PDHonline Course G221 (12 PDH)

Energy Star® Strategies for Upgrading Existing Buildings

Instructor: Jeffrey Havelin, PE

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

An Approved Continuing Education Provider

United States Environmental Protection Agency
Air and Radiation (6202J)
December, 2004

ENERGYSTAR®

Building Upgrade Manual

Introduction

The Energy Star® Upgrade Manual for Buildings is a guide for planning and implementing profitable upgrades that will improve the energy performance of your facilities. The Manual is a guide for developing a comprehensive energy management strategy and an integrated approach to upgrading existing buildings. It also provides information on proven energy-efficient technologies that can produce energy savings of 35% or greater by following the staged process outlined in the manual.

Energy Star Overview

Energy Star is a dynamic voluntary government and industry partnership that makes it easy for businesses and consumers to save money and protect the environment. In 1991, the US Environmental Protection Agency introduced the Green Lights program, a voluntary program that encouraged organizations to upgrade their lighting to energy efficiency lighting systems and controls. The labeling program was launched the following year and the Energy Star brand was introduced. The Energy Star brand identifies energy-efficient products and promotes energy performance that saves energy and protects the environment. In 1996, EPA partnered with Department of Energy to increase the product offerings of the Energy Star label. The label was expanded to include new homes, commercial and institutional buildings, residential heating and cooling equipment, major appliances, office equipment, lighting, and consumer electronics. Green Lights, ClimateWise, and all labeled products have been consolidated under one umbrella; Energy Star. Now, the suite of products and offerings all bear the Energy Star logo. From labeled buildings and homes to labeled products, the Energy Star logo makes it easier for businesses and consumers to recognize the symbol for exemplary energy performance, saving money and pollution prevention.

You Can Make A Difference

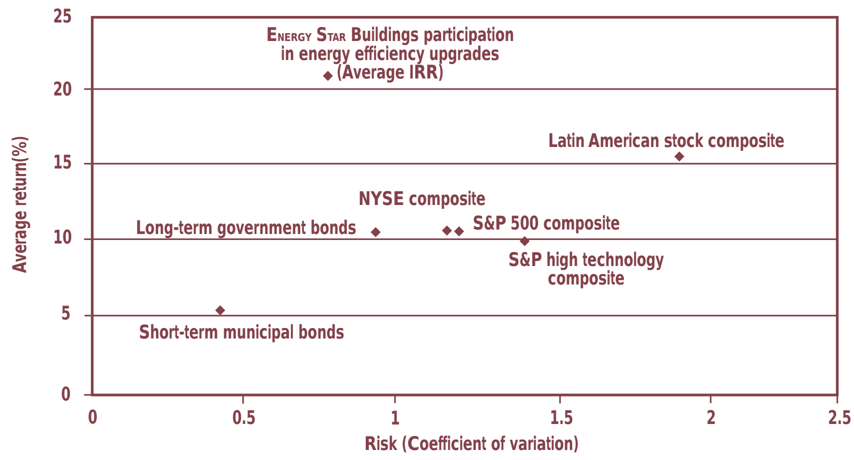
With Energy Star, money isn't all you'll save! Whether your business is education, retail, manufacturing, or healthcare, you can profit from a new source of value by adopting energy management best practices that promotes exemplary energy performance in your buildings. If all US consumers and businesses were to choose Energy Star products and building upgrade strategies over the next decade, the national annual energy bill would be reduced by about $200 billion. Consumers and businesses would not only save money but would also make a huge reduction in air pollution and contribute to protecting the earth's atmosphere for future generations. Energy Star has contributed to 6.4 million metric tons of carbon reductions and 31.6 billion kWh savings since the inception of its flagship program.

Upgrading Your Buildings

Energy efficiency prevents pollution and is good for your bottom line as well as the environment. Your organization will save the money that was previously spent on energy-wasting equipment and technologies. Reductions in energy consumption also enable you to deliver products and services at a lower cost and increase profits, which means being more competitive. The potential savings from an integrated approach to energy-efficient upgrades can be 35% or greater. For example, energy bills for existing US commercial space (approximately 78 billion square feet) total $110 billion annually. EPA estimates that increasing the energy efficiency of this space could save more than $25 billion. In addition to dollar savings, there are several other benefits for incorporating energy efficiency into your business strategy:

- ENERGY STAR upgrades offer superior returns at a lower risk than many other investments (see Figure 1).
- Improvements in energy performance and employee comfort can increase productivity in your upgraded buildings; in fact, revenue generated from increased productivity can be 10 times as high as the energy cost savings received from performing upgrades.
- Every dollar invested in an energy-efficient upgrade can produce between $2 and $3 in increased asset value, which can make commercial properties more attractive to buyers and lenders.

Figure 1: Risk vs. Return



Improving energy performance offers long-term, low-risk returns, reductions in energy consumption and costs, increases in worker productivity, and improved asset value, few other investments can do all that. And each day that you delay your decision to upgrade, you lose those potential savings forever.

An Integrated Upgrade Approach

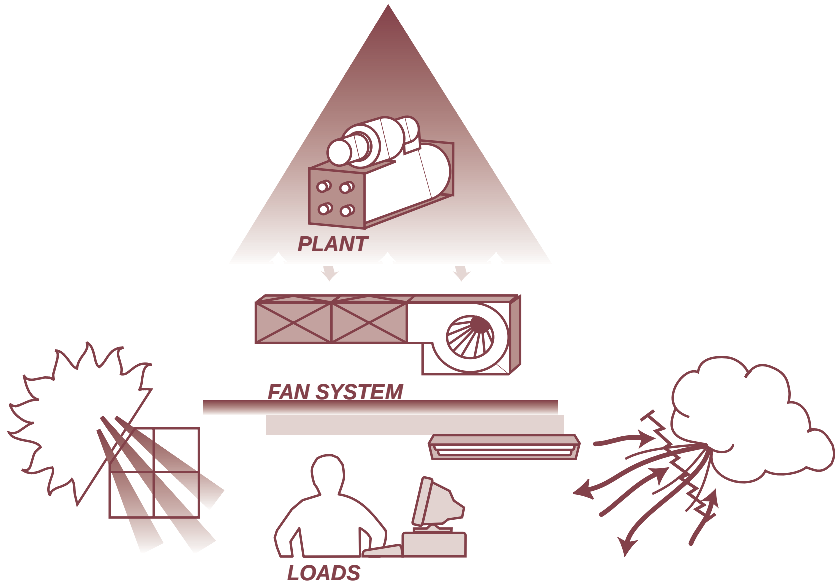
An integrated upgrade approach is a formula for success that includes the following factors:

- Involving the right people in your organization — EPA encourages top management commitment and targets top level executives in promoting energy performance and pollution prevention.
- Benchmarking energy performance — EPA advocates benchmarking energy performance (EPA's portfolio manger) to optimize energy use and achieve maximum energy and cost savings, and using proven energy-efficient technologies and an integrated approach for building upgrades.
- Communicating results —EPA recognizes participants' successes to increase public awareness on the benefits of energy performance. Nothing is more convincing than success!

The rationale and approach to energy efficiency upgrades introduced below are designed to maximize your rate of return for energy-efficient investments.

Underlying the integrated approach for building upgrades is a basic understanding of how to improve energy performance. Figure 2 illustrates how heat and energy flow in a building. Heat is given off by lights, people, and other supplemental loads; such as office equipment requires space cooling. Solar radiation and hot outside air temperatures can also impact space cooling needs. Conversely, cold outside air temperatures create the need for heating. Even when it is cold outside, your building may still require some cooling to remove excess heat given off by lights, people and equipment.

Figure 2: Heat Flow In Buildings



Heat Flow In Buildings: Building Systems Interactions

Figure 2 shows the interaction of heating, cooling, and electrical loads with the HVAC equipment. Arrows indicate heat flow pathways. Reducing heating, cooling, and electrical loads reduces the demand on HVAC equipment, thus saving energy.

The staged approach synthesizes these interactions into a systematic method for planning upgrades that enables you to maximize energy savings. The stages are:

- **Recommissioning:** Periodically examine building equipment, systems, and maintenance procedures as compared to design intent and current operational needs.
- **Lighting:** Install energy-efficient lighting systems and controls that improve light quality and reduce heat gain.
- **Supplemental Load Reductions:** Purchase ENERGY STAR labeled office equipment, install window films and add insulation or reflective roof coating to reduce energy consumption of supplemental load sources.
- **Fan Systems Upgrades:** Properly size fan systems, adding variable speed drives, and converting to a variable-air-volume system.
- **Heating And Cooling System Upgrades:** Replace chlorofluorocarbon chillers, retrofit or install energy-efficient models to meet the building's reduced cooling loads, upgrade boilers and other central plant systems to energy-efficient standards.

When the staged approach is performed sequentially, each stage includes changes that will affect the upgrades performed in subsequent stages, thus maximizing energy and cost savings. The first three stages, Recommissioning, Lighting, and Supplemental Load Reductions, address reducing heating, cooling, and electrical loads. Once these loads are reduced, you can upgrade HVAC equipment to meet the current loads and optimize its performance. By implementing the load reduction strategies first, the savings from fans and HVAC systems will be greater because these systems can be properly sized to handle the reduced loads.

Build Your Building Right

After many requests from our participants to help them achieve ENERGY STAR for new building projects, EPA has expanded its experience in energy performance for existing buildings to the new buildings arena. It has been documented that when high performance buildings are designed from the start, they are generally more efficient and cost less than upgrading after the fact. Buildings systems and materials can be designed as integral network that will improve energy performance.

ENERGY STAR provides guidance for design teams and building owners on new building design strategies to enhance energy performance. The New Building Design initiative is web based and will walk you through the design process and provide tools to help you make informed decisions about energy performance on new design projects. It starts with setting goals and ends with achieving the ENERGY STAR label for your building. It also address all other design phases from pre-design to construction and bid documents. Energy performance is the driving element in the discussion at each phase. It will help you identify or ask the question, "How will this design decision effect the energy performance of the building?"

Target Finder, a web based energy performance calculator, will help you set a target early in the process. You can also measure your progress along the way by comparing your simulated energy consumption to your target. The difference between the simulated and target can assist in determining relative efficiency, identifying gaps and making improvements to energy performance strategies. The benefit is that energy strategies are incorporated as an integral part of the design and can be compared to industry benchmarks to monitor progress toward reaching your energy performance goals.

Get Started Now

You can become an ENERGY STAR partner and receive the benefits of membership! Your organization signs a Partnership Agreement stating that they are committed to improving energy performance by:

1. Measuring, tracking, and benchmarking energy performance using tools such as those offered by ENERGY STAR,
2. Developing and implementing a plan to improve energy performance in your facilities and operations by adopting the strategy provided by ENERGY STAR,
3. Educating your company and community about your achievements and partnership with ENERGY STAR.

EPA will provide you with resources and assistance; such as analytical software tools, publications, and technical guidance to assist you with achieving exemplary energy performance goals. You can learn more about the obtaining the suite of offerings from:

ENERGY STAR on the Web	www.energystar.gov
ENERGY STAR Hotline	1-888-STAR YES (1-888-782-7937)

BUSINESS ANALYSIS

Overview

Energy performance can increase the value of an organization by improving the bottom line. The bottom line in business is net income or earnings; reduced energy costs can be reflected in increased earnings and earnings per share. Every dollar of increased earnings can be valued at the prevailing market earnings multiple, or the Price Earnings Ratio. This approach to valuation is common practice among analysts, who routinely relate market prices for shares of stock to multiples of earnings. You can also use this approach to determine the value of energy performance for your business— that is, increased market capitalization. ENERGY STAR provides tools that quantify, justify and communicate the impact of energy performance to a company's worth.

The process to improved energy performance requires that the financial merits of opportunities be carefully evaluated. All organizations employ basic financial analysis tools to examine the value, risk, and liquidity impacts of investment opportunities competing for limited capital resources. To successfully compete against other business investments, energy performance should be evaluated on the same basis. Understanding basic financial concepts and using simple analysis tools can facilitate an informed decision.

This chapter explains the tools necessary to evaluate profitability, cash flow, and liquidity and presents a framework for using these tools to analyze building upgrade investments to improve energy performance.

Capital Budgeting Basics

Both for-profit and not-for-profit organizations evaluate potential investments based on net income (bottom line). To evaluate net income, an organizations use financial analyses to identify whether an investment exceeds a predetermined hurdle rate while maintaining acceptable first cost and liquidity requirements. Profitability is measured by whether a project's internal rate of return passes the investment hurdle rate. Cash flow and liquidity are evaluated by first cost and payback.

- *First cost* is the up-front cost that is incurred before the investment generates any savings. Large first costs put stress on an organization's balance sheet and may cause an investment to be rejected, even if it is profitable in the long run.
- *Net present value (NPV)* is the total net cash flow that a project generates over its lifetime, including first costs, with discounting applied to cash flows that occur in the future. NPV indicates what a project's lifetime cash flow is worth today.
- *Simple payback* is the amount of time, in years, necessary for future cash flows to

return the original investment. Payback is an indicator of liquidity because it measures the speed with which an investment can be converted into cash. Payback is also used as an indicator of risk. As a general rule, short-term events can be predicted more precisely than events in the distant future. Therefore, assuming everything else is constant, projects with a shorter payback period are generally considered less risky.

- *Internal rate of return (IRR)* is the interest rate that equates the present value of expected future cash flows to the initial cost of the project. Expressed as a percentage, IRR can be easily compared with loan or hurdle rates to determine an investment's profitability.
- *Hurdle rate* is the accept/reject criterion for determining if an investment passes the profitability test. If the IRR is higher than the hurdle rate, the investment is profitable. Hurdle rates are the marginal cost of capital, adjusted for a project's risk. The higher the cost of capital and risk, the higher the required hurdle rate.

Capital Budgeting Glossary

Cost of capital	The discount rate that is used in the capital budgeting process.
Discount rate	The interest rate used to discount future revenue streams.
Hurdle rate	The minimum acceptable internal rate of return for a project.
Internal rate of return	The interest rate that equates the present value of expected future cash flows to the initial cost of the project.
Net present value	The present value of the expected net cash flows of an investment, discounted at an appropriate percentage rate, minus the initial cost outlay of the project.
Simple payback	The number of years required to return the original investment from net cash flows.
Time value of money	Money received today is valued more highly than money received at a future date.

Net Income Analysis

Evaluating investment in long-term building projects requires tools that consider cash flow over the life of a project and account for the time value of money. Simple payback, although frequently used in the energy management industry, is not a good indicator of profitability because it does not consider returns beyond the payback period and ignores the time value of money. The most common tools to evaluate investments are IRR and NPV. IRR is used to compare a project's return against a hurdle rate to determine whether it meets financial criteria and worth pursuing. NPV is useful for comparing and prioritizing amongst competing projects. Together, they provide a comprehensive evaluation of a project's contribution to the bottom line.

In addition to evaluating investment returns, determining the financial value of energy performance investments and its effect on the bottom line is equally important. While NPV can be used to demonstrate today's value of an investment and future returns, understanding how energy performance can impact key financial and profitability metrics such as profit margin, earnings per share, net reserve, and market capitalization should be considered in capital decision making. Valuing the incremental earnings that result from improved energy performance is a way to capture the true worth to an organization. ENERGY STAR has developed a financial value calculator (fvc) to analyze how energy performance projects can improve an organization's net income and corporate value. Visit ENERGY STAR Web site at www.energystar.gov.

Financial Evaluation

ENERGY STAR encourages using energy performance measurement and/or equipment upgrades to maximize energy savings while improving building comfort and indoor air quality. The following framework provides a systematic approach to evaluating energy performance investments and can be applied to comprehensive building upgrades or new designs.

1. Prepare a cash flow analysis for each upgrade or design option.
2. Calculate IRR for each option. Determine each option's profitability against the hurdle rate.
3. Compare competing options and prioritize options within a package using NPV.
4. Maximize energy efficiency by packaging upgrade options or carefully integrating systems where appropriate.

Business Analysis Process

Cash Flow Analysis

Evaluating profitability with IRR and NPV requires the preparation of a cash flow analysis. A simple cash flow estimate (see Table 1) should be prepared for each potential energy-performance option suggested by an energy audit. Cash flow analysis can also be used to compare the theoretical performance of an efficient building design to that of a conventional design. This analysis lists the year-to-year costs and savings for all implementation, operation, maintenance, and disposal costs, and energy and demand savings, over the life of the equipment or building. For this demonstration the investment is evaluated over a period of 10 years. Each option generally has a first cost and a stream of cost savings. In our example, the first cost is the installation cost, which occurs in year zero. In the unusual case that the retrofit is planned over multiple years, provide an estimate of the cost for each year in which the work will be completed. Be sure to document the projected schedule in the list of key assumptions.

Project energy cost savings. Typically, an energy audit report converts your energy and demand savings into monetary savings based on your current energy rates and operating schedules. Similarly, computer energy simulation can estimate annual savings associated with an efficient design. If you anticipate energy price changes, you may want to adjust the amount of savings in future years. Also, for a multiyear project, you will need to phase in the energy savings over the first few years as appropriate. Be sure to document the energy rates that are used for the calculation and the planned operating schedules in the list of key assumptions. In our example, the energy prices and operating schedules will remain constant over the 10-year life of the equipment.

Table 1: Cash Flow Analysis For LED Exit Signs

Year	*Retrofit Cost*	*Energy & Demand Savings*	*Maintenance Savings*	*Omitted Savings*	*Risk Level*
0	$ 3,250	$ 0	$ 0	Neutral	Neutral
1	0	2,181	200		
2	0	2,181	200		
3	0	2,181	200		
4	0	2,181	200		
5	0	2,181	200		
6	0	2,181	200		
7	0	2,181	200		
8	0	2,181	200		
9	0	2,181	200		
10	0	2,181	200		

Key Assumptions:
1. Retrofit will be completed in 3 months.
2. LED exit signs have a 10-year life expectancy.
3. Energy savings are based on the current average energy rate of $0.078/kWh.
4. No changes in energy rates will occur during the 10-year period.
5. Maintenance savings are realized because lamps are changed less frequently.

Estimate the annual savings in maintenance costs. In our example, we are replacing incandescent exit signs with LED signs, and can thus realize substantial savings in labor and materials over the life of the equipment. In some cases, an energy-efficient retrofit can require more maintenance than before, resulting in a negative maintenance savings entry. Document all key assumptions regarding maintenance savings.

Provide qualitative guidance. Additional savings or costs can be difficult to quantify. Potential savings that are hard to measure include worker productivity gains, increased sales attributable to the upgrade, and enhanced corporate image. Omitted savings/costs should simply be classified as having a negative, neutral, or positive influence on the net annual cash flow. For all six of the lighting options in the example, omitted costs/savings are neutral, even though evidence suggests that office lighting retrofits can increase worker productivity.

Classifying the risk level of the project can also be difficult. Because of uncertainty about future events (for example, future prices of electricity), anticipated cash flows may be difficult to estimate. However, compared with other investments that a company may make, such as new product development, energy efficiency projects are still considered a low risk. If you do not know the risk levels of other investments your organization is considering, you may want to classify the risk of energy-efficient investments as neutral to be conservative.

Cash flow analyses for most options will follow this simple example, in which the initial cost occurs in year zero, savings estimates are constant over the life of the project, and risk and omitted cost/savings are neutral.

