	O	O	O	O	1	130
HVAC Water Side	HW1. Inspect chiller and cooling tower, clean as needed	O	O	O	O	O	1	130
	HW2. Test and fix chilled and heating water coil valves	O	O	O	O	O	1	131
	HW3. Inspect and repair damaged pipe insulation	O	O	O	O	O	1	131
	HW4. Calibrate water sensors	RP	RP	RP	RP	RP	1	132
	HW5. Re-enable chilled water supply temperature setpoint reset	O	O	O	O	O	1	132
	HW6. Shut down cooling plant when there's no cooling load	RP	RP	RP	RP	RP	1	132
Other	O1. Implement daytime custodial services	O	O	O	O	O	1	133

RP = measure is part of recommended package
O = measure is not part of recommended package but is an option

3.2 EBCx Recommended Packages

Tables 3.2 and 3.3 summarize the results of the energy and financial analysis of the recommended packages of O&M measures, and identify which measures are included for each climate zone.

At-A-Glance Results

Table 3.2. EBCx Recommended Packages - Results of Common Metrics

	Site Energy Use Intensity (EUI) (kBtu/sf/yr)			Annual Energy Cost per Square Foot		
	Baseline	Post-EBCx	% Reduction from Baseline	Baseline	Post-EBCx	Reduction from Baseline
Hot & Humid	88	75	15%	$2.09	$1.91	$0.18
Hot & Dry	97	75	22%	$2.16	$1.85	$0.30
Marine	94	68	27%	$1.99	$1.63	$0.36
Cold	86	66	24%	$2.24	$1.92	$0.32
Very Cold	91	68	25%	$2.00	$1.71	$0.29
Average	91	70	23%	$2.10	$1.81	$0.29

The O&M measures included in the EBCx packages are shown in Table 3.3.

Table 3.3. EBCx Recommended Package Measures

System	Measure Description	Climate Zones	Appendix Page # Ref.
Envelope	E2. Reduce envelope leakage	All	126
HVAC - Air Side	HA1. Revise air filtration system	All	127
HVAC - Air Side	HA3. Calibrate air sensors	All	128
HVAC - Air Side	HA4. Re-enable supply air temperature setpoint reset	All	128
HVAC - Air Side	HA5. Reduce HVAC equipment runtime, close outside air damper during unoccupied periods	All	129
HVAC - Air Side	HA7. Reduce economizer damper leakage	All, except hot-humid	129
HVAC - Water Side	HW4. Calibrate water sensors	All	132
HVAC - Water Side	HW6. Shut down cooling plant when there is no cooling load	All	132

The “Reduce economizer damper leakage” measure is not included in the Hot-Humid package, since airside economizers are typically not used in these climates, and the reference building (Miami) does not include an airside economizer system.

Rationale for Recommended Measures

The measures in the EBCx package were chosen based upon their frequency of occurrence on EBCx projects, ease of implementation, and likelihood of implementation.

Note that the measures included in the recommended package are only a subset of the O&M measures identified in Table 3.1 in Section 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 future planned work that would affect the measure. The measures in the EBCx package were chosen as a representative mix of measures that would be implemented as part of an EBCx process.

Energy Savings

The energy and demand savings for the recommended EBCx packages are shown in Table 3.4. These values were determined by applying the measures to the office reference building described in Appendix 10.1.

Table 3.4. EBCx Recommended Package Energy Savings Results

	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage	Source EUI Savings (kBtu/sf/yr)	Savings as % of Total Source Usage
Hot & Humid	319,000	4	16,000	13	15%	24	11%
Hot & Dry	497,000	4	26,000	21	22%	38	16%
Marine	410,000	0	37,000	26	27%	35	21%
Cold	341,000	(20)	30,000	20	24%	33	16%
Very Cold	338,000	(60)	34,000	23	25%	35	18%

The source EUI savings are calculated from the site EUI savings and the site-to-source conversion factors for five different utility companies (Florida Power & Light, Nevada Power, Puget Sound, Chicago ComEd, and Minisota Power). The site-to-source conversion factors are calculated based on the utility company's electricity mix and the source energy factor associated with each fuel type for electricity generation. As shown, implementation of O&M measures as part of an EBCx process can yield significant energy savings. The overall reductions in building energy usage shown in Table 3.4 are similar to the range cited in research on actual EBCx projects (Mills, 2009).

Financial Analysis

The cost of individual measures can vary greatly, depending on the baseline condition of the building and the work involved in implementing the measures. Studies have shown that the average cost for an EBCx project is \$0.30/sf (Mills, 2009). Applying this value to the 200,000-ft^2 office building and applying inflation rates for the past two years gives an overall EBCx package cost, including EBCx provider costs and measure implementation costs, of \$61,100. (Table 3.5)

Table 3.5. EBCx Recommended Package Financial Analysis Results

	Total Measure Costs	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (Years)	Net Present Value
Hot & Humid	$61,100	$36,300	$0	$36,300	2	$244,000
Hot & Dry	$61,100	$60,600	$0	$60,600	1	$495,000
Marine	$61,100	$72,000	$0	$72,000	1	$613,000
Cold	$61,100	$63,200	$0	$63,200	1	$522,000
Very Cold	$61,100	$57,100	$0	$57,100	1	$459,000

As shown, EBCx has a fast simple payback and positive net present value, making it an attractive method to achieve energy savings. Studies have shown that EBCx has a simple payback of 1.1 years, on average, based on energy savings (Mills, 2009). Note that the "Measure Costs" shown in the table are the overall EBCx project costs, including the cost of the EBCx provider and the cost of implementing the measures.

Non-energy benefits, such as improved thermal comfort and extended equipment life, can also be achieved by the EBCx process. Studies have estimated the median non-energy impacts of EBCx at $0.18/ft^2 (Mills, 2004). This is significant, when compared to the median energy savings of $0.29/ft^2 related to EBCx (Mills 2009). While there may be savings that are realized beyond the energy savings reported in the table above, some costs may also increase. Additional O&M expenses may be required to maintain optimal energy performance after the EBCx process. For this analysis, the additional non-energy costs and benefits were assumed to cancel out, resulting in zero net impact on O&M expenses.

To maintain the energy benefits related to O&M measures, it's important to maintain the performance of the related equipment and systems through periodic monitoring. The financial analysis assumes that recommissioning is performed every four years to maintain the persistence of benefits, and that, as a result of this periodic recommissioning, the measure life of EBCx is 20 years. The cost of recommissioning is usually less than the cost of initial EBCx. For the financial analysis, the recommissioning cost is estimated to be two-thirds of the initial EBCx cost. This recommissioning cost is not identified separately in the table above, but it is included in the net present value.

3.3 Additional Considerations

The O&M measures proposed in the recommended packages above and comprehensive O&M measure list in Appendix 10.5 provide a starting point for measures to be considered for most office buildings. However, not all measures will be applicable to all buildings, since all buildings are unique. Moreover, other measures not included in the measure list may be applicable to a specific building. The EBCx process, which includes an in-depth investigation into building operations, will identify opportunities for improved performance of the building, including energy performance, occupant comfort, O&M effort, and equipment performance. The extent of the opportunities identified will be partly dependent on the comprehensiveness of the EBCx scope.

Building owners considering implementing the EBCx process will benefit from consulting the detailed description of the O&M measures in Appendix 10.5 to gain an understanding of the types of measures typically implemented as part of an EBCx project. The Appendix includes a discussion of each measure's technical characteristics, special considerations, and technical assumptions for implementing the measure in the reference building.

When evaluating O&M measures to investigate in more detail for a specific building, the following aspects could be considered to help narrow the options to the most feasible measures:

- **Is the measure applicable to the systems and assemblies in the building?**

  Certain measures may not be feasible due to the constraints of the installed systems. For example, lowering condenser water temperatures in the chilled water plant may not be a valid measure to consider if the existing chillers cannot operate correctly at these lowered temperatures.

- **Is the measure relevant to the operations of the building?**

  The capabilities of the operations staff should be considered when evaluating measures. Does the staff have the necessary skills and knowledge to support the measure? If not, is there additional training that they can receive?

- **How difficult will it be to ensure that the measure persists?**

  After measures are implemented, they require periodic monitoring to ensure that the benefits of the measures are realized over time. Sufficient resources and strategies must be put into place to ensure measure persistence.

- **Are there planned retrofits that may wipe out 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 existing fixtures' integral photocells before the retrofit.

The cost of EBCx is an important consideration for most building owners. Much of the cost of EBCx relates to the EBCx provider cost – for the planning, investigation, and hand-off phases of a typical EBCx project. And most of the EBCx provider cost is spent during the in-depth investigation portion of the project. While the cost of implementing O&M measures is typically low, it's important to consider the EBCx provider effort, which is necessary to identify the O&M opportunities. EBCx providers are typically better suited for managing the EBCx process than in-house staff, for the following reasons (U.S. Environmental Protection Agency, 2007):

- 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 to draw upon 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, power monitors.
- EBCx providers have the necessary analytic skills and resources for diagnosing performance issues and determining the cost-effectiveness of identified improvements.

Many factors contribute to the cost-effectiveness of an EBCx project, and some of these factors can be identified prior to starting an EBCx project. Some indicators of a good EBCx building candidate include:

- High, unjustified energy use
- Low performing building equipment or control systems (high failure rate)
- Direct digital controls
- Experienced and available in-house staff
- Up-to-date building documentation

These are just a few of the factors that should be considered. An experienced EBCx provider can help determine if a building is a good candidate for EBCx or not. To help determine a building's suitability for EBCx and to give greater confidence in proceeding with an EBCx project, an ASHRAE Level I energy audit can be conducted.

Building occupants can also signal the suitability of a building for EBCx. A building with a high number of occupant complaints is often a good candidate for EBCx. In such a building, the O&M measures that result from an EBCx project will achieve energy savings and may also provide the additional benefit of helping to retain occupants. The building commissioning industry suggests that it is best practice to engage building occupants during both investigation and persistence phases of commissioning (Building Commissioning Association, 2008).

Small- and Medium-Sized Office Building Considerations

The O&M measures presented in this chapter are measures that would typically be identified and implemented in an average large office building as part of an EBCx process. The EBCx process can also be applied to small and medium sized office buildings, but these buildings may have different O&M measures than large offices, due to the dissimilar characteristics of small, medium and large office buildings besides just building size and number of floors. Even though the specific technologies related to the measures will likely vary between small, medium and large office buildings, the intent of the measures will be the same: improve building performance through implementation of low-cost O&M measures.

The recommended package measures listed in Section 3.2 are generally applicable to small, medium and large office buildings, as these systems typically do not vary greatly between these different building types. However, there can be significant variation in the HVAC measures. Small and medium sized office buildings usually use unitary (packaged) HVAC equipment and systems, while large offices typically use built-up equipment and systems. For example, a small office building would likely use packaged rooftop units (single zone, constant volume, DX cooling, and gas furnace heating), while a large office building would likely use a multi-zone VAV system with chilled water cooling and hot water heating.

Related to this, there may be other applicable O&M-type HVAC measures for small and medium sized office buildings beyond the ones listed in Chapter 3. These measures include:

- Clean cooling and heating coils, and comb heat exchanger fins
- Repair airside economizer
- Correct refrigerant charge

These measures are discussed in more detail in Appendix 10.5.

There may be O&M-type HVAC measures listed in Chapter 3 that do not apply to typical systems in a small or medium sized office building. These include the following measures:

- "Re-enable supply air temperature setpoint reset" does not apply to single zone systems.
- "Remove unused inlet guide vanes from supply fan inlet" does not apply to constant volume HVAC systems.
- All of the "HVAC-Water Side" O&M measures, as these do not apply to HVAC systems that do not use waterside components (e.g., pumps, chillers, and boilers).

There will be exceptions to these generalizations, though. For example, there may be instances where a large office building might use unitary (packaged) HVAC equipment, and a small office building might use a chilled water system for cooling. The intent of the measure lists presented in this guide is to give an idea of the types of O&M measures that could be identified and implemented as part of an EBCx process for typical small, medium, and large office buildings. Different buildings will have different applicable measures, due to variations in building characteristics. See Appendix 10.3 for aspects to consider related to variations in building and climate characteristics.

EBCx Case Study: 522 Fifth Avenue

522 Fifth Avenue is a 23-story mixed-use (predominately office) facility located in the center of Manhattan. Built in 1896 and managed by Hines, this historic building is part of the famous Fifth Avenue Corridor, one of the most desirable office and retail locations in the world.

Although energy efficiency measures such as the installation of a thermal ice storage system had been implemented in the past, the building as a whole was not operating at optimum efficiency. An EBCx program was initiated by project manager Strategic Business Solutions to systematically investigate, analyze and optimize the performance of building equipment and systems.

O&M improvements were initiated by identifying no-cost/low cost measures through a four phase process which included: 1) planning phase 2) investigation phase 3) implementation phase and 4) measurement & verification phases. All major energy consuming systems including the HVAC and lighting controls were investigated for potential O&M measures. After implementation, a training program for operations and maintenance staff was held to review new protocols and equipment, thereby promoting the persistence of energy savings in the future.

The O&M measures implemented achieved impressive results, improving the building systems' ability to perform interactively, and reducing site energy use by 18%. This reduction in energy consumption is above and beyond the savings from capital projects implemented during the same time period, including a chiller replacement and a large lighting project.

The energy savings resulting from the EBCx process, along with the lighting and chiller retrofit, improved the building's ENERGY STAR score from 49 to 80, enabling the facility to qualify for the ENERGY STAR label.

Investigation Costs	Equipment Costs	Installation Costs	Financial Incentives	Net Cost to Owner
$144,000	$221,000	$309,000	$116,000	$558,000

Estimated Annual Electric $ Savings	Estimated Annual Steam $ Savings	Total Estimated Annual Energy $ Savings	ROI	Simple Payback
$366,000	$151,000	$517,000	92%	1.1 years

Estimated Energy Use Intensity (EUI)		Estimated % Site Savings
Before	After	
114 kBtu/sf/yr	93 kBtu/sf/yr	18%

Quick Facts

Owner: Hines A/A/F Morgan Stanley

Location: New York, NY

Gross Square Footage: 547,349 sf

Post-retrofit EUI: 93 kBtu/sf/yr

ENERGY STAR: 49 to 80

Key Measures

- Add Duct static pressure reset
- Optimize condenser pump control
- Repair steam pipe insulation
- Utilize economizer mode for cooling
- Add HVAC air and water-side VFDs
- Implement chilled water differential pressure setpoint reset
- Add optimal start-up strategy for major air systems
- Optimize condenser water temperature setpoint
- Revise lighting EMS occupancy schedule

Disclaimer: Reported energy savings results were provided by the building owner or a third party and have not been verified.

EBCx Case Study: Center Tower

Center Tower, at the Offices of South Coast Plaza, has become a LEED Gold rated building, thanks in part to energy savings from EBCx. The building's owner, Center Tower Associates, strives to manage its buildings efficiently and decided in October 2007 to take the next step and go for LEED certification. Because EBCx was a prerequisite for LEED for Existing Buildings 2.0, the Offices of South Coast Plaza enrolled Center Tower in the local utility's EBCx program. The utility program helped Center Tower attain energy and cost savings by:

- Providing an in-depth investigation to identify efficiency measure opportunities
- Offering implementation incentives and assistance
- Verifying proper implementation of the measures
- Documenting the energy saving measures and training building staff

Center Tower's EBCx project resulted in a 5.1% reduction in energy use with expected annual cost savings of $26,000. Relatively low implementation costs and utility incentives supported a project payback for the company of only six months.

The EBCx provider worked closely with the building staff to provide an in-depth analysis of the building's operating conditions. They found several operational improvements for the chiller, air handling unit controls, and HVAC system scheduling that could bring significant energy and cost savings to Center Tower.

The measures identified through the investigation were primarily implemented by the staff of The Offices of South Coast Plaza. The chiller upgrade and some building control resets were implemented by a controls contractor. Because of the high level of commitment from Engineering Manager Gary Spore and his staff, much of the implementation was complete in one month, with all measures implemented within three months. Spore says that the EBCx process is a useful way to gain energy savings and urges building owners to "take it seriously."

Audit Costs	Installation Costs	Financial Incentives	Net Cost to Owner
$53,000	$15,000	$56,000	$12,000

Est. Annual Energy $ Savings	ROI	Simple Payback
$26,000	210%	0.5 years

Estimated Annual Energy Use		Estimated Annual Energy Use Intensity (EUI)		Estimated Annual % Site Savings
Before	After	Before	After	
23,700 MBtu/yr	22,500 MBtu/yr	51 kBtu/sf/yr	49 kBtu/sf/yr	5%

Quick Facts

Facility Name: Center Tower

Location: Costa Mesa, CA

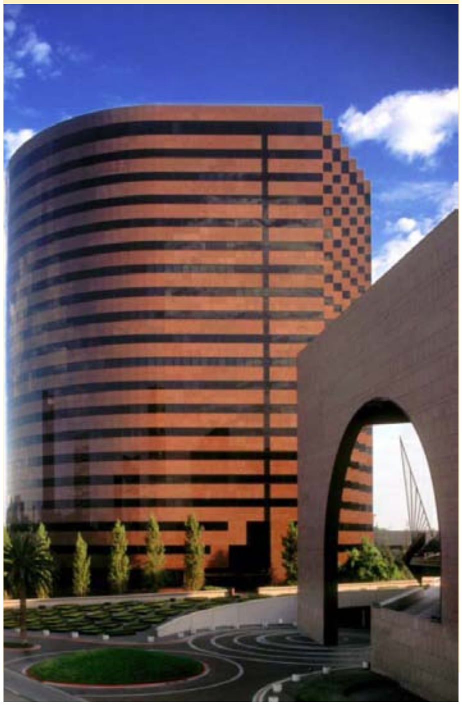
Gross Square Footage: 462,191

Post-retrofit EUI: 49 kBtu/sf/yr

ENERGY STAR: (after EBCx) 99

Key Measures

- Revise AHU fan operating schedule
- Revise chilled water pump operating schedule
- Implement chilled water temperature reset
- Add BAS control of AHUs
- Implement condenser water temperature reset strategy



Disclaimer: Reported energy savings results were provided by the building owner or a third party and have not been verified.

3.4 Additional Resources and Guides

For additional references related to the EBCx process and O&M measures discussed in this chapter, refer to the following.

General Guidance

- 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. Available for free download online; www.peci.org.
- Mills (LBNL), *"Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse Gas Emissions,"* 2009: An investigation of the cost-effectiveness of EBCx that leverages past EBCx project data. Available for free download online; www.lbl.gov.
- Environmental Protection Agency, *"Building Upgrade Manual,"* 2008: A strategic guide for planning and implementing a profitable energy saving building upgrade following a five-stage process. Available for free download online; www.energystar.gov.
- 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.

Technical Guidance

- 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. Available for free download online; www.peci.org.
- PECI, *"Functional Testing Guide,"* 2006: Guidance and sample tests for HVAC systems, as well as advice on how to achieve integrated operation. Available for free download online; www.peci.org.
- Building Operator Certification: 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. More information available at www.theboc.info.

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Standard Retrofits

Standard retrofit measures provide cost-effective and low-risk efficiency upgrade options for building owners who are limited to making incremental capital upgrades to their building. Standard retrofit measures include equipment, system and assembly retrofits. They are different from the EBCx process, which alters a building's O&M strategies based on an in-depth investigation, and from deep retrofits, which simultaneously retrofit equipment on multiple building systems using an integrated design approach. Standard retrofits are often staged, with one measure conducted after another. The sequencing of standard retrofit measures is important, as the impact of a retrofit to one system (e.g., lighting) will have an impact on other systems (reduced HVAC load). See the "Staged Approach" discussion in Section 2.5 "Planning for Energy Performance Improvements".

The scope of Chapter 4 is limited to standard retrofits, except for the Retrofit Measure Summary Table (see Section 4.1), which includes measures that could be implemented as part of either a standard retrofit project or a deep retrofit project. In other words, standard and deep retrofit measures are not mutually exclusive; a measure may be part of a standard retrofit project if implemented in a staged approach, but part of a deep retrofit project if implemented in an integrated design approach. The Retrofit Measure Summary Table provides a starting point for considering retrofit measure options that are relevant for each climate zone.

Following the measure summary, recommended standard retrofit packages are presented. These packages for a representative office building have been developed for five primary climate regions in the U.S. The measures included in the recommended packages were selected for their appropriateness and cost-effectiveness in each climate region and result in energy savings of up to 40% when coupled with implementation of a package of O&M measures. The energy savings and financial analysis for each recommended package takes into account interactive effects between building systems and other retrofit measures in the package to provide as accurate as possible expected results.

Next, additional considerations for standard retrofits are offered that address factors that can influence cost-effectiveness, and aspects to consider when evaluating retrofit measures. Because all buildings are unique and have particular needs and opportunities for energy upgrades, building owners are encouraged to think about how these aspects will influence their projects.

Finally, case studies of office buildings that have successfully implemented standard retrofit measures are provided to show the effectiveness of these retrofits in actual buildings. These case studies provide insight into the process the office building owners went through for completing their standard retrofit project, and exhibit the energy savings and financial results achieved by real world projects.

4.1 Retrofit Measure Summary Table

Table 4.1 lists all standard and deep retrofit measure options investigated in this guide. Appendix 10.6 provides a discussion of the technical details of each of these measures, along with an energy savings and financial analysis for each measure.

Table 4.1. Retrofit Measure Summary Table

System	Measure Number and Description	Applicable To					Stage (see Section 2.5)	Appendix Page # Ref.
		Hot & Humid	Hot & Dry	Marine	Cold	Very Cold		
Lighting	L2. Retrofit interior fixtures to reduce lighting power density by 11%	RP-D	RP-D	RP-D	RP-D	RP-D	2	137
	L3. Retrofit interior fixtures to reduce lighting power density by 21%	O	O	O	O	O	2	137
	L4. Retrofit interior fixtures to reduce lighting power density by 27%	O	O	O	O	O	2	137
	L5. Retrofit interior fixtures to reduce lighting power density by 36%	O	O	O	O	O	2	137
	L6. Install occupancy sensors to control interior lighting	RP-S&D	RP-S&D	RP-S&D	RP-S&D	RP-S&D	2	140
	L7. Add daylight harvesting	RP-S&D	RP-S&D	RP-S&D	RP-S&D	RP-S&D	2	142
	L8. Retrofit exterior fixtures to reduce lighting power density, and add exterior lighting control	RP-S&D	RP-S&D	RP-S&D	RP-S&D	RP-S&D	2	143
Plug & Process Loads	P1. Add advanced on/off control of office equipment	O	O	O	O	O	2	144
	P2. Purchase energy efficient office equipment	O	O	O	O	O	2	146
	P3. Control elevator cab lighting and ventilation	O	O	O	O	O	2	147
Envelope	E3. Add exterior window film	O	O	O	O	O	2	148
	E4. Replace windows	O	O	O	O	O	2	149
	E5. Add exterior window shading and light shelves	O	O	O	O	O	2	150
	E6. Add wall insulation	O	O	O	O	O	2	152
	E7. Add roof insulation	O	RP-D	RP-D	RP-D	RP-D	2	154
	E8. Add a vestibule	O	O	O	O	O	2	156
	E9. Install cool roof	O	O	O	O	O	2	156
HVAC Air Side	HA9. Add optimum start strategy for HVAC equipment	O	O	O	O	O	4	157
	HA10. Revise airside economizer damper control	O	O	O	O	O	3	158
	HA11. Widen zone temperature deadband (replace pneumatic thermostats)	RP-S	RP-S	RP-S	RP-S	RP-S	3	160

System	Measure Number and Description	Applicable To					Stage (see Section 2.5)	Appendix Page # Ref.
		Hot & Humid	Hot & Dry	Marine	Cold	Very Cold		
HVAC Air Side	HA12. Lower VAV box minimum flow setpoints (rebalance pneumatic boxes)	RP-S	RP-S	RP-S	RP-S	RP-S	3	161
	HA13. Widen zone temperature deadband, add conference room standby control (upgrade to DDC zone control)	RP-D	RP-D	RP-D	RP-D	RP-D	3	163
	HA14. Lower VAV box minimum flow setpoints, reset duct static pressure (upgrade to DDC zone control)	RP-D	RP-D	RP-D	RP-D	RP-D	3	165
	HA15. Add demand-controlled ventilation	RP-D	RP-D	RP-D	RP-D	RP-D	3	167
	HA16. Replace supply fan motor and Variable Frequency Drive (VFD)	RP-D	RP-D	RP-D	RP-D	RP-D	3	168
	HA17. Change HVAC system type	O	O	O	O	O	4	170
HVAC Water Side	HW7. Shut down heating plant when there's no heating load	RP-D	PR-D	O	O	O	4	170
	HW8. Increase efficiency of condenser water system	O	RP-D	O	O	O	4	172
	HW9. Increase efficiency of condenser water pumping system	RP-D	RP-D	O	O	O	3	173
	HW10. Change cooling plant pumping system to variable primary.	RP-D	RP-D	O	O	O	3	175
	HW11. Replace cooling and heating plant pump motors	O	O	O	O	O	3	177
	HW12. Add a VFD to one chiller	RP-D	RP-D	O	O	O	4	178
	HW13. Add waterside economizer	O	O	O	O	O	4	179
	HW14. Add chilled water plant heat recovery	O	O	O	O	O	4	180
	HW15. Replace boilers and change heating plant pumping system to variable flow primary	O	O	RP-D	RP-D	RP-D	4	181
	HW16. Replace boiler burners with modulating burners	O	O	O	O	O	4	183
	HW17. Increase the efficiency of the tenant server room pumping system	O	O	O	O	O	3	184
	HW18. Cool the server rooms with transfer air instead of mechanical cooling	O	O	O	O	O	3	185
	HW19. Increase the efficiency of the tenant server room cooling units	O	O	O	O	O	3	186
SHW	S1. Increase efficiency of service hot water system	O	O	O	O	O	N/A	187
Other	O2. Retrofit electric transformers with higher efficiency models	O	O	O	O	O	N/A	189

RP-S = measure is part of standard retrofit recommended package
RP-D = measure is part of deep retrofit recommended package
RP-S&D = measure is part of standard and deep retrofit recommended package
O = measure is not part of recommended package but is an option

4.2 Standard Retrofit Recommended Packages

Tables 4.2 and 4.3 summarize the results of the energy and financial analysis of the recommended packages of standard retrofit measures, and identify which measures are included for each climate zone.

At-A-Glance Results

Table 4.2. Standard Retrofit Recommended Packages - Results of Common Metrics

	Site Energy Use Intensity (EUI) (kBtu/sf)		Site EUI Reduction			Annual Energy Cost per Square Foot		
	Baseline	Post-Standard Retrofit	Post-EBCx	Post-Standard Retrofit	Reduction Beyond EBCx	Baseline	Post-Standard Retrofit	Reduction from Baseline
Hot & Humid	88	**59**	15%	**33%**	18%	$2.09	**$1.57**	$0.52
Hot & Dry	97	**58**	22%	**40%**	18%	$2.16	**$1.50**	$0.66
Marine	94	**54**	27%	**43%**	16%	$1.99	**$1.34**	$0.66
Cold	86	**53**	24%	**38%**	14%	$2.24	**$1.59**	$0.64
Very Cold	91	**57**	25%	**38%**	13%	$2.00	**$1.44**	$0.56
Average	91	**56**	23%	**38%**	15%	$2.10	**$1.49**	$0.61

The retrofit measures included in the standard retrofit packages are shown in Table 4.3. This package is the same for each climate zone.

Table 4.3. Standard Retrofit Recommended Package Measures

System	Measure Description	Climate Zones	Appendix Page # Ref.
Lighting	L6. Install occupancy sensors to control interior lighting	All	140
Lighting	L7. Add daylight harvesting	All	142
Lighting	L8. Retrofit exterior fixtures to reduce lighting power density, and add exterior lighting control	All	143
HVAC - Air Side	HA11. Widen zone temperature deadband (replace pneumatic thermostats)	All	160
HVAC - Air Side	HA12. Lower VAV box minimum flow setpoints (rebalance pneumatic boxes)	All	161

Rationale for Recommended Measures

The measures were chosen for inclusion in the standard retrofit package based on their high energy savings potential, high cost-effectiveness, and relatively simple implementation. These are representative of measures that building owners typically implement solely to realize energy savings. Often, owners will implement these measures before the affected equipment has reached the end of its useful life. For example, the exterior lighting measure may be implemented prior to the fixtures reaching the end of their service life. Note that other measures could be included as part of a standard retrofit package – the measures listed above were chosen as a representative example.

The measures included in the standard retrofit package either add functionality to existing systems, replace an existing system component with a more efficient version, or adjust an existing system to operate more efficiently. They are measures that typically do not require a design process as part of implementation, and usually do not represent changes to system types. For multi-tenant commercial office buildings, they are measures that can be implemented with minimal disruption to the tenants.

The measures were also chosen for simplicity – they can be implemented concurrently or in any order, since the three load-based lighting measures do not impact the two subsequent HVAC measures. Other combinations of standard retrofit measures may benefit from a staged approach, as discussed previously in this guide.

One of the HVAC measures included in the package, "Lower VAV box minimum flow setpoints," applies to a certain type of HVAC system common in multi-tenant commercial office buildings – multi-zone VAV systems. It would not apply to a single zone system or to other types of HVAC systems, such as fan coils. However, the concept could be applied to other types of systems: reduce the energy usage of the system during part load conditions by adjusting the control parameters.

Energy Savings

The analysis of the standard retrofit package assumes that O&M measures are implemented first, as part of an EBCx process, and then the retrofit measures shown in Table 4.3 are implemented. This is estimated to result in savings of more than 30% of site energy usage, based on an analysis of the measures included in the packages using EnergyPlus. In the following table, each climate zone shows significant energy savings, with only small variation between the zones. For the savings of individual retrofit measures included in the package, see Appendix 10.6.

Table 4.4. Standard Retrofit Recommended Package Energy Savings Results

	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site Energy Use Intensity (EUI) Savings (kBtu/sf/yr)	Savings as % of Total Site Usage	Source EUI Savings (kBtu/sf/yr)	Savings as % of Total Source Usage
Hot & Humid	900,000	170	28,000	29	33%	58	26%
Hot & Dry	1,110,000	170	39,000	39	40%	74	32%
Marine	876,000	150	51,000	40	43%	60	36%
Cold	806,000	310	39,000	33	39%	62	30%
Very Cold	788,000	250	41,000	34	38%	60	31%

Financial Analysis

The financial metrics associated with the standard retrofit recommended package in each climate zone are shown in the following table. These metrics include the O&M measures implemented as part of an EBCx process, and implementation of the retrofit recommended package measures. As such, the initial savings were calculated as the difference between the energy use of the baseline reference building and the energy use after both EBCx and the installation of the standard retrofit package. For the financial metrics of individual retrofit measures included in the package, see Appendix 10.6.

The measures included in the standard retrofit package are the same for each of the five climate zones. As shown in Table 4.5, when combined with the savings from the EBCx process, the standard retrofit package has a fast simple payback and positive net present value, making it an attractive method to achieve energy savings.

Table 4.5. Standard Retrofit Recommended Package Financial Analysis Results

	Total Measure Costs	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (Years)	Net Present Value
Hot & Humid	$422,000	$141,000	($4,100)	$137,000	3	$753,000
Hot & Dry	$426,000	$192,000	($4,900)	$187,000	2	$1,220,000
Marine	$439,000	$204,000	($4,800)	$199,000	2	$1,320,000
Cold	$439,000	$192,000	($5,300)	$187,000	2	$1,200,000
Very Cold	$417,000	$169,000	($4,800)	$164,000	3	$1,020,000

The financial analysis of the standard retrofit packages is based on the assumption that the original equipment is replaced before the end of its useful life. The annual cash flows used in the NPV calculation assumes that the original equipment would have been replaced with current technology at year 10 of the 20-year analysis period. After year 10, the energy savings were reduced by 50% to adjust for the improved baseline performance that would most likely have resulted if the original equipment were replaced at the end of its life.

The expected useful life of the standard retrofit package is assumed to be 20 years due to the periodic recommissioning efforts that are implemented throughout this timeframe. Additional costs required to maintain individual measures in the package with less than a 20 year life, such as the photocells and occupancy sensors, are reflected in the higher annual O&M costs.

4.3 Additional Considerations

The standard retrofit measures proposed in the recommended packages above and comprehensive retrofit measure list in Appendix 10.6 provide a starting point for standard retrofit options to be considered for most office buildings. However, not all measures will be applicable to all buildings, and there may be some other measures that are applicable to a specific building yet aren't included in the measure list. The standard retrofit measures presented in this guide are applicable to the reference building used to model the measures' savings, which has characteristics similar to common office buildings in the U.S. See Appendix 10.1 for a detailed discussion of the reference building's characteristics and considerations for how the energy savings results may be impacted by variations in building characteristics.

Building owners considering implementing specific retrofit measures will benefit from consulting the detailed description of the retrofit measures in Appendix 10.6 to gain an understanding of the types of retrofit measures that can typically be implemented. That appendix includes a discussion of each measure's technical characteristics, special considerations, and technical assumptions for implementing the measure in the reference building.

When evaluating standard retrofit measures for application to a specific building, the following aspects besides measure cost-effectiveness could be considered to help narrow the options to the most feasible measures:

- **Are the equipment or 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, owners can evaluate multiple retrofit options considering all potential costs and benefits instead of just replacing the equipment with like equipment once it fails.

- **Is the measure relevant to the operations of the building?**

  The capabilities of the service contractors and/or operations staff should be considered when evaluating measures. Does the staff have the necessary skills and knowledge to support the measure? If not, is there additional training that they can receive?

- **Are there load-based retrofits that can be considered and implemented prior to HVAC retrofits?**

  As mentioned previously in this guide, using a staged approach for standard retrofits can produce greater savings and increased performance than just replacing systems and components with like-sized equipment. Implementing load-based retrofits first, which have an impact on the heating and cooling load, can help lower the cost of subsequent HVAC retrofits, improve the performance of HVAC systems, and reduce the overall energy use of the building.

- **Have the building characteristics changed over time in a way that could impact the retrofit?**

  When replacing equipment, it's important to evaluate whether or not 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 also impact the new equipment. For example, if required lighting levels have changed, this could impact the number and layout of fixtures installed in a lighting retrofit.

- **For multi-tenant leased office buildings, can tenant-owned and operated systems be considered?**

  Office equipment, including computer servers, consume a significant amount of energy, yet this equipment is often owned and operated by the tenants. If tenants can participate in a building's overall retrofit plan, through consideration and implementation of load-reduction measures such as advanced on/off control of computer equipment, plug load measures could be evaluated for retrofit opportunities.

- **Do energy codes apply to the retrofit?**

  Energy codes have minimum efficiency standards for most equipment installed in commercial office buildings. Prior to embarking on a retrofit project, it's important to ensure that the equipment being installed as part of the retrofit meets or exceeds local energy efficiency codes.

- **Are there incentives 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 code requirement. The local utility can provide information on incentive programs.

- **Will the retrofits be commissioned during implementation, to verify performance?**

  Commissioning helps verify that a system is operating as intended. To realize the energy savings related to retrofits, it's important that the retrofits be commissioned to ensure that the systems are operating correctly.

One of the most cost-effective measures that can be implemented in buildings is not found in this chapter, because it does not fit neatly into the mold of retrofits. That measure is promoting occupant behaviors which will reduce energy consumption. Many building loads, notably plug loads, depend directly on occupant behavior. Others, such as HVAC operations, are at least strongly influenced by occupant behavior. Owners typically go to great lengths to shelter building occupants from the impacts of retrofits. Mitigating negative impacts during construction is obviously important, but a retrofit also presents an opportunity to engage occupants in a discussion about their role in building energy consumption. Planning for this discussion may yield additional benefits, beyond those quantified in this chapter.

Small- and Medium-Sized Office Building Considerations

The retrofit measures presented in Section 4.1 are measures that would typically be implemented in an average large office building. Retrofit measures can also be implemented in small and medium sized office buildings, but these buildings may benefit most from different retrofit measures than large offices, due to variations between the characteristics of small, medium and large office buildings besides just building size and number of floors. Even though the specific technologies related to the measures will likely vary between small, medium and large office buildings, the intent of the measures will be the same: reduce overall building energy usage through implementation of capital-intensive retrofit measures.

The recommended package retrofit measures listed in Section 4.2 are generally applicable to small, medium and large office buildings, as the affected systems typically do not vary greatly between these different building types. However, there can be significant variation in the HVAC retrofit measures, due to differences in HVAC system types and HVAC control system types. Small and medium sized office buildings usually use unitary (packaged) HVAC equipment and systems, while large offices typically use built-up equipment and systems. For example, a small office building would likely use packaged rooftop units (single zone, constant volume, DX cooling, and gas furnace heating), while a large office building would likely use a multi-zone VAV system with hydronic heating and cooling from a central plant.

Related to this, there may be other applicable HVAC retrofit measures for small and medium sized office buildings that use unitary rooftop HVAC units beyond the measures listed in Section 4.1. These measures include:

- Replace RTUs with higher efficiency units
- Replace RTUs with high efficiency VAV units
- Replace RTUs with units that use evaporative cooling
- Replace RTUs with air-to-air heat pumps
- Replace HVAC system with a dedicated outdoor air system

These measures are discussed in more detail in section Appendix 10.6.

There may be HVAC retrofit measures listed in Section 4.1 that do not apply to typical systems in a small or medium sized office building. These include the following measures:

- "Control elevator cab lighting and ventilation" does not apply to buildings with no elevators.
- "Lower VAV box minimum flow setpoints" does not apply to single zone constant air volume systems.
- "Lower VAV box minimum flow setpoints, reset duct static pressure" does not apply to single zone constant air volume systems.
- "Replace supply fan motor and VFD" does not apply to constant volume systems without VFDs.
- All of the "HVAC-Water Side" retrofit measures, as these do *not* apply to HVAC systems that do not use waterside components (e.g., pumps, chillers, and boilers).

There will be exceptions to these generalizations, though. For example, there may be instances where a large office building might use unitary (packaged) HVAC equipment, and a small office building might use a chilled water system for cooling. The intent of the measure lists presented in this guide is to give an idea of the types of retrofit measures that could be implemented for typical small, medium and large office buildings. Different buildings will have different applicable measures, due to variations in building characteristics. See Appendix 10.2 and 10.3 for aspects to consider related to variations in building and climate characteristics. Readers may also wish to consult the Advanced Energy Design Guides for small- and medium-sized office buildings, which address energy efficiency measures that are applicable to small and medium sized office buildings.

Standard Retrofit Case Study: Wilson Blvd Building

Situated near the nation's capital just across the Potomac River from the Lincoln Memorial, this 12-story office building has pursued aggressive energy efficiency upgrades since 2004. Starting in mid-2009, building owner, Glenborough, LLC, implemented a more advanced energy management strategy at 1525 Wilson and entered the building into the EPA's National Building Competition.

The building completed a number of operational improvements and retrofits to the lighting and HVAC system and also rolled out a tenant awareness strategy that encouraged tenants to make behavior changes such as making sure window blinds stay down during peak periods of solar load.

While the building experienced some challenges to implementing the energy upgrades, such as start-up and integration of the new HVAC equipment, the building went on to cut its energy use by 28% and take 2nd place in the National Building Competition.

Says Glenborough's VP of Engineering Services, Carlos Santamaria, "Responsible energy management starts with a vision, passion, and a commitment. Once you start seeing results, you see benefits from a 'bottom line' perspective as well as from the social responsibility side of the business."

Audit Costs	Project Costs	Installation Costs	Financial Incentives
$10,000	$1,130,000	$0	$1,140,000

Estimated Annual Energy $ Savings	Estimated Annual O&M $ Savings	Total Estimated Annual $ Savings	Simple Payback	ROI
$250,000	$45,000	$295,000	3.9 years	26%

Estimated Energy Use Intensity (EUI)		Estimated % Site Savings
Before	After	28%
89 kBtu/sf/yr	64 kBtu/sf/yr	

Quick Facts

Owner: Glenborough, LLC

Location: Arlington, VA

Gross Square Footage: 313,959 sf

Post-retrofit EUI: 64 kBtu/sf/yr

Post-retrofit Energy Star: 96

Key Measures

- Alternate HVAC rooftop units on high solar days to reduce the cooling tower's load
- Retrofit pneumatic HVAC controls with digital controls
- Retrofit air handler systems' compressors
- Install LED downlights in underground parking garage
- Promote tenant energy awareness strategy

Disclaimer: Reported energy savings results were provided by the building owner or a third party and have not been verified.

Standard Retrofit Case Study: GUND Partnership

GUND Partnership, an architecture firm in Cambridge, MA, completed a renovation of its offices in the historic Bulfinch Square Buildings in 2008. The project grew out of a need to modernize the workspace and create a more open office environment that invited collaboration among team members. A central goal of the project was to design and implement an environmentally responsible renovation that demonstrated the firm's mission to promote green design.

The project ultimately attained a LEED Gold for Commercial Interiors rating through a combination of sustainability and energy saving initiatives. The building's eight existing historic pendant lighting fixtures were re-lamped, reducing wattage by over 50%. Occupant controls for both overhead and task lighting were installed to allow for reduced lighting when daylight from the office's many windows is sufficient. Finally, ENERGY STAR rated office equipment is used exclusively to further reduce energy costs.

The lighting retrofit project alone is saving the firm an estimated $3,000 per year and will pay for itself in 1.5 years.

Equipment Costs	Installation Costs	Net Cost to Owner
$1,600	$2,800	$4,400

Estimated Annual Electric Savings	Estimated Annual Electric Cost Savings ($)	Simple Payback	ROI
22,000 kWh	$3,000	1.5 years	169%

Estimated Energy Use		Estimated Energy Use Intensity (EUI)		Estimated % Site Savings
Before	After	Before	After	
710 MBtu/yr	640 MBtu/yr	49 kBtu/sf/yr	43 kBtu/sf/yr	12%

Quick Facts

Owner: GUND Partnership

Location: Cambridge, MA

Gross Square Footage:
34,610 (whole building) sf
12,322 (project area) sf

Post-retrofit EUI: 43 kBtu/sf/yr

Key Measures

Lighting retrofit of 8 fixtures

- Original: (4) 120W quartz uplights and (4) 200W incandescents per fixture
- Replacement: (4) 100W compact fluorescent light

ENERGY STAR computers, printers, and office equipment

The reported energy savings results are related to lighting retrofit project only.

Disclaimer: Reported energy savings results were provided by the building owner or a third party and have not been verified.

Standard Retrofit Case Study: Wells Fargo Center – HRO

When it came time for legal firm Holmes Roberts & Owen (HRO) to renew its lease in Denver's Wells Fargo Center, they were allotted tenant improvement funds to improve their space, a common incentive building owners use to attract and retain tenants. The firm chose to use the funds to upgrade many of the design features of its offices, such as furniture and layout, but also opted to use the funds to improve the energy efficiency of the office.

Randy Miller, managing partner at HRO, said HRO chose to invest part of its tenant improvement allowance in energy savings because "[it] provided the best mix of meaningful change. It very much aligned with what HRO was trying to achieve." HRO's motivation for openly demonstrating its commitment to sustainability is to attract top clients and top talent.

HRO, MPG Trust, project manager Fitzmartin Consulting, and the National Renewable Energy Lab (NREL) worked together to design and implement a project that addressed the most cost-effective measures available and reduced the energy consumption of plug loads, the lighting system, and HVAC system. The project ultimately achieved an impressive 33% reduction in EUI and will pay for itself in less than 3 years.

Project Cost (Equipment & Installation)	Financial Incentives	Net Cost to Owner
$42,000	$5,000	$37,000

Estimated Annual Electric Savings	Estimated Annual $ Savings	Simple Payback	ROI
129,000 kWh	$12,000	3 years	33%

Estimated Electric Use		Estimated Energy Use Intensity (EUI)		Estimated % Site Savings
Before	After	Before	After	
384,000 kWh/yr	255,000 kWh/yr	54 kBtu/sf/yr	36 kBtu/sf/yr	33%

Quick Facts

Owner: MPG Office Trust

Location: Denver, CO

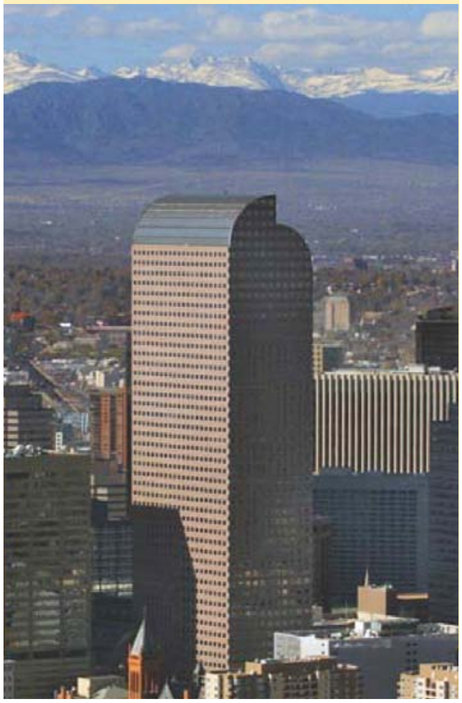
Gross Square Footage:
Whole building: 1,211,000 sf
Project area: 24,298 sf

Post-retrofit EUI: 36 kBtu/sf/yr

Post-retrofit Energy Star: 91

Key Measures

- Add VFDs to air handling unit fans
- Increase thermostat deadband from 1° to 3°
- Reduce corridor lighting LPD by increasing distance between fixtures from 12' to 16'
- Replace existing incandescent lights with CFLs
- Install lighting occupancy sensors
- Use ENERGY STAR rated computers



Disclaimer: Reported energy savings results were provided by the building owner or a third party and have not been verified.

4.4 Additional Resources and Guides

For additional references related to the measures discussed in this chapter, refer to the following.

General Guidance

- Environmental Protection Agency, *"Building Upgrade Manual,"* 2008: A strategic guide for planning and implementing a profitable energy saving building upgrade following a five-stage process. Available for free download online; www.energystar.gov.
- Rocky Mountain Institute, *Retrofit Depot*: Online resource for case studies, advice, and tools & resources related to retrofit project implementation; www.retrofitdepot.org.
- 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; www.techstreet.com.
- 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. More information available at www.boma.org/beep.

Technical Guidance

- ASHRAE, *"50% Advanced Energy Design Guide for Small to Medium Office Buildings,"* 2011: Includes general and detailed technical information on approaches for improving energy performance in office buildings. Concepts presented also apply to larger office buildings. Available for free download online; www.ashrae.org.
- ASHRAE, *"30% Advanced Energy Design Guide for Small Office Buildings,"* 2004: Includes general and detailed technical information on approaches for improving energy performance in small office buildings. Concepts presented also apply to larger office buildings. Available for free download online; www.ashrae.org.
- 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.
- Doty, *"Energy Management Handbook,"* 2009: Provides detailed coverage of effective energy management strategies. Available for purchase online.
- Wulfinghoff, *"Energy Efficiency Manual,"* 1999: A primary reference, how-to guide, and sourcebook for energy efficiency upgrades in all building types.
- ASHRAE, *"Standard 189.1,"* 2009: Provides minimum requirements for the siting, design, construction, and plan for operation of high-performance green buildings. Available for purchase online.
- Lawrence Berkeley National Lab (LBNL), *"Tips for daylighting with windows,"* 1997: Includes guidelines on cost-effective approaches to exterior zone lighting design. Available for free download online; www.lbl.gov.
- 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.

5

Deep Retrofits

INTEGRATED DESIGN

A highly collaborative and iterative design process for efficiency that often yields much larger resource savings than standard design practice. These larger savings are achieved by considering the performance of entire systems and interactions between systems to capture multiple benefits from single expenditures.

A deep retrofit project provides an opportunity for a building owner to reduce energy consumption significantly beyond the savings from O&M and standard retrofit measures. While deep retrofits can reduce a building's energy use by over 50%, they require a larger upfront investment and may have longer payback periods than O&M or standard retrofit measures.

Deep retrofit projects combine many O&M and standard retrofit measures in an integrated whole-building design approach (see Section 2.5 "Planning for Energy Performance Improvements"). The integrated design process enables a deep retrofit project to achieve more than a simple sum of the O&M and standard retrofit parts. These projects affect multiple building systems and assemblies (e.g., envelope, lighting, and HVAC), and the retrofit of each system and assembly must be designed in close consideration of the other retrofits. The planning and design of deep retrofit projects is addressed first in this chapter.

Next, the deep retrofit measure recommended packages are introduced. The energy savings and financial performance of the packages are analyzed for a representative office building in five primary climate regions in the U.S. The deep retrofit measure packages provide a hypothetical example of a project where a bundle of retrofit and O&M measures will result in energy savings of 45% or more. The individual retrofit and O&M measures were listed previously, in Chapter 3 and Chapter 4, and are described in detail in the Appendix. This section focuses on estimating the energy savings and financial benefits of the deep retrofit packages. The analysis accounts for the interactive effects between building systems and measures to provide as accurate as possible estimates of expected results.

Additional considerations for embarking on a deep retrofit process are described following the recommended packages. Because all buildings are unique and have particular needs and opportunities for energy upgrades, building owners are encouraged to think about how these additional factors will influence their projects.

The chapter concludes with several case studies that highlight the results of deep retrofit projects in actual buildings, and provide insight into the process that the building owners went through to complete their projects.

5.1 Planning & Design of Deep Retrofits

The upfront cost of a deep retrofit may be difficult to justify on the basis of energy and maintenance cost savings alone. However, the business case is much easier to make when planned upgrades and the avoided costs of equipment and assembly replacements are taken into account. Many building upgrades must occur throughout the life of a building, and these planned capital improvements represent opportunities to perform a cost-effective deep retrofit. Table 5.1 lists some key opportunities to complete a cost-effective deep retrofit and their alignment with events in a building's lifecycle.

Table 5.1. Opportunities in a Building's Life to Perform a Deep Retrofit

Building Event	Opportunity
Roof, window and siding replacement	Planned roof, window and siding replacements provide opportunities for significant improvements in daylighting and efficiency at small incremental costs. These improvements in turn allow for reduced artificial lighting, and a smaller, more efficient HVAC system.
End (or near end) of life major equipment replacement	Major equipment replacements provide an oppotunity to also address the envelope and other building systems. After reducing thermal and electrical loads, the marginal cost of replacing the major equipment with smaller equipment, or no equipment at all, can be negative, as seen in the Empire State Building Case Study.
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 include building upgrades as part of the transaction. This may offer a lower interest rate than is normally available for upgrades, which improves the cost-effectiveness of a deep retrofit.
Major occupancy change	A major occupancy change presents a prime opportunity for a deep retrofit, for two reasons. First, a deep retrofit can generate layouts that improve energy and space efficiency, while creating more leasable space by downsizing mechanical equipment. Second, owners may be able to leaverage tenant investment in the fit-out.
Building greening	An owner or tenant-driven desire to achieve green building or energy certification may require significant work on the building and its systems, which may then make a deep retrofit economical.
Large utility incentives	Many utilities will subsidize the cost for a deep retrofit. In some regions, the incentives might be large enough to make the deep retrofit economical.
Fixing an "energy hog"	Upon examination, some buildings are found to have such high energy costs the deep retrofits have good economics without leveraging any other building event.
Portfolio planning	The cost-effectiveness of a deep retrofit may be improved when many similar measures are implemented across a portfolio of buildings. This is particularly true when buildings in the portfolio share similar characteristics, allowing both the design and construction teams to achieve some efficiencies of scale.

When building owners are aware of the opportunities presented in Table 5.1, they can engage the integrated design process and make a planned component replacement grow into a deep retrofit. In some cases, the opportunity is obvious. For example, if the roof must be replaced, insulation can be added to the new roof. But other opportunities are less straightforward. For instance, if a building's roof needs replacement in five years but the boiler is slated for replacement now, it probably makes most economic sense to move that roof replacement up, and add insulation to reduce the heating load and the size and cost of the boiler. This latter example highlights how a basic understanding of the deep retrofit process can help building owners reap greater rewards from their investments.

Deep Retrofit Design Overview

Investing in greater efficiency and load reduction can actually eliminate significant costs through downsizing, or even eliminating, HVAC systems. This is a key feature of deep retrofits, but it cannot be achieved without thoughtful, integrated design. The following, step-by-step approach for designing a deep retrofit project will lead to maximum benefits:

1. Define the needs and services required by the building occupants. Start from the desired outcomes. This means identifying a purpose, such as cooling, instead of going directly to a solution, such as chillers.

2. Understand the existing building structure and systems. 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 non-energy reasons? What costs and interruptions to service or occupancy do those renovations entail?
4. Reduce loads. Select measures to reduce loads:
    - First, through passive means (such as increased insulation)
    - 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 the reduced loads.
6. Find synergies between systems and measures. Seek synergies across disciplines and find opportunities to recover and reuse waste streams. This exercise will often identify multiple benefits that arise from a single expenditure.
7. Optimize controls. After the most appropriate and efficient technologies have been selected, the focus should shift to optimizing the control strategies.
8. Realize the intended design. Conduct initial and ongoing commissioning to ensure continued realization of the intended design and its benefits.

This step-by-step approach shows the critical elements of a deep retrofit design process. The following sections describe deep retrofit approaches and considerations for individual building systems.

Lighting

A deep retrofit project often presents opportunities to reduce lighting energy use and improve occupant visual comfort beyond the standard retrofit's lamp replacements, delamping, and occupancy sensors. Lighting upgrades in a deep retrofit can leverage concurrent renovations of the building envelope and redesign of interior layouts to lead to better use of natural daylighting. A comprehensive lighting retrofit can result in a dramatically more appealing space, an improved visual environment that meets the needs of occupants, significant energy savings, and the benefits of controlling solar heat gain and reducing cooling loads.

When it comes to visual comfort, more light does not necessarily equate to better vision. Providing a comfortable visual environment is about tuning that environment to specific tasks at hand. The Illuminating Engineering Society's Lighting Handbook provides detailed lighting guidelines to address different visual tasks in typical space types (DiLaura et al., 2011). Assessing the baseline situation is a good way to understand what opportunities may be present. Measurement of lighting levels and conducting occupant interviews regarding glare and other possible lighting issues are both useful for assessing lighting needs and determining when and why those needs are not being met.

After describing lighting needs, a deep retrofit typically looks to daylight as the preferred resource for meeting those needs. Retrofit projects inherit the pros and cons of existing building orientation, massing, and window count and placement. Daylighting design must consider the geometric proportions of existing spaces in relation to existing windows and skylights. Then, strategies can be developed to improve daylight penetration and distribution throughout regularly occupied areas.

Interior spaces can be shaped and configured to help redirect light, optimize light distribution and illuminance levels, and reduce glare. When changes to windows and exterior shading are possible, relatively inexpensive interior improvements such as light-colored interior surfaces can help make the most of concurrent envelope investments. Even exclusive of window improvements, changes to interior reconfiguration and design can make a big difference in perceived light quality. The Illuminating Engineering Society's Lighting Handbook (DiLaura, et al., 2011) and Architectural Lighting (Egan and Olgyay, 2002) provide detailed practical guidance on daylight design.

Once daylighting has been used to maximum effect, efficient electric lighting can be introduced to meet the remaining needs. Selecting the right fixture for each specific lighting need will help reduce the required lighting power. This means selecting fixtures to meet ambient lighting needs separately from specialized accent and task lighting needs. Once fixtures are selected, they can then be equipped with high efficiency lamps and ballasts and tied to occupancy sensors, where appropriate, to complete the lighting upgrade. Fixtures that are part of a daylighting control strategy should include dimmable ballasts, for maximum system performance and energy efficiency.

Plug and Process Loads

Plug and process loads represent a significant portion of total building energy use and are typically subject to occupant behavior. There are numerous low- and no-cost solutions for reducing plug loads, as well as solutions that require significant capital expenditures. One low cost option is to educate occupants about the importance of turning equipment off when it is not in use. Software solutions are also available that will shut down monitors and computers when they are not in use. Hardware options, which may be part of a deep retrofit, include replacing or decommissioning existing plug load equipment, and adding controls that automatically turn off or turn down equipment when it is not being used.

Surprisingly, most equipment, even small items like cell phone chargers, still use energy when it is plugged in but not serving a useful purpose. Such items can be wired into an energy management system that turns them off when they are not in use. Each of these individual loads may be small, but like other plug loads, the sum total of all the individual loads can be quite large, particularly when interaction with the HVAC system is included in the analysis. Thus, these loads merit consideration as part of a deep retrofit.

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 as a link between indoor and outdoor environments. Standard energy retrofits rarely touch the envelope, but a deep retrofit project should always address the envelope. A deep retrofit project is an ideal time to address many façade and roof issues and correct original construction defects. Such upgrades will often allow aging mechanical equipment to be replaced with downsized equipment, producing significant cost savings relative to a same size replacement. Envelope technology and products have evolved significantly since the 1990s, so any building constructed before that period is a likely candidate for an envelope upgrade.

Building envelope retrofits should address infiltration first and then thermal performance of the envelope materials. Doors and windows are particularly vulnerable to infiltration, as they include multiple joints between different materials, may feature tolerances to allow movement, and must be lightweight enough for human control. Routine maintenance usually aims to protect against water infiltration, but ignores air infiltration. Over time, air infiltration can grow, and the resulting need to condition greater volumes of outside air equates to excess energy consumption. Excessive air infiltration may also result from construction defects present from day one, meaning even relatively new buildings may benefit from envelope improvements. Infrared thermal images will point to areas where air or water is clearly passing through the walls unintentionally. Most often, these are at joints between walls and roof / floor, where materials change such as at the connection of glass to frame, and at penetrations such as vents.

Though infiltration is addressed first, radiation is perhaps the most obvious source of heat gain in commercial buildings. There are two approaches to mitigating radiative effects—modifying the building shading and adjusting the reflectivity of building materials. Building shading changes the amount of radiation that reaches the building's surface. Exterior finish colors and selective surfaces can cause building surfaces to absorb heat (good for cold climates) or reflect heat (good for hot climates), depending on the color and reflectivity. In many commercial buildings, solar radiation offers a benefit for daylighting, but introduces a penalty of heat gain through windows. Spectrally selective window films can address this dichotomy by rejecting a high percentage of heat while admitting visible light.

In addition to infiltration and radiation, the deep retrofit design process should consider the desirability and feasibility of adding thermal insulation. Adding insulation to an existing building envelope can be an expensive proposition. In mild climates and where the existing insulation complies with a building energy code, adding insulation may not be cost-effective. In any location, a careful analysis that includes building energy simulations will help to assess the potential benefit of insulation measures. It's typically most effective to install insulation on the outside of the assembly, to create a layer of continuous insulation that spans the enclosure.

In some buildings, thermal bridging may be more important to address than insulation. Thermal bridging occurs where materials that are good conductors (e.g., the metal and aluminum in door and window frames) allow heat to flow relatively unimpeded between outdoor and indoor environments. Such bridges can be corrected by adding a thermal break, though this often entails replacing entire door or window assemblies.

As with all deep retrofit projects, an integrated design process is critical. Infiltration, radiation and insulation should be evaluated jointly and in light of the other building system upgrades. Envelope retrofits will often prove capable of delivering multiple benefits from single expenditures. However, the first step in addressing envelope condition in a deep retrofit project should always be investigation. Where are the weak points in the system? Is there significant room for improvement? Are envelope conditions affecting more than just energy consumption? This investigation may include interviews with maintenance staff, occupant surveys, infrared thermal imaging, and building energy simulation.

HVAC

HVAC system performance impacts the health, comfort, and productivity of building occupants, as well as the overall energy use of the facility. Though all systems are important in the integrated design process, HVAC systems depend upon and unite the other building systems. Its ultimate performance will, to a great extent, define the success of the integrated design process.

Define Needs

HVAC systems provide for occupants' thermal comfort by controlling the temperature and humidity of the room air. One way to improve HVAC system energy performance is to recognize that there are a range of acceptable temperature and humidity conditions. This recognition leads to one of the most cost-effective way to reduce energy for HVAC systems, which is to expand the system's allowable ranges for indoor temperature and humidity. This range is often referred to as the "deadband," the range of temperatures during which no heating or cooling takes place at the zone (e.g., between 70°F and 75°F). Just a couple of degrees of adjustment can have a significant impact on the performance and energy usage of the system. An appropriate comfort range can be determined using industry guidelines, provided by ASHRAE Standard 55 (ASHRAE 2004), in combination with a study of building occupancy and use.

Another important service provided by the HVAC system is ventilation. Building occupants require outside air to remain healthy and productive. However, conditioning that outside air is one of the most energy intensive jobs that an HVAC system performs. So, an important measure for reducing HVAC system energy usage is minimizing the amount of outside air that needs to be conditioned. This can be done without compromising occupant health or productivity by accurately determining the required exhaust and ventilation based on the building's actual use and occupancy. The default occupancy values that are often used in place of careful analysis are very conservative. Adjusting ventilation based on actual occupancy values can sometimes reduce the amount of outside air by over 30%, saving energy and also reducing the size of the system required.

Design Strategies

A deep retrofit design process will evaluate heating and cooling system options only after the load reduction measures. It's important to reduce heating and cooling loads first since these have a direct impact on the HVAC system energy usage. Also, reduced loads may change the appropriateness of various system type and sizing options. When choosing a system type, it is important to consider whether the extent of the renovation will allow for replacing the existing HVAC system with a wholly different system type. If so, then the local climate and the building's ventilation needs will feature prominently in an analysis to determine the most efficient system type.

In a major renovation, there is sometimes an opportunity to make improvements in the layout of the existing air and water distribution systems. This translates into very significant fan and pump energy savings. Low-energy use ductwork and piping design involves short, direct, and low pressure drop runs. Reducing the number of fittings also reduces turbulence. The efficient duct and piping layouts, together with the previous work to minimized building loads, will yield opportunities for downsizing mechanical equipment. The smaller, accurately sized equipment will have a lower purchase price, lower utility costs, better dehumidification performance, and deliver greater comfort for occupants.

Once the systems type has been chosen and sized, equipment with high peak and part load efficiencies can be selected to complete the efficient HVAC design. Condensing boilers, variable speed drive compressors, variable flow air and water distribution systems, and high efficiency fans, motors, and pumps are all preferred components in an energy efficient design. Part load performance is just as important as the rated efficiency, so consideration of performance curves is important when choosing equipment.

Optimizing HVAC controls is a cost-effective energy saving strategy and is a key component to any comprehensive retrofit. Direct digital control systems offer greater accuracy, performance, and energy savings. Such digital controls, coupled with a building automation system, provide a facility manager with visibility into and control over building operation.

Design Team Organization

The integrated design of lighting, plug and process loads, envelope and HVAC systems calls for a design team with special capabilities. Chief among these capabilities is that of open communication among team members. To foster open communication, design teams are organized differently than traditional design teams. See Figures 5.1 and 5.2 for a comparison of the typical parties involved and structure of relationships between traditional and integrated project design processes.

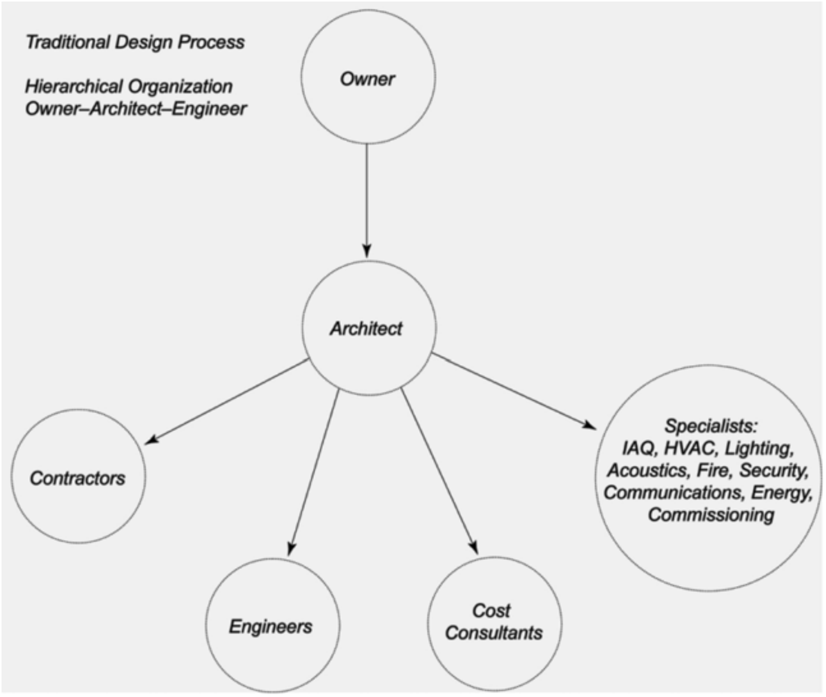


Figure 5.1. Traditional Project Design Team
Reprinted from *Advanced Energy Design Guide for Small to Medium Office Buildings.* © 2011, ASHRAE

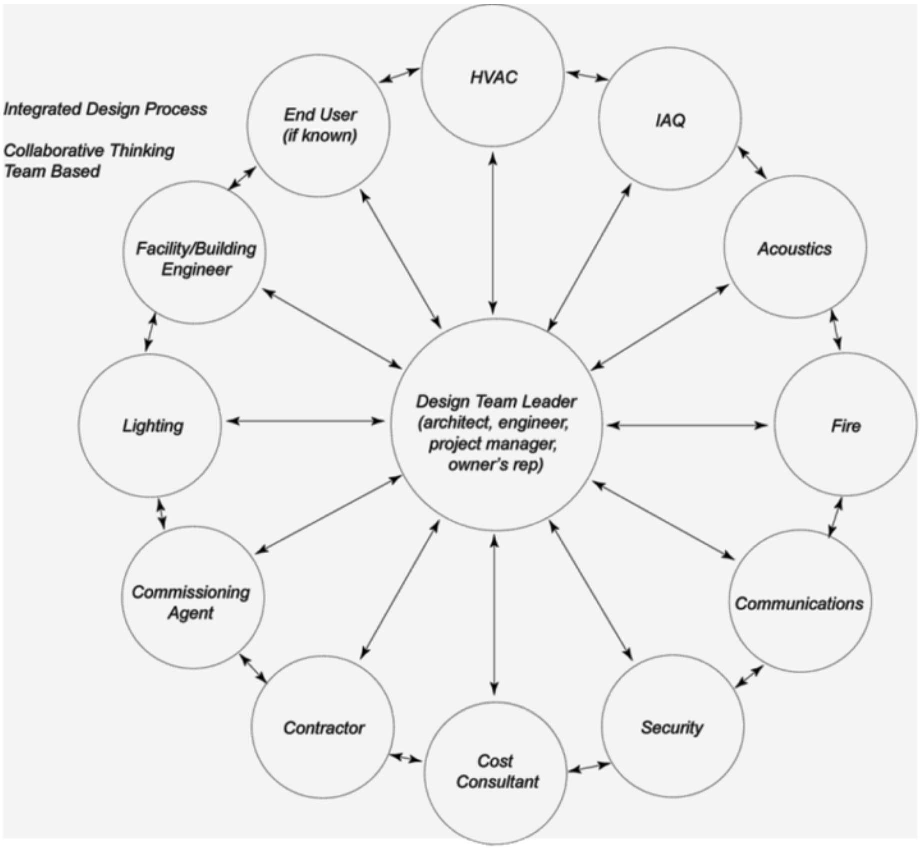


Figure 5.2. Integrated Project Design Team
Reprinted from *Advanced Energy Design Guide for Small to Medium Office Buildings.* © 2011, ASHRAE

The discussion of deep retrofit design that is provided in this section is intended only as an introduction. It provides the foundation needed by building owners to decide when to pursue a deep retrofit. Once that decision is made, an owner will need to engage a skilled, integrated design team, like that represented in Figure 5.2, to carry the project forward.

5.2 Deep Retrofit Recommended Packages

At-A-Glance Results

Table 5.2. Deep Retrofit Recommended Packages - Results of Common Metrics

	Site Energy Use Intensity (EUI) (kBtu/sf/yr)		Site EUI Reduction					Annual Energy Cost per Square Foot		
	Baseline	Post-Deep Retrofit	Post-EBCx	Post-Standard Retrofit	Post-Deep Retrofit	Reduction Beyond EBCx	Reduction Beyond Standard Retrofit	Baseline	Post-Deep Retrofit	Reduction from Baseline
Hot & Humid	88	**48**	15%	33%	**45%**	30%	12%	$2.09	**$1.29**	$0.80
Hot & Dry	97	**46**	22%	40%	**52%**	30%	13%	$2.16	**$1.16**	$1.00
Marine	94	**44**	27%	43%	**53%**	26%	10%	$1.99	**$1.13**	$0.86
Cold	86	**44**	24%	38%	**48%**	25%	10%	$2.24	**$1.36**	$0.88
Very Cold	91	**47**	25%	38%	**49%**	23%	11%	$2.00	**$1.22**	$0.78
Average	91	**46**	23%	38%	**50%**	27%	11%	$2.10	**$1.23**	$0.87

The retrofit measures included in the deep retrofit recommended packages are shown in Table 5.3.

Table 5.3. Deep Retrofit Recommended Package Measures

System	Measure Description	Climate Zones	Appendix Page # Ref.
Lighting	L2. Retrofit interior fixtures to reduce lighting power density by 11%	All	137
	L6. Install occupancy sensors to control interior lighting	All	140
	L7. Add daylight harvesting	All	142
	L8. Retrofit exterior fixtures to reduce lighting power density, and add exterior lighting control	All	143
Envelope	E7. Add roof insulation	All, except hot-humid	154
HVAC - Air Side	HA13. Widen zone temperature deadband, add conference room standby control (upgrade to DDC zone control)	All	163
	HA14. Lower VAV box minimum flow setpoints, reset duct static pressure (upgrade to DDC zone control)	All	165
	HA15. Add demand-controlled ventilation	All	167
	HA16. Replace supply fan motor and VFD	All	168

System	Measure Description	Climate Zones	Appendix Page # Ref.
HVAC - Water Side	HW7. Shut down heating plant when there's no heating load	Hot-humid, Hot-dry	170
	HW8. Increase efficiency of condenser water system	Hot-dry	172
	HW9. Increase efficiency of condenser water pumping system	Hot-humid, Hot-dry	173
	HW10. Change cooling plant pumping system to variable primary.	Hot-humid, Hot-dry	175
	HW12. Add a VFD to one chiller	Hot-humid, Hot-dry	178
	HW15. Replace boilers and change heating plant pumping system to variable flow primary	Marine, Cold, Very cold	181

Rationale for Recommended Measures

The measures included in the deep retrofit packages go beyond the standard retrofit package measures – more system types are affected (lighting, HVAC and envelope), and the level of retrofit is deeper. These are representative of measures that an owner might implement for reasons not limited to energy savings. Such reasons may include:

- Equipment or assemblies are at the end of their useful life and are in need of replacement
- The usage of the building has changed and the systems and assemblies need to be updated to follow suit
- New building codes necessitate upgrades
- Market repositioning effort (e.g., upgrading space from Class B to Class A)

The measures included in the deep retrofit packages range from the addition of simple controls functionality (occupancy sensor control of lighting), to significant changes to the building's systems (replace boilers and convert cooling plant pumping system). Some of the measures are also included in the standard retrofit recommended packages, as they are cost-effective measures with significant energy savings potential.

There are a number of measures that could be included as part of a deep retrofit package, depending on the goals of the project and the outcomes of the integrated design process. The measures included in the table above should be considered representative examples. They may not be applicable to some large office buildings, and there may be other relevant measures that aren't included in the list. The measures listed above are applicable to a reference building that has characteristics similar to most office buildings in the U.S.

The measures were chosen in consideration of their energy savings and cost-effectiveness, and one of the key factors that influenced the attractiveness of measures was the climate zone. For example, boiler replacement yielded higher energy savings in cooler climates than in warmer climates, which is why that measure is included for the Cold, Very Cold, and Marine recommended packages. Similarly, cooling plant-related measures yielded higher savings in warmer climates than in cooler climates.

The measures were also chosen based on their impact on the tenants. The reference building is a multi-tenant commercial office building, whose owner likely cannot afford to ask the tenants to leave for a few years during the remodel. It's assumed that the remodel will occur during occupied conditions. Therefore, as an example, a complete replacement of the building envelope is not a realistic option when tenant impacts are considered. The measures included in the deep retrofit packages listed above were selected based on this constraint.

Some of the measures listed in the table above apply to a specific type of HVAC system commonly found in large multi-tenant commercial office buildings: a multi-zone VAV air system with a water-cooled chilled water plant and a heating water system. This is one of the most common HVAC systems found in existing large office buildings. Some of the HVAC measures would not directly apply to other HVAC system types. For example, the "Add a VFD to one chiller" measure would not apply to a water loop heat pump system. However, the concept for this measure could be applied to other HVAC system types: add functionality to adjust the system operating parameters during part load operation to realize energy savings and extended equipment life.

For more detailed information about the measures included in the deep retrofit packages, see Appendix 10.6.

Energy Savings

The analysis of the deep retrofit packages assumes that O&M measures are implemented first, as part of an EBCx process, followed by the deep retrofit measures included in the recommended package. This is estimated to result in energy savings of over 45% of site energy usage in the reference large office building, based on an analysis of the measures included in the packages using EnergyPlus. Each climate zone shows significant energy savings, with slight variations between the climate zones. See Table 5.4.