Cash Flow Assumptions

Estimating cash flow is the most difficult part of any financial analysis. While initial retrofitting or construction costs can be estimated based on experience, estimates of energy savings and operation and maintenance costs savings are based on more extensive assumptions that may be affected by numerous variables. Because future events may not occur as anticipated in your assumptions, the IRR realized for the project may vary considerably from your original estimate. Recognizing this uncertainty, you should explicitly list the assumptions underlying your cash flow estimates, and reach a consensus with other staff that these assumptions are reasonable. At a minimum, assumptions that should be documented are the future prices of energy and your basic operating conditions.

Taxes can also affect your cash flow estimates. Increasing depreciation, decreasing energy and maintenance expenses, and, if your project is debt financed, increasing the amount of your interest deduction can affect an organization's tax liability. If you are unfamiliar with these tax implications, simply omit them from your analysis and express your results in pre-tax terms.

Profitability Test

If all the options being considered have a single-payment first cost, cash flows that are uniform for the entire time horizon, and equal-length life spans, you can easily determine IRR using a calculator and Table 2.Using the table, a 20% IRR hurdle rate would result in a simple payback of 4.2 years, options with less than a 4.2-year simple payback would be considered profitable.

Calculate the IRR for each project, and simply compare it to your hurdle rate. If the option exceeds the established hurdle rate, that project would be considered profitable and should be pursued. IRR should be used to determine profitability for each project. It should not be used to compare or prioritize projects; this approach can minimizes first cost rather than maximizing energy performance and long-term savings.

Table 2: Project IRR After Simple Payback

Payback (years)	***Time Horizon (years)***														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1.0	0.0%	61.8%	83.9%	92.8%	96.6%	98.4%	99.2%	99.6%	99.8%	99.9%	100.0%	100.0%	100.0%	100.0%	100.0%
1.5		21.5%	44.6%	55.2%	60.4%	63.1%	64.6%	65.5%	66.0%	66.3%	66.4%	66.5%	66.6%	66.6%	66.6%
2.0		0.0%	23.4%	34.9%	41.0%	44.5%	46.6%	47.8%	48.6%	49.1%	49.4%	49.6%	49.7%	49.8%	49.9%
2.5			9.7%	21.9%	28.6%	32.7%	35.1%	36.7%	37.8%	38.5%	38.9%	39.2%	39.5%	39.6%	39.7%
3.0			0.0%	12.6%	19.9%	24.3%	27.1%	29.0%	30.2%	31.1%	31.7%	32.2%	32.5%	32.7%	32.9%
3.5				5.6%	13.2%	18.0%	21.1%	23.2%	24.6%	25.7%	26.4%	26.9%	27.3%	27.6%	27.9%
4.0				0.0%	7.9%	13.0%	16.3%	18.6%	20.2%	21.4%	22.3%	22.9%	23.4%	23.7%	24.0%
4.5					3.6%	8.9%	12.4%	14.9%	16.7%	18.0%	18.9%	19.6%	20.2%	20.6%	20.9%
5.0					0.0%	5.5%	9.2%	11.8%	13.7%	15.1%	16.1%	16.9%	17.6%	18.0%	18.4%
5.5						2.5%	6.4%	9.2%	11.2%	12.7%	13.8%	14.7%	15.3%	15.9%	16.3%
6.0						0.0%	4.0%	6.9%	9.0%	10.6%	11.8%	12.7%	13.4%	14.0%	14.5%
6.5							1.9%	4.9%	7.1%	8.7%	10.0%	11.0%	11.8%	12.4%	12.9%
7.0							0.0%	3.1%	5.3%	7.1%	8.4%	9.5%	10.3%	11.0%	11.5%
7.5								1.5%	3.8%	5.6%	7.0%	8.1%	9.0%	9.7%	10.2%
8.0								0.0%	2.4%	4.3%	5.7%	6.9%	7.8%	8.5%	9.1%
8.5									1.2%	3.1%	4.6%	5.7%	6.7%	7.5%	8.1%
9.0									0.0%	2.0%	3.5%	4.7%	5.7%	6.5%	7.2%
9.5										0.9%	2.5%	3.8%	4.8%	5.6%	6.3%
10.0										0.0%	1.6%	2.9%	4.0%	4.8%	5.6%

Prioritize Options

To compare two competing options or to prioritize options, a net present value (NPV) analysis should be used. NPV discounts the future total net cash flow over a project's life, and tells you what a project's future cash flow is worth in today's dollars. As with IRR, NPV is calculated by using a financial calculator or spreadsheet Note that IRR and NPV are related, a negative NPV indicates that the option generates less than the established rate of return.

For example, you have the option of controlling lighting with a Central Time clock or individual occupancy sensors. Table 3, illustrates that the time clock has a higher IRR and quicker payback, but NPV analysis suggest that occupancy sensors would increase energy savings and net worth of your organization. Similarly, NPV can be used to prioritize and rank the value of options within a package of upgrades (see Table 4).

Bundle Upgrades

What about options that are considered marginally profitable, but can still contribute to maximizing the energy efficiency of a project? In our example, improving office task lighting, when evaluated individually, does not meet our required hurdle rate. However, when task lighting is packaged with the other more profitable aspects of lighting upgrades, the combined project IRR still exceeds the hurdle rate. By using an integrated approach, the task lighting can be included in the upgrade package and still meet investment criteria.

Table 3: Comparing The Profitability Of Upgrade Options

Year	*Upgrade Option 1A Occupancy Sensors*		*Upgrade Option 1B Central Timeclock*	
	Initial Cost	*Savings Generated*	*Initial Cost*	*Savings Generated*
0	$ 42,000	$ 0	$ 9,000	$ 0
1	0	12,200	0	3,550
2	0	12,200	0	3,550
3	0	12,200	0	3,550
4	0	12,200	0	3,550
5	0	12,200	0	3,550
6	0	12,200	0	3,550
7	0	12,200	0	3,550
8	0	12,200	0	3,550
9	0	12,200	0	3,550
10	0	12,200	0	3,550
		Cumulative Savings		
Over Ten Years		$ 122,000		$ 35,500
Simple Payback		3.4 years		2.5 years
IRR		26%		38%
NPV		$ 7,623		$ 4,903

In another example, including a daylight dimming option would not be pursued, because it is not profitable both when evaluated on its own and as part of the overall upgrade package. Incremental costs alone should not dissuade the specifier from including an option that is marginally profitable. Options can be quantified in terms other than cost, particularly if the option can significantly improve aesthetics or lighting quality, or provide other non-tangible benefits.

Other Considerations

Remember that these financial calculations are based on key assumptions. If any of your assumptions change, analyze all of the options again before going forward with a proposed package of options. Another important factor that may affect the decision to pursue an energy-performance investment is the manner in which the project is financed. Financing options affect the balance sheet in different ways and can be a determining factor on whether to accept an investment proposal. See the Financing chapter in this manual for more information on loans, leasing, performance contracting, and other financing alternatives.

Table 4: Assemble A Profitable Package

Stage Two Lighting Options		*NPV*	*First IRR*	*Annual Net Cost*	*Cash Flow*	*Omitted Savings*	*Risk*
1a	Install Occupancy Sensors	$7,623	26%	$42,000	$12,200	Neutral	Neutral
1b	Install Central Timeclock	4,902	38%	9,000	3,550	Neutral	Neutral
2	Install LED Exit Signs	5,606	73%	3,250	2,380	Neutral	Neutral
3	Improve Corridor Lighting	5,106	38%	9,490	3,725	Neutral	Neutral
4	Improve Office Lighting	4,751	23%	57,605	15,100	Neutral	Neutral
5	Upgrade Task Lighting	(929)	16%	9,500	2,000	Neutral	Neutral
6	Install Daylighting Controls	(26,524)	2%	59,080	6,500	Neutral	Neutral

Package Results

Options 1a-4	$23,091	27%	$112,345	$33,405
Options 1a-5	$22,161	26%	$121,845	$35,405
Options 1a-6	$(4,363)	19%	$180,925	$39,905

FINANCING

Overview

Energy performance projects may be different from many other business investments in that they provide an immediate and predictable positive cash flow resulting from lower energy bills. This feature allows them to be financed with both familiar and unconventional financing products.

Regardless of your organizational requirements or constraints, there is a financing option available to help you realize the profitability of energy performance improvements.

Financing section discusses payment and financing options and suggests evaluation criteria to help you select the option that is right for your organization, whether you are in the private or public sector. While the right financing option will depend upon many factors such as debt capacity, in-house expertise, and risk tolerance, there are viable options for virtually any type of organization. The following table summarizes financing options traditionally used in the public and private sectors.

	Public	Private
Purchasing	1	1
Cash	1	1
Loan		1
Leasing		
Capital Lease		1
Tax-Exempt Lease		1
Operating Lease		1
Performance Contracting		
Shared Savings	1	1
Paid from Savings	1	1

Payment and Financing Options

The payment and financing options discussed below include:

- Purchasing equipment and services
- Leasing
- Performance contracting
- Public and Institutional Options

Purchasing Equipment and Services

Cash

A cash purchase is the simplest method for financing energy performance improvements. A cash purchase makes sense if your organization has cash reserves and a strong balance sheet. The advantage of a cash purchase is that all cost savings realized from the upgrade are immediately available to your organization. Additionally, the depreciation of the equipment becomes a tax deduction. The disadvantage of a cash purchase is the loss of opportunities associated with not having that capital available for other investments.

Generally, relatively inexpensive, simple efficiency measures that are likely to pay for themselves in about a year are purchased with cash. Large complex projects are often financed differently.

Cash Purchase	
On balance sheet?	yes
Initial payment	100%
Payments	none
Ownership	owner
Tax deductions	depreciation
Performance risk	owner

Loan

Lenders may require up to a 40 percent down payment on loans for energy projects. Generally, a high-risk loan will have less leverage (ratio of debt to equity for the project), a higher interest rate, and a shorter term of debt. As a borrower, you may put up business or personal assets as security for the loan. Your borrowing ability will depend on your organization's current debt load and credit worthiness. Loan payments may be structured to be equal to or slightly lower than projected energy savings. In this financing arrangement, you bear all the risks of the project and receive all the benefits.

Including high performance features during new building design is simpler to justify, since energy efficiency depends on the selection and combination of components that will be purchased regardless of performance goals. Rightsizing lighting and HVAC equipment may eliminate incremental first cost increases. As a result, many of these projects need no additional funding or a slight increase for extended architectural and engineering services and commissioning.

Loan	
On balance sheet?	yes
Initial payment	downpayment
Payments	fixed
Ownership	owner
Tax deductions	depreciation, interest
Performance risk	owner

Leasing

You may procure your energy performance upgrade through leasing to spread out the term of payments. Lease payments are usually lower than loan payments. Laws and regulations for equipment leasing are complex and change frequently, so be sure to consult your financial executive, attorney, or auditor before entering into a lease agreement.

Capital Lease

Capital leases are installment purchases of equipment. Little or no initial capital outlay is required. With a capital lease, you eventually own the equipment and may take deductions for depreciation and for the interest portion of payments. A capital asset and associated liability will be recorded on your organization's balance sheet.

Based on the criteria defined by the Financial Accounting Standards Board (FASB) Statement No. 13, a lease meeting one or more of the following criteria qualifies as a capital lease:

- The lease transfers ownership of property to the customer at end of the lease term.
- The lease contains a bargain purchase option.
- The lease term covers 75 percent or more of the estimated economic life of the equipment.
- The value of the lease equals or exceeds 90 percent of the fair market value of the equipment at the beginning of the lease.

If you work for a governmental organization, you may be eligible for a tax-exempt capital lease. Because the lessor does not pay taxes on the interest from these leases, the rates are lower than typical market rates. For municipal organizations that can undertake new debt, tax-exempt capital leases can be very attractive.

Tax-Exempt Lease

A tax-exempt lease purchase agreement, also known as a municipal lease, is closer to an installment purchase agreement than a rental agreement. You will own the equipment after the financing term is over. A benefit of the lease purchase agreement is that the lessee's (borrower's) payment obligation usually terminates if the lessee fails to appropriate funds to make lease payments. Because of this provision, neither the lease nor the lease payments are considered debt, and payments can be made from the energy savings in your operating budget. Unlike bond issues, tax-exempt lease purchase financing usually does not require a voter referendum because it is considered an operating rather than capital expenditure due to this non-appropriation language. However, lenders will want to know that the assets being financed are of essential use, which will minimize the risk of non-appropriation. In fact, your organization may already be leasing equipment, and it may be surprisingly easy to add your energy project to the existing lease agreement, especially if your organization has a Master Lease in place with a lending institution.

Capital Lease	
On balance sheet?	yes
Initial payment	none
Payments	fixed
Ownership	owner
Tax deductions	depreciation, interest
Performance risk	owner

Operating Lease

Under an operating lease, the lessor owns the equipment. It is, in effect, "rented" (leased) to your organization for a fixed monthly fee during the contract period. The lessor claims any tax benefits associated with the depreciation of the equipment. At the end of the contract term, you can purchase the equipment at fair market value (or at a predetermined amount), renegotiate the lease, or have the equipment removed.

To meet the FASB definition of an operating lease, the lease term must be less than 75 percent of the equipment's economic life, and the total value of the lease payments must be less than 90 percent of the fair market value of the equipment at the start of the lease. If the equipment has residual value as used equipment, it may be eligible for an operating lease.

Discuss the project's qualifications with a financial decision-maker before entering into an operating lease for energy-efficient equipment.

Operating Lease	
On balance sheet?	no
Initial payment:	none
Payments:	fixed
Ownership:	lessor
Tax deductions:	lessor
Performance risk:	lessor

Performance Contracting

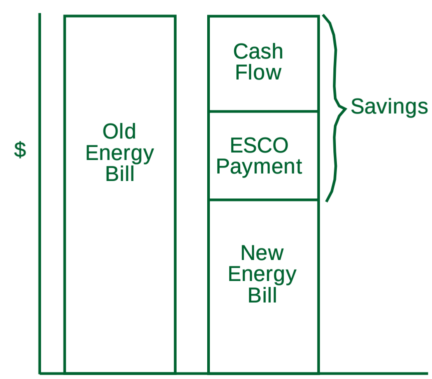
As you research financing options for your project, you will certainly hear about performance contracting. A performance contract may be the preferred financing option if your organization wants to keep the upgrade project off its balance sheet. This type of contracting can be complex, but it is becoming increasingly common.

A performance contract is one in which payment for a project is contingent upon its successful operation (see Figure 1). For an energy performance upgrade, services are rendered in exchange for a share of the future profits from the project.

A performance contract can be undertaken with no up-front cost to the building owner and is paid for out of energy savings. The service provider obtains financing and assumes the performance risks associated with the project. The financing organization owns the upgraded equipment during the term of the contract, and the equipment asset and debt do not appear on your balance sheet. Financing for performance contracts relies little on the financial strength of the building owner, but it is based on the cost savings potential of the project.

Through performance contracting, any of the financing options discussed above can be negotiated to guarantee that, as the customer, you receive the estimated cost savings from the energy performance upgrade. Performance contracting can be applied to purchases or leases.

Figure 1: Performance Contract



In a performance contract, an outside party provides a services package. This package can range from a simple audit, installation, and monitoring to full operation of a facility's energy systems. The service provider typically conducts an energy audit, designs the cost-effective projects, obtains bids, manages the construction, guarantees energy savings, obtains financing, and maintains the energy-saving capital improvements. You use resulting energy savings to pay for the improvements.

Performance contracts are sometimes referred to as "shared savings" or "paid from savings" contracts. These terms refer to the manner in which payment is made for the upgrade.

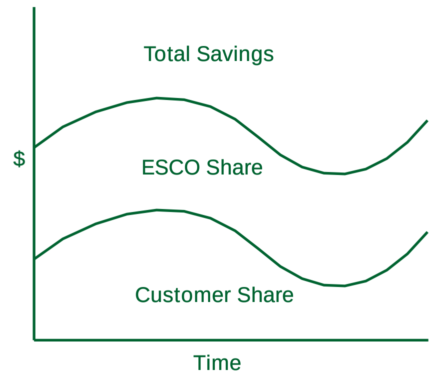
Performance Contracting	
On balance sheet?	no.
Initial payment:	none.
Payments:	variable or fixed.
Ownership:	contractor.
Tax deductions:	contractor.
Performance risk:	contractor.

The service provider pays the energy bill and retains the difference between your payment and the actual bill (for example, the actual bill may be only 60 percent of the expected bill). In this case, if there is an increase in energy usage, the service provider must make up the difference between your payment and the actual bill.

Shared Savings

With shared savings, the dollar value of the measured savings is divided between you and the service provider (see Figure 2). If there are no cost savings, you pay the energy bill and owe the contractor nothing for that period. The percentage distribution of the savings between the service provider and the customer is agreed upon in advance and documented in the performance contract. At the end of the contract, ownership transfers to the building owner as specified in the contract. You either may purchase the equipment at fair market value or simply assume ownership of the equipment paid for during the contract term.

Figure 2: Shared Savings

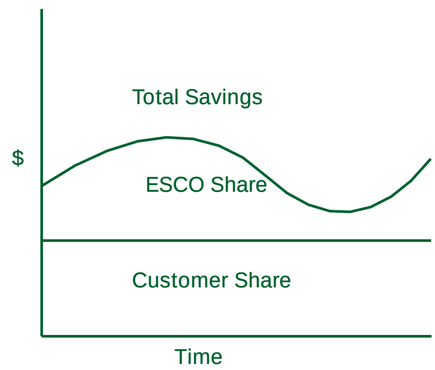


Figures 2 and 3 illustrate the distribution of the cost savings under two scenarios. The specific payment arrangements between you and the service provider are specified in your contract.

Paid from Savings

Almost all energy performance projects are paid for from the savings created by reduced energy usage. Thus, the term "paid from savings" can be used for several different types of energy-upgrade contracts. Here it is being used to refer to another performance contract payment whereby you pay the service provider a predetermined amount each period (for example, an amount equal to 80 percent of the expected energy bill before the upgrade—see Figure 3).

Figure 3: Paid From Savings



Performance contracts can be complex and take a long time to negotiate and implement. The contracts usually:

- Specify detailed work for individual facilities
- Involve large sums of capital
- Cover a wide range of contingencies
- Require significant expertise in law, engineering and finance

For a service provider and financier to make a commitment to an energy efficiency project, the potential for savings must be substantial. Performance contracts are usually arranged for facilities with annual energy costs over $150,000. However, smaller projects may be good candidates depending on the project specifics.

Entering into a performance contract is like forming a partnership with a service provider. You are arranging a complex, long-term relationship through a contractual agreement. It is important for you to remain in close communication with the service provider during contract negotiations and project implementation. Build contingencies into the contract for any issues you can anticipate. For example, an operations change such as adding a piece of manufacturing equipment or changing operating hours can have a significant impact on energy use. By incorporating responses to likely changes up front, you can avert major operational or contractual problems down the road.

A performance contract is a major commitment for you and the service provider. As a financing tool, it offers the benefits of low-risk capital improvements off the balance sheet. Although there are no initial payments to the contractor, you should expect to spend time and resources providing data the service provider will need to perform the audit and establish a baseline from which to estimate energy savings. If you wish to select a service provider through a competitive procurement, you will have to prepare requests for qualifications or proposals and evaluate the submittals.