Table 5.4. Deep Retrofit Recommended Package Energy Savings Results

	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage	Source EUI Savings (kBtu/sf/yr)	Savings as % of Total Source Usage
Hot & Humid	1,520,000	290	28,000	40	45%	87	39%
Hot & Dry	1,780,000	470	41,000	51	52%	105	46%
Marine	1,250,000	240	57,000	60	53%	77	46%
Cold	1,170,000	410	44,000	42	49%	83	40%
Very Cold	1,150,000	340	49,000	44	49%	81	42%

Financial Analysis

The financial metrics associated with the deep retrofit packages in each climate zone are shown in Table 5.5. These metrics include the O&M measures implemented as part of an EBCx process, and implementation of the retrofit measures shown in Table 5.3. The costs and savings shown in this table are incremental costs and savings, since it is assumed that the equipment is at the end of its useful life and is in need of replacement. The incremental cost of the deep retrofit package is based on the difference between similar standard efficiency equipment and an energy efficient option. Full costs were assumed for measures that added functionality to the original system. The estimated savings for the deep retrofit package were reduced by 50% to adjust for the incremental savings realized due to energy code-mandated increases in energy efficiency. The actual realized costs and savings will be greater.

As shown in Table 5.5, when combined with the savings from the EBCx process, the deep retrofit packages have a six-year payback and positive net present value, making them a cost-effective method of achieving significant energy savings.

Table 5.5. Deep Retrofit Recommended Package Financial Analysis Results

	Total Measure Costs	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (Years)	Net Present Value
Hot & Humid	$697,000	$115,000	$1,500	$117,000	6	$227,000
Hot & Dry	$890,000	$159,000	$1,800	$161,000	6	$422,000
Marine	$918,000	$159,000	$2,800	$162,000	6	$369,000
Cold	$885,000	$151,000	$1,900	$153,000	6	$302,000
Very Cold	$837,000	$135,000	$2,500	$137,000	6	$211,000

The useful life of the deep retrofit package is assumed to be 20 years due to the periodic recommissioning efforts that are implemented during this timeframe. Other costs required to maintain individual measures in the package with less than a 20 year life, such as the photocells and occupancy sensors, are reflected in the O&M costs. However, the additional efficiencies and reduction in daily efforts achieved by the installation of DDC zone controls in place of the original pneumatic system more than balance those other costs and result in positive overall O&M cost savings.

5.3 Additional Considerations

The deep retrofit measures proposed in the recommended packages above provide an overview of the types of measures that could be implemented as part of a deep retrofit project. However, not all measures will be applicable to all buildings, and there may be some other measures that are applicable to a specific building yet aren't included in the measure list. See Appendix 10.1 for a detailed discussion of the reference building's characteristics and considerations for how the energy savings results may be impacted by variations in building characteristics.

A deep retrofit project is more than just a collection of individual retrofits. It should include an integrated design process where multiple retrofit package options are developed and evaluated. The package of implemented measures that result from the design process can vary substantially from building to building. Since each building is unique, there's no "off the shelf" deep retrofit package. The various members of the design and operations team should work together to design each system and assembly in consideration of its impact on the building as a whole. Deep retrofit projects usually involve whole building energy simulation, to help determine which options will result in lowest energy usage while still meeting other project goals.

When evaluating whether to embark on a deep retrofit project, the following aspects could be considered:

- **Are the equipment or assemblies in the building nearing the end of their useful lives?**

  Deep retrofit projects are especially suited for buildings that have a significant number of systems and assemblies near the end of their useful lives. Rather than just replacing these systems and assemblies with similar items, deep retrofit projects are a great opportunity to re-evaluate the types of systems and assemblies in the building, considering the current needs of the building and new technologies that have become available over the years.

- **Has the usage of the building changed since the building was originally constructed?**

  If a building's usage has changed significantly since it was originally constructed, the systems and assemblies in the building are likely not optimized to suit the current needs of the building. A deep retrofit project presents a perfect opportunity to evaluate the current systems and assembly types in a building, and present options for alternate systems and assemblies that may be more suited to the building's needs.

- **Is the building owner-occupied, or a multi-tenant leased building?**

  Will there be a break in occupancy in the future? Deep retrofits typically include major renovations to building systems and assemblies. Impact on the occupants must be considered, and this aspect can limit the scope of a deep retrofit. If the occupants can be relocated for the deep retrofit construction period, or if there is a known upcoming break in occupancy, the level of retrofit can likely be deeper than if the occupants remained in the building during the deep retrofit construction period.

- **For multi-tenant leased office buildings, can tenant-operated systems be considered?**

  Office equipment consumes a significant amount of energy, yet this equipment is often owned and operated by the tenants. If tenants can participate in a building's deep retrofit project, through consideration and implementation of load-reduction measures such as advanced on/off control of computer equipment, plug load measures should be evaluated for retrofit opportunities as part of the integrated design approach.

- **Will the project be commissioned?**

  Commissioning is highly recommended for deep retrofits. It provides assurance to building owners that the project was designed and constructed to meet the owner's requirements. Commissioning can start during a deep retrofit's pre-design phase and proceed through construction, to help the project team match the design with the needs of the building, and to help ensure the long term maintainability of the facility. The participation of a commissioning agent is often most useful at the start of a project, when it can have the biggest impact on design and construction activities.

Small- and Medium-Sized Office Building Considerations

See Section 4.3 for a discussion on the applicability of the retrofit measures in the Retrofit Measure Summary Table to small- and medium-sized office buildings. These retrofit measures are most applicable to large office buildings. Some of the HVAC retrofit measures listed may not apply to typical small- and medium-sized office buildings, and there may be other HVAC retrofit measures not listed that are more applicable to small and medium sized offices buildings. Section 4.3 addresses these differences.

Deep Retrofit Case Study: Empire State Building

The effort to complete an energy efficiency retrofit of the iconic Empire State Building began in 2008 when Malkin Holdings brought together the Clinton Climate Initiative (facilitator), Johnson Controls (energy services company), Jones Lang LaSalle (program manager), and the Rocky Mountain Institute (design partner and peer reviewer) to explore energy upgrade options for the 80-year-old building. The design team began by brainstorming all measure options and defining their technical potential.

A key approach the team used to identify technical opportunities was to leverage the concept of the "right steps in the right order." This approach helped to ensure the team considered all options to reduce the need for lighting, heating, and cooling before considering efficient equipment to meet these needs. Ultimately, the energy efficiency measures selected for the Empire State Building retrofit aligned with three key steps: reduce loads, install efficient systems, and energy systems management and monitoring.

The design team used decision-making tools such as energy modeling and Net Present Value (NPV) analyses to evaluate each measure option's cost-effectiveness. The team then created bundles of measures to understand the interactive effects of measures on one another and to compare the cumulative energy savings and carbon emissions of various bundles of measures. Ultimately, the team settled on four different bundles that represented a range of investment and savings options to present to building ownership.

The bundle of measures ultimately approved (detailed at right) have begun to be installed and are scheduled to be completed by 2013. Energy models have estimated the project will achieve a 38% energy use reduction relative to the pre-retrofit building, with the project's incremental costs being recouped after only 3 years.

Project Costs		Estimated Annual Energy $ Savings
Total	Incremental	$4.4M
$106M	$13.2M	

Simple Payback (years)		ROI		NPV
Total Cost	Incremental Cost	Total Cost	Incremental cost	
24	3	4%	33%	$22,100,000

Estimated Energy Use Intensity (EUI)		Estimated % Site Savings
Before	After	38%
88 kBtu/sf/yr	60 kBtu/sf/yr	

For the full version of the Empire State Building retrofit case study, visit http://retrofitdepot.org/casestudies/TrueStories/CaseStudy-EmpireStateBuilding.

Disclaimer: Reported energy savings results were provided by the building owner or a third party and have not been verified. The Empire State Building design is a trademarked image and used with permission by ESBC.

Quick Facts

Owner: Malkin Holdings

Location: New York, NY

Gross Square Footage: 2,700,000 sf

Post-retrofit EUI: 60 kBtu/sf/yr

Post-retrofit Energy Star: 90

Key Measures

- **Upgrade window efficiency** Existing windows were remanufactured on-site to include a suspended coated film and gas fill
- **Install radiative barrier** Insulated reflective barriers were installed behind radiator units to reduce amount of wasted heat
- **Upgrade lighting upgrades** Includes dimmable ballasts, photocells, and plug load occupancy sensors
- **Upgrade HVAC system** Includes four industrial electric chiller retrofits, VFDs, constant volume to variable air volume air handling units, pneumatic to direct digital controls (DDC), primary loop bypasses, and demand control ventilation (DCV)
- **Implement tenant energy management** Energy use and benchmarking software that allows tenants to view energy use in real time and see comparisons to other tenants

Deep Retrofit Case Study: Alliance Center

The Alliance for Sustainable Colorado, a nonprofit organization, purchased a 100-year-old warehouse in Denver's historic Lower Downtown in 2004, and two years later completed a major renovation to the building to create the Alliance Center. Striving to meet its mission of achieving sustainability through collaboration, the Alliance converted the former warehouse to a multi-tenant nonprofit center that would provide multiple organizations a "healthy, efficient, quality, mission-enhancing workspace."

The scope of the project focused on implementing strategies that would promote building health and energy & water efficiency while preserving historic integrity. The project consisted of reconfiguring the interior spaces, updating the building HVAC, telecom and electric systems, and adding new finishes.

The energy upgrades to the building have resulted in 22% energy reduction compared to 2004 while occupancy has doubled. The building uses 39% less energy compared to comparable office buildings. Since project completion, the Alliance Center receives about 1,000 visitors a year who want to learn more about implementing energy-efficient measures in businesses and homes.

Total Project Costs	Energy Efficiency Financial Incentives	Other Incentives	Net Cost to Owner
$168,200	$25,000	$26,200*	$117,000

Estimated Annual $ Savings	Simple Payback	ROI
$8,800	13.3 years	8%

Estimated Energy Use Intensity (EUI)		Estimated % Site Savings
Before	After	22%
Unavailable	42 kBtu/sf/yr	

Quick Facts

Owner: Alliance for Sustainable Colorado

Location: Denver, CO

Gross Square Footage: 38,000 sf

Post-retrofit EUI: 42 kBtu/sf/yr

Post-retrofit Energy Star: 85

Key Measures

- Replace pneumatic controls with Direct Digital Control system
- Add occupancy sensors and photocells to control lighting
- Control lighting and HVAC system through a Building Automation System
- Install high efficiency glazing
- Replace T12 lamps with T8 lamps with dimmable ballasts
- Increase insulation
- Install sun shades (6th floor only)

*Includes $11,200 utility incentive for solar PV system and $15,000 state incentive for upgrades to a historic building
**Building occupancy has doubled during this timeframe
This case study was developed by New Buildings Institute in support of the Northwest Energy Efficiency Alliance's BetterBricks Existing Buildings Initiative. Full case study information available at http://newbuildings.org/measured-performance-case-studies and at www.betterbricks.com/design-construction/existing-building-renewal-initiative
Disclaimer: Reported energy savings results were provided by the building owner or a third party and have not been verified.

Deep Retrofit Case Study: Christman Building

The Christman Building located in Lansing, Michigan, is the national headquarters for the Christman Company, a construction management and general contracting firm. Originally built in 1928 and registered as an historic landmark, the Mutual Building had fallen into a state of disrepair under previous ownership. Christman purchased the building and, using its own team of sustainable design professionals, renovated the building to become a LEED Platinum rated building.

Using an integrated approach, Christman was able to incorporate energy efficiency into the whole building renovation and prove it could be accomplished within a tight budget. Because of the extensive scope of the project, energy efficient equipment related to almost all building systems was installed.

After completing the renovation in 2008, the building was still not meeting its energy performance goals. According to Gavin Gardi, the original building commissioning was not successful as it focused on individual subsystems rather than the building as a whole. Christman pursued a full building commissioning strategy and reduced their energy use by 35% the next year to 66 kBtu/sf, a powerful endorsement of the value of proper commissioning and retrofits.

Total Renovation Costs	Energy Efficiency Financial Incentives	Other Incentives	Total Renovation Cost After Incentives
$12,005,000	$0	$3,092,000*	$8,913,000

Total Costs for Energy Efficiency Upgrades	Estimated Annual $ Savings	Simple Payback	ROI
$23,000	$46,000	0.5 years	200%

Estimated Energy Use (EUI)		% Site Savings
Before	After	35%
Unavailable	66 kBtu/sf/yr	

*Includes brownfield and historic building improvement tax credits
**Comparable office average energy use from the ENERGY STAR Portfolio Manager program based on like type, size, occupancy, hours, and climate – determined from statistical analysis of the EIA's CBECS dataset
This case study was developed by New Buildings Institute in support of the Northwest Energy Efficiency Alliance's BetterBricks Existing Buildings Initiative. Full case study information available at http://newbuildings.org/measured-performance-case-studies and at www.betterbricks.com/design-construction/existing-building-renewal-initiative
Disclaimer: Reported energy savings results were provided by the building owner or a third party and have not been verified.

Quick Facts

Owner: Christman Company

Location: Lansing, MI

Gross Square Footage: 64,200 sf

Post-retrofit EUI: 66 kBtu/sf/yr

Post-retrofit Energy Star: 81

Key Measures

- **Install high efficiency HVAC units** including under-floor air distribution system
- **Add insulation**
- **Install cool roof**
- **Replace windows with double-glazed windows on building's front façade**
- **Upgrade lighting** Including T5 fluorescent lamps, manual task lighting, occupancy sensors and timeclocks
- **Install an Energy Management System**
- **Implement a computer power monitoring control system**
- **Implement ongoing commissioning** including HVAC, lighting, and domestic hot water systems

5.4 Additional Resources and Guides

For additional references related to the measures discussed in Chapter 5, refer to the following.

General Guidance

- Rocky Mountain Institute, *Retrofit Depot*: Online resource for case studies, advice, and tools & resources related to deep retrofit project implementation; www.retrofitdepot.org.
- Environmental Protection Agency, *"Building Upgrade Manual,"* 2008: A strategic guide for planning and implementing a profitable energy saving building upgrade following a five-stage process. Available for free download online; www.energystar.gov.
- 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.
- 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. More information available at www.boma.org/beep.
- American Institute of Architects (AIA), *"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.

Technical Guidance

- ASHRAE, "*50% Advanced Energy Design Guide for Small to Medium Office Buildings,*" 2011: Includes general and detailed technical information on approaches for improving energy performance in office buildings. Concepts presented also apply to larger office buildings. Available for free download online; www.ashrae.org.
- ASHRAE, "*30% Advanced Energy Design Guide for Small Office Buildings,*" 2004: Includes general and detailed technical information on approaches for improving energy performance in small office buildings. Concepts presented also apply to larger office buildings. Available for free download online; www.ashrae.org.
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6

Measurement & Verification (M&V)

TOPICS COVERED

- Definition of M&V
- Planning for M&V
- Overview of M&V approaches
- Developing a M&V plan
- M&V approaches for recommended packages
- Measure characterization
- Building performance tracking

Determining the actual savings from an energy-efficiency retrofit project can help prove the effectiveness of a project. Since savings represent the absence of energy use, they cannot be directly measured. Although pre- and post- retrofit measurements are often used to determine project performance, simple comparisons of energy use before and after a retrofit are typically insufficient to accurately estimate energy savings because they do not account for fluctuations in weather and building occupancy. Measurement and verification (M&V) is the practice of measuring, computing and reporting the results of energy saving projects. Proven M&V strategies provide a means to accurately estimate 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 such as outdoor air temperature, executing engineering calculations, and reporting. The industry guideline for conducting these activities is the International Performance Measurement and Verification Protocol (IPMVP). IPMVP includes a framework for best practices in conducting M&V and outlines four general approaches or options. Following these guidelines allows for transparent and reliable reporting of projects savings. The Table 6.1 below presents key terminology used in IPMVP approaches.

Table 6.1. Key IPMVP M&V Terminology

Measurement Boundary: A hypothetical boundary drawn around equipment and/or systems to isolate its energy or mass flows relevant to determining its energy savings.
Independent Variable: A parameter that is expected to change regularly and have a measurable impact on the enrgy use of the facility, system or piece of equipment.
Baseline Period: The period of time chosen to represent operation of the faciity or system before implementation of the enrgy efficiency project.
Baseline Energy: The energy use ocurring 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 modeling to a different set of operating conditions, typically those of the post-install conditions.
Savings: Typically, the adjusted baseline energy costs minus the post-install energy costs.

The industry guidelines for M&V depict best practice, but are often not fully utilized unless savings are tied to significant levels of monetary compensation or other requirements, such as in a performance contract or when pursuing LEED New Construction M&V credits. Other projects without these requirements may focus their M&V activities on ensuring the building is performing as intended and has a high potential to achieve savings with less emphasis placed on quantifying savings. In many instances, including utility-sponsored incentive programs, less rigorous methods are utilized to establish the level of energy saving, or to ensure savings persist over time. Some of these methods include energy savings calculations alongside or within building performance tracking tools, such as an advanced Energy Information System (EIS) capable of comparing pre and post-project building energy use.

6.1 Planning for M&V

It is important for a building owner to determine early in the project planning process if M&V will be part of the project. If savings are to be accurately measured and verified, special planning is required and may involve metering and measurement activities prior to implementing any changes to the facility. Through metering and utility bill analysis, the baseline energy use and costs are established. Then, baseline energy use is adjusted to represent the costs that would have occurred under the same set of conditions that the post-retrofit costs are based upon. Savings are finally estimated as the difference between the adjusted baseline energy use and the actual post-retrofit energy use.

One of the key issues to consider is how exact the reported savings needs to be, which influences the scope and level of rigor of the M&V activities. Proper planning can help integrate the verification activities into the project and potentially leverage the work of the design team and commissioning agent. A key goal is to keep the cost of the verification activities in line with the scope and needs of the project.

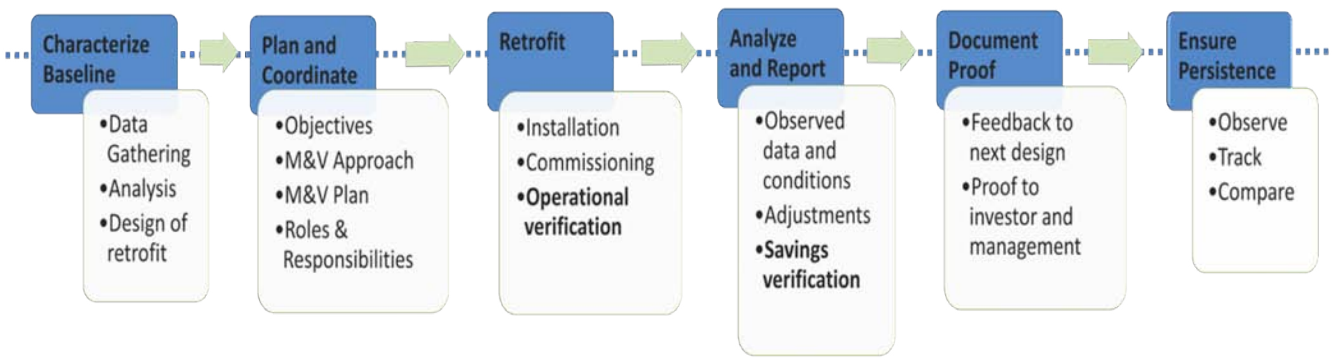

Figure 6.1. M&V Timeline

6.2 Overview of M&V Approaches

There are two essential components of M&V for any energy efficiency improvement project:

- **Operational verification** verifies that the measures are installed and operating properly. Activities include visual inspection, data trending and/or functional testing. This should be achieved through comprehensive commissioning of all affected systems supplemented by more data-driven activities (e.g., monitoring and tracking). Setting clear expectations for equipment or system performance is helpful in ensuring effective operational verification. Operational verification should be conducted even if savings verification activities are not.

- **Savings verification** verifies and calculates the savings resulting from the installed measures. These verification procedures are covered by the IPMVP.

Operational verification and commissioning should be completed prior to implementing other post-retrofit M&V activities. This ensures the savings from measures, control and operation improvements are fully realized.

The four savings verification options defined by the IPMVP include:

- **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 energy use is measured across all operating conditions before and after the retrofit. This strategy is preferred over Option A when there is a high level of variability in the energy use depending on operating conditions.
- **Option C** – Whole building. Utility data from the whole building is correlated with independent variables such as outdoor air temperature, and baseline and post-retrofit energy use is adjusted to the same set of conditions and compared to determine energy savings.
- **Option D** – Calibrated simulation. Typically applied as a whole building approach, energy use of the building is modeled both before and after the retrofit using specialized software and the models are adjusted so they accurately predict building energy use. The before and after models are adjusted to the same set of conditions and compared to determine energy savings.

These options can be put into two general categories: retrofit isolation (Options A and B) and whole building (Options C and D). One of the fundamental differences between these approaches is where the savings boundary is drawn, as shown in Figure 6.2. Retrofit isolation strategies focus on the individual retrofit, and will verify the energy performance of 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 greater than 10% of total electrical or gas usage, and will report on the overall energy performance of the building. In addition to measurement boundary, these methods vary in their requirements for measured data, their appropriate applications, and the level of effort and cost to implement. An overview of the methods is provided in the Table 6.2.

Figure 6.2. Measurement Boundary for M&V Options

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

- Developing a complete M&V plan;
- Measuring baseline energy use overall operating modes of the building or systems;
- Adjusting energy use to the same set of conditions before calculating savings;

- Reporting savings only for the post-installation measurement period, and not extrapolating beyond this period;
- Establishing the acceptable savings accuracy during the M&V planning process.

Table 6.2. Overview of IPMVP Options

Method	Option A	Option B	Option C	Option D
Boundary	Retrofit Isolation	Retrofit Isolation	Whole Facility	Whole Facility
Measured Data	Key Parameters	All Parameters	Utility Data	Utility Bills, End Use, System Equipment
Analysis	Engineering Calculations	Regression Analysis	Regression Analysis	Energy Simulation Software
Applications	Limited variation of some parameters impacting measure savings	Individual measure assessment	Estimated savings >10% of total use	No baseline data; Multiple measures with interactions

6.3 Developing an M&V Plan

Any effective M&V effort must be planned in advance, 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.

Before selecting an M&V approach, it is important to identify the goals and objectives for the M&V activities. For example, M&V cost savings used to determine payments within Energy Saving Performance Contracts will need to be more rigorous than an M&V effort conducted to meet LEED certification requirements. It may be appropriate for low-cost, no-cost measures to rely solely on operational verification methods that only confirm their potential to save energy without attempting to quantify their actual savings.

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 6.3.

Table 6.3. Components of an M&V Plan

Basic M&V Plan Components	
Project Description	• Relevant site characterization • Existing and expected comfort conditions, lighting intensities, temperature set points, etc. • Measurement boundary and metering requirements • Details and data of baseline conditions including equipment specifications and measured data such as energy use, loads, and hours of operation
Project Savings and Costs	• A description of the measures 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 measure(s) • Calculation method to be used (all equations shown)

Basic M&V Plan Components	
M&V Approach	• Selection Option(s) (A, B, C, D) • Details on approach for baseline adjustments • Savings calculation details • Operational verification strategies • Responsibilities for M&V activities and reporting • Content and format of M&V reports • Quality control/quality assurance procedures • Ongoing verification procedures

6.4 M&V Approaches for Recommended Packages

The following tables (Tables 6.4 through 6.7) summarize suggested approaches to M&V for the recommended measure packages presented in this guide. As discussed earlier, M&V ensures that retrofit project savings are achieved and quantified. This section provides examples of effective M&V methods based on the measures selected for the retrofit packages. These M&V methods will depend on whether the measures are implemented in an integrated or staged approach – the approaches are differentiated in the tables below. Included for each measure are estimated cost savings, performance variability, operational verification activities, savings verification approach, savings verification activities, and suggestions for ongoing performance assurance. See below the tables for a discussion of the criteria presented in them.

Table 6.4. M&V Approaches for O&M Measures Implemented as Part of EBCx Packages – Integrated Approach*

** See Section 2.5 "Planning for Energy Performance Improvements" for details of the Integrated Approach to energy performance improvement.*

Measure Description	Energy Cost Savings Impact: Low 0-1%; Med 1-3%; High > 3%	Performance Variability: High, Med, Low	Operational Verfication Activities	Savings Verification Approach	Savings Verification Activities	Ongoing Performance Assurance
Reduce envelope leakage	Low	Low	Visual inspection	None	None	Visual inspection
Revise air filtration system	Low	Low	Visual inspection			Visual inspection
Calibrate air sensors	Low	Medium	Short-term testing			Short-term testing
Re-enable supply air temperature setpoint reset	High	Medium	Building Automation System (BAS) control logic and/or data trending and review			BAS control logic and/or data trending and review
Reduce HVAC equipment runtime, close outside air damper during unoccupied periods	High	Medium	BAS control logic and/or data trending and review			BAS control logic and/or data trending and review

Table 6.4 (cont.)

<table>
<tr><th>Measure Description</th><th>Energy Cost Savings Impact: Low 0-1%; Med 1-3%; High > 3%</th><th>Performance Variability: High, Med, Low</th><th>Operational Verfication Activities</th><th>Savings Verification Approach</th><th>Savings Verification Activities</th><th>Ongoing Performance Assurance</th></tr>
<tr><td>Reduce economizer damper leakage</td><td>Low</td><td>Low</td><td>Visual inspection</td><td rowspan="3">None</td><td rowspan="3">None</td><td>Visual inspection</td></tr>
<tr><td>Calibrate water sensors</td><td>Low</td><td>Medium</td><td>Short-term testing</td><td>Short-term testing</td></tr>
<tr><td>Shut down cooling plant when there's no cooling load</td><td>Medium</td><td>Medium</td><td>BAS control logic and/or data trending and review</td><td>BAS control logic and/or data trending and review</td></tr>
</table>

Table 6.5. M&V Approaches for Retrofit Measures Implemented as Part of Standard Retrofit Packages – Integrated Approach*

** See Section 2.5 "Planning for Energy Performance Improvements" for details of the Integrated Approach to energy performance improvement.*

***Whole building approaches will capture savings from all measures implemented.*

<table>
<tr><th>Measure Description</th><th>Energy Cost Savings Impact: Low 0-1%; Med 1-3%; High > 3%</th><th>Performance Variability: High, Med, Low</th><th>Operational Verfication Activities</th><th>Savings Verification Approach</th><th>Savings Verification Activities</th><th>Ongoing Performance Assurance</th></tr>
<tr><td>Install occupancy sensors to control interior lighting</td><td>Medium</td><td>Medium</td><td>Short-term testing</td><td rowspan="5">Whole Building Approach**</td><td rowspan="5">Utility data analysis <or> Building simulation</td><td>Short-term testing</td></tr>
<tr><td>Add daylight harvesting</td><td>High</td><td>High</td><td>Short-term testing</td><td>Short-term testing</td></tr>
<tr><td>Retrofit exterior fixtures to reduce lighting power density (LPD), and add exterior lighting control</td><td>Medium</td><td>Low</td><td>Visual inspection</td><td>Visual inspection</td></tr>
<tr><td>Widen zone temperature deadband (replace pneumatic thermostats)</td><td>High</td><td>Medium</td><td>Visual inspection</td><td>Visual inspection</td></tr>
<tr><td>Lower VAV box minimum flow setpoints (rebalance pneumatic boxes)</td><td>High</td><td>Medium</td><td>Sample spot measurement</td><td>Sample spot measurement</td></tr>
</table>

Table 6.6. M&V Approaches for Retrofit Measures Implemented as Part of Standard Retrofit Packages – Staged Approach

** See Section 2.5 "Planning for Energy Performance Improvements" for details of the Staged Approach to energy performance improvement.*

***Whole building approaches will capture savings from all measures implemented.*

Measure Description	Energy Cost Savings Impact: Low 0-1%; Med 1-3%; High > 3%	Performance Variability: High, Med, Low	Operational Verfication Activities	Savings Verification Approach	Savings Verification Activities	Ongoing Performance Assurance
Install occupancy sensors to control interior lighting	Medium	Medium	Short-term testing	Whole Building Approach**	Utility data analysis <or> Building simulation	Short-term testing
Add daylight harvesting	High	High	Short-term testing			Short-term testing
Retrofit exterior fixtures to reduce lighting power density, and add exterior lighting control	Medium	Low	Visual inspection			Visual inspection
Widen zone temperature deadband (replace pneumatic thermostats)	High	Medium	Visual inspection			Visual inspection
Lower VAV box minimum flow setpoints (rebalance pneumatic boxes)	High	Medium	Sample spot measurement			Sample spot measurement

Table 6.7. M&V Approaches for Retrofit Measures Implemented as Part of Deep Retrofit Packages – Integrated Approach*

*** See Section 2.5 "Planning for Energy Performance Improvements" for details of the Integrated Approach to energy performance improvement.*

***Whole building approaches will capture savings from all measures implemented.*

Measure Description	Energy Cost Savings Impact: Low 0-1%; Med 1-3%; High > 3%	Performance Variability: High, Med, Low	Operational Verfication Activities	Savings Verification Approach	Savings Verification Activities	Ongoing Performance Assurance
Retrofit interior fixtures to reduce lighting power density by 11%	Medium to High	Low	Visual inspection	Whole Building Approach**	Utility data analysis <or> Building simulation	Visual inspection
Install occupancy sensors to control interior lighting	Medium	Medium	Short-term testing			Short-term testing

Table 6.7 (cont.)

Measure Description	Energy Cost Savings Impact: Low 0-1%; Med 1-3%; High > 3%	Performance Variability: High, Med, Low	Operational Verfication Activities	Savings Verification Approach	Savings Verification Activities	Ongoing Performance Assurance
Add daylight harvesting	High	High	Short-term testing	Whole Building Approach**	Utility data analysis <or> Building simulation	Short-term testing
Retrofit exterior fixtures to reduce lighting power density, and add exterior lighting control	Medium	Low	Visual inspection			Visual inspection
Add roof insulation	Low to Medium	Low	Visual inspection			Visual inspection
Widen zone temperature deadband, add conference room standby control (upgrade to DDC zone control)	High	Medium	BAS control logic and/or data trending and review			BAS control logic and/or data trending and review
Lower VAV box minimum flow setpoints, reset duct static pressure (upgrade to DDC zone control)	High	Medium	Sample spot measurement <AND> BAS control logic and/or data trending and review			BAS control logic and/or data trending and review
Add demand-controlled ventilation	Low	High	BAS control logic and/or data trending and review			BAS control logic and/or data trending and review
Replace supply fan motor and VFD	High	High	BAS control logic and/or data trending and review			BAS control logic and/or data trending and review
Shut down heating plant when there's no heating load	High	Medium	BAS control logic and/or data trending and review			BAS control logic and/or data trending and review
Increase efficiency of condenser water system	Low to Medium	High	BAS control logic and/or data trending and review			BAS control logic and/or data trending and review

Table 6.7 (cont.)

Measure Description	Energy Cost Savings Impact: Low 0-1%; Med 1-3%; High > 3%	Performance Variability: High, Med, Low	Operational Verfication Activities	Savings Verification Approach	Savings Verification Activities	Ongoing Performance Assurance
Increase efficiency of condenser water pumping system	Low	High	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
Change cooling plant pumping system to variable primary.	Medium	High	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
Add a VFD to one chiller	Low to Medium	High	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
Replace boilers and change heating plant pumping system to variable flow primary	High	High	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

The suggested methods in the tables above are illustrative and should not be applied broadly across projects. These tables provide a general idea of the techniques that can be applied to similar measures. Refer to the discussion below for further explanation of the criteria presented in the tables.

6.5 Measure Characterization

Prior to determining a savings verification approach and specifying activities for a retrofit project, the characteristics of the individual measures as well as the overall package should be considered. Based on the measure and package characteristics, savings verification plans may call for a single whole building approach addressing all measures for the project, or several M&V options to jointly cover the different measures of the project.

Projects with a few low-savings measures or measures that don't interact with each other are generally good candidates for a retrofit isolation approach. In contrast, measures or packages with large energy savings (greater than 10% of building energy), may adopt a simple whole building approach, such as utility data analysis using Option C. Alternately, 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.

As previously discussed, one of the primary aims of M&V is to effectively balance the risk of losing savings against the cost needed to verify them. This risk varies from one measure to the next, based on the expected level of energy cost savings as well as the performance variability. In the tables above, levels of energy cost savings were defined as Low (0% to 1%), Medium (1% to 3%), and High (> 3%) based on the overall impact to the energy budget of the building.

Performance variability has also been categorized as Low, Medium, and High based on the level of variability in the energy use of the measure due to operating conditions or user interaction. This criteria defines the likelihood of savings not being realized due to operating conditions being different than predicted. The performance of some measures, such as envelope improvements, will be static and not change regardless of conditions and are ranked as "Low." Measures that are automated but could be disabled or changed, such as adjustments to control setpoints, are ranked as "Medium." Measures that could see a wide range of energy use such as VFDs, which could operate at the same performance level of the baseline, are ranked as "High."

6.6 Operational Verification Activities

Operational verification activities are needed to verify that measures are installed and operating properly. These activities include:

- **Visual inspection** - The physical installation associated with the measure should be inspected to confirm it meets specifications. This is most relevant for "static" measures that impact performance simply by being properly installed (e.g., insulation).
- **Sample spot measurement** - Verify performance by measuring single or multiple key parameters related to energy-use for a representative sample of similar, installed equipment (e.g., a measure involving multiple installations of the same lighting fixture/lamps/ballast). In small sets of measures (e.g., less than five), all installations should be measured. In larger sets, a representative sample can be measured.
- **Short-term testing** - Test for system component functionality and correct implementation of intended control logic. May involve functional testing and measuring key performance and/or operating parameters.
- **Building Automation System (BAS) control logic and/or data trending and review** - May involve setting up and reviewing BAS data trends or reviewing BAS control logic. Measurement period may last for a few days to a few weeks. Duration is dependent on the period of time needed to capture the range of performance/operation associated with the measure.

6.7 Savings Verification & Ongoing Performance Assurance

Considerations for selecting a savings verification approach are discussed in the "Overview of M&V Approaches" section above. These savings verification approaches include:

- None
- Option A - Partially measured retrofit Isolation
- Option B - Fully measured retrofit isolation
- Whole Building Approach (Option C or Option D)

Since some measures can be overridden or disabled, ongoing M&V activities will help to ensure savings persist for the life of the equipment. Ongoing performance assurance activities may be composed of operational verification activities or a combination of operational and savings verification activities.

6.8 Building Performance Tracking

Many building owners are choosing to track energy savings over time, to evaluate performance and ensure that savings persist. These efforts are enabled by an ever increasing amount of building performance tracking tools and services, such as BAS system tracking, fault detection and diagnostic tools, advanced Energy Information Systems (EIS) that track building energy use, and third party utility bill analysis services. Refer to chapter 7 "Continuous Improvement through O&M" for more discussion on building performance tracking approaches, tools, and services.

KEY POINTS

- Measurement and verification (M&V) is the practice of measuring, computing and reporting the results of energy saving projects.
- An M&V plan seeks to effectively balance the risk of losing savings against the cost needed to verify them.
- It is important to determine early in the project planning process if M&V will be part of the project, as special planning is required and may involve metering and measurement activities prior to implementing any changes to the facility.
- IPMVP guidelines offer M&V best practices, including four specific approaches: "Option A", retrofit isolation with partial measurement; "Option B", retrofit isolation with full measurement; "Option C", whole building using utility bill analysis; and "Option D", whole building using calibrated simulation.
- The two essential components of M&V for an energy efficiency improvement project are operational verification and savings verification.

6.9 Additional Resources & Guides

To learn more in-depth information about the M&V concepts presented here, refer to the following additional resources:

- Efficiency Valuation Organization, "*International Performance Measurement and Verification Protocol,*" 2010: Standardized guidelines for performing M&V activities. Available for free download online; www.evo-world.org.
- 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.
- 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.

Building Performance Tracking Case Study: Aventine Building

Glenborough, LLC's Aventine building in La Jolla, California, is a living example of how multiple tools and strategies can be combined to effectively track building performance. The Aventine building's M&V plan does not emphasize quantification of energy savings as outlined above by the IPMVP, but rather focuses on ensuring the building is performing as intended. While IPMVP offers the most accurate evaluation of energy savings results, buildings without a need to pinpoint energy savings to a high degree of accuracy often choose to focus M&V activities on ensuring persistence of savings over time through use of building performance tracking tools and services.