Defining all the terms and conditions of the contract can be a lengthy process and may require hiring independent engineers or other professionals to review the contract on your behalf. The business of performance contracting is growing, so there is an expanding pool of competent and capable service providers available to you. Although the contracting process is complex, it creates an opportunity for organizations with limited debt capacity or capital resources to undertake profitable energy performance projects that would otherwise not be implemented.

Guaranteed Savings Insurance

Guaranteed savings insurance is a method of reducing your risk. This option guarantees that energy cost savings will exceed an established minimum dollar value. Typically, this guaranteed minimum equals the financing payment for the same period to ensure a positive cash flow during the financing term.

Like any insurance policy, you'll pay a premium that compensates the guarantor for the performance risk and covers monitoring costs. This premium is added to your loan or lease payment and the guarantor will maintain and monitor the performance of your upgrade. The supplier, installer, or service provider selling the upgrade usually offers this guarantee.

Public and Institutional Financing Options

The two most common public sector mechanisms are tax-exempt lease purchase agreements and performance contracts. A performance contract can be considered a finance mechanism because it bundles together with performance guarantees one or more of the following components: financing, equipment, energy costs, and maintenance. Both mechanisms are effective alternatives to traditional debt financing, and both may allow you to pay for energy efficiency upgrades by using money that is already in your utility operating budget. By spending only operating budget dollars, you may avoid the cumbersome capital budget process altogether. Both mechanisms will allow you to draw on dollars saved from future energy bills to pay for new, energy-efficient equipment today.

Evaluation Factors

Finding the right financing vehicle for your project requires a thorough evaluation of your options. The following factors will help define your organization's business profile and will enable you to select the financing option that best meets your organization's objectives.

- Balance sheet
- Initial payment
- Payments
- Ownership
- Tax deductions
- Performance risk

A brief description of each follows.

Balance Sheet

If your organization is near the level of debt permitted by your lenders, you may not be able to undertake additional debt without violating certain covenants. There are, however, methods that enable a company that cannot assume more debt to proceed with an upgrade and take advantage of the financial benefits.

Initial Payment

A large initial capital outlay may be an obstacle for some organizations planning energy performance upgrades. If you have large capital reserves or are planning a small project, it makes sense to pay for the project with cash. Then all the cost savings from the project will be immediately available to you to offset the original investment. There are financing options that can move a project forward with no initial capital outlay from you, the customer. If capital resources are tight, you may want to consider a performance contract.

Payments

Your goal is to obtain financing at a minimum cost to your organization. However, benefits such as off-balance sheet financing may justify paying more for your borrowed money. The general advantage of energy performance investments is that even with performance contracts, which tend to be more costly because of the amount of monitoring and verification involved, you are guaranteed to receive

CHANGE FOR THE BETTER WITH ENERGY STAR

Table 1: Financing Options

	Cash	*Bonds*	*Municipal Lease*	*Performance Contracts*
Interest Rates	N/A	Lowest	Low tax-exempt rate	Can be taxable or tax-exempt tax-exempt rate
Financing Term	N/A	May be 20 years of more	Up to 10 years is common and up to 12-15 years is possible for large projects	Typically up to 10 years but may be as long as 15 years
Other Costs	N/A	Underwriting legal opinion, insurance, etc.	None	May have to pay engineering costs if contract not executed
Approval Process	Internal	May have to be approved by tax payers or public referendum	Internal approvals needed. Simple attorney letter required	RFP usually required, internal approvals needed
Approval Time	Current budget period	May be lengthy - process may take years	Generally within one day	Generally within 2-3 days once the award is made
Funding Flexibility	N/A	Very difficult to go above the dollar ceiling	Can set up a Master Lease, which allows you to draw down funds as needed	Relatively flexible. An underlying Municipal Lease is often used
Budget Used	Either	Capital	Operating	Operating
Largest Benefit	Direct access if	Low interest rate because it is a general obligation of the public entity	Allows you to buy capital equipment using operating dollars	Provides performance guarantees which help approval process
Largest Hurdle	Never seems to be enough money available for projects	Very time consuming	Identifying the project to be financed	Identifying the project to be financed and selecting the ESCO

financial benefits immediately upon completion of the project. At the end of the contract term, those savings are yours.

Ownership

If you own your energy performance upgrade equipment, you are entitled to tax deductions for depreciation or interest payments and other benefits. You are also liable for any performance risk associated with the equipment.

Tax Deductions

As an equipment owner, your business is entitled to potential tax benefits such as depreciation and deductions for loan interest. If you finance your upgrade off the balance sheet, you will not be eligible for tax benefits.

Performance Risk

There is risk associated with any investment. Energy performance upgrades can be low-risk investments because they apply proven technologies with long records of performance. However, the financing option you choose will affect who bears the risk of performance failure.

Performance risk of energy upgrades depends on the accuracy of the assumptions concerning maintenance, cost of energy, occupancy, and other factors. Lighting upgrades are typically considered a lower risk investment than HVAC investments, because it is easier to predict energy savings from lighting upgrades.

More Savings Opportunities

When you begin your search for project capital, begin by bargain hunting for special programs that support energy performance. Every organization planning an energy performance upgrade should investigate the availability of utility incentives, state assistance, and other cost-reducing measures.

Utility Incentives

Utilities often provide financial incentives for energy performance upgrades through rebates, fuel switching incentives, low-interest loans, and energy audits. Check with your local utility to learn what programs are available.

State Assistance

Some states offer financial assistance to nonprofit organization or small businesses for operating improvement upgrades. Contact the state agency that monitors the type of service provided by your organization to inquire about these opportunities. For example, Florida's Energy Loan Program was created to motivate small business owners to evaluate their total energy usage and implement energy conservation measures. Funding may be available through the State Energy Programs, energy conservation programs supported by the US Department of Energy.

Summary of Options

Whether your energy performance project involves small improvements or a complete system upgrade, there is a suitable financing option for you. A simple cash purchase yields immediate benefits to the customer and is a straightforward transaction. It is well suited for small or low-risk upgrades. Performance contracting, the most complex type of arrangement, offers the customer the benefit of risk protection. It is also the most costly financing option because of the amount of monitoring and verification required. However, even this more expensive alternative yields a positive cash flow for the customer immediately upon installation. Regardless of your organizational requirements or constraints, there is a financing option available to help you realize the profitability of energy performance improvements.

Table 2: Summary Of Options

Evaluation Factor	*Cash Purchase*	*Loan*	*Capital Lease*	*Operating Lease*	*Performance Contract*
Balance sheet	on	on	on	off	off
Initial payment	100%	downpayment	none	none	none
Payments	none	fixed	fixed	fixed	variable or fixed
Ownership	owner	owner	owner	lessor	contractor
Tax deductions	depreciation	depreciation, interest	depreciation, interest	lessor	contractor
Performance risk	owner	owner	owner	lessor	contractor

RECOMMISSIONING

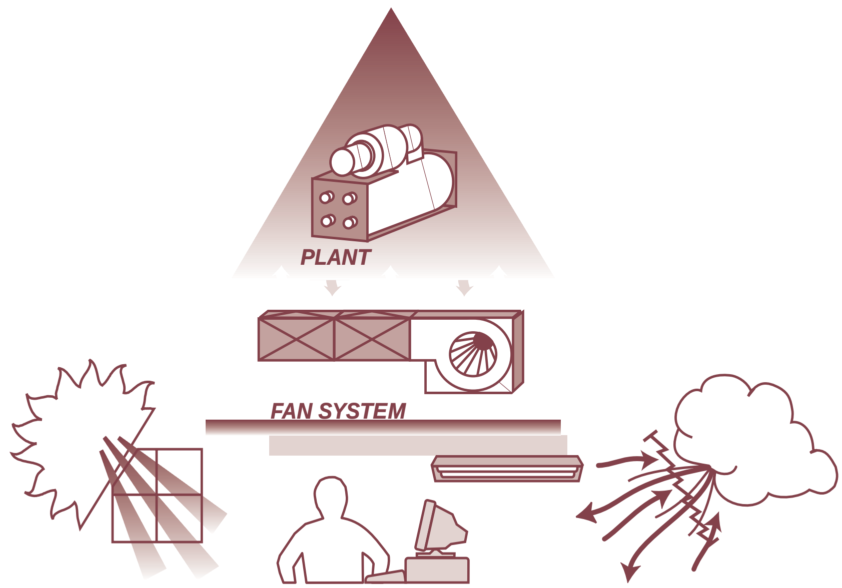
Overview

Recommissioning is essentially the same process as commissioning, but applied to existing building's HVAC, controls, and electrical systems. When standardized maintenance and energy management procedures fail to fix chronic building problems, recommissioning provides a systematic approach for discovering and solving them. Recommsioning entails the examination of actual building equipment systems operation and maintenance procedures for comparison to intended or design operation and maintenance procedures.

The heat flow diagram (Figure 1) illustrates the interaction of all buildings systems and activities. Recommissioning capitalize on heating, cooling, and electrical load reductions by continually monitoring energy consumption to optimize energy performance and savings. Recommisioning can be a cost-effective retrofit in itself, sometimes generating more savings than the cost of the retrofit measure. This can result in additional savings other than direct energy cost reductions. For example, a recommissioning may help avoid the need to install new or additional equipment, resulting in capital savings. In the recommissioning phase, you will continue to implement numerous cost-effective strategies to reduce your heating, cooling, and electrical loads, and your overall energy consumption, while improving occupant comfort.

Previously referred to as Building Tune-Up, the recommissioning chapter will help you understand if the building is operating as intended and if current operational needs are being met. It will help you identify improper equipment performance, opportunities for saving energy and money, and strategies for improving performance of the various building systems. "Best Ways to Save" and "Take Action" are checklists of typical opportunities to tune-up equipment and how to approach funding recommissioning.

Figure 1: Heat Flow In Buildings



Heat Flow In Buildings: Building Systems Interactions

Figure 2 shows the interaction of heating, cooling, and electrical loads with the HVAC equipment. Arrows indicate heat flow pathways. Reducing heating, cooling, and electrical loads reduces the demand on HVAC equipment, thus saving energy.

The Best Ways To Save

- Calibrate building controls such as thermostats and occupancy sensors.
- Adjust operating schedules to ensure equipment is on only when necessary.
- Check for leaking or improperly functioning steam traps.
- Clean heat exchanger tubes in the condenser, evaporator, and boiler to maintain optimal efficiency.

Take Action!

- Recognize building tune-up as an opportunity to reduce energy costs and regain or improve comfort.
- Allocate time and funding to a building tune-up separately from your ongoing maintenance budget.
- Explore available financing options if in-house funds are not available.

Understanding Recommisioning Process

Making low-cost or no-cost adjustments to your building systems will not only minimize your current operating costs but will also lower future maintenance costs. Furthermore, performing a recommissioning will help you understand your building's current operational needs, how it is intended to operate, and how you can improve the current level of performance in the other stages.

Commissioning

Commissioning is a quality assurance process that ensures design intent and operational needs are met for new buildings or major rehabilitation. Ideally, commissioning takes place during the construction process and continues through occupancy.

Maintenance

Maintenance is an ongoing process to ensure that equipment operates at peak performance. It should take place following the initial system tune-up and should be routinely scheduled for the life of the equipment.

Unlike the other four stages of an integrated upgrade approach recommissioning does not necessarily require purchasing and installing new equipment or technology. However, both time and budget should be set aside expressly for a building recommissiong. Savings, though often surprising, can be harder to estimate in advance; yet, because recommissioning plays an integral role in the process of identifying potential upgrade opportunities to be implemented in the other stages, it should be viewed, planned, and funded as a process separate from standard maintenance.

Financing can be a limiting factor, especially if a recommissioning is mistakenly lumped into the maintenance budget. Financing options are often available. See Financing Your Energy-Efficient Upgrade chapter.

Performing a Successful Recommisioning Project

The key to a successful recommissioning process is the commitment of the commissioning team. The commitment may be express through a written contract defining the responsibilities and contractual relationship of team members, and the specific tasks to be performed by each team member according to area of expertise. One major task in the process is for the owner's design professionals and contractors to set realistic contract agreements and assign appropriate responsibilities. Communication among the recommissioning team and facility staff is paramount for uncovering building systems problems and opportunities.

A successful recommissioning effort also depends not only on a deep understanding of building systems but also a firm grasp on how people interact to operate the building systems from day to day. This helps the recommissioning team to collect accurate data and propose cost-effective and energy savings solutions.

Recommissioning may be performed by in-house staff or by outside contractors. A decision to obtain outside expertise should not be viewed as "pointing the finger" at maintenance staff for previous oversights but instead as an opportunity to get a non-bias assessment of building systems operation and maintenance procedures.

Facility staff that are trying to fix these problems work under a variety of constraints, including limited labor force, limited budgets, and limited access to monitoring equipment. Sometimes, facility maangement lack technical expertise or staff to perform diagnostic tests and repair problems.

However, recommissioning will affect the building's future maintenance and operations program, facility staff should be updated on revised maintenance and operations procedures. In addition, facility staff should undergo regular training to learn how to effectively operate and maintain building's systems.

Recommissioning Strategy and Savings Potential

The strategy for recommissioning is a series of building recommissioning that build upon one another in a staged approach. By following the order suggested below, you can capitalize on the benefits of a comprehensive systems upgrade approach.

When recommissioning your building, you should keep in mind the primary goal, does the building operate as intended and are operational needs being met. For example, occupant comfort is paramount in the operational needs assessment. Occupants *will* modify their personal space to achieve comfort. This often results in tampering with thermostats and sensor calibrations, using inefficient portable lighting or space heaters, or even blocking vents, all of which will further increase energy use.

Potential Savings

Building Recommissioning Offer Surprising Paybacks

A detailed assessment of the costs and benefits of tuning up buildings was conducted based on a survey of results from more than 40 tune-up projects. Results from the study confirmed that recommissioning can typically translate into energy savings of 5 to 15 percent. Although it is difficult to pinpoint exactly which tune-up procedures generate the greatest savings, a study performed by the Energy Systems Laboratory of Texas A&M University showed that about 80 percent of all savings from recommissioning come from optimizing building control systems. Improving operations and maintenance accounts for nearly all remaining savings.

Financing the tune-up of a building may require spending funds up front, although parts are generally inexpensive and expenses are minimal. However, you should plan on incurring additional labor costs. If your building's maintenance staff does not have the skills to perform tune-up procedures, or, if your staff is simply too busy, look into outside consultants such as energy service companies or utility companies. Energy service companies have offered tune-up services for years as part of shared-savings contracts. Some utilities continue to conduct re-commissioning on a fee-for-service basis.

Source: "Commissioning Existing Buildings," E SOURCE Tech Update (TU-97-3; March 1997).

Recommissioning will assist you with systematically assessing building performance and effects of occupants and equipment loads on performance. The recommissioning process consist of a series of strategically ordered building recommissioning should be implemented in the following order:

Building Tune-Up Strategy

- Lighting + Supplemental Loads.
- Building Envelope.
- Controls.
- Testing, Adjusting, and Balancing.
- Heat Exchange Equipment.
- Heating and Cooling System.

Lighting

The lighting systems within a building are an integral part of a comfortable working environment. Over the course of its life, all lighting systems become gradually less efficient. Certain efficiency losses are unavoidable, such as reduction in light output are due to the aging of lighting equipment. However, other efficiency losses, such as improperly functioning controls, or dirt accumulation on fixture lenses and housings and lamp lumen depreciation can be avoided by regularly scheduled lighting maintenance.

Insufficient lighting can have a negative impact on energy performance of the building. Without adequate lighting, occupants will bring in less efficient fixtures, thus increasing the lighting and cooling loads in the building.

Lighting Tune-Up

A lighting system tune-up should be performed in the following order:

1. Follow a strategic lighting maintenance plan of scheduled group relamping and fixture cleaning.
2. Measure and ensure proper light levels.
3. Calibrate lighting controls.

(see Lighting chapter for lighting system specifications and details)

Periodically cleaning the existing fixtures and replacing burned-out lamps and ballasts can considerably increase fixture light output. This simple and cost-effective tune-up item can restore light levels in a building close to their initial design specifications.

After the fixtures have been cleaned and group relamping has taken place, the next step is to measure existing light levels to ensure that proper illuminance levels are provided for the tasks being performed in the space. As space use and furnishings may change over time, it is important to match the lighting level to the current occupant requirements. The Illuminating Engineering Society of North America issues recommended illuminance levels depending on the job or activity performed. Overlighted or underlighted areas should be corrected. Lighting uniformity should also be assessed, as relocation of furniture and even walls may have altered lighting distribution.

Once the proper light levels and uniformity have been achieved in the space, examine the automatic lighting controls. Many buildings use a variety of automatic controls for time-based, occupancy-based, and lighting level-based strategies. These controls may have never been properly calibrated during installation or may have been subsequently tampered with by occupants. Adjusting these controls and associated sensors now will reduce occupant complaints, maintain safety, and ensure maximum energy savings.

Many buildings utilize energy management systems, time clocks, and electronic wallbox timers to control lighting automatically based on a predictable time schedule. These systems need to be programmed correctly to ensure that lights are only operating when the building is occupied, and that overrides are operational where required. Exterior lighting schedules must also be changed throughout the year according to the season.

The performance of occupancy or motion sensors depends on customizing the sensitivity and time-delay settings to the requirements of each individual space. The sensor's installed position should also be checked to ensure adequate coverage of the occupied area. Also, keep all furnishings from obstructing the sensor's line of sight. A sample commissioning protocol is available to guide your staff or contractor to commission occupancy sensors properly (call the ENERGY STAR hotline at 1-888-STAR YES for more information).

Any indoor and outdoor photocells should also be checked at this time to ensure the desired daylight dimming or daylight switching response. Set-points should be adjusted so that the desired light levels are maintained. Photocells and dimming ballasts are also used to save energy in non-daylight areas through lumen maintenance control, a strategy to adjust system output to compensate for aging lamps and dirt accumulation on luminaries. To maintain continued energy savings in lumen maintenance control strategies, you will need to tune the set-point manually to reduce the light level by 25 to 30 percent (the expected light level depreciation over the maintenance cycle) each time fixtures are periodically cleaned and re-lamped. This will allow the ballast to increase the system output over time to maintain the illuminance set-point.

Savings

Although the savings associated with performing a lighting tune-up will vary depending on the quality and performance of the current lighting system, they can be significant. For example, cleaning alone may boost fixture light output from 10 percent in enclosed fixtures in clean environments to more than 60 percent in open fixtures located in dirty areas. Simple calibration of occupancy sensors and photocells can restore correct operation, reducing the energy used by the lighting system in those areas by 50 percent or more.

Considerations

- Is a scheduled lighting maintenance policy in place?
- Are spaces provided with the proper light levels?
- Have all automatic controls been calibrated?

Supplemental Loads

The area of supplemental loads is also an opportunity for recommissioning. In the business world, office equipment constitutes the fastest growing portion of electrical loads. However, much of this energy is wasted because equipment is left on when not in use throughout the workday, at night, and on weekends. Electrical loads from office equipment can be reduced by the use of ENERGY STAR labeled office equipment and/or enabling power management features.

Supplemental Loads Tune-up

For existing office equipment models, check to see if they have power management or other energy-saving features and that these features are enabled. Whether or not they may not meet the ENERGY STAR specifications, these features will provide some energy savings if activated.

Educate employees so that they understand what power management is and why it is important. Here are some examples of issues that you should focus on:

- Sleeping equipment still draws some electricity; so turn it off when not in use for long periods of time.
- Heat is a leading cause of equipment failure. When the power-management feature is used, the computer generates less heat, so it may last longer and have improved reliability.
- If screen savers are used in the office, be sure to choose those that will display images for a predetermined period of time and then enter the sleep mode. Graphical screen savers are primarily for entertainment and are not energy-efficient features.

Savings

Energy-efficient equipment with the ENERGY STAR label cost the same as comparable non- labeled equipment. However, the savings are greater for labeled equipment. Products that meet ENERGY STAR specifications use about half as much electricity as conventional equipment. ENERGY STAR labeled and non-labeled equipment produce less heat when powered down or not in use, which results in reduced cooling loads, and energy costs.

Considerations

- Is your organization purchasing office equipment with the ENERGY STAR label?
- Are energy saving features enabled on office equipment?

Building Envelope

The next step of a building tune-up is to reduce air infiltration through the building envelope to enhance occupant comfort. Outside air can penetrate a building through a variety of places, most commonly through the windows, doors, walls, and roof. Drafts created by improperly sealed windows and doors can cause cold hands and feet in the winter and discomfort in the summer.

In general, a building envelope should meet recommended infiltration standards. For commercial buildings, the National Association of Architectural Metal Manufacturers recommends infiltration rates per unit of exterior wall not to exceed 0.06 cubic feet per minute per square foot (cfm/sf) at a pressure difference of 0.3 in. of water (ASHRAE *Fundamentals Handbook*, 2001, 26.24).

A frequent result of infiltration problems, other than general occupant complaints, is an increase in building heating, cooling, and/or electrical loads (when, for example, occupants bring in space heaters or fans). In addition, the escape of conditioned air forces the air handling system to work longer and harder to provide the required space temperature. Thus, tuning up the envelope of a building can reduce HVAC costs while greatly improving occupant comfort.

Tune-Up

The first step in reducing air infiltration is to tighten the existing building by locating all air leaks in the windows, doors, walls, and roofs. Once you have detected the air leaks, seal them with appropriate materials and techniques such as weather-stripping on doors, sealing and caulking on windows, and proper insulation distribution in walls, ceilings, and roofing.

If your building is equipped with revolving doors, you should encourage their use. Revolving doors significantly reduce drafts and conditioned air loss. Automatic doors should be calibrated to minimize air loss from the building envelope.

Savings

Reducing infiltration will result in a reduction in heating and cooling loads. Savings will depend on many factors, including the existing condition of the building; the building surface area-to-volume ratio; construction type; geographical location; and the internal heating, cooling, and electrical loads. Typical savings for a large office building range up to 5 percent of heating and cooling costs.

Considerations

- Are any areas particularly drafty?
- Are any areas routinely serviced?
- Do the windows and doors close and seal properly?
- Are the windows and door frames adequately caulked?
- Is weather stripping installed on windows and doorways?
- Is there any wet or deteriorating insulation that needs to be replaced?

Controls

The energy management system and controls within a building play a crucial role in providing a comfortable building environment. Over time, temperature sensors or thermostats often become out of tune. Wall thermostats are frequently adjusted by occupants, throwing off controls and causing unintended energy consumption within a building.

Poorly calibrated sensors cause increased heating and cooling loads and occupant discomfort. As with envelope infiltration problems, occupants are likely to take matters into their own hands if they are consistently experiencing heating or cooling problems. By integrating mechanical and control recommissioning within each system, you are more likely to improve occupant comfort.

Tune-Up

The first step in tuning up controls is to calibrate the indoor and outdoor building sensors. Calibration of room thermostats, duct thermostats, humidistats, and pressure and temperature sensors should be in accordance with the original design specifications. Calibrating these controls may require specialized skills or equipment, such as computer software. Thus, you should seriously consider the use of outside expertise for this tune-up item.

In addition to calibrating the sensors, damper and valve controls should be inspected to make sure they are functioning properly. Check pneumatically controlled dampers for leaks in the compressed air hose lines. Also examine dampers to ensure they open and close properly. Stiff dampers can cause improper modulation of the amount of outside air being used in the supply air stream. In some cases, dampers may have actually be wired in a single position or disconnected entirely, violating minimum outside air requirements (for a more detailed explanation, see Supplemental Load Reductions).

As part of tuning up controls, be sure to review building operating schedules. Often, while control schedules remain constant, occupancy schedules change frequently over the life of a building. This results in discomfort at the beginning and end of each day. HVAC controls must be adjusted to heat and cool the building properly during occupied hours. For example, operating schedules should be adjusted to reflect Daylight Savings Time.

When the building is unoccupied, set the temperature back to save some heating or cooling energy. Keep in mind that some minimum heating and cooling may be required when the building is unoccupied. In cold climates, for example, heating may be needed to keep water pipes from freezing.

In addition to the building's operation schedule, review the utility rate schedule. Utilities typically charge on-peak and off-peak times within a rate, which can dramatically affect the amount of your electric bills. If possible, equipment should run during the less expensive off-peak hours. For certain buildings, precooling and/or preheating strategies may be called for. (See also Supplemental Load Reductions, Night Precooling, p. 14.)

Savings

The main savings associated with tuning controls result from reductions in charges for heating and cooling energy (and possibly demand). Because savings are heavily dependent on the existing condition of the controls, it is difficult to estimate the actual savings that will result from a tune-up. Savings will depend on many factors related to the building including heating and cooling system types; construction; geographical location; and internal heating, cooling, and electrical loads. Typical savings can range up to 30 percent of annual heating and cooling costs.

Considerations

- Are building sensors, such as thermostats and humidistats, calibrated and operating properly?
- Are damper and valve controls functioning properly?
- Are there any leaks present in the pneumatic control systems?
- Do equipment schedules reflect occupancy schedules and seasonal changes?
- Can certain equipment be scheduled to operate during utility off-peak hours?
- Can temperatures be set-back during unoccupied times?

Testing, Adjusting, And Balancing

Proper air and water distribution in an HVAC system is critical to create comfortable conditions within a given space. Excessive room air temperature fluctuations, excessive draft, and improper air distributions will lead to occupants' discomfort and can increase energy consumption.

Testing, adjusting, and balancing (TAB) involves investigating the current state of a system and making adjustments to bring the HVAC system back into balance and close to its original design specifications. As we mentioned before, over time, occupancy levels and space utilization may change dramatically. The TAB process will help identify and make necessary adjustments to fit these changes, thereby improving occupant comfort and saving energy costs.

A qualified TAB contractor should:

- Verify the current state of the system.
- Identify and correct any problems with the system.
- Ensure the system provides proper indoor air quality.

Testing, Adjusting, And Balancing

Testing, Adjusting, and Balancing (TAB) is the process of adjusting HVAC system components to supply air and water flows to match load requirements.

TAB generally includes:

Testing: The process of evaluating the performance of the equipment in its current state and making recommendations for improvements.

Adjusting: The process of regulating flow rates of air or water for the purpose of balancing the system.

Balancing: The process of proportioning the air or water flows throughout a building to match the loads.

Perform TAB analysis on a building whenever you think that the air or water distribution system is not functioning as designed. Indicators that TAB is needed include frequent complaints from occupants about hot or cold spots in a building, the renovation of spaces for different uses and occupancy, and the frequent adjustment of HVAC components to maintain comfort.

Tune-Up

A TAB analysis usually includes a complete review of a building's design documentation. Typical HVAC system components and parameters to investigate may include:

- Air system flow rates, including supply, return, exhaust, and outside airflow. Flows include main ducts, branches, and supply diffusers that lead to specific spaces in a building.
- Water system flow rates for chillers, condensers, boilers, and primary and/or secondary heating and cooling coils.
- Temperatures of heating and cooling delivery systems (air side and water side).
- Positions and functioning of flow control devices for air and water delivery systems.
- Control settings and operation.
- Fan and pump speeds and pressures.

The TAB contractor will provide a test and balance report with a complete record of the design specifications, preliminary measurements, and final test data. All discrepancies between the design and test data should be outlined along with an analysis. The report should also include recommended and completed adjustments.

Savings

The savings associated with TAB come from the reductions in the energy used by the heating and cooling system. Because savings are heavily dependent on the building's condition, it is difficult to estimate the actual savings that will result from TAB. Savings will differ depending on many factors related to the building including heating and cooling system types, construction, geographical location, and internal heating, cooling, and electrical loads. Savings can range up to 10 percent of heating and cooling costs.

Considerations

- Are occupants frequently complaining about the temperature, humidity, etc., in the building?
- Have HVAC system components been replaced or modified?
- Has any building space been renovated?
- Can the HVAC system satisfy comfort requirements during very hot or very cold days?

renovation of spaces for different uses and occupancy, and the frequent adjustment of HVAC components to maintain comfort.

Tune-Up

A TAB analysis usually includes a complete review of a building's design documentation. Typical HVAC system components and parameters to investigate may include:

- Air system flow rates, including supply, return, exhaust, and outside airflow. Flows include main ducts, branches, and supply diffusers that lead to specific spaces in a building.
- Water system flow rates for chillers, condensers, boilers, and primary and/or secondary heating and cooling coils.
- Temperatures of heating and cooling delivery systems (air side and water side).
- Positions and functioning of flow control devices for air and water delivery systems.
- Control settings and operation.
- Fan and pump speeds and pressures.

The TAB contractor will provide a test and balance report with a complete record of the design specifications, preliminary measurements, and final test data. All discrepancies between the design and test data should be outlined along with an analysis. The report should also include recommended and completed adjustments.

Savings

The savings associated with TAB come from the reductions in the energy used by the heating and cooling system. Because savings are heavily dependent on the building's condition, it is difficult to estimate the actual savings that will result from TAB. Savings will differ depending on many factors related to the building including heating and cooling system types, construction, geographical location, and internal heating, cooling, and electrical loads. Savings can range up to 10 percent of heating and cooling costs.

Considerations

- Are occupants frequently complaining about the temperature, humidity, etc., in the building?
- Have HVAC system components been replaced or modified?
- Has any building space been renovated?
- Can the HVAC system satisfy comfort requirements during very hot or very cold days?

Heat Exchange Equipment

The next steps in building tune-up focus on the heat exchange equipment that cools and heats the air that ultimately reaches building spaces. This equipment usually consists of heating and cooling coils installed in air handlers, fan coil terminal units, or baseboard radiators. These units are typically supplied with chilled water and hot water from a central plant. The heating and cooling coils can also be part of a packaged unit such as a rooftop air conditioning unit or central station air handling unit.

As with other tune-up items, tuning up your heat exchange equipment has the potential not only to save energy costs but also to increase your building occupants' comfort.

Although many of the tune-up recommendations presented below should be performed as normally scheduled maintenance, they are included in Supplemental Load Reductions because of the potential for resultant energy cost savings.

The controls and flow issues for heat exchange equipment were addressed in the previous controls and TAB sections. The remaining action is to ensure that all surfaces and filters are clean. Dirty surfaces reduce heat transfer, increase pressure loss, and increase energy use.

Tune-Up

Clean the air side of heating and cooling coils, whether in an air handler or in a rooftop unit, to reduce deposit buildup. Methods for cleaning may include compressed air, dust rags/brushes, and power washes. Check baseboard heating systems for dust build up and clean if necessary.

The water side of heating and cooling systems is generally inaccessible for mechanical cleaning. Chemical treatments are often the best solution to clean these surfaces. Ongoing water treatment and filtering of the water side is recommended to reduce dirt, biological, and mineral scale buildup. Filters for both air side and water side systems should be cleaned and replaced as necessary.

Avoid covering or blocking terminal fan coil units and baseboards with books, boxes, or file cabinets. Besides creating a fire hazard (in the case of radiators), blocking the units prevents proper air circulation and renders heating and cooling inefficient.

Savings

The savings you will see from a tune-up of your heat exchange equipment are highly dependent upon the existing conditions of the equipment. In general, the more you can improve the heat transfer of surfaces, the more you will save. Additionally, cleaning coils and filters may reduce the pressure drop across the coil and reduce fan or pump energy consumption.

Savings will differ depending on many factors related to the building, including heating and cooling system types; construction; geographical location; and internal heating, cooling, and electrical loads. Typical heating and cooling system cost savings can range up to 10 percent.

Considerations

- Are the heating and cooling surfaces clean?
- Are air and water filters changed regularly?
- Are heating or cooling terminal units and baseboards blocked by furniture or debris?

Heating and Cooling System

Following the framework of the integrated approach, the final step is to tune up the heating and cooling system. The heating and cooling system, generally a central plant, supplies all of the heating and cooling to make building spaces comfortable. Some buildings may have distributed heating and cooling units or a combination of both instead of a designated central plant.

The information gathered during the previous sections may become useful in determining any potential operational changes to the central plant. Additionally, recommissioning conducted on the HVAC and lighting systems should reduce the amount of energy the central plant consumes.

Some of the following tune-up items should be performed as part of normal scheduled maintenance. They are included here because of their potential for resultant energy cost savings. Specially trained and qualified personnel should perform all of these tune-up procedures.

Chiller Tune-Up

Chillers are similar to air conditioners found in any home, except that chillers supply cool water and home air conditioners supply cool air. The cool water from a chiller is eventually pumped through a heat exchanger (i.e., cooling coil), which cools the building's air. (For more information on specific types of chiller equipment, see Heating And Cooling System Upgrades.)

Chilled Water And Condenser Water Temperature Reset – A chiller's operating efficiency can be increased by raising the chilled water temperature and/or by decreasing the temperature of the condenser water. Chilled water reset is the practice of modifying the chilled water temperature and/or condenser water temperature in order to reduce chiller energy consumption.

If you decide to undertake chilled water reset, be careful that all of the considerations are taken into account. Although raising the chilled water will reduce chiller energy consumption, it may increase supply fan energy consumption. Reducing the condenser water temperature may increase the cooling tower fan energy consumption as well. Be sure to consult experts who can analyze all the effects of chilled water reset. If in doubt, using the intended design temperatures is your safest bet (E Source, *Space Cooling Atlas*,).

Chiller Tube Cleaning And Water Treatment – Optimum heat transfer relies on clean surfaces on both the refrigerant and water side of the chiller tubes. Typically, the water side of the condenser needs the most attention because evaporative cooling towers have an open loop and new water is introduced continuously. Thus, water treatment is needed to keep surfaces clean and reduce biological films and mineral scale. Similar treatments may be needed for the chilled water loop.

As part of the tune-up, clean the condenser and evaporator tubes to remove any scale or buildup of biological film. To do this, the surfaces usually have to be physically scrubbed and sometimes treated with chemicals.

Reciprocating Compressor Unloading – Reciprocating compressors are typically used for smaller chillers. Many of these compressors utilize multiple stages (that is, more than one piston for the compressor) of cooling to allow for more efficient part-load performance and reduced cycling of the compressor motor.

At part-load performance, one or more of the stages are unloaded. If the controls of the system fail to unload the cooling stage, then the system may cycle unnecessarily during low cooling loads. Because starting and stopping is inherently inefficient, cycling decreases the efficiency of the cooling system. Additionally, increased cycling can lead to compressor and/or electrical failures (E Source, *Space Cooling Atlas*).

Consult manufacturer's maintenance information to check for proper cooling stage unloading. Unloading may be controlled by a pressure sensor that is set for a specific evaporator pressure. This sensor, and the controls dependent upon it, can fall out of calibration or fail.

Boiler Tune-Up

In many buildings, the boiler is the heart of the heating system. Steam or hot-water boilers are present in approximately 42 percent of heated commercial floor space (CBECS, 1995).

When considering a tune-up for a boiler, always make sure that you and the maintenance staff or contractor know and fully understand all safety precautions. Also, always follow manufacturer's information on maintenance and local safety or environmental codes. Energy Star recommends you consider obtaining specialized expertise for boiler tune-up items.

Boiler System Steam Traps – Steam heating systems use mechanical devices called steam traps to remove condensate and air from the system. Steam traps frequently become stuck in the open or closed position. When a trap is stuck open, steam can escape through the condensate return lines to the atmosphere, and the resulting energy loss can be significant. Check steam traps for leaks frequently and make repairs as needed. Because special tools and experience are required, you should consider the use of outside expertise.

Combustion Air – More air is typically supplied for combustion than is needed. Excess air helps prevent incomplete combustion, which contributes to associated hazards such as smoke and carbon monoxide buildup. If too much air is introduced, some of the fuel is wasted heating this excess air. A tune-up of combustion air consists of adjusting combustion air intake until measured oxygen levels in the flue gas reach a safe minimum. (This tune-up measure does not apply to electric boilers.)

Boiler Tube Cleaning And Water Treatment – Optimum heat transfer relies on clean surfaces on both the boiler's combustion and water or steam side. Surfaces that are dirtied with fouling (see sidebar) will ultimately increase the energy consumption of the heating system. A tune-up consists of removing fouling buildup from both the fire side and water side of the boiler tubes by physically scrubbing the surfaces and sometimes by applying a chemical treatment.

Additionally, treating the heating water may be a good option to reduce the further deterioration of your boiler tubes.

Fouling

Fouling is the buildup of a film that reduces heat transfer. Soot, ash, or other particles can build up on the fire side surfaces of a boiler. Mineral deposits or other materials can build up on the water or steam side surfaces.

Heating and Cooling Equipment Savings

The savings associated with central plant recommissioning are derived from reducing the energy consumption of the heating and cooling system. Savings are highly dependent on the existing condition of the equipment. Other related factors include the heating and cooling system types; construction type; geographical location; and internal heating, cooling, and electrical loads.

Savings for most of the central plant recommissioning are listed below. When all recommissioning are taken together, heating and cooling cost savings can reach upwards of 15 percent.

Chilled Water and Condenser Water Temperature Reset – The savings associated with a water temperature reset will vary, depending on equipment type and system interactions. Because temperature reset does not require the purchase of new equipment, it can often be inexpensive. The complexity of reset, however, could result in incorrect implementation, instead increasing your energy use. Therefore, a professional consultant should be contacted who will be able to estimate the savings potential.

Chiller Tube Cleaning and Water Treatment – The savings achieved by cleaning tube surfaces are highly dependent on the current state of the tubes. Savings can be estimated by looking at what the temperature change through the evaporator or condenser should be and comparing it to the actual temperature change. Contact an HVAC consultant or a chiller specialist for a savings estimate.

Boiler System Steam Traps – The savings achieved by fixing steam trap leaks is highly dependent on the size of the leak and the pressure of the system. Table 1 compares orifice size with the estimated steam leaked per month and the resulting costs.

Table 1: Steam Trap Leaks

Size of Orifice (in.)	*Steam Leak per month (lb.)*	*Total Cost per month ($)*
1/2	835,000	2,480
7/16	637,000	1,892
3/8	470,000	1,396

Based on: 100 psi, boiler efficiency of 80 percent, energy cost of $2 per million Btu.

Source: Wayne C. Turner. *Energy Management Handbook*, 2nd ed., 1993, Fairmont Press, Table 14.17, page 341.