When a chiller plant retrofit and upgraded building automation system (BAS) were installed in 2008, Glenborough wanted to measure energy performance improvement and maintain the improved performance. These goals were achieved by utilizing a third-party utility bill analysis service and leveraging software that tracks key building performance indicators. The utility bill analysis service compares building energy use compared to pre-retrofit conditions as well as provides alerts when usage is off-target, while the software tools automatically optimize system settings and provide alerts when parameters are not optimized.

A strong M&V and building performance tracking plan do not guarantee continued building performance on their own. Equally important are the management strategies that support the use of tools. Glenborough contracts out facility management and gives staff the resources, time, and training needed to identify performance anomalies, diagnose the root cause, fix the issues, and verify the energy savings and improved performance on a regular basis.

The M&V and building performance tracking efforts at Glenborough's Aventine facility highlights these best practices:

- Achieve buy-in and participation from corporate management and site engineers
- Use third-party providers for energy management services if in-house engineering time is limited
- Maintain awareness of facility operation by making the viewing of dashboards and reports part of daily operations.

Key M&V and building performance tracking initiatives:

- **Third party utility bill analysis services**: Uses utility data mining & bill payment service to analyze monthly utility bills and to provide alerts when usage is off-target.
- **System Optimization**: Specialized software tracks chilled water plant performance and automatically optimize settings based on load.
- **Building Automation System (BAS)**: The BAS tracks key HVAC system performance indicators and follows up on alerts reported through other performance tracking tools.

7

Continuous Improvement Through O&M

7.1 What is O&M?

TOPICS COVERED

- What is O&M?
- O&M management
- O&M program development
- Building performance tracking

Operations and maintenance (O&M) is the combination of mental (operations) and physical (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 produces the required capacity when needed, and that it produces this capacity efficiently. Maintenance typically refers to routine, periodic physical activities conducted to prevent the failure or decline of building 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 facility management staff engages in, but the nature of that engagement varies. Some engage in reactive O&M, primarily responding to complaints and breakdowns, while 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. All too often, a lack of funding, time, manpower or even training prevents holistic and optimized O&M. Dedicating the resources can be advantageous, though, as a well-run O&M program can achieve the following (U.S. Department of Energy, 2010):

- Whole building energy savings of 5% to 20%
- Minimal comfort complaints
- Equipment that operates adequately until the end of its planned useful life, or beyond
- Design levels of indoor environmental quality
- Safe working conditions for building operating staff

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

When planning for energy upgrades, a building needs to evaluate how each retrofit will impact its O&M program, and if current O&M practices are adequate. Additional training or resources may be required to maintain the systems and/or assemblies affected by the upgrade, or to maintain the benefits associated with the upgrade. For standard retrofits, the O&M program may not be affected since these retrofits usually replace systems and components with similar but more efficient systems and components. However, even in these instances it's 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 these retrofits.

7.2 O&M Management

Successful O&M practices require the support and coordination of much more than just the operations staff. Integration across all levels of an organization is vital to empowering the right people at the right time to produce and sustain an energy efficient building. Five key elements of a management system capable of producing 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 that 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

While OMETA describes the key elements of O&M management, it's also vital to establish a clear framework for communication and cooperation among the various groups included in an O&M management structure. For an office building, these groups can include:

- Property manager or owner's representative
- In-house operations staff
- Service contractors
- Energy managers
- Building occupants

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. The role of champion is vital to the O&M process, since lack of support from any particular 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, it's important to obtain buy-in from all parties associated with an O&M program. Buy-in from all parties will result in maximizing the persistence of benefits related to the upgrade. The O&M team needs to be closely involved in all core building-related upgrades, since they are the team that 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 a building outsources O&M responsibilities to a maintenance management firm, as is often the case with large office buildings. These firms are often highly skilled and capable of implementing advanced O&M programs, but will only do so if it is specified in the service agreement. Building owners can review their existing service agreements and talk to their service providers to determine what level of O&M activity is currently contracted 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.

7.3 O&M Program Development

There are three general approaches to maintenance: reactive, preventive, and predictive (NEEA, 2011):

> **Reactive maintenance** defers maintenance on components and systems until they fail. This approach saves time and expenses in the short-term, but results in unplanned downtime, additional repairs, and can shorten equipment life.
>
> **Preventive maintenance** involves testing, maintaining, and replacing components at regular time intervals or after specific run-hours so that failures rarely occur. This approach is more cost-effective than reactive maintenance.
>
> **Predictive maintenance** is a type of routine maintenance that is gaining popularity. Predictive maintenance utilizes periodic measurements and experience to help determine the service interval for a particular piece of equipment. For example, instead of tearing apart the chiller annually to service the bearings (preventive maintenance), predictive maintenance would use the results of annual vibration monitoring, oil analysis, and filter analysis to estimate bearing wear. This approach may require specialized diagnostic equipment and staff training, but will maximize equipment life and efficiency.

Most buildings utilize a combination of reactive and preventive maintenance depending on factors such as maintenance expense, energy expense, critical nature of the equipment, and safety concerns (NEEA, 2011).

A comprehensive O&M program is rooted in a detailed O&M plan, which incorporates preventive maintenance and regular performance checks. The O&M plan describes expectations for equipment operations and maintenance, and is usually based on an O&M manual. Some facilities may utilize computerized maintenance management software which can assist in the planning and tracking of work orders, equipment performance, periodic or run-hour-based preventive maintenance, as well as outside service calls. Use of this type of software can improve the overall efficiency of the maintenance program, but requires staff training and integration with existing practices.

A clear and customized preventive maintenance plan should be tailored to the facility and consider both operations and maintenance. Routine maintenance is usually prescribed by equipment manufacturers or designers. Operational components may include checks for overrides in the controls that should be on ‘auto’, for proper temperature setpoints, and to see that equipment operating schedules are up to date and consistent with actual occupancy. These operational checks can help ensure the persistence of benefits related to EBCx and retrofit upgrades implemented throughout the life of a building.

An O&M program should be flexible enough to adapt to changes that occur to a building over time, including the O&M and retrofit measures discussed in this guide. As such measures are implemented, the O&M program, including preventive maintenance tasks, should be revised to address the equipment and assemblies related to these measures – to maintain the capacity, reliability, and performance, including energy performance, of the equipment and assemblies.

7.4 Building Performance Tracking

A common saying in the building industry states "you can't manage what you don't measure." This statement very much applies to a building's O&M practice. Measuring the impact of a proactive O&M program over time, where O&M improvements are investigated and implemented continuously, can help maintain the operational and energy benefits related to upgrades and provides justification to continue investment in the O&M program. Building performance tracking can support Measurement & Verification (discussed in detail in Chapter 6) of O&M measures, to quantify and validate the impact and related benefits of a comprehensive O&M program.

Performance tracking can be integrated into an existing or new O&M management framework, and can be a valuable method to maintain the persistence of benefits associated with building upgrades. The following steps are important considerations to include in the O&M framework when pursuing a performance tracking strategy (California Commissioning Collaborative, 2011):

- Dedicate resources to support the performance tracking program
- Identify the performance tracking program team members, and assign responsibilities and communications protocols
- Document baseline performance
- Set quantifiable performance goals
- Consider incentives to motivate staff to achieve the goals
- Include performance tracking language in contracts
- Track performance on an ongoing basis. Take corrective action where needed, and regularly compare progress to goals.

Building energy performance tracking can occur at two levels that can be deployed independently or together as part of an O&M program: 1) energy tracking for whole building and major sub-meters; and 2) system tracking for main energy end-uses, using a building automation system (BAS) (California Commissioning Collaborative, 2011). Energy tracking provides a general overview of the building and can be used to identify unexpected changes, or to look for expected reductions in overall building energy use. System tracking helps ensure individual end-uses are performing as expected, and provides more metrics to track at a higher resolution than whole building tracking. This level of detail can aid in pin-pointing the problem when an issue is identified. Both types of tracking can help ensure the continued energy performance of retrofits.

Building performance tracking can also be a useful tool for increasing awareness among tenants and pursuing behavior based energy savings. Tenants may have their own motivations for reducing energy consumption, such as sustainability goals, or curbing expenses where they are responsible for utility bills. Energy tracking, particularly when available at sub-meters, will support tenants in their efforts to meet those goals. Even where tenants are not independently motivated to act, energy tracking can be used to educate tenants on the benefits of retrofits and O&M programs.

The strategies and tools available to assist either energy tracking or system level tracking range from simple utility bill tracking and benchmarking to system level fault-detection and diagnostics software. This wide spectrum of tools provides ample flexibility to align with a building's specific energy management goals and O&M strategy.

The benefits of an O&M program are not limited to the building's energy performance. Additional non-energy metrics that are impacted by O&M programs and can be tracked include:

- Work orders generated and closed out, including occupant comfort complaints
- Backlog of preventive and reactive maintenance items
- Actual equipment life
- Safety record
- Absentee rate and staff turnover
- Overtime worked

Proactively tracking the energy and non-energy metrics related to O&M program impact can help justify costs related to equipment purchases, program modifications, and staff hiring (U.S. Department of Energy, 2010).

KEY POINTS

- Operations and maintenance (O&M) is the combination of mental (operations) and physical (maintenance) activities that are both required to keep a building and its energy systems functioning at peak performance.
- Five key elements of a management system capable of producing a comprehensive and optimized O&M strategy can be described by the acronym "OMETA": Operations, Maintenance, Engineering Support, Training and Administration.
- A comprehensive O&M program is rooted in a detailed O&M plan, which incorporates preventive maintenance and regular performance checks.
- Measuring the impact of a proactive O&M program over time can help maintain the operational and energy benefits related to upgrades and provides justification to continue investment in the O&M program.

7.5 Additional Resources

For more in-depth information about the O&M concepts presented here, refer to the following additional resources:

- Department of Energy, "*Operations & Maintenance Best Practices,*" 2010: A comprehensive guide to O&M management considerations, tools, and strategies. Available for free download online; www.eere.energy.gov.
- 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.
- *BetterBricks*, O&M online resources: includes management advice, tools, technical advice, and training resources; www.betterbricks.com.
- Pacific Northwest National Laboratory, (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.

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Conclusions

Office buildings use 17% of total commercial building energy use – the most energy use of any sector – and existing offices contain ample opportunity for energy saving improvements. 60% of existing office buildings were built before 1980, and the equipment in those buildings looks increasingly inefficient when compared to newer technologies.

This guide demonstrates that 25% energy savings are relatively easy to achieve and savings of 50% or greater are accessible for owners who are willing to invest in deep, holistic approaches. The rigorous financial analysis methods presented in this guide show that the long-term benefits from these deep 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 activity to maintain competitiveness.

A growing body of evidence links elevated building performance to improved occupant comfort, higher building occupancy rates, higher rents, and greater asset value. With energy costs typically constituting 30% of overall operating costs, embracing energy efficiency as a core strategy will allow commercial real estate owners to substantially increase net operating income and asset value.

While most would agree that improved building performance is the right way to go, and acknowledge the wide range of options, navigating those options and developing a profitable long-term strategy has been far from easy. This guide breaks down the myriad of options into recommended packages for key U.S. climate zones that can provide a strong start for any building owner. Crucially, the guide presents a cost-effectiveness metric for each package that recognizes the complexity of companies' business processes.

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. Companies can drive their buildings towards higher performance by setting goals, creating a long-term plan, and carefully tracking progress. The roadmap presented in this guide will lead building owners from recognition of the opportunity through the full journey that leads to high performance.

A wide array of resources are available to building owners seeking to enhance building performance. This guide includes links to a host of other resources that owners may wish to consult. With the help of information and assistance offered by many government agencies, utility companies, and other organizations, nearly every building owner is within easy reach of an energy saving project.

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Appendix

10.1 Baseline Building Characteristics and Simulation Approaches

Large Office Reference Building Characteristics

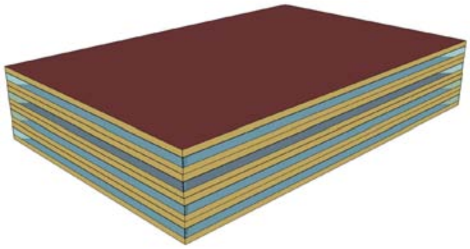
To evaluate the energy impacts of various energy efficiency measures, a hypothetical baseline building was developed as a reference. This baseline building model is based on the DOE reference model for large office buildings discussed previously (Deru et al., 2011) and the prototype building used to support 50% energy savings in large office buildings (Leach et al., 2010). During the course of this Advanced Energy Retrofit Guide (AERG) project, numerous adjustments were made to the above reference models for the following reasons:

- The baseline model for the AERG project needs to be able to accommodate the necessary changes caused by the building retrofit measures.
- The baseline model should not have the worst or best performance among buildings with similar age. Instead, it should represent the typical design and operating condition based on engineering judgment.
- The building may have been upgraded with various retrofits since it was originally constructed.

The characteristics of the large office reference building used for the AERG project are shown in the following table. This reference building was used to model the energy and demand impacts of the individual measures and the recommended packages.

Table 10.1. Office Reference Building Characteristics

Item		Descriptions
Program		
	Vintage	PRE-1980 CONSTRUCTION
	Location (Representing 8 Climate Zones)	Zone 1A: Miami (Hot & Humid) Zone 3B: Las Vegas (Hot & Dry) Zone 4C: Seattle (Marine) Zone 5A: Chicago (Cold) Zone 7: Duluth (Very Cold)
	Available fuel types	gas, electricity
	Building Type (Principal Building Function)	Office
	Building Prototype	Large Office

Item		Descriptions
Form		
	Total Floor Area (ft^2)	200,000
	Building shape	
	Aspect Ratio	1.5
	Number of Floors	4
	Window Fraction (Window-to-Wall Ratio)	40%
	Window Locations	evenly distributed among four orientations
	Shading Geometry	none
	Azimuth	non-directional
	Floor to floor height (ft)	13
	Floor to ceiling height (ft)	9
	Glazing sill height (ft)	3.6
Architecture		
	Exterior walls	
	Construction	Concrete Block Wall
	U-value (Btu/h * ft^2 * °F)	Miami (Hot & Humid): 0.23 Las Vegas (Hot & Dry): 0.23 Seattle (Marine): 0.175 Chicago (Cold): 0.156 Duluth (Very Cold): 0.136
	Dimensions	based on floor area and aspect ratio
	Tilts and orientations	Vertical
	Roof	
	Construction	Insulation entirely above deck
	U-value (Btu/h * ft^2 * °F)	Miami (Hot & Humid): 0.10 Las Vegas (Hot & Dry): 0.10 Seattle (Marine): 0.085 Chicago (Cold): 0.072 Duluth (Very Cold): 0.06
	Dimensions	based on floor area and aspect ratio
	Tilts and orientations	horizontal
	Window	
	Dimensions	based on window fraction, location, glazing sill height, floor area and aspect ratio
	Glass-Type and frame	Hypothetical window with the exact U-factor and SHGC shown below
	U-factor (Btu/h * ft^2 * °F) SHGC (all)	Miami (Hot & Humid): U-1.22 SHGC-0.54 Las Vegas (Hot & Dry): U-1.22 SHGC-0.54 Seattle (Marine): U-1.22 SHGC-0.54 Chicago (Cold): U-0.62 SHGC-0.41 Duluth (Very Cold): U-0.62 SHGC-0.41

Item		Descriptions
	Skylight	
	Dimensions	NA
	Glass-Type and frame	NA
	U-factor (Btu/h * ft^2 * °F)	NA
	SHGC (all)	
	Visible transmittance	
	Foundation	
	Foundation Type	Slab-on-grade floors (unheated)
	Construction	8″ concrete slab with carpet covering
	Dimensions	based on floor area and aspect ratio
	Interior Partitions	
	Construction	0.5 in gypsum board + 0.5 in gypsum board
	Dimensions	based on floor plan and floor-to-ceiling height 2 ft^2 thermal mass per ft^2 floor area
	Air Barrier System	
	Infiltration	Peak: 0.84 cfm/sf of above-grade envelope surface area at 0.3 in. W.C. (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on)
HVAC		
	System Type	
	Heating type	Two gas-fired boilers
	Cooling type	Two water-cooled, electric, centrifugal chillers, each sized for 50% of the peak cooling load.
	Distribution and terminal units	VAV terminal box with damper and hot-water reheating coil
	HVAC Sizing	
	Air Conditioning	autosized to design day
	Heating	manual calculation
	HVAC Efficiency	
	Boiler	76%
	Chiller	Full load rated COP = 4.93
	HVAC Control	
	Thermostat Setpoint	73°F Cooling/71°F Heating
	Thermostat Setback	80°F Cooling/60°F Heating, no setback for computer server rooms
	VAV supply air temperature	55°F
	Chilled water supply Temperature	44°F
	Hot water supply temperature	180°F
	Condenser water supply temperature	80°F
	Economizers	No economizer (Miami, Hot & Dry) Economizer based on fixed dry bulb at 70°F (Las Vegas, Hot & Dry; and Seattle, Marine) Economizer based on fixed enthalpy at 24 Btu/lb (Chicago, Cold; and Duluth, Very Cold) Maximum 70% outside air due to lack of maintenance

Item		Descriptions
	Ventilation	Outdoor air dampers fixed at 15% open.
	Demand Control Ventilation	NA
	Energy Recovery	NA
	Supply Fan	
	Supply Fan Total Efficiency	About 42% including motor and drive
	Supply Fan Pressure Rise	6 in. W.C. for the whole fan system
	Pump	
	Pump Type	Constant speed pumps
	Rated Pump Head	69 ft (Chilled water pump) 50 ft (Hot water pump) 51 ft (Condenser water pump) 34 ft (Tenant server closet pump)
	Motor efficiency	88%
	Cooling Tower	
	Cooling Tower Type	Two open cooling towers with constant speed tower fan
	Cooling Tower Power	autosized
	Service Water Heating	
	SWH type	Storage Tank
	Fuel type	Natural Gas
	Thermal efficiency	80%
	Water temperature setpoint	120°F
	Water consumption	1000 gal/day
Internal Loads & Schedules		
	Lighting	
	Average power density	1.33 W/ft^2 in space area weighted average
	Daylighting Controls	NA
	Occupancy Sensors	NA
	Plug load	
	Average power density for spaces other than computer server rooms	0.75 W/ft^2
	Average power density for computer server rooms	25 W/ft^2
	Occupancy	
	Average people	Occupant density follows ASHRAE Standard 62.1-2004 Average 190 ft^2 per occupant
Miscellaneous		
	Elevator	
	Quantity	4
	Motor type	hydraulic
	Peak power per elevator	20 hp
	Exterior Lighting	
	Peak Power	33.6 kW

Simulation Approach

Building energy simulation was intensively used in this project to support the retrofit guide development. Due to its strong capability to model different HVAC systems and equipment, EnergyPlus version 6.0 was selected as the simulation program to assess and quantify the energy and cost saving potential for each individual energy efficiency measure. The quantified savings is then used together with the measure implementation cost for the cost-effectiveness analysis, which formed the basis to determine the EBCx, standard retrofit and deep retrofit packages. Each tiered package is further evaluated in terms of its energy saving and cost-effectiveness. Figure 10.1 shows the series of steps followed in this work to conduct the energy simulation for development of the guide.

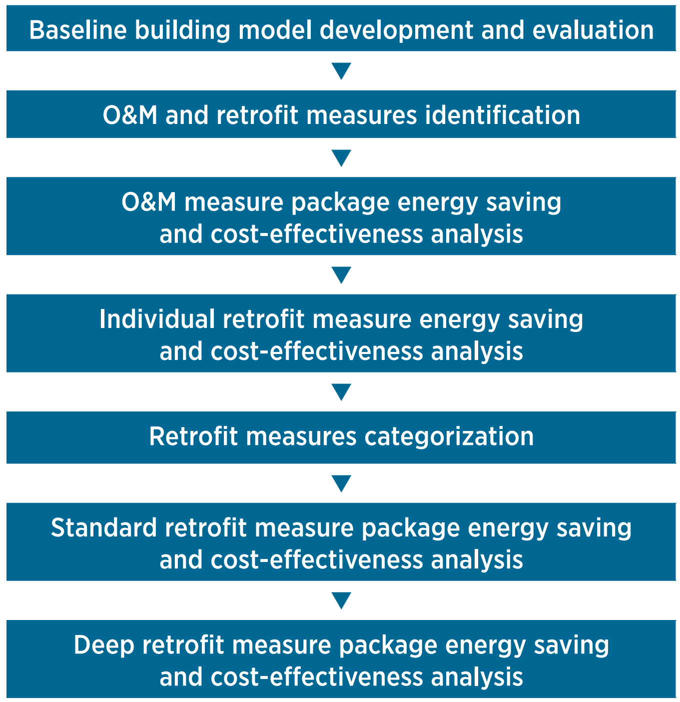


Figure 10.1. Workflow of Simulation Support for Retrofit Guide Development

Additional detail on these steps is provided here:

- *Baseline building model development and evaluation*. A baseline building model was developed as a first step. This model is based on the DOE reference model for large office buildings discussed previously (Deru et al., 2011) and the prototype building used to support 50% energy savings in large office buildings (Leach et al., 2010). Numerous adjustments were made to reflect the most common building design and operation practice for pre-1980 vintage buildings in each climate location. Only the large office building model was simulated to estimate the impact of implementing the measures.

- *O&M and retrofit measures identification*. Based on the defined baseline building model, the project team's past experience with O&M and retrofit measures implemented as part of EBCx and retrofit projects, and other resources[(1)], a list of potential O&M and retrofit measures was identified with specific improvements relative to the baseline assumptions. Most of the measures affect the interior and exterior lighting, plug and process loads, HVAC equipment and control, service hot water system, and building envelope. At this step, the measures were not distinguished with respect to the measure package that they belong to.

(1) Including ASHRAE (2011), IEA (2009), and U.S. Environmental Protection Agency (2008).

- *EBCx measure package energy savings and cost-effectiveness analysis*. The O&M measures that could be modeled in EnergyPlus were evaluated as a package to determine the energy savings potential from implementing an EBCx process in each of the five climate locations. Not all of the O&M measures were modeled with EnergyPlus simulation for two reasons: 1) some O&M measures may not result in energy savings; and 2) some building system operational faults or degradation cannot be accurately modeled in the EnergyPlus simulation program.
- *Individual retrofit measure energy savings and cost-effectiveness analysis*. Each retrofit measure was individually evaluated in terms of its energy savings and cost-effectiveness. With the commissioned building from the previous step as the reference, each individual retrofit measure was added to the building model to generate a new model for each measure. The new model and the reference model have the same hardcoded equipment size and settings such as supply fan maximum flow rate, chiller and boiler sizes, and minimum terminal box damper positions. Site energy consumption was obtained by running EnergyPlus for the new model. In addition, based on the predefined utility rates, EnergyPlus also calculated the energy cost, including both energy consumption cost and demand cost. The site energy difference between the reference and the new model is regarded as the energy savings for that measure. The peak demand savings is the difference in the annual peak demand between the reference and the new model. The energy cost difference is the annual energy cost savings. This energy cost savings is then used together with the estimated measure implementation cost to calculate cost-effectiveness metrics such as simple payback and net present value. Section 10.6 "Retrofit measures" provides the detailed results of each individual retrofit measure.
- *Retrofit measures categorization*. Based on the energy savings and the cost-effectiveness metrics for the retrofit measures from the previous step, retrofit measures were selected for development of the standard retrofit and deep retrofit packages. In general, the standard retrofit package includes relatively simple measures that are implemented for energy reasons, while the deep retrofit package includes measures where the equipment is assumed to be at the end of its useful life, the building is going through a major upgrade, or where the measures involve a substantial upgrade to the systems.
- *Standard retrofit measure package energy savings and cost-effectiveness analysis*. After the standard retrofit package was determined, its overall energy savings and cost-effectiveness was estimated as a whole in comparison with the original baseline. The package analysis takes into account the interactions between different measures. Hence, the packaged energy savings is not simply the sum of total individual measures. For the standard package, the capacity of equipment that was not directly affected by the measures included in the package stayed the same between the new model and the reference model.
- *Deep retrofit measure package energy savings and cost-effectiveness analysis*. Similar to the standard package, after the deep retrofit package was determined, its overall energy savings and cost-effectiveness was estimated as a whole in comparison with the original baseline. The package analysis takes into account the interactions between different measures. Hence, the packaged energy savings is not simply the sum of total individual measures. For the deep retrofit package, equipment capacities were changed between the new model and the reference model, to reflect the "deep" nature of the package (e.g., VAV box airflow rate settings). However, equipment that was not directly affected by the measures included in the package stayed the same between the new model and the reference model (e.g., chiller capacities).

10.2 Modeling Results Considerations

The estimated energy savings and costs of the energy efficiency measures included in this guide are based on energy simulation results from the EnergyPlus whole building energy simulation software program. The user-defined inputs of the model's pre-retrofit conditions are defined by a theoretical reference building with characteristics similar to common large office buildings in the U.S. For a detailed discussion of the reference building characteristics and modeling approach, see Appendix 10.1.

While the reference building reflects common existing office building characteristics, the multitude of building characteristic variables means there will inevitably be differences between the characteristics of the reference building and actual buildings. These differences can lead to different costs and energy savings results in the real world compared to the estimated costs and savings of the measures discussed in this guide. The cost and savings values in this guide should be used to gain a general idea of the cost-effectiveness of energy efficiency measures. For an actual building, costs and measures should be calculated separate from the values presented in this guide.

Some of the primary variables that will impact the baseline energy performance and measure energy savings of an actual building compared to the model's reference building include the following:

1) Outdoor climate

Outdoor climate conditions, including temperature, solar load, and humidity levels, are key variables that impact the expected energy savings and suitability of many of the measures. The five climate zones used to model the measures' energy savings represent a wide variety of climate conditions, but are not comprehensive. A rough approximation of measure savings for a building in a climate that seems to fall between two of the five represented climate zones could be estimated by taking the average of the savings associated with the two most similar climate zones.

2) Envelope thermal characteristics and geometries

Envelope building characteristics affect most O&M and retrofit measure savings by impacting the building's heating and cooling load, which results in an impact on the building's HVAC systems. A comparison of the reference building's envelope characteristics (see Appendix 10.1 for details) with an actual building's characteristics can help inform expected energy savings. Some of the key building characteristics that should be considered include:

- Building geometry and orientation, including:
  - Number of floors and distance from floor to floor
  - Floor plan aspect ratio
  - Percent window and skylight area
- Building envelope component thermal characteristics, including:
  - Roof insulation, reflectance, and thermal mass
  - Wall insulation and thermal mass
  - Window and skylight insulation, solar heat gain coefficient, visible light transmittance, shading devices, and frame type
  - Building air tightness

3) Building occupancy

The occupancy schedule, occupancy load, and type of occupancy of a building impact the amount of thermal heat added from human activity, which in turn impacts the load on the building's HVAC system. Occupancy schedule relates to when people are in the building, occupancy load is defined by how many people are in the building, and type of occupancy reflects the activity level and, thus, thermal heat output of each person. Each of these can have an impact on building energy performance. For example, buildings with reduced occupancy schedules may have lower cooling loads and increased heating loads compared to similar buildings with more typical occupancy schedules. Building occupancy can have an impact on the energy used by HVAC systems, due to its impact on space heating and cooling loads and building ventilation.

4) Internal equipment load

Also referred to as "plug loads," this end use includes energy-consuming devices such as office equipment and appliances. The power consumed by these devices has a direct impact on the energy used by a building, and this energy is also released to the space as heat, which translates to either a cooling load or a form of space heating. Computer server usage can also have a significant impact on building energy usage. While the floor area of computer servers may be relatively small, the high energy density of computer servers makes this equipment an important consideration in overall building energy usage.

5) Building HVAC system type

The type of HVAC system used can have a significant impact on building energy usage. Different types of HVAC systems will have varying levels of overall cooling and heating efficiency, at part load and full load conditions. Also, some HVAC systems such as the one used in the reference building have a certain amount of simultaneous heating and cooling associated with them, due to reheat required for maintaining acceptable ventilation.

6) Building equipment efficiencies and efficacies

This typically relates to building HVAC systems, but can also apply to other building systems. The higher the equipment efficiency, the less energy consumed (input) to produce the same amount of useful energy (output).

Efficacy typically refers to lighting, and is a measure of how much light is produced by a lamp for a given unit of power. Lamps with higher efficacy will draw less power to achieve the same resultant lighting level compared to lower efficacy lamps.

7) Operation of building equipment

In addition to the load, efficiency, and efficacy of building systems, their operating schedules and control strategies can also have a significant impact on total energy use. Variables to consider include:

- HVAC equipment operating schedule and equipment staging strategies
- Lighting operating schedule
- Temperature and pressure setpoints of HVAC system
- HVAC controls strategies used
- Amount of minimum ventilation air
- Lighting control strategies (e.g., occupancy sensors or manual on/off)

8) Equipment zoning

The layout of the lighting and HVAC zones can have an impact on overall energy usage. Smaller lighting zones give greater opportunity for shutting off lights when areas are not in use. The same concept holds true for HVAC zones – smaller zones are more suited for standby mode when zones are unoccupied. The depth of the perimeter zones is another factor that can influence energy usage.

The reference building was chosen as a representative "average" large office building. Actual building characteristics, including installed systems and components and their operating characteristics, may vary from these reference building characteristics, which can have an impact on building energy usage.

In general, if your building uses less energy than the reference building due to higher equipment efficiencies and higher envelope thermal performance, for example, you can expect reduced savings compared to the numbers presented in this guide. It's important to compare the reference building's characteristics to your building's characteristics, to get an idea of how applicable the measure costs and savings are for your situation.

10.3 Reference Climate Zone Characteristics

The following table can be used by building owners to compare the characteristics of their climate zone with the characteristics of the five represented climate zones in this guide. ASHRAE provides climatic information for most large cities in the United States. Climatic information for the five climate zones addressed in this guide is shown in Table 10-2 (ASHRAE, 2009b).

Table 10.2. Reference Climate Zone Characteristics

Climate Zone	Winter design temperature[1], °F	Summer design temperature[2], °F	Summer design humidity level, % RH	Annual heating degree days[3], °F-day	Annual cooling degree days[3], °F-day
Miami (Hot & Humid)	47.7	91.8	53%	130	4,458
Las Vegas (Hot & Dry)	30.5	108.3	11%	2,105	3,348
Seattle (Marine)	24.5	84.9	34%	4,729	177
Chicago (Cold)	-4	91.9	45%	6,311	842
Duluth (Very Cold)	-19.5	84.5	49%	9,425	209

[1] Reasonably expected minimum temperature. Winter design temperature = ASHRAE 99.6% Dry-Bulb (DB).

[2] Reasonably expected maximum temperature. Summer design temperature = ASHRAE 0.4% DB. Summer design humidity based on ASHRAE 0.4% DB/MCWB.

[3] Heating and cooling degree days are base 65°F.

10.4 Cost-Effectiveness Analysis Methodology

The economic analysis of retrofit measures is one of the most challenging topics to address in a guidebook, yet is absolutely essential for building owners or facility managers trying to develop a convincing business case for a retrofit project. This guide provides best practice methodologies for calculating both net present value (NPV) and simple payback period. We recognize that while NPV is the preferred metric because it better captures the full range of benefits and costs associated with an investment over time, simple payback remains the most well-established metric for quantifying the cost-effectiveness of energy retrofit projects. Simple payback is determined by dividing the initial investment (costs incurred at year 0) by the first year energy savings.

In this appendix, we address the economic analysis of retrofits measures in a much more practical manner than has been attempted in other retrofit guides. We provide methods for accurately quantifying multi-year 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, 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, tax credits, etc.) on multi-year cash flows. Indirect benefits such as productivity improvements and reduction in sick days are discussed qualitatively, but are not quantified in the cash flow analysis.

The recommended methodology described in this guide is applied to an example building, described in Appendix 10.1, resulting in the selection of building improvement packages for projects at three levels of improved energy performance (existing building commissioning, standard retrofit, and deep retrofit). The reference building is a representative low-rise office of pre-1980s vintage, developed by three DOE national laboratories for the purpose of evaluating the energy savings potential of new technologies and deployment initiatives (Deru et. al. 2011). The purpose of using this reference building is to illustrate the analysis and measure selection process in the context of a realistic scenario, and to provide the reader with some idea of the energy savings potential of the measures described in this guide. However, it is important to note that certain measures may be highly cost-effective in the reference building, but may be a very poor choice in a different situation. Age of equipment, cost structure, financing terms, tax incentives, local weather conditions, and system interactions can all have very large impacts on the cost-effectiveness of a particular measure.

Overall Net Present Value Calculation

As discussed in Section 2.6, "Business Case for Upgrading Building Performance," NPV is the financial analysis metric that best captures the full economic value of a retrofit measure or package of measures. NPV is an integral component of life cycle cost analysis, but we will limit our analysis to direct costs and benefits that impact a commercial building's typical budget. Societal and environmental costs will not be addressed, except to the extent they are reflected in taxes, financial incentives, purchase costs, and disposal costs.

The following general equation is used for NPV analysis in the context of a building energy retrofit project:

$$\text{NPV} = C_0 + \sum_{t=1}^{N} \frac{C_t}{(1+DF)^t} \quad \text{(A-1)}$$

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 was adopted for this particular study. This time period is longer than the useful life of most of the measures that will be evaluated, and provides a fair cut-off point for energy savings and other benefits associated with a measure. Predicting the cash flows beyond a 20-year timeframe would likely introduce unforeseen risks as significant modifications to a building or its use could occur beyond 20 years. These changes to the building and its operation could negate the effectiveness of certain retrofit measures. Finally, since cash flows beyond 20 years are significantly discounted in the NPV calculation, they no longer hold much weight in the analysis.

The appropriate discount factor 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. Based on an informal survey of typical building owners, a discount rate of 6.5% was adopted for the large office cash flow analysis.

Components of Multi-Year Cash Flows

There can be a large number of cash flows associated with a particular retrofit measure, both positive and negative. Positive cash flows represent net inflows of money, while 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 they 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 (i.e., adjusted for inflation).

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

Where:

C_{pur}	=	purchase cost of equipment, the "material" cost
C_{inst}	=	installation cost of measure/package, the "labor" cost
$C_{salv,ref}$	=	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 measures)

$$C_t = \left[C_{energy,elec,t}\times\left(R_{esc,elec}\right)^t + C_{energy,gas,t}\times\left(R_{esc,gas}\right)^t - C_{om} - C_{mv}\right]\times(1 - R_{tax,inc})$$
$$-C_{repl,eem} + C_{repl,ref} + C_{depr,eem,t} - C_{depr,ref,t} + C_{salv,eem,20} - C_{salv,ref,20} \quad \textbf{(A-3)}$$

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% (U.S. EIA, 2011b)
$R_{esc,gas}$	=	fuel price escalation rate for natural gas = 2.0% (U.S. EIA, 2011b)
C_{om}	=	additional O&M costs (negative if O&M savings)
C_{mv}	=	additional M&V costs (=0 for individual measures)
$C_{repl,eem}$	=	replacement cost for measure/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)
$C_{salv,eem,20}$	=	salvage value of measure (=0 except in year 20)
$C_{salv,ref,20}$	=	salvage 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.

Purchase Cost (C_{pur})

The purchase cost of the measure or package of measures includes the cost of equipment and associated materials. It does not include labor costs. Purchase cost for a particular product or piece of equipment is relatively consistent from project to project, but may still vary depending on the volume purchased, presence of local competition, and any negotiated purchasing agreements with suppliers. For our analysis, a professional cost-estimating firm was contracted to estimate purchase costs associated with each measure based on the building type (large office) and geographic location.

Installation Cost (C_{inst})

Unlike purchase cost, the installation costs associated with a measure 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 at night or on weekends to avoid disrupting building operations
- Hazardous materials must be removed or controlled (asbestos, mold)

The analysis for this guide assumes that none of these complications are present, and that typical installation costs apply.

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 most cases, we assume that equipment cannot be re-used, and the value of recyclable components (such as copper, aluminum, and glass) is approximately the same as the cost of hauling the equipment away.

Tax Benefits Associated with Disposing of Existing Equipment ($C_{tax,0}$)

If existing capital equipment is replaced before it is fully depreciated, the difference between the un-depreciated value of the equipment (or adjusted basis) and the salvage value (if any) is considered an operating loss, which can be deducted from corporate taxes. In subsequent years, the depreciation tax deduction that would have been available for the existing equipment is lost. $C_{tax,0}$ is equal to the net present value of these competing tax implications. However, for this analysis, the specific tax benefits from operating losses were not considered.

Financial Incentives (C_{incent})

Financial incentives from utilities or government entities can take many different forms, including rebates, subsidies, tax credits, accelerated depreciation, low interest loans, guaranteed loans, and free energy audits. 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 analysis, however, we do not include these incentives because they may come and go over time, and our intention is to identify packages of measures that pay for themselves strictly through energy cost savings.

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 a measure. 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 large compared to other costs associated with a project. For the example analysis, we estimated disposal costs using professional cost estimators.