Boiler Combustion Air – The savings for the reduction of combustion air depend on the type of fuel used and the exiting flue gas temperature. Stage Five—Heating and Cooling System Upgrades includes a detailed plot of boiler fuel savings as excess air is adjusted. For example, for every 10 percent reduction in excess air, the boiler efficiency will increase 0.7 percent (based on burning No. 2 fuel oil with a flue gas temperature of 500° F).

Boiler Tube Cleaning and Water Treatment – The savings achieved by cleaning the tube surfaces is highly dependent on the current state of the tubes. Tables 2 and 3 illustrate the increased fuel consumption that results from surface fouling on the combustion and water side of a boiler.

Table 2: Boiler Combustion Fouling

Soot layer on heating surface (in.)	Increase in fuel consumption (%)
1/32	2.5
1/16	4.4
1/8	8.5

Source: W.H. Axtman, *Boiler Fuel Management and Energy Conservation*, American Boiler Manufacturers Association.

Table 3: Boiler Water Side Fouling

Thickness of scale (soft carbonate scale) (in.)	Increase in fuel consumption (%)
1/32	7.0
1/16	12.5
1/11	15.0

Source: W.H. Axtman, *Boiler Fuel Management and Energy Conservation*, American Boiler Manufacturers Association.

Considerations

Chillers

- Have you consulted an expert to determine the implications of chilled water temperature reset on supply fan energy consumption?
- How dirty are your evaporator and condenser tubes?
- Are reciprocating compressor cylinders unloading at part load?

Boilers

- Have the steam traps been inspected for leaks?
- Has combustion air been checked in the last year?
- Have the combustion and water or steam side heat transfer surfaces been cleaned recently?

Summary

To recap, your strategy for recommissioning should follow the framework an integrated staged approach. Keep in mind that the overriding concern in performing recommissioning is to ensure that the building operates as intended and meets current operational needs.

Building tune-up strategies should be implemented in the following order:

- Lighting + Supplemental Loads
- Building Envelope
- Controls
- Testing, Adjusting, And Balancing
- Heat Exchange Equipment
- Heating And Cooling System

Next Steps

- Make certain that facility staff receive training so that they are familiar with tuning and maintaining building systems.
- Use the information learned in recommissioning to identify and implement other energy performance strategies and savings opportunities in throughout the entire building and its systems.

LIGHTING

Overview

Lighting consumes 25 – 30% of energy in commercial buildings, and is a primary source of heat gain and waste heat. Excess heat and energy can be reduced by implementing an energy-efficient lighting system. Upgraded lighting systems can also improve lighting quality to increase occupant comfort and productivity.

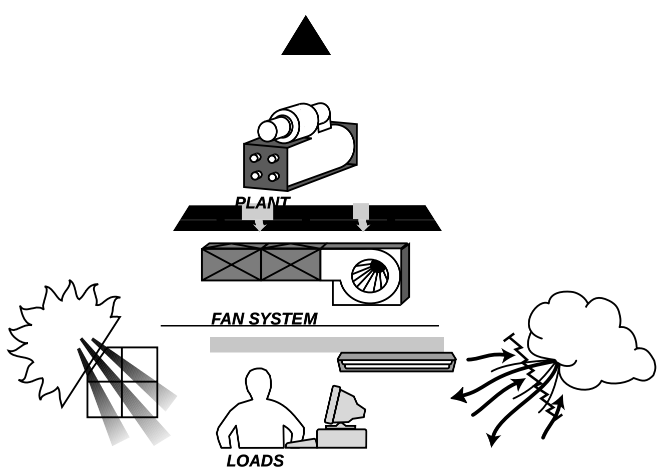
Figure 1 illustrates how heat from the lighting system effects cooling loads in the building. Comprehensive lighting upgrades create opportunities to improve the efficiency of electrical distribution and HVAC systems by reducing these loads. The additional energy savings from lighting upgrades are discussed in subsequent stages of the upgrade process.

Benefits of a comprehensive lighting upgrade:

- Highly profitable energy savings and low-risk investment.
- Maximize energy savings opportunities for subsequent building systems upgrades.
- Successful lighting upgrades can increase management and occupant acceptance of other energy-efficiency projects.

This chapter will identify opportunities and strategies to improve the efficiency of lighting systems. “Best Ways to Save” and “Take Action” are checklists to perform a quality lighting upgrade and maximize energy savings.

Figure 1: Heat Flow In Buildings



Heat Flow In Buildings: Building Systems Interactions

Figure 2 shows the interaction of heating, cooling, and electrical loads with the HVAC equipment. Arrows indicate heat flow pathways. Reducing heating, cooling, and electrical loads reduces the demand on HVAC equipment, thus saving energy.

Best Ways to Save

- Design **light quantity** and **quality** for the task and occupants' needs.
- Maximize **lamp and ballast efficiency**.
- Maximize **system efficiency**, not just the components.
- Use **automatic controls** to turn lights off or dim lights in daylit spaces.
- Establish maintenance schedule for **group relamping and fixture cleaning**.
- Use **ENERGY STAR Labeled exit signs**.
- Establish responsible **disposal practices**.

Take Action!

- Develop an implementation plan and budget for lighting upgrade projects.
- Communicate project objectives and process to occupants.
- Perform trial installations to assess light levels, occupants acceptance, and energy use.

The Importance of Lighting

Lighting and The Environment

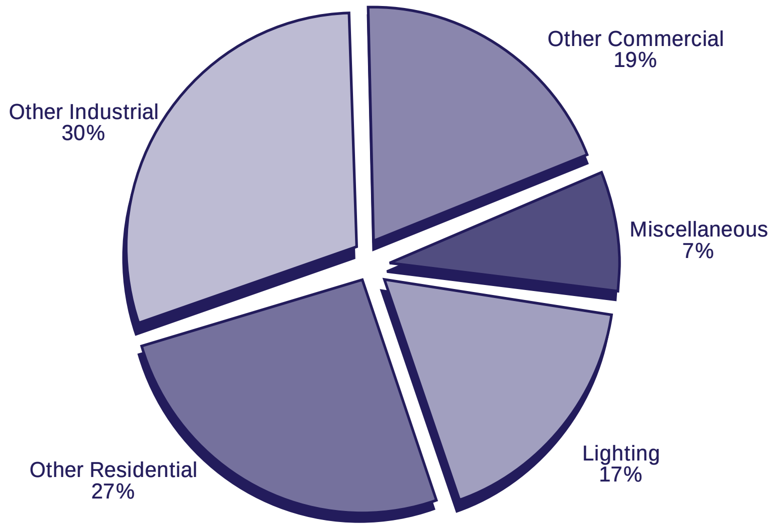
Lighting consumes a tremendous amount of energy and financial resources. Lighting accounts for approximately 17 percent of all electricity sold in the United States (see Figure 2, E SOURCE 1994, *Lighting Technology Atlas*, Ch. 4).

ENERGY STAR estimates that if efficient lighting were used in all locations where it has been shown to be profitable throughout the country, the nation's demand for electricity would be cut by more than 10 percent. This could save nearly $17 billion in ratepayer bills and result in the following annual pollution reductions:

- 202 million metric tons of carbon dioxide, the primary cause of global climate change. This would be the equivalent of taking 15 million cars off the road.
- More than 1.3 million metric tons of sulfur dioxide, which contributes to acid rain.
- 600,000 metric tons of nitrogen oxides, which contribute to smog.

Table 1 illustrates potential lighting energy savings.

Figure 2: Lighting Share Of All Electric Energy Use



Source: E SOURCE 1994, *Lighting Technology Atlas*, Ch. 4.

Table 1: Potential Lighting Energy Savings

Lamps and Ballasts	20 to 40 %
New Fixtures	30 to 50 %
Task/Ambient Lighting	40 to 60 %
Outside Lighting	30 to 50 %

Green Lights lighting upgrades save 48 percent of a building's lighting energy use on average.

Source: EPA Green Lights Program.

Lighting And Your Business

Lighting is also a significant expense in operating buildings. Lighting is the largest cost component of a commercial building's electricity bill (see Figure 3) and a significant portion of its total energy bill.

Lighting and Your Building

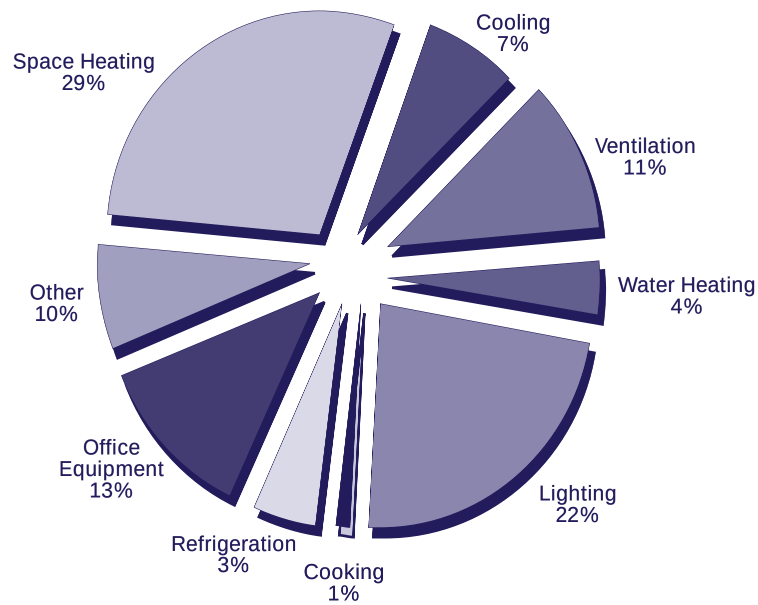
Reduce Heat Gain

In addition to visible light, all lighting systems produce heat. Lighting is typically the largest source of waste heat, often called "heat gain," inside commercial buildings. Improving lighting efficiency reduces heat gain, which affects your buildings in two ways.

Waste heat is a useful supplement when the building requires heat, it must be removed by the HVAC system when the building needs to be cooled. The impact of this tradeoff—the penalty for increased heating costs versus the bonus for reduced cooling costs—depends on your building type, its geographic location, and its HVAC system. Although heating costs may rise, they will rarely exceed the resultant cooling savings, even in buildings in northern climates that use electric resistance heat.

By reducing internal heat gain, efficient lighting also reduces your building's cooling requirements. Consequently, your existing cooling system may be able to serve future

Figure 3: Lighting Share Of Office Building Electricity Use



Source: U.S. Department of Energy, Energy Information Administration, *Energy End Use Intensities in Commercial Buildings*, Sept. 1994. DOE/EIA–05555(94)/2.

added loads, or may be appropriate for "rightsizing". Given the large impact lighting upgrades can have on your HVAC system requirements and the high cost of cooling equipment, you should always quantify HVAC and lighting interactions. There are simplified methods available for calculating the impacts of lighting upgrades on heating and cooling systems. (See EPRI *Lighting Bulletin*, no. 6, April 1994.)

Improve Power Quality

Lighting also affects the power quality of your building's electrical distribution system. Poor power quality is a concern because it wastes energy, reduces electrical capacity, and can harm equipment and the electrical distribution system itself.

Upgrading to lighting equipment with clean power quality (high power factor and low harmonic distortion) can improve the power quality in your building's electrical system. Furthermore, upgrading with higher efficiency and higher power factor lighting equipment can also free up valuable electrical capacity. This benefit alone may justify the cost of a lighting upgrade.

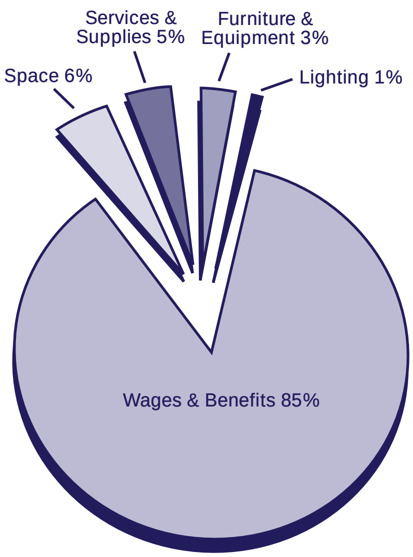
Lighting and People

A lighting upgrade is an investment not only in reducing electricity consumption but also in improving the performance of the building in supporting its occupants. A building's lighting directly affects the comfort, mood, productivity, health, and safety of its occupants. Moreover, as the most visible building system, it also directly affects the aesthetics and image of the building and your business. Successful lighting upgrades take into account the impact of energy performance choices on the building occupants and seek to marry efficiency with improved lighting quality and architectural aesthetics wherever possible.

Productivity

The relationship of lighting to task performance and visibility is well understood. Improved lighting enhances visual comfort, reduces eye fatigue, and improves performance on visual tasks. Well-designed lighting is likely to improve performance, increase productivity, and reduce absenteeism. Because costs associated with your employees greatly outweigh the other building costs (see Figure 4), any lighting changes that improve your occupants' workspaces are worth investigating.

Figure 4: Annual Operating Costs Per Square Foot, Typical Office Space



Source: *Lighting Management Handbook.*

Safety

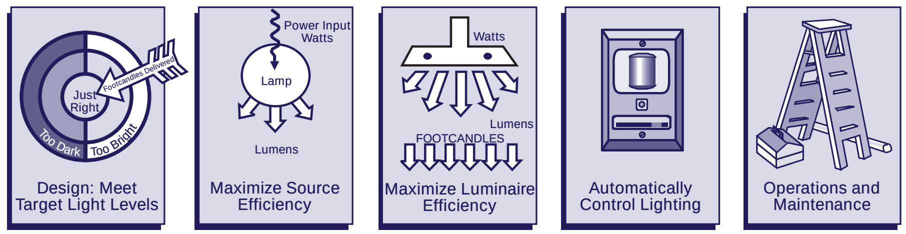
Lighting also contributes to the safety of occupants and the security of buildings. Emergency lighting must be available during power outages, and minimum levels of light must be available at night when most lighting is turned off. In addition, safety codes require exit signs to highlight escape routes during fires or other emergencies. Outside lighting and indoor night lighting deters crime by exposing intruders' movements and permitting occupants to move safely through the building or to cars.

Although such effects are difficult to quantify, comfort, mood, productivity, health, safety, and other impacts on people should be considered as part of every lighting upgrade.

Maximizing Efficiency and Quality

A comprehensive lighting upgrade achieves your qualitative lighting objectives while maximizing efficiency and profitability. With rewards beyond the sum of its parts, this process integrates equipment replacement with deliberate design, operation, maintenance, and disposal practices. This whole-system approach takes what is frequently regarded as a complex system of individual decisions and unites them into a strategic approach that ensures that each opportunity is addressed and balanced with other objectives (see Figure 5).

Figure 5: Comprehensive Lighting Upgrade Strateg



Avoid implementing only the easiest and quickest payback opportunities. While this may seem appealing, you will forgo quality-enhancing and savings opportunities that result from comprehensive upgrades. A simplified upgrade may yield faster payback, but you will sacrifice long term energy savings over the life of the system.

Table 2 illustrates the economic impacts of pursuing incrementally more aggressive upgrades while maintaining profitability and lighting quality and quantity. (See E Source, *Lighting Technology Atlas*, Chapter 3, for more detail.)

Lighting Design

Successful lighting design begins with an assessment of several design issues to meet the occupants' lighting needs, which depend on the tasks performed in the workspace. The lighting system should be designed to provide the quantity and quality of light responsive to those requirements. Chapter 10, "Quality of the Visual Environment," of the IESNA Lighting Handbook 9th edition, identifies several issues such as color, daylight availability, glare and, light distribution that should be considered. Retrofits that skip this assessment may perpetuate designs that have become inadequate because of workspace rearrangements or changing tasks (for example, paper-based to computer-based tasks).

Table 2: Performance Comparison of Fluorescent Retrofit Options

	Base case: T12 Lamps w/ magnetic ballasts Case 1	*"Energy saving" T12 lamps Case 2*	*T8 lamps, electronic ballasts Case 3*	*T8 lamps, electronic ballasts, reflector lens, + 50% delamping Case 4*	*Same as Case 4 + occupancy sensors Case 5*	*Same as Case 5 + maintenance Case 6*
Avg. maintained footcandles (fc)	28	25	30	27	27	27
Input watts per fixture	184	156.4	120	60	60	50
Total kW	2.208	1.877	1.440	0.720	0.720	0.600
Annual energy use (kWh)	8,832	7,507	5,760	2,880	1,800	1,500
Costs						
Energy savings (%)	N/A	15%	35%	67%	80%	83%
Annual operating cost for energy ($)	883.70	750.74	576.00	288.00	212.40	177.00
Upgrade cost ($)	N/A	312	1,440	1,620	1,970	1,970
Savings						
Energy savings (%)	N/A	15%	35%	67%	80%	83%
Operating cost savings (%)	N/A	15%	35%	67%	76%	80%
Simple payback (years)	N/A	2.4	4.7	2.7	2.9	2.8
Internal Rate of Return (10-year)	N/A	41%	17%	35%	32%	34%

Source: Adapted from E SOURCE, *Lighting Technology Atlas*, Table 3.1.

It is important to recognize that people do not see absolute levels of illuminance, the amount of light shining on a surface. They see differences in luminance or brightness—the amount of light reflected back from the surface. The fundamental relationship between lighting and occupant tasks makes it essential that the lighting, task, and surrounding area be evaluated together. Although lighting retrofits are generally limited to the lighting equipment, good design should evaluate and modify work environments where appropriate. For example, a lighting redesign may reorient computer monitors away from windows or increase the contrast between tasks and their backgrounds.

Room dimensions and finishes also affect the required light output and thus the energy consumption of all interior lighting systems. As much as one-third of the energy use of a lighting system depends upon the surrounding interior features, such as the ceiling height, windows, and color and reflectivity of room surfaces and furnishings. Where possible, the lighting designer should work with both the architect and interior designer to ensure that features that significantly enhance lighting levels, such as large windows and light-colored finishes, are utilized wherever possible. This helps minimize the required light output and therefore the energy consumption of the lighting system.

The same principals and guidance that apply to interior lighting are applicable to exterior lighting as well. Outdoor lighting that is designed and implemented properly should be cost effective, control light by directing it where needed; reduce glare and distribute illumination evenly; and reduce light trespass.

The Right Quantity of Light

A common misperception contributing to the proliferation of ineffective and inefficient lighting is that more light equals higher quality light. Lighting-level requirements have evolved with the changes in our workplaces and our knowledge of visual science. The Illuminating Engineering Society of North America (IESNA) has developed consensus-based guidelines to select appropriate illuminance levels for hundreds of indoor and outdoor activities. These recommendations, some of which are listed in Table 3, are starting points, suggesting a range of values based on design issues, locations, and tasks. Listed below are several design issues outlined by IESNA:

- Appearance of Space and Luminaires
- Color Appearance (and Color Contrast)
- Daylighting Integration and Control
- Direct Glare
- Flicker (and Strobe)
- Light Distribution on Surfaces
- Light Distribution on Task Plane (Uniformity)
- Luminances of Room Surfaces
- Modeling of Faces and Objects
- Point(s) of Interest
- Reflected Glare
- Shadows

- Source/Task/Eye Geometry
- Sparkle/Desirable Reflected Highlights
- Surface Characteristics
- System Control and Flexibility

Table 3: Recommended Light Levels (footcandles)

Average Reading and Writing	50 fc
Offices with Computer Screens	
Task Lighting	25 fc
Ambient Lighting	25 fc
Hallways	10 fc
Stockroom Storage	30 fc
Loading and Unloading	10 fc
High-Volume Retail	100 fc
Low-Volume Retail	30 fc
Roadway Lighting	.3 – 1.6 fc
Parking Lots	.8 – 3.6 fc
Building Entrance	5 fc

Source: *IESNA Lighting Handbook.*

It is important to note that these are **average maintained** target levels for the task and should not necessarily be applied uniformly as the ambient light level for the entire space. Lighting levels should be customized through the use of supplemental task lighting in areas requiring higher localized levels. Target lighting levels should be the sum of the ambient and task lighting levels. This task and ambient lighting design approach creates flexibility to accommodate individual tasks or worker requirements, creates visual interest, and can save considerable energy in comparison to a uniform ambient level approach.

The Right Quality of Light

Of equal importance to the quantity of light is the quality of light. The quality of light is dependent on both the properties of the light and how that light is delivered to the space. The fundamental quality issues include all of the IESNA "design issues" listed above with special consideration given to:

- Glare
- Uniformity of luminance
- Color temperature and color rendition

The eye does not see absolute levels of illuminance; the amount of light shining on a surface. It sees differences in luminance, the amount of light reflected back from the surface. Eyestrain and fatigue are caused when the eye is forced to adapt continually to different luminances. Therefore, it is important not only to provide the right level of light but also to ensure that light is evenly distributed across the task area. Balancing light levels also ensures that task lighting levels will be adequate throughout the space. Uniformity on vertical surfaces should also be maintained to avoid a gloomy, cavelike atmosphere.

IESNA recommends as good design practice an average **luminance ratio** of no more than 3 to 1 for close objects and 10 to 1 for distant objects and outdoor applications (*IESNA Lighting Handbook*, Sect. 11—Office Lighting). In other words, the difference in light level between the task area and the background should be less than a factor of three. While some designers use illuminance variation as an organizing theme, such as defining hallways leading to open offices, or as a highlighting strategy, such as in retail and merchandising locations, large footcandle variations within a workspace should be avoided.

Glare is the most important quality factor. Glare results when luminance levels or the differences in luminance levels are too high, and objects appear too bright. Because glare creates discomfort, loss of visual performance, and impaired visibility, it should be minimized wherever possible.

The two types of glare you will encounter are direct glare and reflected glare. **Direct glare** occurs when light from a bright object enters the eye directly. It can be controlled through the use of luminaire lenses, louvers, and window blinds, all of which block the direct viewing of sources.

Reflected glare is produced when reflected light creates a shining or veiling reflection, which reduces or washes out task contrast. This commonly occurs on shiny, light-colored surfaces and computer screens. Although veiling reflections are more difficult to control, they can be minimized by moving the light source, reorienting the task, and installing reflectors, lenses, or louvers on luminaires. Good general practices to minimize glare include the use of lower ambient light levels, task lighting, indirect lighting, and luminaires with a high **visual comfort probability** (VCP) rating. The VCP index provides an indication of the percentage of people in a given space that would find the glare from a fixture to be acceptable. You should ensure a minimum VCP rating of 70 for commercial interiors and 80 for computer areas.

The color mix of a light source is described by the terms **color rendering** and **color temperature**. The ability of a light source to accurately reveal the true colors of objects is measured by its color rendering index (CRI), which ranges between 0 and 100 (see Table 4). Lamps with a higher CRI make people and objects appear more natural and bright. Because high CRI lamps improve visual clarity and aesthetics, use the highest CRI lamps economically practical.

The color temperature of lamps, measured in degrees Kelvin (° K), refers to the relative warmth or coolness of their light color. The higher the color temperature, the cooler the light source. Lamps with a color temperature of 3500° K are generally considered neutral (see Figure 6).

Table 4: Typical CRI Values For Selected Light Sources

Source	*Typical CRI Value*
Incandescent/Halogen	98+
Fluorescent	
Cool White T12	62
Warm White T12	53
High Lumen T12	73–85
T8	75–98
T10	80–85
Compact	80–85
Mercury Vapor (clear/coated)	15/50
Metal Halide (clear/coated)	65/70
High-Pressure Sodium	
Standard	22
Deluxe	65
White HPS	85
Low-Pressure Sodium	0

While color temperature is largely an architectural choice, it also relates to design lighting levels. While warmer sources, with a temperature below 3500° K, are generally preferred in lower illuminance environments, cooler sources, with a temperature above 3500° K, are preferred in higher illuminance environments.

Maximize Source Efficiency

Too often, lighting retrofits start and finish with the objective of pairing lamps with ballasts to turn electricity into visible light most efficiently. While the majority of energy savings potential often resides here, pursuit of high efficiency alone may lead to compromises in light quality and controllability and higher system installation and maintenance costs. Lamp and ballast specification should seek to optimize efficiency while maintaining a balance with these other considerations.

Figure 6: Color Temperatures of Various Light Sources

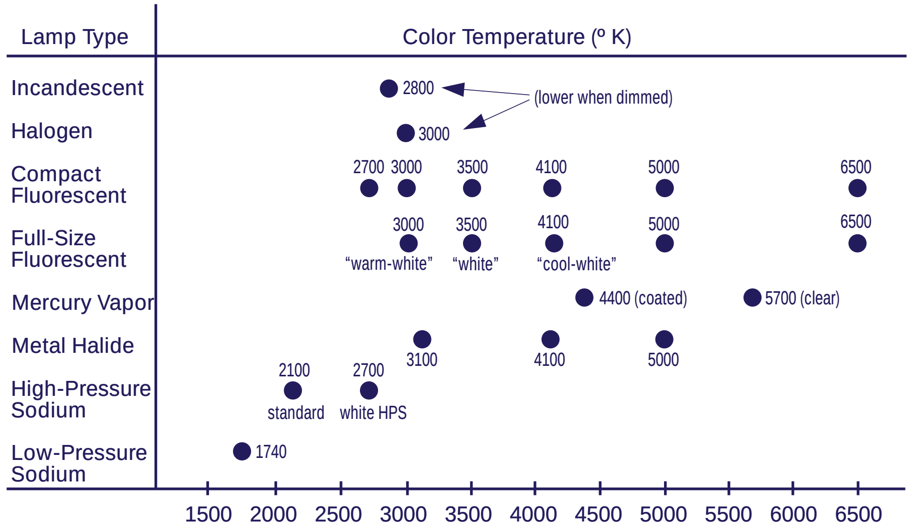


Table 5: Lamp Characteristics

	Standard Incandescent	*Full-Size Fluorescent*	*Mercury Vapor*	*Metal Halide*	*High-Pressure Sodium*
Wattages	3–1,500	4–215	40–1,250	32–2,000	35–1,000
System Efficacy (lm/W)	4–24	49–89	19–43	38–86	22–115
Average Rated Life (hrs)	750–2,000	7,500–24,000	24,000+	6,000–20,000	16,000–24,000
Color Rendering Index	98+	49–85	15–50	65–70	22–85
Life Cycle Cost	High	Low	Moderate	Moderate	Low
Source Optics	Point	Diffuse	Point	Point	Point
Start-to-Full Brightness	Immediate	0–5 Seconds	3–9 Minutes	3–5 Minutes	3–4 Minutes
Restrike Time	Immediate	Immediate	10–20 Minutes	4–20 Minutes	1 Minute
Lumen Maintenance	Good/ Excellent	Fair/ Excellent	Poor/Fair	Good	Good/ Excellent

While a wide range of light sources are available, the predominant types used in commercial and industrial spaces are fluorescent and high-intensity discharge (HID). Historically, fluorescent lighting has been used for high-quality, general-purpose indoor diffuse lighting. HID has been used for industrial and outside lighting. However, technical advances and a flood of new products have increased the use of HID in interiors.

Although fluorescent sources are still limited by their inability to function in very hot or cold environments or as spotlights, advances in physical size, thermal performance, and light quality are allowing wider application in industrial, manufacturing, and residential environments. Likewise, in the past, HIDs have typically been limited by their high light output and their inability to render color accurately or to be switched on and off frequently or dimmed. Today, however, HID lamps are used indoors in some applications where light quality is critical and where dimming and lower light outputs are necessary. While practical limitations still exist, now, more than ever, specifiers need to research lamp capabilities and understand the tradeoffs between efficiency and performance. For example, linear T5 lamps, which have recently been introduced, are becoming popular in direct/indirect pendent mounted systems, cove lighting and retail display lighting. But should not be used in retrofit applications because of the following limitations.

- Available only in metric lengths
- Lamp holder design is different that T8 and T12
- Higher tube luminance, which will cause glare problems in existing lighting equipment.

Ballast selection is integral to lamp performance. All fluorescent and HID lamps require a ballast to provide the necessary starting voltage and regulate lamp current and power quality. Ballasts determine the lamp's light output, life, and control capabilities. Similar to advances in lamp technology, electronics advances have greatly expanded ballast capabilities and selection.

The three types of fluorescent ballasts are magnetic, electronic, and hybrid ballasts. Magnetic ballasts, also known as electromagnetic ballasts, have improved from the standard-efficiency, core-coil ballasts last made in 1989 to higher efficiency models. Electronic ballasts have been developed for almost all fluorescent lighting applications to replace their conventional magnetic counterparts directly. Electronic ballasts operate fluorescent lamps at a higher frequency, which improves system efficiency by about 30 percent when used in conjunction with T8 lamps to replace T12 lamps and standard magnetic ballasts. Electronic ballasts also offer these advantages:

- Less audible noise and virtually no lamp flicker.
- Dimming capability (with specific ballast models).
- Ability to power up to four lamps, increasing energy efficiency by an additional 8 percent, while reducing first cost and maintenance costs.

Hybrid ballasts, which combine features of magnetic and electronic ballasts, are also available. Although these ballasts offer the same efficiency benefits as electronic ballasts, they cannot power more than three lamps.

Instant-start circuitry offers an additional 5 percent efficiency compared with rapid-start electronic ballasts. However, if lamps are frequently switched on and off, additional lamp and maintenance costs may exceed energy savings.

Programmed-start ballasts offer increased lamp life compared to instant or rapid start ballasts. Programmed-start ballasts are designed to soft start the lamp, which decreases lamp cathode damage. These ballasts are an excellent choice when luminaires are switched on and off frequently, such as in spaces controlled by an occupancy sensor.

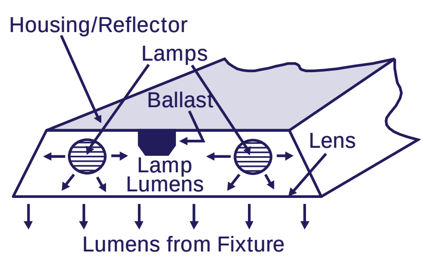
Selecting ballasts for HID lamps involves matching a ballast type to the electrical distribution system in your building to control the lamp light output when line voltage varies. The level of this control is then balanced against ballast losses, power factor, lamp life, and cost. Electronic ballasts are also available for most types of HID lamps, these ballasts are becoming more popular because of their smaller size, weight, decreased lamp color shifting, and increased compatibility with lighting controls Nominal efficiency improvements of only 5 to 7 percent make retrofits difficult to justify on energy savings alone. Linear reactor circuit ballasts have been developed which, when used with matched, pulse-start, metal halide lamps, can cut ballast losses in half and offer a 20-percent improvement in efficiency.

Maximize Luminaire Efficiency

A luminaire, or light fixture, is a system of components designed to direct light efficiently while providing a high level of visual comfort (see Figure 7).

Getting a large percentage of light to exit the fixture while controlling its distribution usually requires a compromise. Generally, the most efficient fixtures have the poorest visual comfort. Conversely, fixtures with excellent glare control are the least efficient.

Figure 7: Luminaire Components



When installing new fixtures, the lighting designer will determine the best compromise between fixture efficiency and visual performance and specify optimized fixtures that fit into the architectural design objectives. When retrofitting fixtures, however, lamps are repositioned, and reflectors and shielding materials are added to balance these objectives.

Reflectors are inserts designed to reduce the internal light loss in fixtures by using highly reflective surfaces to redirect light out of the fixture. They can be used in new fixtures or installed in existing fixtures as part of an energy savings retrofit strategy. In retrofits, reflectors improve fixture efficiency by improving the internal surface reflectance by up to 17 percent in new fixtures and more if fixture surfaces are old or deteriorating (see *Lighting Upgrade Technologies*, p. 10, EPA 430-B-95-008). By modifying the light distribution of the fixture, reflectors can also facilitate additional energy savings when reducing lighting levels through delamping or relamping.

Reflector performance is largely determined by specific design and installation rather than material selection. As reflector retrofits usually accompany a redesign of lighting quantity and quality in the space, evaluate changes in fixture appearance, target light levels, uniformity, and glare through trial installations.

Most indoor commercial fixtures use some type of diffuser, lens, or louver over the face of the fixture to block direct view of the lamp or to diffuse or redirect light. Although these shielding media improve visual comfort, each one has strengths and weaknesses with regard to visual performance, efficiency, and appearance (see Table 6).

In general, diffusers are simply semitranslucent plastic sheets that hide lamp images and diffuse light evenly across the face of the fixture. Because they spread light in all directions and absorb a large amount of light, diffusers are not only inefficient but also ineffective at controlling glare. By using clear plastic lenses with small prismatic surface patterns instead of diffusers, one can improve efficiency and the distribution of light.

Table 6: Shielding Media Options

Shielding Material	*Luminaire Efficiency Range (%)*	*VCP Range (%)*
Standard Clear Lens	60–80	50–70
Low-Glare Clear Lens	60–80	75–85
Deep-Cell Parabolic Louver	50–90	75–99
Translucent Diffuser	40–60	40–50
White Metal Louver	35–45	65–85
Small-Cell Parabolic Louver	40–65	99

Louver retrofits, depending on cell size and depth, can provide a better balance between superior light control and energy efficiency. Avoid small paracube louvers (cells less than 1 inch) whenever possible; although they provide excellent glare control, they are quite inefficient. Larger "deep cell" louvers provide high efficiency and excellent light control and are available for retrofit into many existing fixtures. New parabolic louvered fixtures are now designed to combine high efficiency (90 percent) with very high VCP ratings above 90. When retrofitting shielding media, evaluate changes in light output, distribution, and fixture appearance using trial installations.

The best type of lighting system for glare control and visual comfort is a direct/indirect pendent mounted system. By providing some up-light against the ceiling and a direct component to the work surface, direct/indirect lighting minimizes the extreme brightness between the ceiling surface and the fixture. Installing pendent mounted systems is usually only cost effective during complete renovations and new construction. However, these systems continue to come down in price and some contractors have experienced that the installed cost of a pendent mounted system is nearly the same as the installed cost of a new lay-in parabolic troffer, and their clients usually like the direct/indirect lighting system better.

Automatically Control Lighting

Reducing the connected load (wattage) of the lighting system represents only half of the potential for maximizing energy savings. The other half is minimizing the use of that load through automatic controls. Automatic controls switch or dim lighting based on time, occupancy, lighting-level strategies, or a combination of all three. In situations where lighting may be on longer than needed, left on in unoccupied areas, or used when sufficient daylight exists, you should consider installing automatic controls as a supplement or replacement for manual controls.

Time-Based Controls

The most basic controlling strategies involve time-based controls, best suited for spaces where lighting needs are predictable and predetermined. Time-based controls can be used in both indoor and outdoor situations. Common outdoor applications include automatically switching parking lot or security lighting based on the sunset and sunrise times. Typical indoor situations include switching lighting in production, manufacturing, and retail facilities that operate on fixed, predefined operating schedules. Time-based control systems for indoor lighting typically include a manual override option for situations when lighting is needed beyond the scheduled period. Simple equipment, such as mechanical and electronic timeclocks and electromechanical and electronic photocells, can be independent or part of a larger centralized energy-management system.

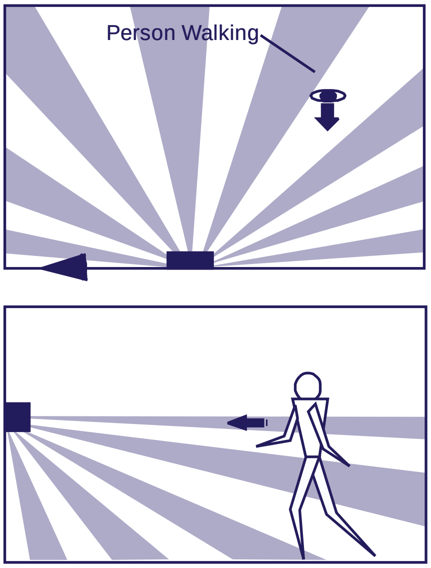
Occupancy-Based Controls

Occupancy-based strategies are best suited to spaces that have highly variable and unpredictable occupancy patterns. Occupancy or motion sensors are used to detect occupant motion, lighting the space only when it is occupied. For both initial and sustained success in using occupancy sensors, the sensor must be able to see the range of motion in the entire space while avoiding either on or off false triggering. This requires proper product selection, positioning, and testing.

Occupancy sensors should first be selected based on the range of body motion expected to occur throughout the entire lighted space. Controls for hallways, for example, need only be sensitive to a person walking down a narrow area, while sensors for offices need to detect smaller upper body motion, such as typing or reaching for a telephone. Once sensitivity and coverage area is established, sensors are selected from two predominant technology types.

Passive infrared sensors detect the motion of heat between vertical and horizontal fan pattern detection zones. This technology requires a direct line of sight and is more sensitive to lateral motion, but it requires larger motion as distance from the sensor increases. The coverage pattern and field of view can also be precisely controlled (see Figure 8). It typically finds its best application in smaller spaces with a direct line of sight, warehouses, and aisles.

Figure 8: Infrared Sensor Coverage Patterns



Ultrasonic sensors detect movement by sensing disturbances in high-frequency ultrasonic patterns. Because this technology emits ultrasonic waves that are reflected around the room surfaces, it does not require a direct line of sight, is more sensitive to motion toward and away from the sensor, and its sensitivity decreases relative to its distance from the sensor (see Figure 9). It also does not have a definable coverage pattern or field of view. These characteristics make it suitable for use in larger enclosed areas that may have cabinets, shelving, partitions, or other obstructions. If necessary, these technologies can also be combined into one product to improve detection and reduce the likelihood of false on or off triggering.

To achieve cost-effective, user-friendly occupancy sensor installations, both types of technologies need to be carefully commissioned at installation to make sure that their position, time delay, and sensitivity are properly adjusted for the space and tasks.

To ensure proper performance, the position of both wall- and ceiling-mounted sensors needs to be evaluated carefully. Ultrasonic sensors, for example will respond to strong air movement and need to be located away from ventilation diffusers. Infrared sensors should have their line of sight checked to ensure that it is not blocked by room furnishings. Both types of technologies should be positioned and adjusted so that their coverage area is not allowed to stray outside of the intended control area. See Table 7 for appropriate occupancy sensor applications.

All sensors have an adjustable time delay to prevent the lights from switching off when the space is occupied but there is little activity. Some infrared and all ultrasonic sensors also have an adjustable sensitivity setting. Customizing these settings to the application is necessary to balance energy savings with occupant satisfaction.