Project Planning (C_{plan})

Overall project planning includes all of the preparatory work conducted by the building owners and design team prior to the selection of measures that will be implemented. 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 for standard retrofit projects:

- 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
- For deep retrofit projects, there is typically an added expense related to the associated design effort. Deep retrofit projects involve an integrated design process, usually involving an architect and engineering disciplines, to design the retrofits from a whole building perspective, to minimize resultant energy use.

For the example analysis, we used a project planning cost of 10% of the total initial construction cost for the deep retrofit packages, based on values shown in RS Means Building Construction Cost data. We did not include project planning costs for the standard retrofit packages, assuming that these costs could be absorbed in-house.

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

Energy savings can be difficult to calculate without using a sophisticated modeling tool. Even straightforward measures such as lighting improvements have large interactions with space conditioning energy. As a result, we do not recommend using oversimplified techniques to quantify energy savings 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 for selecting the right tool. If in-house expertise is not available to conduct a comprehensive energy cost savings analysis, consider contracting with a third party firm. The identification of energy savings opportunities and associated energy and cost saving estimates are commonly included in energy audits or existing building commissioning (EBCx) projects.

Annual electricity cost savings includes reductions in both energy use (kWh) and peak demand (kW). Natural gas cost savings is based simply on the reduction in 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 utilized for the purpose of calculating electricity cost savings. If actual utility rates cannot be found, estimated energy prices for each state are published by the U.S. Energy Information Administration (EIA) (http://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. Our assumption for the analysis is that comprehensive O&M and M&V protocols are implemented to ensure that the performance of new equipment is sustained. The cash flows associated with O&M and M&V are consistent with this assumption. The energy savings for a retrofit project can also diminish over time because 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 five years of useful life remaining, we can expect that boiler to be replaced in five years by a new boiler with combustion efficiency greater than 80%, as required by the Federal equipment standards. As a result, the energy savings for a boiler retrofit measure would diminish in five years because the energy use for the reference building would have decreased anyway.

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 (http://www.eia.gov/forecasts/aeo/). Fuel price escalation rates should not include the effect of inflation. All values in the cash flow analysis should be in base year dollars.

In the example large office analysis, EnergyPlus software was used to calculate energy savings for each relevant measure and for each package of measures 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 (http://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 (http://www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf). A more comprehensive overview of the modeling approach is presented in Appendix 10.1.

Table 10.3. Energy Cost Rates for Reference Cities

Criteria	Miami (Hot & Humid)	Las Vegas (Hot & Dry)	Seattle (Marine)	Chicago (Cold)	Duluth (Very Cold)
Marginal Electricity Rate ($/kWh)	$0.0539	$0.0673	$0.0650	$0.0840	$0.0831
Demand Charge, Summer ($/kW)	$11.05	$19.23	$5.76	$5.75	$4.87
Demand Charge, Winter ($/kW)	$11.05	$0.50	$8.65	$5.75	$4.87
Duration of Summer Demand Rate (months)	6	4	6	4	6
Gas Rate ($/therm)	$1.0240	$0.9510	$0.9835	$0.8650	$0.7774
Energy Tax Rate	8.0%	8.0%	8.5%	8.0%	6.0%

Additional O&M Cost (C_{om})

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

A maintenance escalation rate may be applied to O&M costs in future years. In general, this rate is not much higher than the inflation rate, and the effect is small compared to the uncertainty in projecting future O&M costs. We do not recommend using a maintenance escalation rate unless O&M costs are very well defined.

For simplicity, we include what is sometimes referred to as repair and replacement (R&R) costs in the O&M category. Replacements in this category should be limited to components or elements of each measure, not replacement of the entire measure.

For the example building analysis, professional cost estimators provided the relative O&M costs for each measure. In some cases, there was no basis for assuming any change to O&M costs, and a value of zero was used.

Additional M&V Cost (C_{mv})

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

For the example analysis, we assigned M&V costs to packages of measures as a whole. Consequently, we used a value of zero for C_{mv} when evaluating the NPV of individual measures. For the standard retrofit and deep retrofit packages, we assumed that annual M&V costs are equal to 10% of the estimated annual energy cost savings.

Replacement Cost for Measure ($C_{repl,eem}$)

It should be assumed that each measure is replaced at the end of its useful life with a system of the same design and efficiency. In some cases, replacement cost may be much less than the original installation cost because the infrastructure is already in place and there are records of specific components, vendors, and procedures that were used the first time. In other cases there may be very little difference in cost.

The useful life can be estimated for most common measures 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 measures. Estimated useful life estimates for other measures, including envelope, domestic hot water, lighting, and refrigeration, can be found in life cycle cost analysis guidance published by the State of Washington General Administration (www.ga.wa.gov/eas/elcca/simulation.html). Recommended replacement schedules for most building components 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 our example analysis, which assumes a 20 year analysis period. Most energy efficiency measures that involve mechanical or electrical equipment are replaced at least once during that time period. Envelope measures usually last longer.

Replacement Cost for Reference Case ($C_{repl,ref}$)

In order to correctly evaluate net cash flows associated with a measure, a realistic reference case must be developed for comparison. This reference case must include the equipment replacements and upgrades that would have occurred if the measure was 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 may be a significant upgrade over the existing equipment, due to improvements in technology and updates to energy codes with higher efficiency requirements.

Typically, existing 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.

In some cases, equipment may be considered at the end of its useful life because it is broken beyond repair, or there are building modifications underway for non-energy 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 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.

For our analysis of individual retrofit measures and for the standard retrofit packages, we assumed that all equipment is 50% through its useful life. We used the State of Washington service life estimates to determine the original useful life for existing equipment. For the deep retrofit packages analyses, we assumed that any equipment replaced as part of the packages is at the end of its useful life.

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

The vast majority of energy efficiency measures discussed in this guide are capital expenditures that can be depreciated over a number of years for tax purposes, assuming the building owner is a for-profit entity. The depreciable basis for such measures includes both the purchase cost and the installation cost of the equipment. The use of the Modified Accelerated Cost Recovery System (MACRS) is required by the Internal Revenue Service for most categories of equipment. Certain measures may be treated as operating expenses and deducted immediately, including O&M measures and equipment with a useful life of less than one year.

If 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. The net present value can be reduced by the corporate tax rate (usually 35%) to approximate the overall effect of taxes on the investment.

Salvage Value of Measure and Reference Equipment at the End of the Analysis Period ($C_{salv,eem,20}$ and $C_{salv,ref,20}$)

At the end of the 20-year analysis period, both the measure and the equipment in the reference building are likely to have some remaining salvage value. In order to produce a fair estimate of net present value, the 20 year value of both the measure and reference equipment is calculated based on straight-line depreciation. The difference between the depreciated values of the equipment at the end of the analysis period is included in the year 20 cash flow. No capital loss or gain tax benefits were included at the end of the analysis period.

Approach to Costing Measures

A key input to the cash flow analysis for each measure and recommended package was the estimated current installation and equipment costs. This “costing” exercise was carried out through the following approach.

Measures were priced in January 2012 dollars. Each was priced as if they were to occur separately (except as noted). The pricing was based on the Seattle metropolitan geographic region and then normalized to the other reference cities (Miami, Las Vegas, Chicago, and Duluth) using the RS Means City Cost Indexes from the 2010 Edition of RS Means Building Construction Cost Data.

Pricing was based on outside contractors performing the work in a competitive bid environment at prevailing or union wage, not via a service contract or physical plant staff. In order to account for hoisting, demolition, architectural repairs, on-site supervision and other potential soft costs, a 20% multiplier was added to the direct work total for all measures. It was assumed that the work would be performed during normal working hours and that the crews would have adequate access to the work zones in a manner that would allow normal work flow.

Any new equipment is assumed to fit within the existing physical space allowed without structural or architectural changes. Temporary systems, workarounds and shutdown impacts cannot be accurately quantified without knowledge of the operations of each building and are excluded. Furthermore, any code, seismic or fire life safety upgrades that may be triggered by the type or valuation of the work of the measure are excluded from this study.

10.5 O&M Measures

The following section includes a technical description and special considerations for each O&M measure investigated in this guide.

O&M Measure Index

LIGHTING O&M MEASURES

L1. Calibrate Exterior Lighting Photocells

Technical Description

Exterior lighting typically only needs to operate during the night. However, lights that are manually switched can accidentally be left on, and lights that operate based on a time clock do not account for varying sunrise and sunset times. Photocell lighting control tailors the lighting operating schedule to the specific needs of the area by operating the lighting only when needed – at night (Wulfinghoff, 1999).

Photocells that are out of calibration could be causing energy waste or unsafe conditions. If the lights are operating beyond nighttime hours, when they don't need to be operating, energy is being wasted. If the lights are not operating enough during nighttime hours, this could result in unsafe conditions due to under lit spaces. To maintain proper operation, the photocells should be cleaned and calibrated periodically.

Measure Special Considerations

When calibrating the photocells, make sure that they are mounted in representative locations, out of direct sunlight and away from the effect of other light sources.

BUILDING ENVELOPE O&M MEASURES

E1. Replace Worn out Weather Stripping at Exterior Doors

Technical Description

Weather stripping helps to reduce the amount of outside air infiltration into the space between the door and the frame. Over time, this weather stripping develops gaps due to normal wear and tear. By replacing worn out weather stripping, energy savings can be realized due to reduced infiltration and, thus, reduced load on the building HVAC equipment (Wulfinghoff, 1999).

Measure Special Considerations

When selecting weather stripping, each of the four sides of a door should be considered. There are different types of weather stripping for different types of door/frame combinations.

E2. Reduce Envelope Leakage

Technical Description

Air leakage through the building envelope most often occurs where building envelope elements are connected together. Leakage is typically a result of either improper design or construction, lack of maintenance, or normal degradation over the life of a building (Wulfinghoff, 1999). Envelope leakage is most pronounced when the HVAC system is off, i.e., when the building is not mechanically pressurized. Significant nighttime air leakage causes the HVAC systems to operate harder upon morning start-up, to bring the building back to temperature.

Energy savings can be achieved by identifying significant air leaks in the building envelope and sealing them. Specific methods of sealing will vary depending on the component(s) being sealed. In general, large gaps should be sealed with structural material before applying caulk. Tools to help identify air leaks include as-built drawings and an infrared camera.

Measure Special Considerations

For office buildings, common areas of air leakage include curtain wall structures, soffits, roof-to-wall joints, expansion joints, parapet flashing, and roof penetrations (Wulfinghoff, 1999).

Air leakage can affect occupant comfort, HVAC system performance, window and door performance, and building energy usage.

HVAC – AIRSIDE O&M MEASURES

HA1. Revise Air Filtration System

Technical Description

Many large built-up air handling systems include both pre-filters and final filters for cleaning the air before it is supplied to the zones. The pre-filters are installed to extend the life of the final filters, yet typically they do not achieve this since it's easy for dust to pass through and around the pre-filters. In addition, the pre-filters impose significant additional pressure drop and maintenance costs. Extended surface area filters are now available that can replace both the pre-filter and final filter. These extended surface filters have a long life (high dust holding capacity) and low pressure drop characteristics. Both maintenance (labor) and energy savings can be achieved by using these types of filters (Taylor, 2007).

Measure Special Considerations

Extended surface filters typically cost more than pre-filters or final (bag) filters. However, their longer life and low pressure drop often make them cost-effective.

For simplicity, many facilities change their filters on a routine schedule, e.g., every six months, instead of monitoring pressure drop across the filters and changing them when the pressure drop reaches a certain level. With this scheduled approach, it's important to check the pressure drop at the time of change out. If it's at or above the manufacturer's recommended maximum pressure drop, it may be worth changing the filters more frequently to maintain filter performance and realize energy savings. If it's well below the manufacturer's recommended maximum pressure, it may be worth leaving them in longer to save on filter replacement costs (material and labor) (Taylor, 2007).

HA2. Increase Duct System Efficiency

Technical Description

For all-air HVAC systems, duct system efficiency can have a significant impact on energy usage. Duct system inefficiencies are typically "invisible" energy wasters, meaning that the issues aren't readily apparent to occupants or building operators; the HVAC system just has to work harder to overcome these inefficiencies. Examples of typical duct system inefficiencies include:

- Leaky ductwork
- Excessive sharp elbows in duct system
- Excessive use of flexible ductwork

Duct systems can be periodically evaluated and tested to identify inefficiencies and determine corrective action. Aerosol duct sealing technology is available to seal relatively small gaps in ductwork without the need for accessing each gap. When excessive sharp elbows in the ductwork are unavoidable due to space constraints, the installation of turning vanes can help reduce pressure drops. Replacing flexible ductwork with solid ductwork, especially for long lengths of duct runs, will reduce the overall system pressure drop.

Measure Special Considerations

By their nature, systems with minimal ductwork (e.g., rooftop HVAC units with supply outlets and return inlets directly below the unit) have a low amount of duct system losses. However, for systems serving multiple floors that have long lengths of supply ductwork, the duct system should be periodically inspected for leaks and other inefficiencies.

HA3. Calibrate Air Sensors

Technical Description

HVAC systems rely on input from sensors to determine how to operate. However, these sensors can drift out of calibration over time. Sensors found in typical HVAC systems can include, but aren't limited to, temperature, pressure, and flow sensors. If these sensors are not calibrated - i.e., if the value being reported by the sensor does not match the actual condition – this could negatively impact equipment performance and occupant comfort, and could result in energy waste due to simultaneous heating and cooling. Calibrated sensors are necessary for automatic control sequences to operate properly, and for accurate diagnoses of system performance (PECI, 2006).

This measure consists of developing and implementing a sensor calibration plan. In general, sensor calibration consists of comparing reported sensor readings (e.g., at the BAS) with readings from a calibrated device, and taking corrective action where there's a significant difference between the two readings. Corrective action might include simple offsets or multipoint calibrations to align the readings. If the sensor is significantly out of calibration, replacement may be necessary.

Measure Special Considerations

Large office buildings typically include many HVAC sensors, at the central equipment as well as the occupied spaces. It's usually most effective to concentrate on calibrating the key sensors first, namely those that are used as global inputs for multiple control sequences. For example, if the supply air temperature setpoint is reset based on outside air temperature, then it's important to ensure that the outside air temperature sensor is calibrated and located in a representative location.

HA4. Re-enable Supply Air Temperature Setpoint Reset

Technical Description

For multi-zone air systems, whether CAV or VAV, automatically changing the supply air temperature setpoint to better match the needs of the zones is typically more energy efficient than maintaining a constant setpoint, due to reduced amount of zone reheat (simultaneous heating and cooling). The supply air temperature setpoint is typically reset based on either outside air temperature or an indication of zone demand - e.g., average difference between zone temperature and zone temperature setpoint (Wulfinghoff, 1999).

Measure Special Considerations

Care should be taken when implementing this measure to verify that internal zones receive enough cooling at higher supply air temperatures. While significant reheat energy can be saved by implementing this measure, there is usually a slight increase in fan energy usage due to internal zones requesting more airflow at the higher supply air temperatures to maintain space conditions (Wulfinghoff, 1999). This fan energy penalty should be weighed against the reheat energy savings.

HA5. Reduce HVAC Equipment Runtime, Close Outside Air Damper During Unoccupied Periods

Technical Description

The maximum energy savings related to an HVAC system can be achieved by shutting the system off when not in use to minimize run time. While equipment scheduling is relatively simple to implement, reducing excessive runtime is one of the most common opportunities implemented as part of an EBCx process (Effinger, 2009). This measure reduces the scheduled operating hours of the HVAC system, including fans, pumps, chillers and boilers, to more closely match the occupancy of the building.

In addition, many HVAC fan systems operate with the outside air damper open whenever the fans are operating, even during morning warm-up and cool-down periods, prior to the occupied period. Energy consumption can be reduced by closing the outside air damper during non-economizer operation in unoccupied hours. This feature eliminates the energy associated with cooling and heating outside air when ventilation is not required.

Measure Special Considerations

If operating schedules are adjusted to accommodate a temporary event, the control system should be set up to automatically revert the operating schedule back to the original schedule once the after-hours event has passed.

Many office buildings have their HVAC systems start a bit earlier than usual on Monday mornings, to give the system time to bring the building back up to temperature from the weekend (when the HVAC system is off).

HA6. Remove Unused Inlet Guide Vanes from Supply Fan Inlet

Technical Description

Inlet guide vanes (IGV) are one method of varying airflow for VAV systems. They are a series of dampers installed in a radial fashion at the inlet to the supply fan. Their position is modulated to maintain a setpoint such as duct static pressure. As the inlet vanes close, fan power is reduced. This method of control was common in the past, but has been replaced by VFDs as the preferred method of fan speed control since VFDs draw even less power than IGVs at part load conditions.

Many facilities have upgraded their supply fan speed control from IGVs to VFDs. Some of these facilities have left their IGVs in place, though, in a fixed open position. Since the IGVs offer resistance to the air, even in a fixed open position, energy savings can be achieved by removing these abandoned IGVs and sealing any resultant holes in the fan inlet cone.

Measure Special Considerations

In installations that have sub-optimal inlet conditions, e.g., an elbow right at the inlet to the fan, the fixed open IGVs can actually help straighten the air before it enters the fan. For most supply fan installations in commercial buildings, though, removal of the IGVs will result in energy savings. Even for those that have sub-optimal inlet conditions, those conditions should be rectified to allow for proper inlet conditions.

HA7. Reduce Economizer Damper Leakage

Technical Description

An airside economizer cycle utilizes outside air for cooling a facility when conditions are right – namely, when the outside conditions are cooler than inside conditions. Economizer cycles reduce the amount of mechanical cooling energy necessary for cooling a facility. During integrated airside economizer cycle operation, when the outside temperature is cooler than the indoor temperature yet warmer than the supply air temperature necessary for cooling the space, the outside air dampers are fully open and the return air dampers are fully closed. If the return dampers are leaky, meaning if they don't have blade and jamb seals and/or they are not adjusted to close fully when commanded to do so, the effectiveness of the economizer cycle is reduced and more mechanical cooling is required than would be necessary if the dampers leaked less (Doty, 2009).

Some HVAC systems include a morning warm-up/cool-down cycle. During this cycle, the space is cooled or heated to address the heat gained or lost during the night (unoccupied period). Typically this cycle occurs prior to the start of the occupied period, and the minimum outside air dampers remain closed during this period. If these dampers are leaky, more outside air would be drawn in than is necessary, adding an unnecessary load on the HVAC system.

Minimizing the air leakage through closed outside and return air dampers can reduce HVAC system energy use during integrated economizer operation and morning warm-up/cool-down cycles.

Measure Special Considerations

To maintain the energy benefits associated with airside economizer and morning warm-up/cool-down cycles, periodic functional testing of the dampers can be performed to verify that the dampers are operating correctly, and that leakage is minimal when the dampers are closed.

While many economizer cycle systems are temperature-based, as described in 'Technical description' above, some are based on enthalpy, especially for facilities located in more humid environments. Enthalpy-based economizer controls will incur the same energy impacts as temperature-based controls when the dampers leak.

HA8. Implement a Night Purge Cycle

Technical Description

A night purge cycle is a method of cooling the building at night using 100% outside air (no mechanical cooling), to pre-cool the building for the next day. The night purge cycle typically compares outside air temperature to average indoor temperature, and operates for a couple of hours just before the occupied period when the conditions are beneficial.

In addition to saving mechanical cooling energy, night purge cycles can also reduce the building's peak demand, which may be desirable in areas that have high electric peak demand charges.

Measure Special Considerations

A night purge strategy is only effective for buildings with high thermal mass that are unoccupied at night, in climates with warm daytime temperatures and cold nighttime temperatures. The night purge cycle is beneficial only during this narrow set of outside air conditions. It's most effective in dry climates, such as the Southwest.

For VAV systems, the terminal units should be fully open when the night purge cycle operates (Wulfinghoff, 1999).

HVAC – WATERSIDE O&M MEASURES

HW1. Inspect Chiller and Cooling Tower, Clean as Needed

Technical Description

Chillers and cooling towers need to be inspected and cleaned regularly in order to maintain the performance of this equipment. Chiller evaporator and condenser tube bundles are prone to fouling, which can increase energy consumption due to lower heat transfer effectiveness. They should be inspected and cleaned regularly. Evaporator tubes should require fewer inspections since this is a closed system with less potential for contamination.

Open-loop cooling towers, which are common for water-cooled chilled water systems in office buildings, can gather contaminants from the water spray and foul the chiller's condenser tubes, if not treated properly. Fouling reduces the heat transfer effectiveness which can increase energy use as a result. Chemical treatment and bleed help eliminate biological fouling. Other areas to regularly inspect include the intake and fan guard screens, drift eliminators, water distribution nozzles, sumps, and condenser water strainers (Wulfinghoff, 1999).

Measure Special Considerations

Closed-loop and open-loop cooling towers each require periodic inspection and maintenance, but require different strategies. Open-loop towers are open to the air, as the name implies, and typically have more maintenance needs than closed-loop systems.

HW2. Test and Fix Chilled and Heating Water Coil Valves

Technical Description

Water control valves are a common component of a facility's HVAC system. These valves are typically either open/closed, or modulating. Chilled and heating water systems usually include water control valves as a means of varying flow through a heat exchanger (coil) in response to demand. The actuators for these valves should have sufficient seating force to close the valve completely when commanded to do so against the system's pressure. Over time, valves and actuators can degrade to the point that they are no longer capable of closing completely. When this happens, a small amount of water can leak by to the coil, and this can create an unnecessary heating or cooling load on the system which results in energy waste (Doty 2009). More specifically, simultaneous heating and cooling could be taking place. Periodically testing the valves and actuators can identify leaky valves, and corrective action can then be determined and conducted to eliminate the related energy waste (PECI, 2006).

Measure Special Considerations

Periodic functional testing of valves can be performed as part of a facility's preventive maintenance program. If there are a large number of valves in a facility, it may be prudent to focus on testing the larger valves and test a portion of the smaller valves over time so that each smaller valve is tested every five years or so.

Building automation systems can be programmed to perform automated functional testing of valves. This strategy employs a set of rules programmed into the BAS that are used during automated periodic testing of the valves. With this strategy, there must be a sufficient number of temperature sensors, and these sensors should be calibrated on a regular basis for accurate diagnosis of system performance (Welsh, 2009).

HW3. Inspect and Repair Damaged Pipe Insulation

Technical Description

Pipe insulation helps reduce the amount of thermal conduction through the walls of the pipe inherent with heated or cooled water flows. Damaged pipe insulation can increase the thermal conduction through the pipe walls and thus the load on the heating or cooling plant. Pipe insulation also helps to protect workers from high-temperature piping. Damaged insulation can be a safety risk for workers (Doty, 2009). Periodic inspection of pipe insulation, especially in high traffic areas or areas that are prone to abuse, can keep energy costs down as well as protect workers from unsafe conditions.

Measure Special Considerations

Inspection of pipe insulation can be included as part of a facility's preventive maintenance program.

HW4. Calibrate Water Sensors

Technical Description

HVAC systems rely on input from sensors to determine how to operate. However, these sensors often drift out of calibration over time. Typical waterside sensors can include temperature, pressure, and flow sensors, to name a few. If these sensors are not calibrated – i.e., if the value being reported by the sensor does not match the actual condition – this could negatively impact equipment performance and occupant comfort, and could result in energy waste due to simultaneous heating and cooling. Calibrated sensors are necessary for automatic control sequences to operate properly, and for accurate diagnoses of system performance (PECI, 2006).

This measure consists of developing and implementing a sensor calibration plan. In general, sensor calibration consists of comparing reported sensor readings (e.g., at the BAS) with readings from a calibrated device, and taking corrective action where there's a significant difference between the two readings.

Measure Special Considerations

Office buildings typically include many water HVAC sensors. It's usually most effective to concentrate on calibrating the key sensors first, namely those that are used as inputs for high-impact control sequences. For example, if chillers are staged based on measured chilled water flow, then it's especially important to regularly calibrate the chilled water flow sensor to maintain performance, equipment reliability, and energy efficient operations.

HW5. Re-enable Chilled Water Supply Temperature Setpoint Reset

Technical Description

Chillers operate more efficiently at higher chilled water supply temperatures. Systems that hold the chilled water supply temperature at a low, constant value, e.g., 44°F, typically can realize energy savings by raising the chilled water supply temperature during periods of low cooling load. The chilled water supply temperature setpoint can be raised either manually or automatically. Automatic reset is usually the preferred strategy, if implemented properly, as it can continually determine the optimal chilled water supply temperature setpoint that will minimize energy use while maintaining zone comfort conditions (Wulfinghoff, 1999).

Measure Special Considerations

In climates with high summertime humidity, the chilled water supply temperature may need to stay somewhat low in order to allow the air handlers to dehumidify. Automatic reset strategies can be programmed to account for this.

While significant chiller energy can be saved by implementing this measure, there may be a slight increase in pumping energy usage in variable flow chilled water systems. However, typically more energy is saved in the chiller than is lost in the pumps with this measure (Wulfinghoff, 1999).

HW6. Shut Down Cooling Plant When There's No Cooling Load

Technical Description

Facilities often run their cooling plants continuously during occupied periods of the cooling season. This includes the chiller, cooling tower, and related pumps. Operators may start and stop the plant manually. However, there may be periods during the cooling season when the plant does not need to run, especially when airside economizer cooling is used at the air handlers, e.g., during the morning, when outside air temperatures may be cold enough to cool the building sufficiently.

Operating the cooling plant when it's not needed wastes energy in a number of ways: at the pumps, at the primary cooling equipment (chiller compressors) due to false loading of the chillers, and at the heat rejection equipment (cooling tower fans, condenser fans) due to rejection of waste heat picked up from the distribution system (e.g., through the walls of the piping). If there is a space that requires continuous cooling, even after hours, it may be more efficient to install a small cooling system to serve this space, and turn off the larger plant (Wulfinghoff, 1999).

Automatic controls can be added to turn off the entire cooling plant when cooling is not needed in the facility during occupied hours. Two common automatic methods include:

- Outside air temperature or enthalpy-based lockout. When the temperature or enthalpy drops below a certain value, turn off the cooling plant.
- Enable plant based on the cooling demand. When there is no demand (e.g., all air handler cooling coil valves are closed), turn off the cooling plant. Turn it back on when there is sufficient demand. Adequate time lags and proper trigger points need to be programmed with this strategy to prevent the plant from cycling on and off excessively.

Measure Special Considerations

Before implementing this measure, first make sure that the cooling plant is not operating after hours. This is typically easier to implement than cooling plant shutdown during occupied hours, due to greater building operator buy-in.

For facilities with multiple chillers, the chiller staging strategy can have a large impact on the energy consumption of the plant. It's often beneficial to shut off chillers at low load, to reduce pumping energy consumption and increase chiller efficiency. Each facility is different, and will have its own optimal chiller staging strategy. BAS software overlays are available that will continually optimize the performance of a chilled water plant (Hartman, 2001).

In addition to energy savings, this measure should result in increased equipment life due to less run hours for the cooling plant.

OTHER O&M MEASURES

O1. Implement Daytime Custodial Services

Technical Description

Traditionally, office space cleaning activities occur at night, when the building is unoccupied, to minimize disruptions to the occupants. Shifting some or all of the cleaning activities to normal business hours as part of an overall green cleaning program can reduce energy costs due to reduced nighttime lighting and HVAC system operation (BOMA, 2009).

Measure Special Considerations

Occupant disruptions should be considered when shifting cleaning activities to normal business hours. For some facilities, all of the cleaning activities can occur during normal business hours. Others may elect to use weekday daytime cleaning services for the common areas (e.g., restrooms and lobby) and keep the cleaning of private office areas as a nighttime activity, to minimize disruption.

ADDITIONAL O&M MEASURES FOR SMALL AND MEDIUM SIZED OFFICE BUILDINGS

Many of the previously described O&M measures apply to the typical built-up equipment and systems found in average large office buildings. Small and medium sized offices usually use simpler systems, such as unitary (packaged) HVAC equipment. The remaining O&M descriptions include specific measures that might apply to the HVAC equipment found in most small and medium offices.

Clean Cooling and Heating Coils, and Comb Heat Exchanger Fins

Technical Description

The efficiency of HVAC components such as evaporator and condenser heat exchangers eventually degrades as the coils are blocked by debris, corrosion or damage to heat exchanger fins. Blocked coils reduce the overall system efficiency by restricting both heat transfer and air flow. Removing the flow restrictions by periodically cleaning the coils and straightening (combing) damaged heat exchanger fins will restore the system efficiencies to normal (Wulfinghoff, 1999).

Measure Special Considerations

This measure is relatively simple to implement and should require minimal costs and time investments if the applicable coils are relatively accessible. This work should be included in a facility's preventive maintenance tasks, and done on an annual basis. Otherwise, the coils will likely return to their blocked state within a year after they are cleaned.

In addition to increased cooling and heating efficiency, supply fan efficiency may increase with this measure when associated fans are equipped with VFDs. The measure would allow the fans to operate at a lower speed to maintain the desired airflow.

Repair Airside Economizer

Technical Description

An airside economizer cycle utilizes outside air for cooling a facility when conditions are right – namely, when the outside conditions are cooler than inside conditions. Economizer cycles reduce the amount of mechanical cooling energy necessary for cooling a facility. For rooftop units, the economizer cycle operates as the first stage of cooling if outside conditions are cool enough. Some economizer systems can operate in "integrated economizer" mode, meaning that mechanical cooling is allowed even if the outside air dampers are open 100%.

Airside economizer dampers are prone to failure, especially in packaged rooftop units. Oftentimes the result of their failure is higher-than-necessary energy bills, so the failures are commonly overlooked or not detected. They can fail due to lack of maintenance, failed control components, or improper control sequences. A study found that 64% of installed rooftop units have failed economizers (Jacobs, 2003). Restoring the proper operation of economizer dampers can result in significant energy savings.

Measure Special Considerations

To maintain the energy benefits associated with airside economizer, periodic functional testing of the dampers can be performed to verify that the dampers are operating correctly, and that leakage is minimal when the dampers are closed.

Correct Refrigerant Charge

Technical Description

Data from 74 commercial rooftop units in California have shown that nearly half of the systems are operating with an incorrect refrigerant charge (Jacobs, 2003). Improperly charged units can negatively impact the unit efficiency by as much as 20%. This measure involves restoring the refrigerant charge to the recommended level.

Measure Special Considerations

Check for any leaks in the system and repair as part of this measure, otherwise the benefits from correcting the refrigerant charge will not persist for very long.

Improper refrigerant charge may increase cooling energy consumption by as much as 5-11% (NBI, 2004).

10.6 Retrofit Measures

The following section includes a technical description, special considerations, energy savings results, and financial analysis results for each retrofit measure investigated in this guide.

The costs and savings analysis of the following retrofit measures are based on an assumed equipment condition in the reference building. Each measure was analyzed independently based on the assumption that the equipment was replaced or enhanced before the end of its useful life in order to save energy by installing more efficient equipment.

As such, many of the individual Net Present Value (NPV) results are negative. However, a negative NPV for an individual measure does not necessarily indicate a lack of cost-effectiveness for all situations. Differences between the reference building used to model the energy savings for this guide and actual building's equipment types, labor rates, financial assumptions such as a specific discount rate, availability of financial incentives and synergies between individual measures may produce significantly different results than those reported here.

Identifying potential synergies between measures or processes can improve the cost-effectiveness of a project. For example, many of the low cost O&M measures identified through an EBCx process may offset the installation of a less cost-effective retrofit or package of retrofits, while still maintaining a positive NPV for the entire project and realizing significant energy savings.

Retrofit Measure Index

LIGHTING RETROFIT MEASURES

PLUG & PROCESS LOAD RETROFIT MEASURES

BUILDING ENVELOPE RETROFIT MEASURES

HVAC - AIRSIDE RETROFIT MEASURES

HVAC - WATERSIDE RETROFIT MEASURES

SERVICE HOT WATER RETROFIT MEASURES

OTHER RETROFIT MEASURES

ADDITIONAL RETROFIT MEASURES FOR SMALL AND MEDIUM SIZED OFFICE BUILDINGS

LIGHTING RETROFIT MEASURES

L2 - L5. Retrofit Interior Fixtures to Reduce Lighting Power Density

Technical Description

Overhead interior lighting accounts for a significant portion of overall energy use in a typical office building. Utilizing more energy efficient lighting technologies to reduce the amount of energy devoted to the lighting end-use can result in significant whole building energy savings.

Available lighting efficiencies have steadily increased over the last few decades. Minimum efficiencies prescribed in building energy codes and federal regulations are frequently increased to keep pace with these improved efficiencies.

Measure Special Considerations

When evaluating lighting technologies, other factors should be considered in relation to cost besides energy savings and first cost. These include:

- Human productivity. The new lights should provide at least the same level of quality as the existing lights.
- Lamp replacement frequency and costs, including labor costs.

A lighting retrofit requires lighting design to achieve appropriate illumination with minimal energy usage. The design should evaluate the existing lighting system in terms of lighting orientation, layout, type, and control. It should evaluate each activity area and fixture individually, accommodate future changes in activities and space layout, and stress visual quality (Wulfinghoff, 1999).

An efficient lighting system consists of efficient lamps, fixtures, control, and light path. All four of these should be considered as part of lighting design for a retrofit.

Technical Assumptions for Implementing Measure in Reference Building

The lighting system for the baseline reference building consists primarily of overhead linear direct/indirect fluorescent lighting, at a level comparable to that indicated in ASHRAE 90.1-1999. This guide presents four lighting retrofit measures, each with a different level of reduction of lighting power density (LPD):

- **L2. Reduce LPD by 11%** through replacement of lamps and ballasts with 2010 technology.
- **L3. Reduce LPD by 21%** through replacement of lamps, ballasts, and fixtures with 2010 technology.
- **L4. Reduce LPD by 27%** through a full lighting system redesign that meets the LPD requirements of ASHRAE 90.1-2010.
- **L5. Reduce LPD by 36%** through installation of high-performance linear fixtures and LED downlights.

Energy Savings Results

L2. 11% LPD Reduction

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	113,942	33	(1,237)	1.3	1.8%
Hot & Dry	109,714	36	(1,502)	1.1	1.5%
Marine	102,175	31	(1,731)	0.9	1.3%
Cold	103,908	32	(1,713)	0.9	1.4%
Very Cold	101,200	44	(1,990)	0.7	1.1%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

L3. 21% LPD Reduction

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	224,233	68	(2,763)	2.4	3.2%
Hot & Dry	216,375	67	(3,203)	2.1	2.8%
Marine	200,361	59	(3,774)	1.5	2.2%
Cold	204,797	62	(3,695)	1.6	2.5%
Very Cold	202,181	74	(4,113)	1.4	2.1%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

L4. 27% LPD Reduction

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	285,694	87	(3,724)	3.0	4.0%
Hot & Dry	277,500	85	(4,235)	2.6	3.5%
Marine	254,475	76	(5,015)	1.8	2.7%
Cold	260,850	122	(4,962)	2.0	3.0%
Very Cold	259,158	135	(5,447)	1.7	2.5%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

L5. 36% LPD Reduction

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	374,267	113	(5,185)	3.8	5.0%
Hot & Dry	365,069	112	(5,861)	3.3	4.4%
Marine	333,208	100	(6,884)	2.2	3.3%
Cold	341,097	148	(6,873)	2.4	3.6%
Very Cold	337,806	162	(7,586)	2.0	2.9%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

L2. 11% LPD Reduction

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$223,393	$171,184	$394,577	$10,212	$0	$10,212	>20	$(159,308)
Hot & Dry	$225,402	$172,723	$398,125	$8,530	$0	$8,530	>20	$(182,482)
Marine	$233,436	$178,879	$412,315	$8,480	$0	$8,480	>20	$(190,760)
Cold	$220,938	$169,302	$390,241	$11,519	$0	$11,519	>20	$(143,301)
Very Cold	$220,046	$168,618	$388,664	$10,302	$0	$10,302	>20	$(155,636)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

L3. 21% LPD Reduction

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$664,323	$329,022	$993,345	$19,412	$0	$19,412	>20	$(469,220)
Hot & Dry	$670,296	$331,980	$1,002,276	$16,618	$0	$16,618	>20	$(508,948)
Marine	$694,188	$343,813	$1,038,001	$16,133	$0	$16,133	>20	$(538,860)
Cold	$657,023	$325,406	$982,429	$21,002	$0	$21,002	>20	$(445,970)
Very Cold	$654,368	$324,092	$978,460	$19,410	$0	$19,410	>20	$(460,460)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

L4. 27% LPD Reduction

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$877,712	$548,032	$1,425,744	$24,351	$0	$24,351	>20	$(845,860)
Hot & Dry	$885,604	$552,959	$1,438,563	$21,097	$0	$21,097	>20	$(893,893)
Marine	$917,170	$572,669	$1,489,838	$20,245	$0	$20,245	>20	$(944,552)
Cold	$868,067	$542,010	$1,410,076	$26,194	$0	$26,194	>20	$(815,205)
Very Cold	$864,559	$539,820	$1,404,379	$24,755	$0	$24,755	>20	$(826,112)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

L5. 36% LPD Reduction

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$984,169	$505,083	$1,489,251	$31,319	$0	$31,319	>20	$(829,485)
Hot & Dry	$993,017	$509,624	$1,502,641	$27,433	$0	$27,433	>20	$(885,332)
Marine	$1,028,412	$527,789	$1,556,201	$26,086	$0	$26,086	>20	$(943,953)
Cold	$973,354	$499,532	$1,472,886	$33,845	$0	$33,845	>20	$(790,300)
Very Cold	$969,421	$497,514	$1,466,935	$31,719	$0	$31,719	>20	$(808,837)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

L6. Install Occupancy Sensors to Control Interior Lighting

Technical Description

Since lighting is typically required only when people are present, fixed lighting operating schedules may use more energy than necessary in zones with intermittent occupancy. Installing occupancy sensors in applicable zones will automatically match the lighting operation with occupancy. This helps minimize lighting run time and should save energy when compared with fixed operating schedules (Wulfinghoff, 1999).

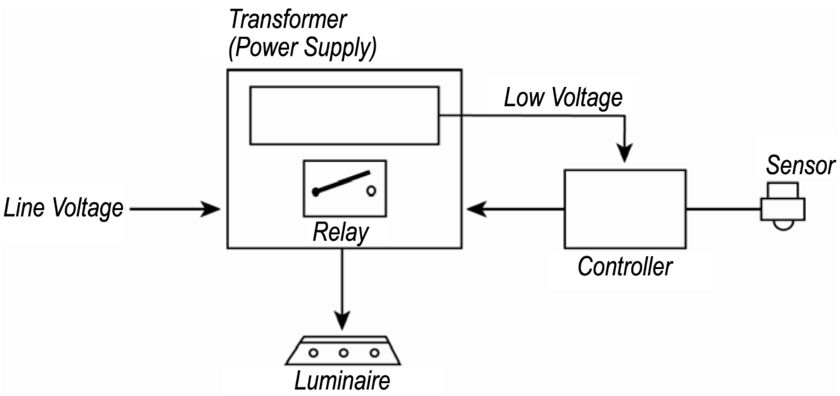


Figure 10.2. Occupancy Sensor Control Schematic
Reprinted from Advanced Energy Design Guide for Small to Medium Office Buildings. © 2011, ASHRAE

Measure Special Considerations

Occupancy sensors work best in locations where there will be a minimal amount of false triggering, and where the lighting fixtures can respond (turn on) quickly. The sensors should not be equipped with an "on" switch to override the control, as occupants often just set these sensors to "on" all the time (Wulfinghoff, 1999).

The most common occupancy sensor types are ultrasonic (motion detection) and passive infrared (heat detection). In general, ultrasonic sensors are more suited for larger areas, and passive infrared sensors are more suited for smaller areas, within a 15-foot range. Some sensors use a combination of these two sensor types.

Occupancy sensors are most cost-effective when they serve spaces that are intermittently occupied, such as conference rooms.

Technical Assumptions for Implementing Measure in Reference Building

In the baseline reference building, the lights are manually controlled with a nighttime sweep. For the measure, occupancy sensors are installed in the following spaces to control the overhead lighting: open offices, closed offices, conference rooms, restrooms, stairwells, and break rooms. The other spaces (mechanical/electrical rooms, storage rooms, lobby, and corridors) remain manually switched, with nighttime sweep. Emergency lighting remains the same between the baseline and the measure case.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	108,944	32	(1,174)	1.3	1.7%
Hot & Dry	104,944	35	(1,432)	1.1	1.4%
Marine	97,686	29	(1,652)	0.8	1.2%
Cold	99,419	31	(1,632)	0.9	1.3%
Very Cold	96,844	43	(1,901)	0.7	1.0%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$45,935	$29,674	$75,609	$9,792	$(652)	$9,140	8	$11,485
Hot & Dry	$46,348	$29,941	$76,289	$8,168	$(765)	$7,403	10	$(11,024)
Marine	$48,000	$31,008	$79,008	$8,118	$(750)	$7,368	11	$(14,900)
Cold	$45,430	$29,348	$74,778	$11,089	$(832)	$10,257	7	$20,236
Very Cold	$45,247	$29,229	$74,476	$9,907	$(757)	$9,150	8	$9,865
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs are based on the required hardware, such as a passive infrared occupancy sensor and the required wiring. Costs assume the addition of 320 occupancy sensors. Additional labor may be required to re-circuit individual areas for occupancy control. Labor and wiring was not factored into the measure replacement cost. The EUL for this measure is estimated at 10 years (WSDGA, 2006).

L7. Add Daylight Harvesting

Technical Description

Overhead interior lighting accounts for a significant portion of overall energy use in a typical office building. Daylighting is becoming a popular strategy to generate savings in this energy intensive end-use (Doty, 2009). This measure involves the installation of photocells to sense the space lighting level and control the overhead lighting in the perimeter zones to maintain a constant light level in the space. This measure also includes replacing the overhead lighting with dimmable ballasts, since dimmable ballasts are necessary to realize energy savings.

Measure Special Considerations

The lighting next to the exterior windows needs to be on a separate circuit from the other lighting, so that these lights can be controlled separate from the interior zone lights.

The design of a daylight harvesting system should account for sensor location, sensor orientation, and number of sensors. During installation, the light sensitivity settings need to be adjusted so that the desired lighting level is maintained in the space. Also, the system should be periodically tested for proper functionality.

Technical Assumptions for Implementing Measure in Reference Building

The baseline system does not have daylight harvesting, i.e., it does not reduce lighting levels in the presence of daylight. The measure adds daylighting control for the lighting fixtures in the perimeter zones, and replaces the overhead lighting with dimmable ballasts.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	177,969	82	(3,110)	1.5	2.0%
Hot & Dry	173,328	78	(3,538)	1.2	1.6%
Marine	141,075	68	(4,335)	0.2	0.3%
Cold	156,231	69	(4,384)	0.5	0.7%
Very Cold	149,806	121	(4,761)	0.2	0.3%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$32,143	$77,309	$109,452	$17,085	$(1,304)	$15,782	7	$72,057
Hot & Dry	$32,432	$78,004	$110,436	$14,119	$(1,446)	$12,674	9	$35,503
Marine	$33,588	$80,784	$114,372	$10,567	$(1,500)	$9,067	13	$(9,755)
Cold	$31,790	$76,459	$108,249	$14,659	$(1,663)	$12,996	8	$41,478
Very Cold	$31,661	$76,150	$107,811	$13,599	$(1,514)	$12,085	9	$31,404
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs are based on the required hardware, such as photocell sensors, new ballasts, and the required wiring. Costs include the addition of 420 dimmable ballasts and 60 photocells. Additional labor may be required to re-circuit individual areas. Labor and wiring was not factored into the measure replacement cost. The EUL for this measure is estimated at 20 years (WSDGA, 2006).

L8. Retrofit Exterior Fixtures to Reduce Lighting Power Density, and Add Exterior Lighting Control

Technical Description

This measure involves replacing a facility's parking area lighting fixtures with more efficient fixtures that will deliver the same illumination at reduced power draw, and reducing the lighting level during unoccupied periods.

Parking areas are traditionally lit with high-intensity discharge (HID) lighting fixtures, typically metal halide or high pressure sodium lights. Replacing these fixtures with newer, more efficient technologies such as fluorescent, induction, or light-emitting diode (LED) fixtures will yield energy savings. (PG&E, 2009)

For office buildings, exterior lighting typically consists of parking area, walkway, and building façade lighting. This lighting is typically turned on at sunset and turned off at sunrise, based on photosensor or astronomical timeclock control. Energy savings can be realized by lowering the exterior lighting level below full load power during times when nobody is present.

Measure Special Considerations

Overall lighting system efficiency, fixture life, light output depreciation, maintenance, environmental impact, and controllability should all be considered when replacing lighting fixtures. (U.S. Department of Energy, 2011) In addition to reducing the lighting power density of parking area lighting, façade lighting should also be evaluated for LPD reduction opportunities.

The exterior lighting system needs to be designed and operated in a manner to maintain minimum required illumination levels in all affected spaces during both modes of operation (full power and reduced power). For implementation of this measure, bi-level fixtures are typically required to shut off some of the lamps in each fixture during lighting reduction periods. If bi-level fixtures are not used and a portion of the fixtures are shut off instead, dark spots may result.

Lighting power should not be reduced until one hour after normal business closing (ASHRAE, 2009).

Technical Assumptions for Implementing Measure in Reference Building

The baseline reference building is assumed to use high pressure sodium lighting for the parking area, and metal halide and incandescent lighting for the entrances and façade. The measure replaces these with metal halide lighting in the parking area, and metal halide and fluorescent lighting at the entrances and façade.

For the control portion of this measure, in the baseline case, the exterior lighting is assumed to be at 100% power whenever it is dark outside, as sensed by a photocell. For the measure case, the parking lot lights are reduced to 25% power at 7 pm, which corresponds to one hour after normal business closing of 6 pm. This 75% reduction in parking lot power corresponds to a 75% reduction in illumination, to a level that still provides adequate illumination for security concerns. The other lights remain on at full power. In both the baseline and measure cases, the lights are turned off at sunrise (ASHRAE, 2009). The reference building's parking area is a surface lot, not a parking garage.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	100,314	0	0	1.7	2.3%
Hot & Dry	97,369	0	0	1.7	2.2%
Marine	97,572	0	0	1.7	2.4%
Cold	97,442	0	0	1.7	2.5%
Very Cold	97,644	0	0	1.7	2.5%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$43,179	$44,355	$87,534	$5,840	$0	$5,840	16	$(8,221)
Hot & Dry	$43,567	$44,754	$88,321	$6,241	$0	$6,241	15	$(4,691)
Marine	$45,120	$46,349	$91,469	$7,023	$0	$7,023	14	$1,281
Cold	$42,704	$43,867	$86,572	$9,075	$0	$9,075	10	$28,823
Very Cold	$42,532	$43,690	$86,222	$8,685	$0	$8,685	10	$25,048
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs were based on retrofits to 136 fixtures and the addition of a lighting control panel, time clock and some minor recruiting. The EUL for this measure is estimated at 30 years for the fixtures, with bulb replacement every ten years (U.S. Department of Energy, 2011). The EUL for the controls portion of this measure is estimated at seven years (WSDGA, 2006).

PLUG AND PROCESS LOADS RETROFIT MEASURES

P1. Add Advanced On/Off Control of Office Equipment

Technical Description

Office equipment, including computers, monitors, printers, and copiers, make up 9% of a typical office building's overall energy usage (U.S. Energy Information Administration, 2006). Office equipment typically consumes over half of the overall plug load for a typical office building (Sabo, 2010). Besides the electric power draw of these loads, they also have an impact on the building's HVAC system, creating an internal heat gain on the system. Technologies are available to turn off plug loads when they're not in use. These include:

- Adding computer power management software to optimize the energy performance of computers
- Rewiring electric circuits and implementing controls to shut off office appliances such as printers and copy machines based on sensed occupancy from motion sensors.
- Using "smart" power strips that use personal occupancy sensors to turn off task lighting when spaces are unoccupied

- Adding VendingMiser, CoolMiser, and SnackMiser controls on vending machines
- Adding time switches to turn off water coolers and coffee makers
- Reducing the power draw of plug loads can also reduce the overall HVAC system energy usage.

Measure Special Considerations

Since significant energy savings can be realized from reducing computer and monitor usage, a company's information technology (IT) department should be engaged in evaluating technologies.. Server rooms, while typically small in floor area, can consume a significant amount of energy, so server equipment should be evaluated for energy savings opportunities as well.

Technical Assumptions for Implementing Measure in Reference Building

In the baseline reference building, office equipment is assumed to be controlled manually by the occupants. This includes computers, monitors, printers, copy machines, vending machines, water coolers, coffee makers, and task lighting. The measure adds the following technologies to achieve energy savings:

- Adding computer power management software to optimize the energy performance of computers
- Using "smart" power strips that use personal occupancy sensors to turn off task lighting when spaces are unoccupied
- Adding VendingMiser, CoolMiser, and SnackMiser controls on vending machines
- Adding time switches to turn off water coolers and coffee makers

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	131,083	11	(1,219)	1.6	2.2%
Hot & Dry	123,139	12	(1,376)	1.4	1.9%
Marine	110,750	9	(1,732)	1.0	1.5%
Cold	114,539	15	(1,785)	1.1	1.6%
Very Cold	110,678	27	(2,110)	0.8	1.2%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$86,128	$42,949	$129,077	$7,812	$0	$7,812	17	$(254,985)
Hot & Dry	$86,902	$43,335	$130,238	$7,690	$0	$7,690	17	$(259,713)
Marine	$90,000	$44,880	$134,880	$6,983	$0	$6,983	19	$(280,220)
Cold	$85,182	$42,477	$127,659	$10,654	$0	$10,654	12	$(219,282)
Very Cold	$84,837	$42,306	$127,143	$9,614	$0	$9,614	13	$(229,568)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Estimated costs for this measure include 1,200 smart power strips and replacing (12) existing panels with smart panels. Vending Miser comes with the vending machine supplier. The EUL for this measure is estimated at 5 years.

P2. Purchase Energy Efficient Office Equipment

Technical Description

Plug loads can make up a substantial portion of an office building's overall energy usage. Replacing this equipment with more efficient technologies can help a building's energy performance through direct reduction in the plug load usage as well as reduced cooling energy due to reduced cooling load.

High efficiency plug-load equipment that operates at reduced power consumption when not in use is available from numerous manufacturers. ENERGY STAR® labeling is a recognized means to identify this efficient equipment.

Computers and monitors consume the majority of office plug load consumption.

Measure Special Considerations

Most owners only consider replacing plug load appliances at the end of useful life. This measure can be implemented over time as part of an owner's policy for replacing office equipment with ENERGY STAR-rated equipment.

This measure is most attractive for owners if they are responsible for paying the energy bills for their spaces (pass-through billing).

Technical Assumptions for Implementing Measure in Reference Building

The baseline building includes equipment that's typical for office buildings – desktop computers, laptop computers, computer monitors, laser printers, copiers, fax machines, water coolers, refrigerators, and vending machines. ENERGY STAR-certified options are available for all of this equipment. The measure assumes that all of the equipment is replaced at once with ENERGY STAR-certified equipment, even though in practice it's more likely that the equipment will be replaced over time, at the end of its useful life. The net present value should remain the same, though, since energy savings and costs will scale proportionally together with the amount of equipment being replaced.

Replacement of office equipment is most effective as part of an office's purchasing policy. With a purchasing policy, it's more likely that ENERGY STAR-certified equipment will be procured.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	158,661	35	(1,580)	1.9	2.5%
Hot & Dry	151,406	38	(1,836)	1.7	2.2%
Marine	140,072	33	(2,209)	1.3	1.9%
Cold	143,239	34	(2,201)	1.3	2.0%
Very Cold	139,047	46	(2,614)	1.1	1.6%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$1,801,593	$0	$1,801,593	$12,732	$0	$12,732	>20	$(855,577)
Hot & Dry	$1,817,791	$0	$1,817,791	$11,117	$0	$11,117	>20	$(883,091)
Marine	$1,882,584	$0	$1,882,584	$10,858	$0	$10,858	>20	$(922,086)
Cold	$1,882,584	$0	$1,882,584	$14,712	$0	$14,712	>20	$(877,898)
Very Cold	$1,774,596	$0	$1,774,596	$13,275	$0	$13,275	>20	$(834,345)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

The costs and savings estimates are based on the assumption that all of the office equipment is replaced with Energy Star equipment at once, even though this typically isn't done in practice. Replacing the equipment over a number of years would yield the same results, and the resultant NPV would be similar. The EUL for this measure is estimated at 10 years, assuming that the equipment is replaced with Energy Star-certified equipment as part of a company's equipment purchasing policy.

P3. Control Elevator Cab Lighting and Ventilation

Technical Description

Elevator cabs require lighting and ventilation for maintaining acceptable conditions in the cab for occupants during operation. In older model elevator cabs, this lighting and ventilation is often on continuously, even when the building is unoccupied. Motion sensor controls can be added relatively easily to shut off the cab lighting and ventilation when the cab is unoccupied, thus reducing the energy usage of the system.

Measure Special Considerations

None.

Technical Assumptions for Implementing Measure in Reference Building

For the reference building, it is assumed that the cab lighting and ventilation in each of the four cabs is on continuously, even when the building is unoccupied. The measure adds a motion sensor in each cab to turn off the lights and ventilation when the cabs are unoccupied.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	5,050	0	0	0.1	0.1%
Hot & Dry	5,053	0	0	0.1	0.1%
Marine	5,050	0	0	0.1	0.1%
Cold	5,050	0	0	0.1	0.1%
Very Cold	5,050	0	0	0.1	0.1%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$4,593	$0	$4,593	$361	$0	$361	13	$(1,920)
Hot & Dry	$4,635	$0	$4,635	$373	$0	$373	12	$(1,838)
Marine	$4,800	$0	$4,800	$404	$0	$404	12	$(1,702)
Cold	$4,800	$0	$4,800	$504	$0	$504	9	$(557)
Very Cold	$4,525	$0	$4,525	$475	$0	$475	9	$(527)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs are based on discussions with an elevator manufacturer (PECI, 2011). The EUL for this measure is estimated at 10 years (WSDGA, 2006).

BUILDING ENVELOPE RETROFIT MEASURES

E3. Add Exterior Window Film

Technical Description

Solar control window film can be applied to the interior surface of existing glazing to reduce solar heat gain by about 35% to 65%. This can significantly reduce the cooling load, and thus the energy usage of the HVAC system. These films are less effective than replacing the glazing with higher performance glazing, but may be more cost-effective than replacing the glazing (Wulfinghoff, 1999).

Measure Special Considerations

Films that reduce solar heat gain also reduce the potential for passive heating. Window films are more cost-effective in warmer climates with a large solar load.

When selecting window films, the following aspects should be considered: manufacturers' performance, amount of visible light transmission, amount of solar infrared transmission, color, scratch resistance, and appearance.

Window films have some limitations, including limited service life, potential for appearance defects, and risk of thermal breakage. These should all be considered when selecting window film for a particular application (Wulfinghoff, 1999).

Technical Assumptions for Implementing Measure in Reference Building

The baseline reference building is assumed to not have any window film on the glazing. For the measure case, low emissivity solar control window film is applied on the east, south, and west glazing.

The energy model for this measure showed a net energy benefit for this measure only in the hot and humid climate zone. It showed an electric energy benefit in all climates, related to reduced cooling load, but the gas penalty related to increased heating load outweighed the electric benefit in all climates except the hot and humid climate zone. For the hot and humid climate zone, the net benefit is a reduction in EUI of only 0.2%. For these reasons, specific savings and costs values are not presented for this measure. The modeling results indicate that this measure may not be cost-effective for most climates.

E4. Replace Windows

Technical Description

Windows can account for a significant portion of a building's heat loss and heat gain. Replacing old, inefficient window assemblies with newer ones that offer better thermal performance can reduce building energy usage. It also can improve occupant comfort through reduced solar radiation heat gain and quality of view.

Factors to consider when evaluating existing window assemblies and selecting replacements include the number of surfaces (panes), insulating properties of the frames, low-emissivity coatings, insulating fill gases, visible light transmittance, infrared transmission, interactions with daylighting systems, color, and reflective appearance (Wulfinghoff, 1999).

Measure Special Considerations

Installing high performance windows, along with other measures that reduce heat gain or losses through the building envelope, could result in smaller sized HVAC systems when also pursuing a general HVAC replacement measure. This measure is typically not a standalone measure unless the existing windows are at the end of their useful life or are being upgraded for another purpose, such as improving the building's cosmetics.

Windows with lower solar heat gain properties should reduce cooling loads but may incur an energy penalty with increased heating loads. When evaluating window assembly options, the energy performance should be evaluated on an annual basis, not just for one season.

Technical Assumptions for Implementing Measure in Reference Building

The reference building includes single-glazed tinted glass in hot and mild climates, and double–glazed tinted glass in cold climates. This overall measure is divided into two specific measures: replacing the windows with code-minimum windows ("Code", ASHRAE, 2010), and replacing the windows with higher performance windows ("AEDG", ASHRAE, 2011).

Energy Savings Results

Code

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	130,872	45	(5,361)	(0.4)	(0.6%)
Hot & Dry	204,608	76	(7,551)	(0.3)	(0.4%)
Marine	57,194	23	1,092	1.5	2.2%
Cold	29,447	0	(653)	0.2	0.3%
Very Cold	22,847	22	4,355	2.6	3.8%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

AEDG

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	154,414	48	(6,392)	(0.6)	(0.7%)
Hot & Dry	210,750	77	(7,648)	(0.2)	(0.3%)
Marine	58,156	22	3,299	2.6	3.9%
Cold	34,011	7	2,000	1.6	2.4%
Very Cold	38,100	60	6,855	4.1	6.0%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Code

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$1,813,284	$776,301	$2,589,585	$6,200	$0	$6,200	>20	$(1,519,663)
Hot & Dry	$1,829,587	$783,281	$2,612,868	$11,635	$0	$11,635	>20	$(1,472,975)
Marine	$1,894,800	$811,200	$2,706,000	$6,989	$0	$6,989	>20	$(1,583,522)
Cold	$1,793,358	$767,771	$2,561,128	$3,097	$0	$3,097	>20	$(1,541,555)
Very Cold	$1,786,112	$764,668	$2,550,780	$6,452	$0	$6,452	>20	$(1,495,276)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

AEDG

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$1,933,863	$783,281	$2,710,164	$7,159	$0	$7,159	>20	$(1,629,248)
Hot & Dry	$1,951,250	$811,200	$2,734,532	$12,343	$0	$12,343	>20	$(1,586,518)
Marine	$2,020,800	$767,771	$2,832,000	$9,329	$0	$9,329	>20	$(1,682,695)
Cold	$1,912,612	$764,668	$2,680,382	$6,541	$0	$6,541	>20	$(1,621,325)
Very Cold	$1,904,884	$776,301	$2,669,553	$9,966	$0	$9,966	>20	$(1,573,758)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

The implementation cost of the code-minimum window replacement assumes double panes. The higher performance windows were priced based on triple panes. The EUL of this measure is estimated at 20 years.

E5. Add Exterior Window Shading and Light Shelves

Technical Description

Exterior windows are often installed almost flush with the exterior wall surface, with no adjacent surfaces on the exterior or interior surfaces to minimize solar heat gain and increase the depth of daylight penetration.

In warm climates, external shading devices installed near the windows that receive direct sunlight can reduce the amount of solar heat gain, and thus reduce the cooling load on the cooling plant. Specific shading methods include projecting horizontal shelves installed above the level of the windows on south facing windows, fixed louvers on the east, south and west windows, and external blinds (Wulfinghoff, 1999).

Light shelves are horizontal surfaces installed on the interior face of windows to increase the depth of daylight penetration. Typically they are installed on tall windows, with the shelves located a few feet down from the top of the window and extending a few feet into the interior space. Using light shelves can increase the depth of daylight penetration by 10 to 20 feet in a typical installation, increasing the energy efficiency of the daylighting system (Wulfinghoff, 1999).

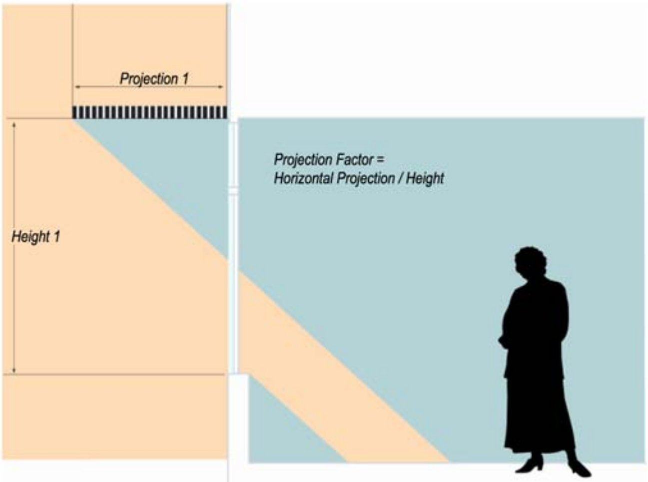


Figure 10.3. Fixed External Window Shading
Reprinted from Advanced Energy Design Guide for Small to Medium Office Buildings. © 2011, ASHRAE

Measure Special Considerations

Adding exterior shading devices or interior light shelves can have a significant impact on the appearance of a facility. They should integrate cleanly with the existing structure.

Design and selection considerations for exterior window shading include shading effectiveness, effect on view, daylighting potential, passive heating potential, appearance, longevity, and method of attachment to the building. Since shading effectiveness depends on the performance of the system at all sun positions, the system should be designed based on the specific location and orientation of the facility (Wulfinghoff, 1999).

Light shelf systems utilize the light shelf, the window, and the ceiling to extend the zone of daylighting. External shading devices are typically installed on the bottom portion of the window to minimize glare and solar heat gain during sunny periods. Light shelves are only effective at reducing energy usage when installed as part of a designed daylighting system that utilizes dimmable lighting ballasts to lower the lighting power draw during sunny periods (Wulfinghoff, 1999).

Technical Assumptions for Implementing Measure in Reference Building

The baseline reference building does not have any exterior shading devices or interior light shelves. For the measure case, exterior shading devices with a 0.5 projection factor are installed on the south windows for all climates except the very cold climate zone, which would likely incur an overall energy penalty for this measure. For maximum energy savings to be achieved with this measure, it should be implemented in tandem with the 'Add daylight harvesting' measure.

Light shelves need to be kept clean for maximum effectiveness. This activity can be included in the cleaning crew's scope. The costs also assume the new shading devices are supported by the existing window system or building envelope without supplemental supports. The EUL for this measure is estimated at 20 years.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	36,972	10	(413)	0.4	0.6%
Hot & Dry	51,483	14	(907)	0.4	0.6%
Marine	19,286	24	(1,199)	(0.3)	(0.4%)
Cold	13,444	(0)	(728)	(0.1)	(0.2%)
Very Cold	-	-	-	-	-
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$189,323	$198,876	$388,199	$3,356	$0	$3,356	>20	$(349,720)
Hot & Dry	$191,026	$285,039	$476,064	$3,503	$0	$3,503	>20	$(435,908)
Marine	$197,834	$262,246	$460,080	$1,742	$0	$1,742	>20	$(440,109)
Cold	$187,243	$344,651	$531,894	$1,492	$0	$1,492	>20	$(514,787)
Very Cold	-	-	-	-	-	-	-	-
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

E6. Add Wall Insulation

Technical Description

The thermal energy gained or lost through walls via conduction accounts for a large percentage of conditioning costs in a building. Adding additional insulation to an existing wall can reduce the amount of heat transfer. The best time to install insulation is during initial construction. However, there are an increasing number of options available to increase insulation for existing structures, especially when the building has large areas of unobstructed wall space.

Measure Special Considerations

To reap the maximum benefits from adding wall insulation, it's important to also take steps to minimize infiltration.

Heat is lost more easily through windows than walls, so buildings with a large percentage of glazing may not notice a significant change in energy performance with additional wall insulation. It's important to evaluate the wall assembly as a whole, including opaque and translucent surfaces, to optimize its performance.

Technical Assumptions for Implementing Measure in Reference Building

The exterior wall of the reference building consists of a concrete block wall with rigid insulation. The amount of insulation is greater in cold climates than in warm climates. This overall measure is divided into two specific measures: adding insulation to meet the current code-minimum walls ("Code", ASHRAE, 2010), and adding insulation to meet higher performance design standards ("AEDG", ASHRAE, 2011).

Energy Savings Results

Code

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	(39,678)	(10)	628	(0.4)	(0.5%)
Hot & Dry	17,878	5	225	0.4	0.6%
Marine	856	(1)	1,109	0.6	0.8%
Cold	(1,114)	(0)	1,286	0.6	0.8%
Very Cold	5,692	0	2,747	1.5	2.0%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

AEDG

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	10,661	2	(234)	0.1	0.1%
Hot & Dry	24,342	7	284	0.6	0.7%
Marine	339	(1)	1,494	0.8	1.1%
Cold	294	(1)	2,237	1.1	1.7%
Very Cold	6,911	20	3,769	2.0	3.0%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Code

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$112,541	$120,124	$232,665	$(2,585)	$0	$(2,585)	-	$(197,348)
Hot & Dry	$130,933	$198,253	$329,186	$1,839	$0	$1,839	>20	$(206,304)
Marine	$135,600	$182,400	$318,000	$1,151	$0	$1,151	>20	$(207,701)
Cold	$128,340	$239,716	$368,056	$1,085	$0	$1,085	>20	$(239,947)
Very Cold	$136,871	$218,036	$354,907	$2,546	$0	$2,546	>20	$(214,279)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

AEDG

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$104,502	$194,650	$299,152	$611	$0	$611	>20	$(231,544)
Hot & Dry	$139,623	$196,400	$336,023	$2,517	$0	$2,517	>20	$(210,180)
Marine	$144,600	$203,400	$348,000	$1,483	$0	$1,483	>20	$(238,896)
Cold	$136,859	$192,511	$329,369	$2,181	$0	$2,181	>20	$(194,236)
Very Cold	$152,707	$191,733	$344,440	$3,468	$0	$3,468	>20	$(198,287)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Cost estimates include the removal and replacement of the existing drywall along with the installation of additional insulation. Incremental costs should be considered between the code minimum and advanced standard for this measure. Evaluating the measure on an incremental basis would increase the NPV values. The EUL of this measure is estimated at 20 years.

E7. Add Roof Insulation

Technical Description

A roof represents a significant source of heat loss in cold climates and heat gain in warm climates. For roofing systems that have insulation entirely above the deck surface, which is a common roof arrangement in commercial office buildings, it's relatively simple to add insulation to reduce heat transfer into or out of the building (Wulfinghoff, 1999).

Measure Special Considerations

Adding insulation to the roof will likely require the removal of the existing membrane. Most owners may consider this measure when the existing roof is in need of replacement. Also, replacing the membrane with reflective coatings, such as a cool roof, at the time of the insulation installation may also help to decrease overall cooling loads in hot climates.

Existing roof penetrations and curbs need to be considered when increasing the insulation, to maintain the minimum distance between the top of the membrane and the top of curbs.

Technical Assumptions for Implementing Measure in Reference Building

The roof of the baseline reference building consists of a steel deck with the insulation entirely above the deck surface, for an unbroken insulating surface. The amount of insulation is greater in cold climates than in warm climates. This overall measure is divided into two specific measures: adding insulation to meet the current code-minimum windows ("Code", ASHRAE, 2010), and adding insulation to meet higher performance design standards ("AEDG", ASHRAE, 2011).

Energy Savings Results

Code

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	8,217	6	(208)	0.0	0.0%
Hot & Dry	23,222	8	308	0.5	0.7%
Marine	6,681	2	970	0.6	0.8%
Cold	5,436	(1)	1,112	0.6	0.9%
Very Cold	1,431	0	1,092	0.6	0.8%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

AEDG

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	11,875	9	(313)	0.0	0.1%
Hot & Dry	27,036	10	383	0.7	0.9%
Marine	11,047	3	1,429	0.9	1.3%
Cold	9,014	0	1,843	1.1	1.6%
Very Cold	4,186	0	2,829	1.5	2.2%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Code

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$101,057	$141,964	$243,021	$821	$0	$821	>20	$(195,704)
Hot & Dry	$119,346	$228,252	$347,598	$2,802	$0	$2,802	>20	$(261,067)
Marine	$123,600	$210,000	$333,600	$1,625	$0	$1,625	>20	$(268,966)
Cold	$116,983	$275,989	$392,971	$1,658	$0	$1,658	>20	$(306,282)
Very Cold	$126,691	$248,245	$374,936	$972	$0	$972	>20	$(288,148)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

AEDG

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$104,502	$207,856	$312,358	$1,128	$0	$1,128	>20	$(263,257)
Hot & Dry	$139,044	$237,533	$376,577	$3,314	$0	$3,314	>20	$(286,109)
Marine	$144,000	$246,000	$390,000	$2,469	$0	$2,469	>20	$(317,694)
Cold	$136,291	$232,830	$369,120	$2,771	$0	$2,771	>20	$(271,894)
Very Cold	$152,707	$260,168	$412,876	$2,569	$0	$2,569	>20	$(309,799)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Installation costs include removal and replacement of the roof membrane along with the addition of new insulation. Incremental costs should be considered between the code minimum and advanced standard for this measure. Evaluating the measure on an incremental basis would increase the NPV values. The EUL of this measure is estimated at 20 years.

E8. Add a Vestibule

Technical Description

Vestibules help reduce the heating and cooling load related to exterior doors opening and closing. They're especially effective when used in high traffic areas, such as the main building entrance.

Measure Special Considerations

Adding a vestibule can have an impact on the appearance and function of a building. The vestibule should be designed in consideration with other building elements, and should not significantly interrupt occupant flow into and out of buildings. Code exiting requirements should also be maintained when considering this measure.

Vestibules are especially effective in extreme climates, with cold winters and warm summers.

Technical Assumptions for Implementing Measure in Reference Building

This measure was not modeled for the reference building, therefore costs and savings values are not presented for this measure. For buildings in extreme climates without vestibules, this measure is worth consideration.

E9. Install cool roof

Technical Description

Cool roofs are constructed with a material that reflects sunlight and emits thermal energy. In effect, the roof is "cooler" than conventional roofs, which reduces the amount of heat transferred into the building. Reducing the amount of heat transfer will also reduce the amount of mechanical cooling required in the building. This measure involves replacing the existing roof membrane with a cool roof membrane.

Measure Special Considerations

Net annual energy cost savings tend to be greatest for buildings located in climates with long cooling seasons and short heating seasons (Levinson, 2009). Cool roofs will likely incur a heating penalty, which may be significant in heating dominated climates.

Technical Assumptions for Implementing Measure in Reference Building

This measure was not modeled for the reference building, as the energy modeling software does not accurately model this measure. This measure is likely more cost-effective in the hot and humid climate zone, which has a long cooling season, than in the very cold climate zone, for example. For office buildings located in warm climates, this measure is worth consideration.

HVAC – AIRSIDE RETROFIT MEASURES

HA9. Add Optimum Start Strategy for HVAC Equipment

Technical Description

HVAC equipment is typically started and stopped based on a fixed schedule. Usually the HVAC system starts a certain amount of time prior to when occupants arrive to the building, to give the system time to bring the building to temperature after being off all night. An optimum start strategy can be implemented to start the equipment based on indoor and outdoor conditions. This typically results in energy savings and reduced equipment wear and tear, as the system will not have to start as early during mild weather conditions.

Optimum start is an adaptive control sequence that learns how long the HVAC system takes to reach the desired setpoint. During abnormally cold or hot weather, the HVAC equipment will automatically start earlier than mild temperature days to ensure the zone temperature setpoint is achieved at the start of occupancy. In addition to optimum start, optimum stop can also be implemented, which turns the equipment off before the end of the normally scheduled occupancy and lets the building coast down without mechanical conditioning.

Measure Special Considerations

Optimum start/stop sequences are typical options in DDC systems, but some sophisticated timeclocks also have this feature. These timeclocks require temperature inputs from the applicable zone and outside.

For hybrid control systems (DDC at the plant level, pneumatic at the zones), DDC temperature sensors can be placed in representative zones to provide feedback from the zones and give input to the optimum start/stop strategy.

Optimum start is most effective when the system can ‘learn’ over time how long it takes for a building to warm up or cool down, based on indoor and outdoor conditions, and factor these experiences into the algorithm.

Technical Assumptions for Implementing Measure in Reference Building

The baseline HVAC operating schedule for the reference building is Monday-Friday 6am–6pm, and Saturday 6am–2pm. The measure implements an optimal start strategy for the equipment, to delay start until after 6am during mild conditions. For estimating the savings related to this strategy, the start time is delayed until 7 am for the months of March-May and September-November.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	15,089	0	620	0.6	0.8%
Hot & Dry	8,308	0	635	0.5	0.6%
Marine	7,483	0	716	0.5	0.6%
Cold	6,989	0	542	0.4	0.5%
Very Cold	5,472	0	469	0.3	0.4%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$68,475	$133,214	$201,689	$1,423	$2,868	$4,290	>20	$(220,228)
Hot & Dry	$69,091	$190,928	$260,019	$1,159	$3,180	$4,339	>20	$(278,388)
Marine	$71,554	$175,661	$247,214	$1,207	$3,300	$4,507	>20	$(273,477)
Cold	$67,723	$230,859	$298,582	$1,106	$3,660	$4,766	>20	$(330,373)
Very Cold	$67,449	$192,271	$259,720	$802	$3,332	$4,133	>20	$(291,014)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Costs for this measure are based on the conversion to DDC for 132 VAV boxes, power to 8ea 24VDC transformers. Replacement at EUL excludes control wiring. Costs also include programming and set up of new controls as well as any work to test, adjust and balance the new boxes. Costs would be less, and NPVs would be higher, if the control system already includes DDC at the zone level. The EUL of this measure is estimated at 10 years (WSDGA, 2006).