Figure 9: Ultrasonic Sensor Coverage Patterns

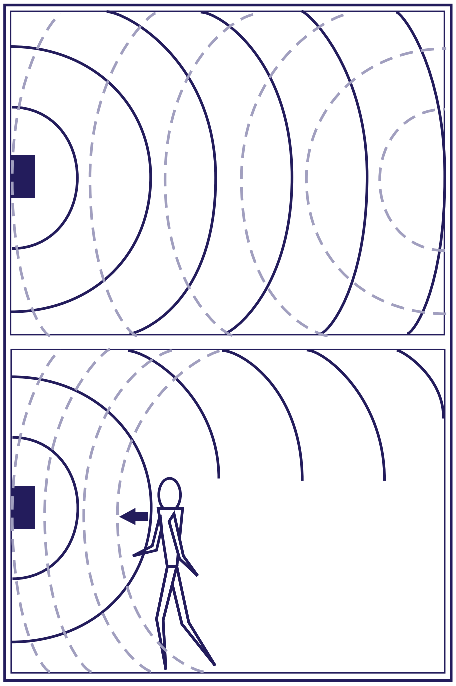


Table 7: Occupancy Sensor Applications

SensorPrivate Technology	*Office Office*	*Large Open Office Plan*	*Partitioned Conference Plan*	*Room*	*Copy Restroom*	*Closets/ & Rooms*	*Hallways Warehouse Corridors*	*Aisles*
Ultrasonic Wall Switch	3			3	3	3		
Ultrasonic Ceiling Mount	3	3	3	3	3	3		
Infrared Wall Mount		3			3		3	
Infrared Ceiling Mount	3	3	3	3		3		
Ultrasonic Narrow View							3	
Infrared High-Mount Narrow View							3	3
Corner-Mount Wide-View Technology		3		3				

Although increasing time delays will reduce the possibility of the lighting being switched off while the space is occupied, it will also reduce the energy savings. Setting the sensitivity too high may turn the lighting on when the room is unoccupied, wasting energy. Similarly, setting the sensitivity too low will create occupant complaints, as the lighting may turn off when the room is occupied. Evaluating the potential savings from an occupancy sensor installation should, and can, go beyond guesswork or speculation. Although sensors primarily affect energy use, they also affect energy demand, load on HVAC system, and lamp life. Evaluating the economic feasibility of an installation is best done by monitoring lighting and occupancy patterns. The use of inexpensive loggers will indicate the total amount of time the lights are on when the space is vacant, the time of day the savings take place, and the frequency of lamp cycling. This information will help you make an informed decision on the economic feasibility of potential occupancy-control opportunities.

Lighting Level-Based Controls

Lighting level-based strategies take advantage of any available daylight and supply only the necessary amount of electric light to provide target lighting levels. In addition to saving energy, lighting level controls can minimize overlighting and glare and help reduce electricity demand charges. The two main strategies for controlling perimeter fixtures in daylighted areas are **daylight switching** or **daylight dimming.**

Daylight switching involves switching fixtures off when the target lighting levels can be achieved by utilizing daylight. To avoid frequent cycling of the lamps and to minimize distraction to occupants, a time delay, provided by a deadband, is necessary. Several levels of switching are commonly used to provide for flexibility and a smooth transition between natural and electric lighting.

Daylight dimming involves continuously varying the electric lighting level to maintain a constant target level of illumination. Dimming systems save energy by dimming fluorescent lights down to as low as 10 to 20 percent of full output, with the added benefit of maintaining consistent lighting levels. Because HID sources cannot be frequently switched on and off, they are instead dimmed for time, occupancy, and lighting level-based control strategies.

Build In an Operations And Maintenance Plan

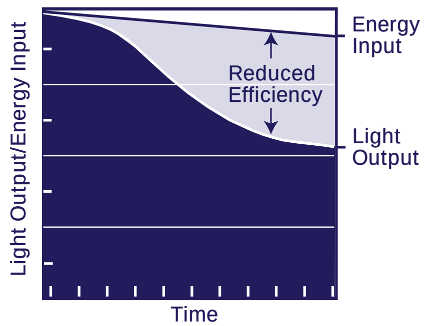
A lighting upgrade does not end with the installation of efficient equipment. Many cost-effective opportunities for reducing energy and maintenance costs and improving occupant satisfaction are frequently missed simply because operations and maintenance issues are ignored or addressed in an ad hoc fashion after the upgrade. The following decisions need to be integrated into your upgrade design from the beginning.

All lighting systems experience a decrease in light output and efficiency over time from three factors:

- Lamp light output decreases (lamp lumen depreciation).
- Dirt accumulates on fixtures (luminaire dirt depreciation).
- Lamps burn out.

Over time, these factors can degrade a system's efficiency by up to 60 percent (see Figure 10), wasting energy and maintenance costs and compromising safety, productivity, and building aesthetics. A planned maintenance program of group relamping and fixture cleaning at a scheduled interval minimizes this waste and maximizes system performance.

Figure 10: Efficiency Loss Over Time



Integrating a planned maintenance program into your lighting upgrade saves money in two ways. First, you will not have to overcompensate with higher initial lighting levels to ensure adequate lighting over time. The lighting system can be rightsized, saving on annual energy use and material first costs.

Second, while replacing lamps as they burn out on a spot basis may seem like a cost-effective practice, it actually wastes valuable labor. Group relamping times the replacement of lamps at their maximum economic value, generally at about 70 percent of their calendar life. Although it means replacing lamps before they expire, group relamping dramatically reduces the time spent replacing each lamp (not to mention the time spent responding to service calls and complaints), which can reduce your overall lighting maintenance budget by more than 25 percent. In addition, planned maintenance reduces the cost of lamps through bulk-purchase discounts, the storage space needs for replacement lamps, and disruptions in the workplace.

To sustain an efficient, high-performance lighting upgrade, assemble an operations and maintenance (O&M) manual. Use it as both the lighting management policy and a central operating reference for building management and maintenance staff. This manual should include the following information:

- Facility blueprints.
- Fixture and controls schedule.
- Equipment specifications, including product cut sheets.
- Equipment and service provider sources and contacts (include utility contacts).
- Fixture cleaning and relamping schedule with service tracking log.
- Procedures for relamping, reballasting, and cleaning fixtures.
- Procedures for the adjustment of photosensors and occupancy sensors.
- Procedures for proper lamp and ballast disposal.

Review the O&M manual with the staff responsible for lighting maintenance. Make training mandatory for all new maintenance personnel. Correct operation and maintenance should be built into job descriptions and should become part of all annual performance reviews.

Exterior Lighting

The three main considerations for exterior lighting are energy waste, glare, and light trespass. Energy waste and glare are discussed earlier in this chapter.

Light trespass, also known as spill light, is light that strays from its intended target and becomes an annoyance or nuisance. Maximizing the utilization of light output where and when it is needed will reduce light trespass. IES recommended light levels makes good economic sense and will minimize adverse environmental impacts associated with light trespass.

Strategies for Exterior Lighting

1. Use lighting fixture with directional control.
2. Direct and control light output to locations where it is needed.
3. Use time controls/dimmers to turn lights on and off and reduce light levels.
4. Design and install lighting to minimize glare.
5. Use the right amount of light for the task
6. Use energy efficient light sources and fixtures.

Environmental Effects

Exterior lighting can also have effects on the environment, excessive lighting near wildlife areas can adversely impact migrating bird life, nocturnal insects and other species. State and local ordinances have been established to protect natural wildlife from light pollution.

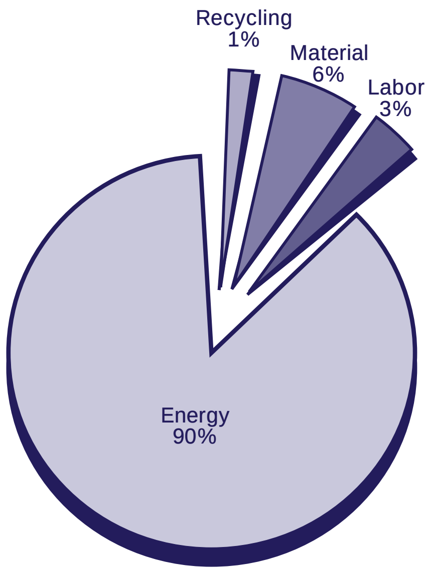
Ordinances and Community Standards

Outdoor lighting ordinances and codes encourage better quality lighting, which reduces glare, light trespass, and energy waste. Many codes are now including the concept of E-zones to distinguish between different types of lighting areas. For example, near national or state parks, wildlife refuges, or astronomical observatories lighting levels should be much lower than in city centers. The ordinances and community standards vary and local zoning departments should be contacted before implementing an outdoor lighting project.

Disposal

A lighting upgrade will most likely require the removal and disposal of lamps and ballasts. Group relamping every several years, and occasional spot relamping as necessary, will also create additional lamp waste. Some of this waste may be hazardous. As the waste generator, you must manage it according to applicable federal, state, and local requirements. While your specific requirements and your selected disposal options will determine the expense, it is important to note that disposal costs are rarely a "deal breaker" in a lighting upgrade. Typically, disposal costs constitute a very small percentage of the overall life-cycle costs of operating a lighting system (see Figure 11). Investigate and budget for these disposal costs both as a first cost during the upgrade and as an ongoing operation and maintenance expense.

Figure 11: Fluorescent Lamp Life Cycle Cost



Assumptions:

(2) T8 32-W lamps
62-W system wattage (w/electronic ballast)
Electricity at 7¢/kWh
Lamps at $2.65 each
Relamp labor at $1.50 each (group relamping)
Lamp life at 20,000
Lamp recycling at $0.50 each

Contact & Resource Information at a glance

Name	*Activity*	*Website/ Publications/Contact*
Resource Conservation and Recovery Act (RCRA)	Lamp Disposal	www.epa.gov/rcraonline/ Publication: Some Used Lamps are Universal Wastes RCRA Hotline 1.800.424.9346 (DC Metro Area 703.412.9810)
National Electrical Manufacturer's Association (NEMA)	Lamp Recycling	www.lamprecycle.org
Toxic Substances Control Act (TSCA)	Disposal of Ballasts with PCBs	www.epa.gov/pcb TSCA Hotline (202) 554-1401 E-mail tsca-hotline@epa.gov

Many lamps contain mercury, and are therefore considered hazardous waste under the Resource Conservation and Recovery Act (RCRA). In 1999, EPA added hazardous waste lamps to the universal waste program. Examples of common universal waste lamps include fluorescent, high intensity discharge, neon, mercury vapor, high pressure sodium, and metal halide lamps. Visit EPA's online RCRA Web site at www.epa.gov/rcraonline/ for more details. Recycling spent mercury-containing lamps is an alternative disposal method. The National Electrical Manufacturer's

Association (NEMA) encourages this practice and offers information on a website www.lamprecycle.org designed specifically to address lamp recycling issues.

The proper method for disposing of used ballasts depends on several factors, such as the type and condition of the ballasts. Generally, ballasts manufactured after 1978 contain the statement "No PCBs" and have not been found to contain PCBs. The disposal of Polychlorinated biphenyls (PCBs) is regulated under the Toxic Substances Control Act (TSCA). Information regarding the disposal of PCBs can be found on the PCB Home Page at www.epa.gov/pcb. Additional information can be obtained from the TSCA Hotline, which is reachable by phone at (202) 554-1401 or by e-mail at tsca-hotline@epa.gov. Other factors controlling the disposal of ballasts will depend on the regulations and recommendations in effect in the state(s) where you remove or discard them. Because disposal requirements vary from state to state, check with regional, state or local authorities for all applicable regulations in your area.

If you generated lighting material wastes, you are responsible for managing its disposal according to federal, state, and local laws or requirements.

Summary

Lighting has described opportunities for upgrading your building's lighting system at a profit. Keep the following strategies in mind as you upgrade your lighting system.

- Design **light quantity** and **quality** tailored to the task and occupants' needs.
- Maximize **lamp and ballast efficiency**.
- Maximize **fixture efficiency**.
- Use **automatic controls** to turn lights off or down when not needed.
  Reduce **light pollution** from exterior lighting
- Establish **operation, maintenance, and disposal** practices.

Next Steps

- Assess whether the existing lighting system meets occupant requirements.
- Communicate the lighting upgrade's objectives and process to all staff and occupants.
- Specify equipment that maximizes *system* efficiency, not just *component* efficiency.
- Perform trial installations to assess energy use and user acceptance.
- Move forward with lighting upgrades.

SUPPLEMENTAL LOAD REDUCTIONS

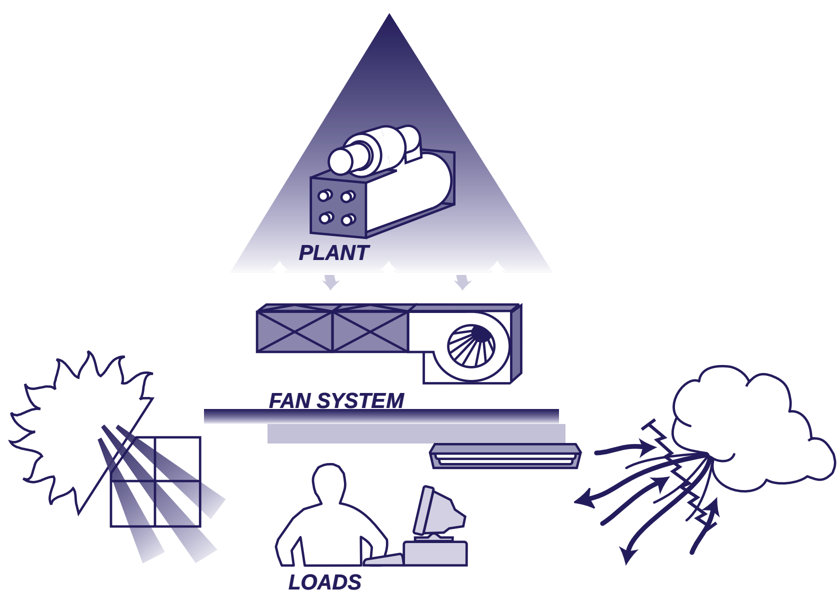
Overview

Supplemental load sources are secondary load contributors to energy consumption in buildings. Some typical supplemental load sources are people, computers, lights and the building itself. These loads can adversely effect heating, cooling and electrical loads. However, the effect of supplemental loads can be controlled and reduced through strategic planning and implementing energy efficient upgrades.

The heat flow diagram (Figure1) illustrates how supplemental load sources effect the heating, ventilation, and air-conditioning (HVAC) system. With careful analysis of these sources and their interaction with HVAC systems, you can reduce equipment size and cost associated with upgrades. These upgrades can increase HVAC energy savings and reduce wasted energy.

Supplemental Load Reductions section will help you identify these load sources and provide strategies to mitigate their negative impact on energy performance. "Best Ways to Save" and "Take Action", will provide you with checklists for reducing supplemental loads. "Load Reduction Strategy", will discuss various technologies, equipment and activities that provide opportunities for reducing supplement loads.

Figure 1: Heat Flow In Buildings



Heat Flow In Buildings: Building Systems Interactions

Figure 2 shows the interaction of heating, cooling, and electrical loads with the HVAC equipment. Arrows indicate heat flow pathways. Reducing heating, cooling, and electrical loads reduces the demand on HVAC equipment, thus saving energy.

Supplemental Load Reductions Strategy

- Reduce heating, cooling, and electrical loads to allow the installation of smaller and lower first-cost HVAC equipment in Fan Systems and Heating and Cooling Systems.
- If possible, delay the installation of HVAC equipment until **all** loads are reduced and the impacts on HVAC systems can be measured directly.
- If HVAC equipment installation cannot be delayed, take the time to predict the magnitude of load reductions from upgrade projects.

The Best Ways To Save

- Ventilation Upgrades
  - Control ventilation rates to meet minimum requirements
  - Install air side cooling economizer cycle
  - Utilize energy recovery equipment (i.e., heat pipes and heat wheels)
- Equipment Upgrades
  - ENERGY STAR® labeled office equipment
- Building Envelope Upgrades
  - Window films and/or shading
  - Roof insulation

Take Action!

1. Assess supplemental load sources in your building to determine reduction opportunities.
2. Contact vendors, contractors, or an engineering consultant to specify upgrades for supplemental load sources.
3. Install energy efficient upgrades to reduce the effect of supplemental load sources on heating, cooling, and electrical systems.

Load Sources

In the first stage of the upgrade process, Recommissioning, you had an opportunity to assess, plan and perform some reductions to the primary and secondary energy loads in buildings. The next step completing high-efficiency lighting upgrades, you achieved even more significant cooling and electrical load reductions. The third step in the process is Supplemental Load Reductions, which explores and identifies additional load reductions that can not only save energy and money, but will further increase savings when upgrading equipment for Fan Systems and Heating and Cooling Systems.

We have briefly introduced the three primary types of loads in all buildings and the benefits of reducing them. Next we discuss the supplemental load sources—that is, the individual characteristics that contribute to heating, cooling, and electrical loads. The magnitude of the effect on heating, cooling and electrical loads is determined by the following load sources:

- Lighting
- Occupants
- Ventilation Systems
- Equipment
- Building Envelope

Supplemental load sources affect more than one primary load type. Windows, for example, affect your cooling and heating loads. Lighting affects all three.

Lighting

Typically, 70 to 80 percent of the electrical energy used by lighting ends up in the conditioned space as heat. Upgrading to energy efficient lighting can reduce electrical and cooling loads, by eliminating heat generated by the lighting system; an inefficient and expensive form of heating.

The electrical load of lighting systems in office space ranges from 1 watt per square foot (W/sf) or less for efficient lighting to more than 2 W/sf for older systems. The Lighting stage seeks to reduce both the connected electrical load (kW) and energy consumption (kWh) of lighting equipment. Proven technologies provide equal light output with reduced electrical input and better color rendition. Lighting controls can significantly reduce operating hours and costs by turning off lighting when spaces are unoccupied. (For further detail, see Lighting Chapter, Automatically Control Lighting.)

Sample Calculation: Cooling Bonus

Replacing standard fluorescent lights with T8 lamps and electronic ballasts and adding occupancy sensors could save 300,000 kWh per year of electricity in a typical 100,000-sf office building. Furthermore, the cooling system removes less heat from the lights, and the additional cooling energy savings is approximately 41,000 kWh per year for a **cooling bonus** of 14 percent.

(Assumptions: 1 W/sf savings, 3,000 lighting operating hours per year, cooling efficiency of 0.6 kW/ton, 80% of lighting waste heat removed by cooling system)

Occupants

You have undoubtedly noticed that when a small room is filled with people, it tends to become warmer. People emit heat primarily through breathing, perspiration, and, to a lesser extent, through radiation. An average adult will generate 400 to 600 Btu of heat per hour. This heat generates a load on your cooling system.