HA10. Revise Airside Economizer Damper Control

Technical Description

Airside economizers are used to increase the amount of outside air drawn into a building when outside conditions are cool and the system requires cooling. They reduce the amount of energy required for mechanical cooling. For most commercial buildings, outdoor climate and indoor climate needs are the main factors in determining whether or not to use an airside economizer cycle, and which type of control to use. Ongoing maintenance costs can also be a factor in choosing which type of control to use.

In the hot and humid climate zone, economizer cycles are typically not used since outside conditions are not cool enough for enough hours to make their use cost-effective. For other climates, many economizer control options exist, including single point dry bulb temperature (OA), differential dry bulb temperature (OA & RA), single point enthalpy (OA), and differential enthalpy (OA & RA) (Wulfinghoff, 1999). This measure consists of upgrading the economizer controls for more energy efficient operation and reduced maintenance costs.

Measure Special Considerations

While enthalpy-based economizer control may be more energy efficient than temperature-based control in some climates, especially humid climates, enthalpy sensors are often inaccurate due to the typical high level of error related to relative humidity sensors, even in new sensors. It is often more cost-effective to use temperature-based economizer control when sensor error and maintenance costs are factored in (Taylor, 2010).

Technical Assumptions for Implementing Measure in Reference Building

The reference building is thirty years old. It is assumed that airside economizer capability and controls were installed when the building was first constructed, and that the type of control has not changed over the life of the building.

- Baseline: no economizer in the hot and humid climate zone. Economizer based on fixed outside air temperature (70°F setpoint) in the hot & dry and marine climate zones. Economizer based on fixed outside air enthalpy (24 Btu/lb setpoint) in the cold and very cold climate zones.
- Measure: no economizer in the hot and humid climate zone. Integrated economizer based on differential dry bulb temperature in all other cities (ASHRAE, 2009; Taylor, 2010).

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	-	-	-	-	-
Hot & Dry	2,378	0	5	0.0	0.1%
Marine	678	0	3	0.0	0.0%
Cold	9,656	13	9	0.2	0.2%
Very Cold	364	2	33	0.0	0.0%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	-	-	-	-	-	-	-	-
Hot & Dry	$2,607	$7,604	$10,211	$156	$0	$156	>20	$(13,865)
Marine	$2,700	$6,996	$9,696	$88	$0	$88	>20	$(13,856)
Cold	$2,555	$9,194	$11,750	$1,455	$0	$1,455	8	$(1,333)
Very Cold	$2,545	$7,658	$10,203	$832	$0	$832	12	$(6,095)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

In addition to controls programming, new temperature sensors are likely required for implementation of this measure. Costs are based on the purchase, installation and programming of six sensors. The EUL of this measure is estimated at 10 years (WSDGA, 2006).

HA11. Widen Zone Temperature Deadband (Replace Pneumatic Thermostats)

Technical Description

Centralized HVAC systems consist of two main components: the central HVAC equipment (e.g., boilers, chillers, air handlers), and the distribution system (e.g., piping, ductwork, terminal units). While the direct energy consumption of distribution systems is usually much lower than the consumption of the central equipment, their performance and control settings can have a significant impact on the energy consumption of the central equipment.

For example, widening the zone temperature deadband will result in measurable energy savings at the central equipment. The deadband is the difference between the zone heating and cooling temperature setpoints. It's common for HVAC systems to operate with little to no deadband, meaning that there is one temperature setpoint during winter and summer seasons.

Specific zone control energy conservation modifications will vary by HVAC system type and the specific needs and capabilities of each facility. Occupant comfort needs to be maintained with any zone control strategy (ASHRAE, 2004). In general, for centralized HVAC systems, it's important to integrate the controls of both the central equipment and the distribution system for maximum energy efficiency and occupant comfort (Taylor, 2007).

Measure Special Considerations

Widening the deadband with pneumatic controls will likely involve replacing the thermostats with 'zero energy band'-type thermostats that have an adjustable deadband and manually setting the deadband at each thermostat. If a system already has DDC control at the distribution level, widening the deadband can be as simple as a global change to the heating and cooling setpoints made from the main operator workstation.

Space temperatures will change as a result of implementing this measure. However, conditions in the space should still be comfortable for occupants, and significant energy savings will be realized. ASHRAE indicates that most occupants are comfortable at space temperatures between 68-74° F in the winter, and 73-79° F in the summer (ASHRAE, 2004). The six degree deadband related to this measure (69-75° F) falls within these ranges.

Technical Assumptions for Implementing Measure in Reference Building

The baseline reference building is assumed to have DDC control of the central equipment (boilers, chillers, pumps, air handlers), and pneumatic control of the distribution equipment (VAV terminal units). This measure includes keeping the pneumatic controls at the distribution equipment, and replacing the pneumatic thermostats with ones that have an adjustable deadband.

- Baseline: 71°F heating setpoint, 73°F cooling setpoint.
- Measure: 69°F heating setpoint, 75°F cooling setpoint.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	60,669	40	8,899	5.5	7.3%
Hot & Dry	69,294	133	10,333	6.3	8.4%
Marine	19,314	24	11,063	5.9	8.6%
Cold	23,206	182	8,971	4.9	7.4%
Very Cold	18,553	173	8,324	4.5	6.6%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$22,049	$41,341	$63,390	$17,075	$0	$17,075	4	$153,357
Hot & Dry	$22,247	$41,713	$63,960	$24,242	$0	$24,242	3	$235,125
Marine	$23,040	$43,200	$66,240	$14,970	$0	$14,970	4	$127,307
Cold	$21,807	$40,887	$62,694	$15,324	$0	$15,324	4	$133,702
Very Cold	$21,718	$40,722	$62,440	$10,934	$0	$10,934	6	$83,563
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Costs for this measure assume the replacement of 74 pneumatic thermostats in same locations as original. The EUL for this measure is estimated at 13 years (WSDGA, 2006).

HA12. Lower VAV Box Minimum Flow Setpoints (Rebalance Pneumatic Boxes)

Technical Description

Centralized HVAC systems consist of two main components: the central HVAC equipment (e.g., boilers, chillers, air handlers), and the distribution system (e.g., piping, ductwork, terminal units). While the direct energy consumption of distribution systems is usually much lower than the consumption of the central equipment, their performance and control settings can have a significant impact on the energy consumption of the central equipment.

For example, with VAV systems, reducing the zone supply airflow during periods of low cooling and heating load will result in measurable energy savings at the central equipment.

Specific zone control energy conservation modifications will vary by HVAC system type and the specific needs and capabilities of each facility. Occupant comfort needs to be maintained with any zone control strategy (ASHRAE, 2004). In general, for centralized HVAC systems, it's important to integrate the controls of both the central equipment and the distribution system for maximum energy efficiency and occupant comfort (Taylor, 2007).

Measure Special Considerations

During periods of no heating and cooling, VAV boxes must still deliver air to the zones in order to provide ventilation air for the occupants. For commercial office buildings, this airflow rate, the "minimum airflow", is almost always a fraction of the peak airflow rate required during peak cooling periods. Oftentimes these minimum airflow rates are set higher than needed – a common strategy is to set the minimum at 50% of the maximum, even though less than 50% of maximum airflow is required for ventilation. Energy savings can be realized by lowering the minimum airflow rate to a level that still provides adequate ventilation air for the occupants, but will result in reduced fan and reheat energy used by the system.

The minimum airflow rates should be calculated for each zone, since each zone will have different requirements. The minimum airflow rate is based on the percentage of ventilation air in the supply air from the air handlers, and the ventilation needs of the zones.

Lowering the VAV box minimum flow setpoints mostly involves TAB (testing, adjusting and balancing) work. If a system already has DDC control at the distribution level, the minimum flow setpoints can be lowered at the main operator workstation.

Technical Assumptions for Implementing Measure in Reference Building

The baseline reference building is assumed to have DDC control of the central equipment (boilers, chillers, pumps, air handlers), and pneumatic control of the distribution equipment (VAV terminal units). This measure includes keeping the pneumatic controls at the distribution equipment, and rebalancing the boxes to lower the minimum flow setpoints.

- Baseline: 50% minimum airflow setpoint.
- Measure: 40% minimum airflow setpoint.

The measure is modeled using a 40% minimum airflow setpoint as an average, for all VAV boxes. Actual buildings will have varying minimum airflow percentages, based on the particular needs of each zone.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	131,397	2	8,029	6.3	8.3%
Hot & Dry	147,031	1	9,054	7.0	9.3%
Marine	105,708	(42)	8,549	6.1	8.9%
Cold	83,989	0	6,457	4.7	7.1%
Very Cold	85,911	0	5,274	4.1	6.0%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$0	$36,684	$36,684	$17,654	$(2,173)	$15,481	2	$141,767
Hot & Dry	$0	$37,014	$37,014	$20,065	$(2,550)	$17,514	2	$164,915
Marine	$0	$38,333	$38,333	$18,480	$(2,500)	$15,980	2	$145,985
Cold	$0	$36,281	$36,281	$15,387	$(2,772)	$12,615	3	$109,575
Very Cold	$0	$36,134	$36,134	$12,263	$(2,524)	$9,739	4	$76,643
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Costs are based on labor required to rebalance 132 VAV boxes. The EUL for this measure is estimated at 13 years (WSDGA, 2006).

HA13. Widen Zone Temperature Deadband, Add Conference Room Standby Control (Upgrade To DDC Zone Control)

Technical Description

Centralized HVAC systems consist of two main components: the central HVAC equipment (e.g., boilers, chillers, air handlers), and the distribution system (e.g., piping, ductwork, terminal units). While the direct energy consumption of distribution systems is usually much lower than the consumption of the central equipment, their performance and control settings can have a significant impact on the energy consumption of the central equipment.

For example, widening the zone temperature deadband (the difference between the zone heating and cooling temperature setpoints) and reducing the supply airflow further when zones are unoccupied during normal business hours will result in measurable energy savings at the central equipment. It’s common for HVAC systems to operate with little to no deadband, meaning that there is one temperature setpoint during winter and summer seasons. Increasing the deadband will save energy. Also, putting the HVAC system in standby mode for zones that are unoccupied will also result in energy savings.

Specific zone control energy conservation modifications will vary by HVAC system type and the specific needs and capabilities of each facility. Occupant comfort needs to be maintained with any zone control strategy (ASHRAE, 2004). In general, for centralized HVAC systems, it’s important to integrate the controls of both the central equipment and the distribution system for maximum energy efficiency and occupant comfort (Taylor, 2007).

Measure Special Considerations

Space temperatures will change as a result of implementing this measure. However, conditions in the space should still be comfortable for occupants, and significant energy savings will be realized. ASHRAE indicates that most occupants are comfortable at space temperatures between 68-74° F in the winter, and 73-79° F in the summer (ASHRAE, 2004). The six degree deadband related to this measure (69-75° F) falls within these ranges.

For hybrid systems (DDC at the plant, pneumatic at the zones), extending DDC control to the distribution level and providing enough capacity in the DDC system to allow for communication between the central equipment and the distribution system paves the way for implementing advanced control sequences that will help minimize energy consumption of the HVAC system, especially during non-peak heating and cooling periods. Extending DDC control to the distribution level also allows operators to monitor performance of these systems and troubleshoot issues faster (ASHRAE, 2007).

Technical Assumptions for Implementing Measure in Reference Building

The baseline reference building is assumed to have DDC control of the central equipment (boilers, chillers, pumps, air handlers), and pneumatic control of the distribution equipment (VAV terminal units). This measure includes upgrading the distribution equipment controls to DDC, widening the deadband and adding conference room standby control.

- Baseline: 71°F heating setpoint, 73°F cooling setpoint. Conference room temperature deadband and minimum airflow setpoints are the same as the other office spaces.
- Measure: 69°F heating setpoint, 75°F cooling setpoint. When a conference room is sensed as unoccupied for at least 10 minutes by the lighting occupancy sensors, lower the minimum airflow setpoint to 15% and increase the space temperature deadband to 10°F (67°F heating setpoint, 77°F cooling setpoint). When conference room is sensed as occupied, conference room HVAC system operates the same as the other office spaces. This measure requires implementation of the 'Install occupancy sensors to control interior lighting' measure, at least in the conference rooms.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	93,564	37	10,751	7.0	9.3%
Hot & Dry	99,258	130	12,261	7.8	10.3%
Marine	44,619	23	12,913	7.2	10.6%
Cold	45,189	191	10,405	6.0	9.1%
Very Cold	40,278	178	9,288	5.3	7.9%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$66,500	$147,308	$213,808	$21,441	$4,345	$25,786	8	$89,912
Hot & Dry	$67,098	$148,632	$215,730	$28,554	$4,345	$32,899	6	$172,867
Marine	$69,490	$153,930	$223,420	$18,925	$4,345	$23,270	9	$55,870
Cold	$65,769	$145,689	$211,458	$19,509	$4,345	$23,854	9	$74,392
Very Cold	$65,504	$145,100	$210,604	$14,089	$4,345	$18,434	11	$10,986
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

The cost for implementation of this measure includes the entire cost related to upgrading the zone-level control from pneumatic to DDC. The conversion includes DDC for 132 VAV boxes, bringing power to eight 24VDC transformers and programming to set up new controls. Test, adjust and balance work of the new boxes is included as well as occupancy sensors in conference rooms to reset box minimums. The EUL for this measure is estimated at 13 years (WSDGA, 2006).

HA14. Lower VAV Box Minimum Flow Setpoints, Reset Duct Static Pressure (Upgrade to DDC Zone Control)

Technical Description

Centralized HVAC systems consist of two main components: the central HVAC equipment (e.g., boilers, chillers, air handlers), and the distribution system (e.g., piping, ductwork, terminal units). While the direct energy consumption of distribution systems is usually much lower than the consumption of the central equipment, their performance and control settings can have a significant impact on the energy consumption of the central equipment.

For example, with VAV systems, reducing the zone supply airflow during periods of low cooling and heating load will result in measurable energy savings at the central equipment. In addition, reducing or resetting the duct static pressure setpoint will also result in energy savings.

Specific zone control energy conservation modifications will vary by HVAC system type and the specific needs and capabilities of each facility. Occupant comfort needs to be maintained with any zone control strategy (ASHRAE, 2004). In general, for centralized HVAC systems, it's important to integrate the controls of both the central equipment and the distribution system for maximum energy efficiency and occupant comfort (Taylor, 2007).

Measure Special Considerations

For hybrid systems (DDC at the plant, pneumatic at the zones), extending DDC control to the distribution level and providing enough capacity in the DDC system to allow for communication between the central equipment and the distribution system paves the way for implementing advanced control sequences that will help minimize energy consumption of the HVAC system, especially during non-peak heating and cooling periods. Extending DDC control to the distribution level also allows operators to monitor performance of these systems and troubleshoot issues faster (ASHRAE, 2007).

During periods of no heating and cooling, VAV boxes must still deliver air to the zones in order to provide ventilation air for the occupants. For commercial office buildings, this airflow rate, the "minimum airflow", is almost always a fraction of the peak airflow rate required during peak cooling periods. Oftentimes these minimum airflow rates are set high than needed – a common strategy is to set the minimum at 50% of the maximum, even though less than 50% of maximum airflow is required for ventilation. Energy savings can be realized by lowering the minimum airflow rate to a level that still provides adequate ventilation air for the occupants, but will result in reduced fan and reheat energy used by the system.

The minimum airflow rates should be calculated for each zone, since each zone will have different needs. The minimum airflow rate is based on the percentage of ventilation air in the supply air from the air handlers, and the ventilation needs of the zones.

Lowering the VAV box minimum flow setpoints mostly involves TAB (testing, adjusting and balancing) work. If a system already has DDC control at the distribution level, the minimum flow setpoints can be lowered at the main operator workstation.

Prior to lowering the duct static pressure setpoint or implementing an automatic reset strategy, it's a good idea to verify the integrity of the duct system. Check to see if there is excessive leakage in the system. If a certain area has recurrent comfort complaints, check to see if there are obstructions in the ductwork (e.g., duct liner that has peeled away from the duct, closed fire dampers). Also check to see if there are an excessive number of duct elbows in the ductwork serving that area.

VAV box damper position is a good input variable to use for resetting the duct static pressure setpoint: raise the setpoint if a certain number of dampers are 100% open, lower the setpoint if most of the dampers are less than 100% open.

Technical Assumptions for Implementing Measure in Reference Building

The baseline reference building is assumed to have DDC control of the central equipment (boilers, chillers, pumps, air handlers), and pneumatic control of the distribution equipment (VAV terminal units). This measure includes upgrading the distribution equipment controls to DDC, and implementing the following control strategies:

- Baseline: 50% minimum airflow setpoint, constant supply duct static pressure setpoint.
- Measure: 40% minimum airflow setpoint, duct static pressure setpoint is reset off of VAV box damper position.

The measure is modeled using a 40% minimum airflow setpoint as an average, for all VAV boxes. Actual buildings will have varying minimum airflow percentages, based on the particular needs of each zone.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	278,675	31	8,030	8.8	11.7%
Hot & Dry	318,300	13	9,016	9.9	13.1%
Marine	228,714	(26)	8,477	8.1	11.9%
Cold	205,519	1	6,133	6.6	10.0%
Very Cold	209,094	22	4,366	5.8	8.5%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$61,907	$164,980	$226,887	$30,339	$4,345	$34,684	7	$132,594
Hot & Dry	$62,463	$166,463	$228,927	$33,495	$5,100	$38,595	6	$168,757
Marine	$64,690	$172,397	$237,086	$29,838	$5,000	$34,838	7	$118,403
Cold	$61,226	$163,167	$224,393	$29,251	$5,545	$34,796	7	$125,832
Very Cold	$60,979	$162,508	$223,487	$24,948	$5,048	$29,995	8	$76,066
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

The cost for implementation of this measure includes the entire cost related to upgrading the zone-level control from pneumatic to DDC. The conversion includes DDC for 132 VAV boxes, bringing power to eight 24VDC transformers and programming to set up new controls. Test, adjust and balance work of the new boxes is included. The EUL for this measure is estimated at 13 years (WSDGA, 2006).

HA15. Add Demand-Controlled Ventilation

Technical Description

Adequate ventilation air, or outside air, is required to maintain acceptable indoor air quality. In general, the greater number of people in a space, the greater the amount of ventilation air required. This ventilation air increases the energy used by an HVAC system due to the energy required to heat, cool, humidify, and dehumidify the ventilation air, depending on the outdoor conditions and the needs of the space (Wulfinghoff, 1999).

Most office building HVAC systems, especially older systems, are designed to deliver a constant amount of ventilation air during occupied periods, regardless of how many people are in the space. Energy savings can be realized by controlling the amount of ventilation air provided based on the ventilation needs of the space. For office buildings, this is typically accomplished by sensing the CO_2 concentration in the space, and adjusting the amount of ventilation air accordingly between preset maximum and minimum values. When using this method, it's important to consult and consider ventilation rate standards such as ASHRAE 62.1 – Ventilation for Acceptable Indoor Air Quality. This standard covers demand-controlled ventilation strategies.

Demand-controlled ventilation is most cost-effective in buildings that have highly variable occupancies or high minimum outside airflow rates. In buildings that schedule their HVAC system to operate according to the building's main occupancy schedule, there's typically not enough variation in occupancy during equipment operation to make demand-controlled ventilation cost-effective. However, this measure is worth evaluating for any facility, as there may be enough HVAC system operating hours during partial occupancy to make this measure cost-effective.

Measure Special Considerations

Calculating the necessary ventilation rate is usually easier than controlling the HVAC system to maintain that ventilation rate. It's not as great a challenge with constant air volume systems (compared to VAV systems), but it's still something to consider. With constant volume systems, even though the minimum outside airflow rate should not vary significantly, it's important to recognize that the percent that the outside air damper is open probably does not correlate directly with the outside airflow percentage, due to damper performance characteristics.

With VAV systems that use a fixed minimum outside air damper position, the outside airflow rate will change depending on the amount of system supply and return airflow. Directly measuring the outside airflow rate is the preferred method of maintaining minimum airflow rates with VAV systems, even though this requires regular calibration of the outside airflow sensors.

For systems serving multiple zones, it's preferred to sense the CO_2 concentration in multiple spaces, not just in the return air duct, for a more accurate representation of space ventilation needs. As with other HVAC sensors, CO_2 sensors are prone to drift out of calibration, and thus require periodic maintenance.

For VAV systems that operate often in economizer mode, it may be cost-effective to reset the VAV box minimum airflow settings downward during economizer operation based on sensed CO_2 concentration in the space, for fan energy savings. VAV boxes have minimum airflow settings for maintaining adequate ventilation to the space, and these settings are typically based on minimum outside air operation. Since the supply air during economizer operation has a higher percentage of outside air than during non-economizer operation, the minimum airflow can be reduced while still providing adequate ventilation to the space. This strategy can realistically only be accomplished if the zones are DDC-controlled.

Energy recovery ventilators, which transfer energy between the outgoing exhaust/relief and incoming outside air streams, can help reduce energy usage. These systems are more cost-effective in extreme climates, with hot, humid summer and/or cold winters.

Technical Assumptions for Implementing Measure in Reference Building

For the baseline reference building, the outside air damper is at a fixed minimum position of 15% during non-economizer operation. The measure resets the outside air damper position between the baseline position and 5% open, based on sensed CO_2 concentration in the space. The measure also lowers the minimum airflow settings of the VAV boxes during economizer operation, down to half of the non-economizer operation minimum airflow setting.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	25,972	10	(27)	0.4	0.6%
Hot & Dry	25,581	12	(45)	0.4	0.6%
Marine	350	2	8	0.0	0.0%
Cold	2,431	0	166	0.1	0.2%
Very Cold	525	0	1,037	0.5	0.7%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Energy savings estimates were calculated using EnergyPlus. EnergyPlus was not able to model the strategy of lowering VAV box minimum airflow setpoints during economizer operation, so the savings calculated by EnergyPlus are low for all climate zones except the hot and humid climate zone, which does not have airside economizer capability.

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$78,581	$154,455	$233,036	$2,591	$2,868	$5,458	>20	$(216,369)
Hot & Dry	$79,288	$221,372	$300,659	$3,530	$3,180	$6,710	>20	$(270,030)
Marine	$82,114	$203,670	$285,784	$55	$3,300	$3,355	>20	$(300,154)
Cold	$77,717	$267,669	$345,387	$411	$3,660	$4,070	>20	$(357,312)
Very Cold	$77,403	$222,928	$300,332	$848	$3,332	$4,179	>20	$(305,755)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

The cost for implementation of this measure includes the entire cost related to upgrading the zone-level control from pneumatic to DDC. Costs would be less, and NPVs would be higher, if the control system already includes DDC at the zone level. Also, costs include the purchase and installation of (32) CO_2 sensors. The EUL for this measure is estimated at 10 years (WSDGA, 2006).

HA16. Replace Supply Fan Motor and VFD

Technical Description

This measure involves replacing a facility's supply fan motors and VFDs with premium efficiency motors and VFDs with current technology. Standard motor efficiencies have steadily increased over the last few decades due to improvements in motor design and manufacturing, and VFD efficiencies have increased greatly over the past decade, especially at part load conditions (U.S. Department of Energy, 2002, 2008). Minimum motor efficiencies prescribed in building energy codes and federal regulations are frequently increased to keep pace with these improved efficiencies.

Measure Special Considerations

Most facilities do not consider upgrading motors or VFDs with higher efficiency models until the existing motors or VFDs need to be replaced due to failure or system replacement/reconfiguration. However, it may be worth replacing large, old VFD/motor combinations that operate frequently with more efficient models even before failure (Wulfinghoff, 1999).

Technical Assumptions for Implementing Measure in Reference Building

The reference building is thirty years old. It is assumed that the supply fan was originally controlled by inlet guide vanes, and that these vanes were fixed open and replaced with a VFD and new inverter duty motor ten years ago. The measure replaces this motor and VFD with higher efficiency equipment. It is assumed that the supply fan motor and VFD are at the end of their useful lives.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	120,097	32	(8)	2.0	2.7%
Hot & Dry	153,133	72	(15)	2.6	3.4%
Marine	116,283	34	(9)	2.0	2.9%
Cold	99,542	69	(35)	1.7	2.6%
Very Cold	108,072	88	(85)	1.8	2.7%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$24,116	$18,374	$42,490	$11,505	$0	$11,505	4	$43,717
Hot & Dry	$25,491	$19,698	$45,189	$15,235	$0	$15,235	3	$65,114
Marine	$21,480	$15,888	$37,368	$11,243	$0	$11,243	3	$45,430
Cold	$18,172	$12,493	$30,665	$11,796	$0	$11,796	3	$53,234
Very Cold	$18,099	$12,443	$30,541	$11,979	$0	$11,979	3	$54,451
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

The costs for this measure are based on the replacement of three fan motors and VFD's of various sizes between each climate zone. The EUL for this measure is estimated at 15 years, which is the lower of the EUL values for VFDs (15 years) and high-efficiency electric motors (17 years) (WSDGA, 2006).

HA17. Change HVAC System Type

Technical Description

There are many types of HVAC systems that are suitable for commercial office buildings. The HVAC system for a specific building is selected based on a variety of factors, including indoor environmental quality, energy performance, first cost, ongoing costs, space availability, and climatic considerations, to name a few. If an entire HVAC system is nearing the end of its useful life, if the usage pattern of the building has changed, or if there are other reasons why HVAC system replacement may be imminent, it might be worth considering replacing the original system with a different type of HVAC system.

Most large office buildings are conditioned with overhead VAV systems. Other types of HVAC systems to consider include:

- Dedicated outdoor air system with four-pipe fan coils
- Radiant heating
- Chilled beams
- Displacement ventilation
- Natural ventilation
- Water-source heat pumps

There are numerous variations of HVAC systems. If a building is embarking on a deep retrofit project, different HVAC system types should be considered.

Measure Special Considerations

Replacing an entire HVAC system typically involves work in the occupied spaces. For most multi-tenant commercial office buildings, where it's not possible to ask the tenants to leave for a year or so while the HVAC system is upgraded, this measure is not a realistic possibility. However, for owner-occupied buildings, it may be a good option to pursue.

Technical Assumptions for Implementing Measure in Reference Building

Since the reference building is a multi-tenant commercial office building, replacing the entire HVAC system is not a realistic option. Therefore, alternate HVAC system types are not modeled and presented in detail here. As indicated previously, for owner-occupied buildings undergoing a deep retrofit project, different HVAC system types should be analyzed and considered.

HVAC – WATERSIDE RETROFIT MEASURES

HW7. Shut Down Heating Plant When There's No Heating Load

Technical Description

Facilities often run their heating plants throughout the year, even on warm days. This is often done to satisfy year-round reheat loads that are inherent in multi-zone VAV systems commonly used in large office building. Summertime reheat loads can occur in zones that require ventilation yet have relatively low cooling requirements. Reheat is provided to prevent overcooling these zones, which are typically interior zones (PECI, 2006). In humid climates, reheat may also be required at the air handler level to reheat the air after dehumidification.

If the reheat load can be reduced, then there is less need for heating plant operation and energy can be saved. If the reheat load can be eliminated altogether, greater savings can be achieved by shutting off the entire heating plant (boilers and pumps) to reduce standby and distribution losses, and to reduce auxiliary equipment operation (Wulfinghoff, 1999).

Measure Special Considerations

A common strategy for implementing this measure is to shut down the heating plant when the outside air temperature is above a certain value, e.g., 75°F. To be able to do this, though, reheat loads above this temperature must be eliminated or, at least, greatly reduced. Many HVAC systems in large commercial buildings operate with a certain amount of simultaneous heating and cooling, due to the nature of the systems. Minimizing this paves the way for shutting off the heating equipment.

In addition to energy savings, this measure should result in increased equipment life due to less run hours for the heating plant.

Technical Assumptions for Implementing Measure in Reference Building

The following is assumed for implementing this measure in the reference building:

- Baseline: The heating plant (boilers, heating water pumps) operates whenever the main air handlers operate.
- Measure: The heating plant operates only at outside air temperatures less than 75°F, whenever the main air handlers operate.

Implementation of this measure first requires implementation of the "Widen zone temperature deadband", "Lower VAV box minimum flow setpoints", and "Re-enable supply air temperature setpoint reset" measures, which significantly reduce the reheat load. If these measures are not implemented first, then zone overcooling is likely to occur with shutting off the heating plant during warm outside air temperatures, especially in buildings that have a deep floor plate (i.e., many internal zones). For this individual measure, however, the savings values shown in the following table do not account for implementation of those other measures.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	109,458	25	6,974	5.4	7.1%
Hot & Dry	102,592	27	2,871	3.2	4.2%
Marine	44,703	21	(1,278)	0.1	0.2%
Cold	50,853	24	(271)	0.7	1.1%
Very Cold	45,658	36	(1,364)	0.1	0.1%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$0	$1,837	$1,837	$17,904	$0	$17,904	0	$203,317
Hot & Dry	$0	$1,854	$1,854	$12,620	$0	$12,620	0	$142,722
Marine	$0	$1,920	$1,920	$2,868	$0	$2,868	1	$30,861
Cold	$0	$1,817	$1,817	$6,454	$0	$6,454	0	$72,074
Very Cold	$0	$1,810	$1,810	$4,580	$0	$4,580	0	$50,595
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

A simple programming change is sufficient to implement this measure. The EUL for this measure is estimated at 10 years. (WSDGA 2006)

HW8. Increase Efficiency of Condenser Water System

Technical Description

Many large commercial office buildings use water-cooled chillers to transfer heat from the building to the outdoors. In these systems, heat is ultimately rejected at the cooling tower through the condenser water system. Two common measures that can be applied to condenser water systems to increase the energy efficiency of the system include adding VFDs to the cooling tower fans, and adding a condenser water supply temperature setpoint reset strategy.

Many older cooling towers use constant speed (on/off) or two-speed (high/low/off) fans that cycle to maintain the condenser water supply temperature setpoint. Adding VFDs to the cooling tower fans and varying the speed of the fans to maintain the condenser water supply temperature setpoint yields energy savings with no associated pump penalty or sacrifice in performance.

In most situations, chiller efficiency increases with decreasing condenser water temperature, typically by 1-1.5% per degree reduced (Doty, 2009). Therefore, lowering the condenser water supply temperature setpoint will reduce the energy consumption of the chiller. There is a tradeoff, though – to achieve that lower temperature, the cooling tower fans will need to run harder. This should be accounted for in determining the energy benefit related to resetting the condenser water supply temperature setpoint.

Measure Special Considerations

To achieve maximum energy savings when adding VFDs to cooling tower fans, it's more efficient to run multiple fans at the same low speed than to run one fan at a higher speed. Pumping energy and control should also be considered when determining the optimum number of fans to operate.

Before implementing this measure, it's necessary to verify that the existing chiller(s) will accept cooler condenser water temperatures. Some chillers, especially older models, will not operate correctly at cooler condenser water temperatures (Wulfinghoff, 1999).

Technical Assumptions for Implementing Measure in Reference Building

The following is assumed for implementing this measure in the reference building:

- Baseline: The cooling tower is a multi-cell cooling tower with constant speed fans. The condenser water supply temperature setpoint is a constant 80°F.

- Measure: The cooling tower is a multi-cell cooling tower with variable speed fans controlled by VFDs. All fans operate at the same speed, down to 20% minimum speed, to maintain the condenser water supply temperature setpoint. The condenser water supply temperature is reset between 70°F and 80°F based on the outside air wetbulb temperature (setpoint = OA wetbulb + 10°F).

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	39,053	0	0	0.7	0.9%
Hot & Dry	82,375	17	0	1.4	1.9%
Marine	21,503	12	0	0.4	0.5%
Cold	23,092	15	0	0.4	0.5%
Very Cold	13,158	9	0	0.2	0.3%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$24,460	$12,693	$37,153	$2,551	$(217)	$2,334	16	$(17,287)
Hot & Dry	$26,998	$18,192	$45,190	$7,561	$(241)	$7,320	6	$30,189
Marine	$25,560	$16,738	$42,298	$2,682	$(250)	$2,432	18	$(22,393)
Cold	$24,192	$21,997	$46,189	$2,950	$(277)	$2,673	17	$(24,357)
Very Cold	$24,094	$18,320	$42,414	$1,638	$(252)	$1,385	>20	$(34,541)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

The cost of this measure assumes existing wiring and circuits are in place. Two fan motors and VFDs are also included in the estimate. The EUL for this measure is estimated at 15 years (WSDGA, 2006).

HW9. Increase Efficiency of Condenser Water Pumping System

Technical Description

This measure applies to cooling plants that use water-cooled chillers, which is a common type of cooling plant for large office buildings. Condenser water pumps circulate water between the chiller and the cooling tower. Most cooling plants use constant speed condenser water pumps piped in parallel, with one pump dedicated for each chiller. For systems that have multiple chillers, the condenser water system pumps are typically balanced when all of the chillers and condenser water pumps are operating. During part load conditions, however, when fewer chiller/pump combinations are running, these systems can be out of balance due to pressure characteristics of the common piping system. (ASHRAE 2008)

For example, a system has two chillers, each with a dedicated condenser water pump. Each chiller is rated at 500 gpm of condenser water flow, which is the flow that each condenser water pump delivers when both chillers are on. When only one chiller operates, however, the flow through the one chiller may be 700 gpm, 200 gpm greater than what the chiller is rated for.

Reducing the speed of the condenser water pumps at part load conditions (when chillers are shut off) to the design condenser water flow will yield energy savings.

Measure Special Considerations

For most HVAC applications, VFDs are controlled to maintain a setpoint of some measured variable, e.g., temperature or pressure. With the strategy outlined above, the ‘part load’ speed is a set speed. Continuing with the example above, when both chillers are operating, each condenser water pump would operate at 100% speed. When only one chiller operates, the speed of the one operating condenser water pump might be 80% speed. The ‘part load’ speed should be determined by measuring the condenser water flow, and manually adjusting the speed until the flow equals design flow.

The discharge valves related to constant speed condenser water pumps are often throttled slightly, as a way to balance the system to design flow with all chillers operating. If VFDs are installed, these valves should be opened up for additional energy savings.

Modulating condenser water pump speeds below design flow is typically not recommended for system performance, energy efficiency, and maintenance reasons (Dieckmann, 2010).

Technical Assumptions for Implementing Measure in Reference Building

The following is assumed for implementing this measure in the reference building:

- Baseline: Two condenser water pumps, one dedicated for each of the two chillers, are assumed. They have constant speed motors. Each pump’s discharge valve is slightly throttled.
- Measure: The motors are replaced with inverter-duty motors, and a VFD is added to each pump. The discharge valves are wide open. One pump operation and two pump operation pump speeds are set based on the number of chillers operating.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	30,180	0	0	0.5	0.8%
Hot & Dry	35,880	0	0	0.6	0.9%
Marine	11,253	0	0	0.2	0.3%
Cold	13,093	0	0	0.2	0.3%
Very Cold	8,775	0	0	0.1	0.2%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$16,307	$8,559	$24,866	$2,523	$(217)	$2,306	11	$(2,285)
Hot & Dry	$17,033	$12,267	$29,300	$2,786	$(255)	$2,531	12	$(4,992)
Marine	$17,040	$11,286	$28,326	$941	$(250)	$691	>20	$(24,929)
Cold	$16,128	$14,832	$30,960	$1,327	$(277)	$1,050	>20	$(23,966)
Very Cold	$16,063	$12,353	$28,416	$685	$(252)	$433	>20	$(28,001)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

The cost of this measure assumes existing wiring and circuits are in place. Two pumps and associated VFDs are included. The EUL for this measure is estimated at 15 years (WSDGA, 2006).

HW10. Change Cooling Plant Pumping System to Variable Primary

Technical Description

This measure applies to cooling plants that use chillers, which is a common type of cooling plant for large office buildings. Chilled water pumping systems generally fall into one of two categories: primary-only, and primary-secondary. In primary-only systems, one set of pumps circulates chilled water between the chiller(s) and the air handler(s). These systems can either be constant flow or variable flow. In primary-secondary systems, the primary pumps circulate chilled water through the chiller(s), and the secondary pumps draw from that loop to circulate chilled water to the air handler(s).

In general, primary-only variable flow systems use less energy than primary-only constant flow and primary-secondary systems, due to reduced pumping energy usage. However, they are usually more complex to design and operate. They are generally better suited for larger facilities with multiple chillers and sophisticated operating staff (Taylor, 2002).

Measure Special Considerations

For proper operation of a primary-only variable flow chilled water system, it's especially important that:

- The control sequences are designed and implemented to maximize energy efficiency without impacting performance
- The control loops are tuned properly
- The chilled water flow meter is calibrated regularly

Complex control systems such as a primary-only variable flow chilled water system especially require proper setup and adequate maintenance to maintain performance and avoid chiller staging issues (Taylor, 2002). Minimum required flow through the operating chillers must be maintained at all times, which is typically accomplished through use of a flow meter and bypass valve.

If controls complexity is a barrier to implementing this measure, another measure worth considering is converting the primary-only constant flow system to a primary-secondary system. Changing to this type of system involves replacing and adding pumps (VFD-equipped for the secondary pumps), modifying the chilled water piping in the mechanical room, and modifying the controls. While this system would not save as much energy as a primary-only variable flow system, it's less complex to operate, and would consume less energy than a primary-only constant flow system.

BAS software overlays are available that will continually and automatically optimize the performance of a primary-only variable flow chilled water plant (Hartman, 2001).

Technical Assumptions for Implementing Measure in Reference Building

The baseline reference building has a constant flow primary-only chilled water system, with two chillers each sized at 50% of the peak cooling load, two constant speed chilled water pumps (one per chiller), and 3-way chilled water coil control valves at the air handlers. The measure case uses the same chillers, but changes the system to a variable flow primary-only system. This work includes:

- Changing the pumping arrangement to a headered arrangement.
- Replacing the chilled water pump motors with inverter duty-rated motors, and adding VFDs to the pumps. Control the chilled water pump VFDs based on system differential pressure and minimum required chiller flow.
- Changing the air handler chilled water coil control valves from 3-way to 2-way.
- Adding a bypass valve and flow meter near the chillers.
- Stage the chillers based on calculated load on the plant. Calculated load is based on flow meter readings and chilled water supply and return temperatures.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	58,089	9	0	1.0	1.3%
Hot & Dry	62,111	15	0	1.1	1.4%
Marine	18,253	7	0	0.3	0.4%
Cold	22,875	0	0	0.4	0.5%
Very Cold	13,981	(6)	0	0.2	0.3%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$37,782	$26,868	$64,649	$4,873	$(217)	$4,656	14	$(10,930)
Hot & Dry	$45,595	$39,552	$85,146	$5,789	$(241)	$5,548	15	$(21,234)
Marine	$39,480	$35,429	$74,909	$2,084	$(250)	$1,834	>20	$(53,588)
Cold	$37,366	$46,562	$83,928	$2,613	$(277)	$2,336	>20	$(56,901)
Very Cold	$37,215	$38,779	$75,994	$1,470	$(252)	$1,217	>20	$(61,752)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs assume two new VFDs, new pump motors, and modifications to the piping including removal of 3-way coil control valves, installation of 2-way coil control valves, a bypass pipe at the end of the water line, and two differential pressure sensors. Costs also include modification to the controls and a new flow meter installation. The EUL for this measure is estimated at 20 years (WSDGA, 2006).

HW11. Replace Cooling and Heating Plant Pump Motors

Technical Description

This measure involves replacing a facility's pump motors with premium efficient motors, to reduce motor energy usage. Standard motor efficiencies have steadily increased over the last few decades due to improvements in motor design and manufacturing. Minimum motor efficiencies prescribed in building energy codes and federal regulations are frequently increased to keep pace with these improved efficiencies.

Measure Special Considerations

Most facilities do not consider upgrading motors with higher efficiency models until the existing motors need to be replaced due to failure, or related to installation of a VFD (VFDs require inverter duty-rated motors). However, it may be worth replacing large, old motors that operate frequently with more efficient models even before failure (Wulfinghoff, 1999).

Technical Assumptions for Implementing Measure in Reference Building

The reference building is thirty years old. It is assumed that the cooling and heating plant pump motors are original to the building and are in need of replacement. This includes motors related to the following pumps: chilled water, condenser water, heating water. The server room pumps are assumed to be newer and not in need of replacement.

This measure overlaps with the following other Retrofit measures:

- Change cooling plant pumping system to variable primary
- Add VFDs to condenser water pumps
- Change heating plant pumping system to primary-secondary
- Replace boilers and change heating plant pumping system to variable flow primary

In these measures, the related pump motors would be replaced with inverter-duty motors to accommodate the VFDs.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	7,772	2	0	0.1	0.2%
Hot & Dry	7,175	2	0	0.1	0.2%
Marine	3,903	2	0	0.1	0.1%
Cold	4,297	2	0	0.1	0.1%
Very Cold	3,681	1	0	0.1	0.1%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$18,259	$12,348	$30,607	$709	$0	$709	>20	$(11,937)
Hot & Dry	$20,393	$18,546	$38,939	$684	$0	$684	>20	$(17,621)
Marine	$19,080	$16,283	$35,363	$397	$0	$397	>20	$(18,629)
Cold	$18,059	$21,399	$39,458	$511	$0	$511	>20	$(20,006)
Very Cold	$17,986	$17,822	$35,808	$402	$0	$402	>20	$(18,861)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs are based on the replacement of six motors using existing wiring. Incremental costs should be considered between the code minimum and advanced standard for this measure. Evaluating the measure on an incremental basis would increase the NPV values. The EUL of this measure is estimated at 17 years (WSDGA, 2006).

HW12. Add a VFD to One Chiller

Technical Description

This measure applies to centrifugal chillers, which is a common type of cooling plant for large office buildings. At low load, the efficiency of these chillers is less than the full load efficiency. Also, these chillers have limited turndown capability. Part-load efficiency and turndown can be improved by converting the compressors from constant speed to variable speed through the addition of a VFD. (Wulfinghoff 1999) For cooling plants with multiple chillers, one chiller can be retrofit with a VFD and used as the lead, since it will operate most efficiently at part load. The other chillers in the plant can come online when the load increases beyond the load of the one chiller. Then the VFD-equipped chiller modulates to maintain the setpoint while the other chillers operate fully loaded (Bahnfleth, 2004).

Measure Special Considerations

Not all centrifugal chiller compressors can be retrofitted with a VFD, due to refrigerant performance and torsional resonance. The chiller manufacturer should be consulted before adding VFDs to the compressors. The VFD retrofit should be designed for the particular chiller model, and installed by a qualified person (Wulfinghoff, 1999).

To maximize energy efficiency, the existing chiller staging strategy should be modified to allow part load operation of the VFD-equipped chiller and full load operation of the constant speed chillers.

The energy savings related to this measure depends on the building cooling load profile and the number and size of chillers in the plant. The more variable the cooling load profile and the fewer number of chillers, the greater the energy savings potential. It may be more efficient to install a small chiller to handle low loads than to install a VFD on one of the existing compressors (Wulfinghoff, 1999).

Technical assumptions for implementing measure in reference building

The baseline reference building has two constant speed centrifugal chillers, each sized for 50% of the peak cooling load.

The measure adds a VFD to one of the chillers, and modifies the control sequence so that this chiller operates during single chiller operation, and the other chiller operates at full load during two chiller operation (when the cooling load is too great for one chiller to handle).

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	73,575	3	0	1.3	1.7%
Hot & Dry	66,164	22	0	1.1	1.5%
Marine	19,789	10	0	0.3	0.4%
Cold	25,533	3	0	0.4	0.6%
Very Cold	13,314	2	0	0.2	0.3%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$38,126	$11,799	$49,925	$5,839	$(217)	$5,622	9	$5,656
Hot & Dry	$38,469	$16,912	$55,380	$6,527	$(241)	$6,286	9	$6,838
Marine	$39,840	$15,559	$55,399	$2,473	$(250)	$2,223	>20	$(39,751)
Cold	$37,707	$20,448	$58,155	$2,733	$(277)	$2,455	>20	$(40,331)
Very Cold	$37,555	$17,030	$54,585	$1,486	$(252)	$1,233	>20	$(50,140)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs are based on installation of one VFD for a 200hp compressor. The EUL for this measure is estimated at 15 years (WSDGA, 2006).

HW13. Add Waterside Economizer

Technical Description

Many large office buildings utilize a water-cooled chilled water system to transfer heat from the building to the outdoors. A waterside economizer system can be added to this system to increase the cooling plant system efficiency. With this system, the chiller is turned off during cool outside air conditions and condenser water is cooled low enough to draw heat from the chilled water loop and maintain the required chilled water temperatures. Adding a waterside economizer system to an existing chilled water plant usually consists of adding a heat exchanger between the condenser water and chilled water loops, and revising the controls to enable the waterside economizer (bypass the chiller) when outside air temperatures are low enough (Wulfinghoff, 1999).

Measure Special Considerations

Waterside economizers are less beneficial in humid climates with high outside air wet bulb temperatures, since they cannot cool the condenser water low enough to be beneficial.

Waterside economizers are especially attractive in facilities that have a cooling load even at low outside air temperatures (e.g., data centers) and do not utilize airside economizers.

Some chillers allow for "free cooling" without the need for installing a heat exchanger. In these systems, the chiller compressor is turned off, and refrigerant is allowed to migrate between the condenser and evaporator bundles. With this arrangement, the chiller effectively operates as a heat pipe, transferring heat between the bundles with the refrigerant migration (Wulfinghoff, 1999).

Technical Assumptions for Implementing Measure in Reference Building

The baseline reference building does not have a waterside economizer. It has airside economizers at the air handlers (for all of the climate zones except hot and humid), and the tenant server room cooling units are cooled with the condenser water loop. Since the baseline reference building does not have a need for chilled water at low outside air temperatures, adding a waterside economizer system is of no benefit – it will not increase the system efficiency. For the hot and humid climate zone, the wet bulb temperatures are high enough that a waterside economizer system would be of very limited benefit.

For these reasons, costs and savings have not been estimated for this measure.

HW14. Add Chilled Water Plant Heat Recovery

Technical Description

Chilled water plants reject a tremendous amount of heat to the outdoors, equivalent to the facility cooling load plus the heat from the chiller compressors. Capturing this heat for reuse in the facility rather than rejecting it to the outdoors increases the overall thermal efficiency of the facility and reduces its overall energy usage. The load on the chilled water plant is reduced, as well as the load on the system that utilizes the waste heat (e.g., space heating, domestic water heating).

For most large commercial buildings, there are two options for chilled water plant heat recovery:

- Recover the heat directly from the condenser water loop, diverting and utilizing (cooling) the warm condenser water before it reaches the cooling tower.
- Use a heat recovery chiller, or a chiller with an auxiliary condenser for heat recovery.

Chilled water plant heat recovery requires a careful analysis of the costs and benefits, specific for each facility's needs and characteristics. The benefit of recovering heat must be weighed against the efficiency penalty on the chilled water plant (Wulfinghoff, 1999).

Measure Special Considerations

Heat recovery can be an attractive measure if a facility has significant simultaneous heating and cooling loads. Examples include:

- Facilities with a large floor plate that may simultaneously require heating at the exterior zones and cooling at the interior zones during cold outside air conditions.
- Facilities with continual and high zone reheat loads
- Facilities that require reheat after dehumidification, to prevent overcooling the zones.

Heat recovery can also be beneficial for facilities that have significant domestic hot water loads. The heat from the chilled water plant can be used to preheat the domestic cold water entering the water heaters.

For most large offices, though, this measure is typically not cost-effective. The domestic hot water load is usually very low, and there is typically not enough simultaneous heating and cooling to make the measure worthwhile. Heat recovery is more applicable for facilities such as hospitals, where there is a high and constant domestic hot water load and the system operates continuously. It is typically more cost-effective for large offices to focus on reducing zone heating and domestic hot water loads than to implement chilled water plant heat recover to meet the existing loads.

Heat recovery usefulness increases with increasing condensing temperatures. Increased condenser temperatures should be balanced against the efficiency penalty on the chiller, which can be a 1-2% decrease in COP per increased condensing water degree F. Chiller capacity should also be considered, since capacity decreases with increasing condensing water temperature.

Warmer climates are more suitable for condenser heat recovery than colder climates, since chillers operate more often in warmer climates (Wulfinghoff, 1999).

Technical Assumptions for Implementing Measure in Reference Building

For the reference building, chilled water plant heat recovery is likely not a cost-effective measure due to the low heating/hot water load when the chiller is operating. In the reference building, heat recovery could be utilized for:

- Summertime VAV terminal unit reheat
- Domestic hot water preheat
- Air handler dehumidification reheat

However, these loads are relatively low, and are probably not worth the sacrifice in chiller efficiency. Therefore, costs and savings are not estimated for this measure. Heat recovery probably makes most sense in the hot and humid climate zone, which typically has a significant dehumidification reheat load at the air handlers. Even though this measure is likely not cost-effective for the reference building, it's worth consideration for other buildings, especially those that have different operating characteristics from the reference building.

HW15. Replace Boilers and Change Heating Plant Pumping System to Variable Flow Primary

Technical Description

Most large office buildings, especially older facilities, use non-condensing boilers in a primary-only constant flow piping arrangement as their heating plant. Replacing the boilers with condensing boilers and converting the piping system to a variable flow primary system would reduce energy usage of the heating plant through increased boiler efficiency, reduced pumping energy due to VFDs installed on the pumps, and reduced heat loss through the secondary piping due to lower loop temperatures.

Unlike non-condensing boilers, condensing boilers are designed to allow the flue gases to condense in the boiler and flue. These boilers are more efficient than non-condensing boilers, and operate even more efficiently at lower return water temperatures (ASHRAE. 2008). Lower water temperatures will also reduce piping conduction heat losses.

Implementation of this measure requires replacing the boilers and pumps, changing any 3-way heating coil control valves to 2-way valves, adding differential pressure sensors, and modifying the control of the heating water plant to keep the loop temperatures as low as possible while still satisfying the heating load.

Measure Special Considerations

This measure is most suitable for facilities that operate at part load heating for a significant amount of time. Part load heating allows for reduced pump speeds and reduced heating water supply temperature, increasing the efficiency of the system.

Lowering the heating water supply temperature, and thus the return water temperature, will increase the boiler efficiency. However, the performance of the existing heating coils must be evaluated at lowered heating water supply temperatures. In some instances, the coils may not perform adequately at lowered temperatures, especially with heating coils that have a low number of rows. In these instances, either the heating coils must be replaced, or the heating water supply temperature must be kept high enough to maintain adequate coil performance.

Minimum flow rates must be maintained through the boiler(s). This is typically not a major issue, but is one that should be considered during design and operation of the system.

Differential pressure-based pump speed control and heating water supply temperature setpoint reset are both strategies that increase the efficiency of the system, but care must be taken in implementing these strategies together as they often overlap. For example, for a given heating load, lowering the temperature setpoint will result in increased pump speeds since the heating valves will open in response to the lowered temperature setpoint.

The pumps typically operate to maintain a constant differential pressure setpoint in the system. Resetting this setpoint based on an indication of load (e.g., heating water valve position) would result in more efficient operation.

Technical Assumptions for Implementing Measure in Reference Building

The baseline reference building includes two non-condensing boilers, each sized for 60% of the peak heating load, in a primary-only constant flow arrangement with 3-way valves at the heating coils and a 180°F heating water supply temperature setpoint. The measure case includes:

- Replacing the boilers with high-efficiency condensing boilers.
- Replacing the pumps with VFD-controlled pumps in a headered arrangement.
- Changing most of the heating coil control valves from 3-way valves to 2-way valves. Maintain enough 3-way valves to maintain minimum flow through the boilers. Another option would be to install a bypass valve and flow meter near the boilers, to measure and maintain minimum flow through the boilers.
- Adding differential pressure sensors near the end of the piping run to control the pump speeds. Reset the pressure setpoint based on the position of the terminal unit heating water control valves.
- Resetting the heating water supply temperature setpoint off of outside air temperature.
- Upgrading the controls as needed to accomplish the above.

This measure first requires upgrading the VAV boxes to DDC control, to provide valve position feedback for differential pressure setpoint reset.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	76,056	17	1,185	1.9	2.5%
Hot & Dry	89,286	18	2,632	2.8	3.8%
Marine	78,594	17	5,059	3.9	5.7%
Cold	73,039	15	4,107	3.3	5.0%
Very Cold	80,686	15	6,087	4.4	6.5%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$201,595	$202,160	$403,755	$8,126	$4,345	$12,471	>20	$(259,460)
Hot & Dry	$223,847	$203,978	$427,824	$10,304	$5,100	$15,405	>20	$(247,506)
Marine	$230,290	$211,248	$441,538	$12,618	$5,000	$17,618	>20	$(235,608)
Cold	$234,474	$199,938	$434,413	$12,445	$5,545	$17,990	>20	$(223,157)
Very Cold	$241,581	$199,131	$440,711	$12,948	$5,048	$17,996	>20	$(226,433)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

The cost for implementation of this measure also includes an upgrade of the zone-level control from pneumatic to DDC. Costs would be less, and NPVs would be higher, if the control system already includes DDC at the zone level. The EUL for this measure is estimated at 20 years (WSDGA, 2006).

HW16. Replace Boiler Burners with Modulating Burners

Technical Description

Boilers are typically rated by their combustion efficiency. However, the actual overall boiler efficiency (dynamic efficiency) is lower than the rated combustion efficiency due to heat lost from the surface of the boiler, and standby losses. Standby losses are due to convection (through the flue when the boiler is off) and purging (to empty the combustion chamber of fuel vapors). These losses can be reduced by using a modulating fire configuration, which allows the burner to operate at part load rather than turning off. Modulating burners have larger turndown ratios and, thus, lower standby losses than conventional burners (Wulfinghoff, 1999).

Measure Special Considerations

Modulating burners are most suitable for heating systems that operate often at part load conditions, or if the load is highly variable, such as for comfort heating. This is due to their higher turndown ratio than standard burners. In practice, a boiler system rarely operates at its design load. In addition, if a boiler is oversized then the fraction of time at low fire will increase even further.

A modulating fire boiler with the traditional jackshaft (single-point) control system uses large amounts of excess air at low fire, thus inducing a significant efficiency penalty. Parallel position (linkageless) control or oxygen trim controls can help maintain the proper mixture (Wulfinghoff, 1999).

Technical Assumptions for Implementing Measure in Reference Building

The reference building includes two gas-fired non-condensing heating water boilers, each sized for 60% of the peak heating load, with standard burners that have a 2:1 turndown ratio (100% fire : 50% fire). The measure replaces these burners with modulating burners that have a 5:1 turndown ratio (full turndown firing rate of 20%, or 100% fire : 20% fire).

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	0	0	237	0.1	0.2%
Hot & Dry	0	0	387	0.2	0.3%
Marine	0	0	447	0.2	0.3%
Cold	0	0	498	0.2	0.3%
Very Cold	0	0	638	0.3	0.4%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$4,019	$29,420	$33,440	$269	$0	$269	>20	$(20,007)
Hot & Dry	$4,635	$42,167	$46,801	$401	$0	$401	>20	$(27,701)
Marine	$5,400	$38,795	$44,195	$477	$0	$477	>20	$(25,035)
Cold	$6,247	$50,985	$57,232	$539	$0	$539	>20	$(33,295)
Very Cold	$5,656	$42,463	$48,119	$505	$0	$505	>20	$(27,412)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs include the new modulating burners and no additional electrical work is anticipated. Incremental costs between non-modulating and modulating burners should be considered for this measure. Evaluating the measure on an incremental basis would increase the NPV values. The EUL for this measure is estimated at 20 years (WSDGA, 2006).

HW17. Increase the Efficiency of the Tenant Server Room Pumping System

Technical Description

Multi-tenant commercial office buildings often include small server rooms scattered throughout the building that house the tenants' computer servers. These spaces are typically unoccupied, and are often cooled by a small dedicated DX cooling fan coil unit. For many large office buildings, these spaces are located near the core of the floor plate, making it difficult to locate a small dedicated condensing unit outside to reject the heat from the fan coils. For these spaces, heat is typically rejected to a building fluid cooler/condenser water loop dedicated for the server rooms.

With this system, heat is ultimately rejected to the outdoors through the building's cooling tower, or a dedicated fluid cooler. Fluid coolers are often used in cold climates, where the cooling tower is drained during the wintertime. They usually utilize a glycol/water mixture as the fluid, to prevent freezing during cold outside air conditions.

Constant speed pumps typically circulate the water between the server room fan coils and the fluid cooler/cooling tower. The efficiency of the pumping system can be increased by adding VFDs to control the pumps based on the needs of the system, thus lowering the energy consumed by the pumps. The savings related to this measure can be substantial since these pumps typically operate continuously, due to continuous cooling loads in the server rooms.

Measure Special Considerations

To fully take advantage of the energy benefits of variable flow systems, flow should be shut off at the server room DX unit coils when cooling is not needed, rather than bypassed around the coils. Therefore, as part of implementing this measure, any 3-way fan coil water control valves should be changed to 2-way valves for maximum energy savings.

Adding VFDs to the pumps is most beneficial in systems that have variable cooling loads. As the cooling load drops and the amount of fan coil DX cooling lowers, pump speeds can be reduced.

Technical Assumptions for Implementing Measure in Reference Building

The server room load in the reference building is quite low, resulting in small server room pump sizes. Adding VFDs to these pumps in the reference building would not be cost-effective. For buildings with large server room pumps (greater than about five HP), this measure is worth consideration.

HW18. Cool the Server Rooms with Transfer Air Instead of Mechanical Cooling

Technical Description

In multi-tenant commercial office buildings, it's typical for each small server room to be cooled by a small dedicated DX cooling fan coil unit. These rooms typically have temperature setpoints similar to the adjacent office spaces (e.g., 72°F). Energy savings can be realized by eliminating the mechanical cooling and using transfer air from adjacent spaces to cool the room. This can only be accomplished if the room temperature's setpoint is raised, to as high as 90°F.

Measure Special Considerations

Some servers may not operate well at higher space temperatures. Implementing this measure requires close coordination with a company's IT department.

The inlet and outlet air locations should be located far enough apart to avoid short cycling of the air.

This measure typically involves adding a fan that pulls air from the adjacent occupied space, draws it through the server room, and then exhausts it to the return air plenum. The fan operates to maintain the space temperature setpoint. Exhausting to the return air plenum will increase the cooling load and decrease the heating load on the main HVAC system during non-airside economizer operation.

Tenant server room HVAC equipment is often owned and operated by the tenants. Implementation of this measure would likely be initiated more from the tenants than the building owner.

This measure can be implemented on individual server rooms. Even if only a fraction of the server rooms implement this measure, energy savings would be realized since it would reduce the load on the server room water loop.

Technical Assumptions for Implementing Measure in Reference Building

The reference building's server rooms are each cooled by a DX cooling fan coil unit, and transfer the heat to the building's tenant water loop. It's assumed that the servers in the building will not accommodate the higher space temperatures, so this measure cannot be implemented in the reference building. Therefore, costs and savings estimates are not calculated for this measure. However, this measure is worth consideration for buildings that have a significant server room load, with newer servers that can work properly at higher space temperature conditions.

HW19. Increase the Efficiency of the Tenant Server Room Cooling Units

Technical Description

Multi-tenant commercial office buildings often include small server rooms scattered throughout the building that house the tenants' computer servers. These spaces are typically unoccupied, and are often cooled by a small dedicated DX cooling fan coil unit. For many large office buildings, these spaces are located near the core of the floor plate, making it difficult to locate a small dedicated condensing unit outside to reject the heat from the fan coils. For these spaces, heat is typically rejected to a building fluid cooler/condenser water loop dedicated for the server rooms.

With this system, heat is ultimately rejected to the outdoors through the building's cooling tower, or a dedicated fluid cooler. Fluid coolers are often used in cold climates, where the cooling tower is drained during the wintertime. They usually utilize a glycol/water mixture as the fluid, to prevent freezing during cold outside air conditions.

Energy savings can be realized by replacing the server room fan coils with units that have higher-efficiency compressors and waterside economizer capability. These units would have two cooling coils: one using condenser/fluid cooler water to cool the air (first stage cooling), the other using refrigerant to cool the air (second stage cooling).

Measure Special Considerations

The reduced mechanical cooling energy usage due to the waterside economizer must be weighed against the increased energy usage of the fluid cooler/cooling tower to cool the water to a lower temperature and the added air pressure drop due to the second cooling coil. It may be more efficient to have a higher water loop temperature setpoint at warmer outside air conditions (for DX cooling at the server room units), and a colder water loop setpoint at cooler outside air conditions (to allow waterside economizer cooling at the server room units).

Tenant server room HVAC equipment is often owned and operated by the tenants. Implementation of this measure would likely be driven more from the tenants than the building owner.

Technical Assumptions for Implementing Measure in Reference Building

The reference building uses standard efficiency water-cooled DX fan coil units to cool the small server rooms throughout the building. For the measure, these units are replaced with ones that have higher efficiency compressors and waterside economizer capability. Also, the BAS is programmed with a loop temperature reset strategy to maximize efficiency of the system as a whole.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	44,992	6	0	0.8	1.0%
Hot & Dry	50,719	8	0	0.9	1.1%
Marine	46,108	7	0	0.8	1.2%
Cold	48,903	7	0	0.8	1.3%
Very Cold	48,308	8	0	0.8	1.2%
Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$31,810	$22,012	$53,822	$3,520	$0	$3,520	15	$(2,092)
Hot & Dry	$32,096	$22,210	$54,306	$4,007	$0	$4,007	14	$3,095
Marine	$33,240	$23,002	$56,242	$3,937	$0	$3,937	14	$768
Cold	$33,164	$17,927	$51,091	$5,100	$0	$5,100	10	$18,124
Very Cold	$33,030	$17,854	$50,884	$4,737	$0	$4,737	11	$14,147
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs assume cold and very cold climate zones utilize a separate glycol fluid cooler while the other climate zones use the existing cooling tower. The estimated EUL for this measure is 15 years (WSDGA, 2006).

Service Hot Water Retrofit Measures

S1. Increase Efficiency of Service Hot Water System

Technical Description

On average, the energy used for heating domestic hot water in large office buildings makes up only about 2% of a building's total consumption. This is a relatively small amount in comparison to other end uses such as HVAC (40%), lighting (32%), and office equipment and computers (11%) (U.S. Energy Information Administration, 2006). Efforts at reducing overall facility energy usage should target these larger energy consumers first. That said, there are opportunities for increasing the efficiency of service hot water systems in large office buildings, including:

- Inspect and repair pipe and tank insulation. This task can be included in a facility's existing preventive maintenance program.
- Replace lavatory faucets with sensor controlled low-flow faucets. This measure will reduce water consumption in addition to water heating usage.

- Turn off hot water circulating pump during unoccupied hours. Operate pump during occupied hours only when needed to maintain loop temperature. This measure is applicable for systems that use a central water heater.
- Install a solar collector for pre-heating the cold water inlet. This measure is applicable for systems that use a central water heater.
- Replace the water heater with a more efficient model.
- Replace the water heater with a heat pump water heater. Pipe the waste cooling to a nearby server room, to reduce the cooling load on the server room HVAC unit. This measure is applicable for systems that use a central water heater.
- Replace the water heater with point-of-use electric water heaters. This measure is applicable for systems that use a central water heater.

Measure Special Considerations

For large office buildings that have a cafeteria, food court, or other occupancy that uses a significant amount of domestic hot water, increasing the efficiency of the domestic water heating system can yield substantial energy savings.

For any system, the domestic hot water temperature should not be lowered below a level that will encourage growth of legionellla pneumophilia. This dangerous bacteria colonizes in warm water temperatures below 115°F. Typically, service hot water systems are kept at 140°F to inhibit growth of the bacteria (ASHRAE, 2007).

Technical Assumptions for Implementing Measure in Reference Building

For the reference building, the following measure is implemented to represent increasing the efficiency of the service hot water system:

- Baseline: Gas-fired tank-type water heater with 80% thermal efficiency serving the lavatories, service sinks, and break room sinks located throughout the building. A small pump circulates water around the building to minimize the length of time it takes hot water to reach the fixture when turned on.
- Measure: Similar to the baseline system, except the water heater is a condensing-type water heater with 95% efficiency. The existing flue is replaced with a PVC flue.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	0	0	184	0.1	0.1%
Hot & Dry	0	0	234	0.1	0.2%
Marine	0	0	325	0.2	0.2%
Cold	0	0	337	0.2	0.2%
Very Cold	0	0	407	0.2	0.3%

Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$8,613	$3,890	$12,503	$209	$0	$209	>20	$(7,222)
Hot & Dry	$8,690	$5,576	$14,266	$243	$0	$243	>20	$(8,178)
Marine	$9,000	$5,130	$14,130	$347	$0	$347	>20	$(6,893)
Cold	$8,518	$6,742	$15,260	$365	$0	$365	>20	$(7,553)
Very Cold	$8,484	$5,615	$14,099	$321	$0	$321	>20	$(7,161)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs are based on a new condensing water heater and an additional electrical circuit within 50' of a panel. The EUL of this measure is estimated at 12 years (WSDGA, 2006).

OTHER RETROFIT MEASURES

O2. Retrofit Electric Transformers with Higher Efficiency Models

Technical Description

Transformers are used in commercial office buildings to reduce the voltage supplied by the utility to the building to a level that can be used by certain end-uses. Typically, the utility supplies 480/277v power, and the building transformers reduce a portion of the load to 208/120v for use by lighting, plug loads, and other 208/120v loads. These transformers can be upgraded to higher efficiency models to realize energy savings. Many high efficiency transformers reach their peak efficiency at part load conditions, where most transformers operate (Thomas, 2002).

Measure Special Considerations

Upgrading transformers to higher efficiency models is typically not a cost-effective measure unless the transformer is at the end of its useful life. If they are replaced, or if new transformers are added as part of an addition, it may be worth using a higher efficiency transformer (Thomas, 2002).

Some office buildings may have just a couple transformers located near the main electrical service entrance, while others will have transformers located throughout the building.

Technical Assumptions for Implementing Measure in Reference Building

The reference building is assumed to have one main building transformer near the utility service entrance, lowering the voltage from 480/277v to 208/120v. The baseline transformer efficiency is 95%, while the measure transformer efficiency is 98.5%.

Energy Savings Results

Climate Zone	Electricity Savings (annual kWh)	Electric Demand Savings (peak kW)	Gas Savings (annual therms)	Site EUI Savings (kBtu/sf/yr)	Savings as % of Total Site Usage
Hot & Humid	39,656	8	0	0.7	0.9%
Hot & Dry	39,658	8	0	0.7	0.9%
Marine	39,656	8	0	0.7	1.0%
Cold	39,656	8	0	0.7	1.0%
Very Cold	39,656	8	0	0.7	1.0%
Energy savings estimates were calculated using a spreadsheet-based analysis. Values presented in this table are total savings from the reference building baseline usage, not incremental savings from a current code baseline.					

Financial Analysis Results

Climate Zone	Equipment Cost	Install Cost	Total Cost	Total Annual Energy Cost Savings	Annual O&M Cost Savings	Total Annual $ Savings	Simple Payback (years)	NPV
Hot & Humid	$65,687	$4,827	$70,514	$3,444	$0	$3,444	>20	$(16,098)
Hot & Dry	$66,278	$6,918	$73,196	$3,281	$0	$3,281	>20	$(20,132)
Marine	$68,640	$6,365	$75,005	$3,593	$0	$3,593	>20	$(17,963)
Cold	$64,965	$8,365	$73,330	$4,303	$0	$4,303	17	$(8,549)
Very Cold	$64,703	$6,967	$71,669	$4,036	$0	$4,036	18	$(10,269)
Values presented in this table are total costs and savings, not incremental costs and savings from a current code baseline.								

Implementation costs assume the standard efficiency transformer is replaced with a high efficiency transformer (300 kVA). Incremental costs should be considered for this measure, for when the transformers are at the end of their useful lives. Evaluating the measure on an incremental basis would increase the NPV values. The EUL of this measure is estimated at 30 years (WSDGA, 2006).

ADDITIONAL RETROFIT MEASURES FOR SMALL AND MEDIUM SIZED OFFICE BUILDINGS

The retrofit measures presented above are typical of systems found in an average large office building. The remaining retrofit descriptions include specific measures that might apply to the typical packaged HVAC equipment found in most small and medium offices. These measures were not analyzed in detail, since the reference building model is a large office building with more complex HVAC systems. Therefore, savings values and cost-effectiveness analysis results are not presented for these measures.

Replace RTUs with Higher Efficiency Units

Technical Description

This measure involves replacing the original packaged roof top units with more efficient models. Direct expansion, furnace and motor efficiencies of RTUs have steadily increased over the last few decades due to improvements in manufacturing and technologies. Minimum efficiencies prescribed in building energy codes and federal regulations are frequently increased to keep pace with these improved efficiencies.

Measure Special Considerations

Replacing a functioning RTU with a more efficient model for energy savings alone is not usually cost-effective (Wulfinghoff, 1999). However, older units that require significant maintenance costs, units that are near the end of their useful lives, or units that operate continuously might be good candidates for replacement.

Replace RTUs with High Efficiency VAV Units

Technical Description

This measure involves replacing the original CAV packaged roof top units with VAV units that have higher cooling and heating efficiency. While CAV units deliver a constant volume of air whenever the units are on, VAV units modulate the airflow to meet the needs of the zones. Significant fan energy savings can be realized by using VAV units with VFD-controlled supply fans. They're most suited for zones that have varying cooling and heating loads.

RTU cooling and heating efficiencies have steadily increased over the last few decades. Minimum efficiencies prescribed in building energy codes and federal regulations are frequently increased to keep pace with these improved efficiencies. Units with higher cooling and heating efficiencies use less energy than units with standard efficiencies.

Measure Special Considerations

DX cooling coils require minimum airflow for proper operation to avoid coil freezing. Minimal flows must be considered when selecting and operating VAV units with DX cooling.

The controls will need to be upgraded with the conversion from CAV to VAV. VAV units are able to modulate both the air volume and the supply temperature, which is more energy efficient at the expense of added controls complexity. The controls should be set up to maximize the efficiency of the system while still maintaining comfort conditions in the zone (Wulfinghoff, 1999).

Replace RTUs with Units that Use Evaporative Cooling

Technical Description

Evaporative cooling (EC) may provide an efficient replacement for traditional direct expansion air conditioning in some climates. In drier climates, EC can save up to 70% of the energy and demand required by an equivalent direct expansion (DX) system (ASHRAE, 2008a). Direct EC works by evaporating water directly in the airstream, either by spray or direct contact with a media. In addition to energy savings, EC improves air quality and doesn't require the use of refrigerants.

This measure involves replacing standard packaged rooftop units with models capable of evaporative cooling.

Measure Special Considerations

Evaporative cooling works best in hot, dry climates. Many areas in the country would not receive the full benefits of an EC system.

Replace RTUs with Air-To-Air Heat Pumps

Technical Description

Air-to-air heat pumps are different from standard electric (DX) cooling, gas heating units in that they use the refrigerant cycle to provide both heating and cooling. They are typically all-electric units. Air-to-air heat pumps use the refrigerant cycle to reject heat to the outdoors during cooling mode and extract heat from the outdoors in heating mode, reversing the direction of the refrigerant depending on the operating mode (ASHRAE, 2008a).

Measure Special Considerations

Air-to-air heat pumps are most suited for mild climates. In heating mode, the heating efficiency and capacity decrease with decreasing outdoor air temperature. Similarly, in cooling mode, the cooling efficiency and capacity decrease with increasing outdoor air temperature.

In cold climates, supplemental heat may be required (e.g., electric duct heaters), since heat pumps cannot operate in heating mode at cold outside air temperatures.

Replace HVAC System with a Dedicated Outdoor Air System

Technical Description

A dedicated outdoor air system (DOAS) decouples the heating and cooling of the outside air from the space heating and cooling. With this system, a dedicated outside air unit provides 100% outside air to a space, heated and cooled to a neutral or slightly cool condition by the unit, while the other HVAC units operate in 100% recirculation mode to heat and cool the space. A DOAS may be more energy efficient than a traditional system that supplies ventilation air from each unit. It also makes it more cost-effective to implement air-to-air energy recovery between outgoing (exhaust) and incoming (outside air) airstreams, since all of the outside air is brought in at a central location.

Using a DOAS helps address the fact that sensible and latent cooling loads on cooling equipment do not peak at the same time (Morris, 2003).

Measure Special Considerations

Typically, air from the 100% outside air unit is ducted to each occupied space, while the other HVAC units serve only their specific spaces. There may be more ductwork associated with DOAS than with conventional systems.

DOAS is most effective in hot, humid climates. When coupled with air-to-air energy recovery, it can be cost-effective in all climates.

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