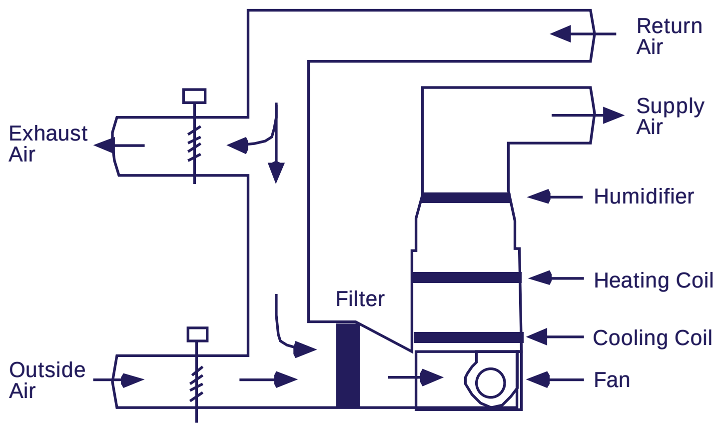
It is difficult to change the contribution occupants make to the energy balance in a building. Nevertheless, it is important to assess this contribution accurately and recognize that improvements to distribution systems and space conditioning equipment will lessen its effect on cooling loads and associated costs, while still maintaining or improving occupant comfort.

Ventilation Systems

Buildings with mechanical cooling-air distribution systems generally mix a portion of outdoor air with return air from the space to maintain an acceptable level of indoor air quality (see Figure 2). Outside air requirements for maintaining occupant health and comfort vary depending on the type of facility, the level of occupancy, and other factors. (Consult local building codes for outside air requirements; many locations have adopted ASHRAE Standard 62-1989 as part of their code for ventilation and some are beginning to consider ASHRAE Standard 62-1999.) In the summer, hot and humid ventilation air increases cooling loads. In the winter, cold ventilation air increases heating loads.

Many buildings require air-conditioning although the outside air is relatively cool and dry, due to internal or supplemental loads. An economizer cycle can be used to increase amounts of outside air to reduce mechanical cooling load.

Figure 2: Central Air System



Equipment

Equipment powered by electricity will, of course, affect your electrical loads. It is important to remember, however, that for many types of equipment, much of the electrical use in a space will ultimately end up in that space as heat. Thus, improving the efficiency of your electrical equipment not only reduces your electrical loads but also reduces your cooling load and, as with lighting, allows you the opportunity to replace that heat more efficiently, when needed, with gas heat or electric heat pumps.

Office Equipment

Office equipment (whether mechanical, electrical, or electronic) that consumes energy generates heat in the conditioned space. A typical non-ENERGY STAR labeled computer and color monitor draw a continuous electrical load of 120 watts or more (*User Guide to Power Management for PCs and Monitors*, Lawrence Berkeley National Laboratory, January 1997). Moreover, the heat they generate can be provided to the space more efficiently when needed.

Example: Computer Load Reduction

Typical load reduction (for 10 ENERGY STAR labeled PCs and monitors): 1,000 watts

Replacing 10 PCs with ENERGY STAR labeled models represents a reduction of 3,413 Btu/h no longer lost to the conditioned space. So, at $0.08 per kWh, 8 hr. per day, the heating cost was $0.64 per day.

Assuming gas costs $0.80 per therm and contains 100,000 Btu/therm, with a heating efficiency of 75%, *the new heating cost is $0.29 per day.*

Heating Cost Savings: 54%

Kitchens

Most commercial buildings have small kitchen areas for occupants to prepare coffee, lunch, or snacks. Microwave ovens, coffee machines, and refrigerators are common in these areas. Microwave ovens and stoves generally consume energy in direct proportion to the need for warming foods, whereas refrigerators run continuously, and coffee machines may be left on longer than necessary. Vending machines are typically lighted and often refrigerated continuously, consuming energy 24 hours a day. Because this equipment is located within conditioned space, its electricity usage leads to heat generated in the space.

Domestic Hot Water

Small domestic hot water tanks are often located in bathrooms or cabinets within the conditioned space. Larger units may be located in mechanical rooms where some of the heat generated by mechanical room equipment may reach the space conditioning system. Heat loss from tanks occurs 24 hours a day.

Building Envelope

Building envelope components include windows, doors, walls, the roof, and the foundation. Heat flows from the warmer side of the building shell to the colder side. The most commonly discussed parameters of heat flow through the building envelope, in or out, are conduction, infiltration, and solar radiation. Insulation, building design and materials, and maintenance (such as caulking and weather-stripping—see Recommissioning) all determine the levels of these heat flows. Ventilation rates determine the magnitude of the ventilation load as discussed previously. Mechanical heating and cooling are used to make up the heat lost (or gained) through conduction, infiltration, and solar radiation.

Heat Transfer Basics

How does heat travel? As you know from experience, heat will always move from warm to cold. You may not, however, recognize the three ways in which heat travels.

Conduction is heat flow through a material from hot to cold. This phenomenon explains why the handle on a stove pot becomes hot. It also explains why we add insulation to walls.

Infiltration, a form of convection, is heat flow by movement of air. This phenomenon explains why we feel cold when the door is open on a winter day. It also explains why we fill small cracks around windows with caulking.

Radiation is heat flow over a distance from hot to cold. This phenomenon explains how the sun's warmth reaches earth. It also explains why we use window shades in summer.

Conduction (Roofs, Walls, And Windows)

The materials used in the building shell determine the level of conductivity. Insulation slows, but does not stop, the flow of heat through walls and roofs. R-value is a measure of insulation that demonstrates the relative resistance to heat flow through a solid. The larger the R-value, the more insulation the wall or roof provides and the less heat that flows through that wall or roof by conduction in a given time. Similarly, storm windows or double-pane windows rely on an insulating air space between the panes of glass (see Figure 3) to achieve their increase in R-value.

Infiltration

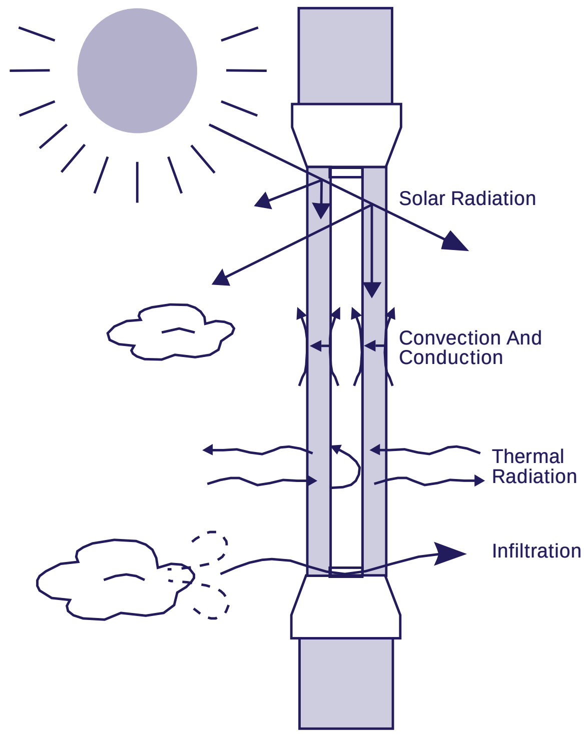
It is likely in older buildings that heat will leak through breaks in insulation or around windows. This kind of air leakage, called infiltration, can greatly reduce the effectiveness of insulation. Thus, R-values alone do not fully describe the energy efficiency of a wall or roof.

All buildings allow some level of uncontrolled airflow through the building envelope. Infiltration paths include seals around operable windows, cracks or seams in exterior panels, doorjambs, and shell penetrations such as holes for wiring or roof curbs for HVAC equipment. Air flowing into or out of these leakage paths is driven by pressure differences caused by HVAC equipment between the inside and outside of the building, between windward and leeward sides of the building, and between upper and lower floors (natural convection, most commonly called the chimney effect) of the building. In buildings with mechanical ventilation systems, it is desirable to minimize uncontrolled air leakage to reduce cooling loads.

Solar Radiation

The sun's influence on the heating of a building is a concept that has been recognized for a long time.

Figure 3: Window Heat Flow



Now, in houses with a south aspect, the sun's rays penetrate into the porticoes in winter, but in summer, the path of the sun is right above the roof so that there is shade. If, then, this is the best arrangement, we should build the south side loftier to get the winter sun, and the north side lower to keep out the cold winds.

Socrates, 360 B.C.

Solar radiation can have an enormous influence on the heating and cooling required in a space. The sun often makes perimeter spaces uncomfortably hot, and it also creates glare and fades fabrics. Reducing solar gain (heating caused by solar radiation) offers very profitable opportunities for cooling-load reductions and energy savings.

Heat can also be radiated out of the building through the windows in winter if outdoor temperatures are much lower than room temperature. Yet, the amount of heat lost through radiation is far less significant than that of other types of heat gain or loss.

Supplemental Load Reduction Opportunities

As the heat flow diagram (Figure 1) illustrates, load reductions made in this stage can significantly and positively affect equipment modifications that will be made in the remaining stages.

Fan System Upgrades addresses fan systems, which can usually be right-sized to a smaller capacity or operated more efficiently as a result of load reductions.

Sample Calculation: Chiller Cost Reduction

Looking again at the chiller energy savings in a 100,000-sf building, the 1 W/sf reduction in lighting load would allow a chiller capacity reduction of approximately 23 tons (assuming that 80 percent of the waste heat reaches the conditioned space). If you assume a typical chiller cost of $450 per ton, then you could figure on reducing the first cost of a new chiller by more than $10,000 based on the 23-ton reduction. Other load reductions would further reduce the chiller size requirement.

Heating and Cooling System Upgrades address equipment that also can be right-sized, usually to a smaller capacity, and/or operated more efficiently as a result of load reductions.

Upgrades that effect load reductions have the potential for both future energy savings and lower first costs in Fan Systems and HVAC Systems. A analysis done on supplemental load reductions will pay back more than once.

Distribution System Benefits

Distribution system motor size may be reduced with smaller cooling loads. The first cost on a fan motor, for example, would be $26 less for every ton of reduced cooling load. (Assumptions: motor cost @ $65/hp x 1 hp/1,000 cfm x 400 cfm/ton = $26/ton)

Load Reduction Strategy: Energy Star Labeled Office Equipment

In the business world, office equipment constitutes the fastest growing portion of electrical loads. However, much of this energy is wasted because equipment is left on when not in use throughout the workday, at night, and on weekends.

Electrical loads from office equipment, as well as cooling loads, can be reduced by the use of Energy Star labeled office equipment. Virtually all office equipment manufacturers offer a wide range of Energy Star labeled models, including copiers, printers (and some mailing machines), fax machines, monitors, computers and workstations, scanners, and multifunction devices. Office equipment with the Energy Star label saves energy and money by powering down and entering “sleep” mode or off mode when not in use. Products that meet the Energy Star specifications use about half as much electricity as conventional equipment.

Energy-efficient equipment with the Energy Star label cost the same as comparable non- labeled equipment. However, the savings are greater for labeled equipment, as shown in Table 2. The estimated savings below are per unit and can be multiplied to estimate savings for an office with hundreds of energy-efficient products.

Table 2: ENERGY STAR Labeled Office Equipment Savings

Product	*Estimated Annual Savings/Unit*
Large Copier (plus $650 if double-sided copying feature is used)	$130
Printer	$40
Computer and Monitor	$20
Fax	$15

Source: Lawrence Berkeley Laboratories.

ENERGY STAR labeled equipment produce less heat by powering down when not in use. This reduces cooling load, and energy costs of air-conditioning and contributes to a cooler and more comfortable workspace. In addition, building occupants can do their part to minimize loads and costs by turning off equipment (including ENERGY STAR labeled models) at night and on weekends.

Managing Your Office Equipment

Here are four steps organizations should take to ensure that they realize the benefits offered by ENERGY STAR labeled office equipment.

Check Equipment Specifications – Look for and request the ENERGY STAR label when purchasing new equipment. It may appear on the product itself, in advertisements and promotional materials, or on the packaging. If the label isn't visible, ask the manufacturer, or retailer if the model meets the ENERGY STAR specifications.

For existing models in the office, check to see if they have power management or other energy-saving features. Although they may not meet the ENERGY STAR specifications, these features will provide some energy savings if activated. In addition, control devices are available for non-ENERGY STAR labeled computers, monitors, and printers. These external hardware units are designed to reduce the energy consumption of older equipment by turning them off when not in use. To request a list of control device manufacturers and their products, call the ENERGY STAR hotline at 1-888-STAR YES.

Ensure Proper Equipment Setup – Confirm information systems or support staff that the equipment is installed properly with the power-management features enabled. Each employee has different work habits and should be encouraged to adjust the time settings to accommodate individual work patterns. If the computer power-management feature is not compatible with the network environment, disable the feature on computers, but continue to use it on all of the monitors. Monitors consume 80 percent of the energy used by the two components.

Set a Corporate Policy – Inform employees through regular training and other internal materials, that ENERGY STAR is an organizational policy. E-mail and voicemail messages can be sent to employees providing them with ENERGY STAR information as well as updates on the air pollution reductions resulting from their using energy-efficient equipment. Displaying ENERGY STAR posters in copy rooms, lounges, and other areas can also help to remind employees to use the energy-saving features and to turn off their equipment at the end of the day.

Educate Employees – Educate employees so that they understand what power management is and why it is important. Here are some examples of issues that you should focus on:

Is "Sleep" the same as "Off?" No. Sleeping equipment still draws some electricity; so turn it off when not in use for long periods of time.

Will the power-management feature shorten the lifetime of my computer or monitor? No. Heat is a leading cause of equipment failure. When the power-management feature is used, the computer generates less heat, so it may last longer and have improved reliability. In addition, manufacturers have increased the reliability of components, such as hard drives and microprocessors, that "cycle" when power management is used.

Does a screen saver help save energy? No, but there are screen savers available that won't interfere with the power-management features. If screen savers are used in the office, be sure to choose those that will display images for a predetermined period of time and then enter the sleep mode. Graphical screen savers are primarily for entertainment and are not energy-efficient features.

Table 3: ENERGY STAR Labeled Office Equipment

Equipment	*ENERGY STAR Specifications*
Computers	Automatically enter a low-power sleep mode after a period of inactivity. Efficiency specifications based on power supply.
Copiers	Depending on copier speed, automatic power-down and shutoff to 5–20 watts or less after 30–90 minutes of inactivity. Separate specifications available for large format copier models. Recommended automatic double-sided copying on medium- and high-speed models.
Fax Machines	Automatically power down to 15–45 watts after 5–15 minutes of inactivity, depending on fax speed.
Monitors	Automatically enter two successive low-power modes of 15 watts and 8 watts after 15–30 minutes of inactivity.
Multifunction Devices	Automatically power down to 5–105 watts after 15–120 minutes of inactivity, depending on equipment speed. Automatic double-sided copying on machines that copy at 44 pages or faster per minute.
Printers	Automatically power down to 15–45 watts, depending on print speed.
Scanners in use.	Automatically power down to 12 watts or less when not

Energy Star Specifications

Computers – Energy Star labeled computers automatically enter a low-power sleep mode after a period of inactivity. The newest Energy Star specifications allow workstations to qualify for the Energy Star label. Most Energy Star labeled computers are compatible with the primary network environments (for example, Novell NetWare, Banyan Vines, and LAN Manager). Consult with the manufacturer before purchasing a computer to ensure it is designed to be compatible with your particular network environment.

Monitors – As of January 1998, Energy Star labeled monitors automatically enter two successive low-power modes of 15 watts and 8 watts. In addition to reducing wasted energy, Energy Star labeled monitors emit fewer electromagnetic fields when sleeping because most of their electronic components are turned off.

Printers/Fax Machines – Typically, printers and fax machines are left on 24 hours a day, although they are active for only a small percentage of that time. To conserve energy, Energy Star labeled printers and fax machines, after a period of inactivity, automatically enter a low-power mode of 15 to 45 watts, depending on product speed. Approximately 95 percent of the printers and fax machines available in the United States meet the Energy Star criteria. When purchasing new equipment, consider a combination printer/fax machine, which consumes half as much energy when idle as two stand-alone products.

Copiers – Energy Star labeled copiers include a low-power mode and an off mode. About 70 percent of US black-and-white copier models carry the Energy Star label. Even if a copier is used frequently during business hours, the auto-off feature will save energy by turning off the copier at night and on weekends. The average office worker uses 10,000 sheets of copy paper each year. Selecting the double-sided copying (or duplexing) feature will reduce waste, save paper, and cut mailing and storage costs.

Scanners – Scanners that qualify for the Energy Star label automatically enter a low-power mode of 12 watts or less when not in use. When the user wants to scan another image, the machine will "wake up" and resume activity.

Multifunction Devices – Energy Star labeled multifunction devices offer copying as well as printing, faxing, scanning, and/or other capabilities. To reduce wasted energy, they automatically enter a sleep mode of 5 to 105 watts (depending on output speed) after a period of inactivity. High-speed multifunction devices also include an automatic double-sided copying feature.

Load Reduction Strategy: Control Ventilation Rates To Minimum Requirements

If your building was designed and built before the mid-1970s and there have been no substantial modifications of equipment or controls, the chances are good that energy savings can be achieved not only through improved equipment efficiency but also by improving the control of outside air. This can be done by controlling outside air to the minimum required for health and comfort when outside air is an energy burden and by increasing outside air delivery when outside air can provide free cooling or nighttime precooling. In most cases, any opportunity to save energy by increasing the delivery of outside air will also tend to improve the building's air quality.

A testing, adjusting, and balancing contractor (see Fan System Upgrades) can be engaged to determine the quantities of outdoor air provided by your air-handling units at both full-load and part-load conditions. These quantities can be compared to occupancy levels to determine the recommended ventilation rates per occupant. If they exceed ASHRAE Standard 62-1989, which is 15 cfm per occupant for office spaces without significant sources of pollution (see Load Sources), reducing the rates to the minimum required, particularly during occupied hours in the summer, could result in substantial energy savings.

CO_2 Sensors and Time Clocks

Because occupants are most often the primary source of CO_2 in buildings, CO_2 is sometimes used as a surrogate for determining levels of occupant-related contaminants. Accordingly, there is some interest in using CO_2 sensors to control outdoor air ventilation. When CO_2 levels are low, outdoor air ventilation rates are reduced to save energy, and, when CO_2 levels are high, outdoor air rates are increased to reduce occupant-related contaminants. Because demand-controlled ventilation using CO_2 sensors does not account for other sources of pollution, it is important to be aware of other sources that may create indoor air quality problems. Although the opportunities to reduce cooling and heating loads with CO_2 monitoring can be significant, the risk of causing occupant discomfort is also significant. Thus, ENERGY STAR recommends obtaining outside expertise to implement this load reduction strategy.

Time clocks that automatically reduce ventilation rates during unoccupied periods can greatly reduce the energy load in buildings. If your building does not currently have nighttime setback of the ventilation system, consider investing in time clocks.

Load Reduction Strategy: Air Side Cooling Economizer Cycle

There are times when increasing outside air beyond ASHRAE 62-1989 requirements will lower cooling loads.

It is often possible, through the use of an economizer, to use outside air to cool a space either totally or partially. An economizer consists of local controls and dampers capable of delivering 100 percent outside air. Air-side economizers come in two types: dry-bulb and wet-bulb economizers. A dry-bulb economizer is activated by outdoor air temperature. When the temperature is below a certain set-point, the outside air damper opens to its maximum aperture to allow 100 percent outside air in. A wet-bulb economizer operates in the same manner; its only difference is that both temperature and relative humidity are measured. If you are familiar with the saying "it's not the heat, it's the humidity," you can understand why relative humidity is important.

Table 4: Economizer Savings

Climate	*Savings (%)*
Humid-climate commercial buildings	25
Temperate-climate commercial buildings	50
Desert-climate small commercial buildings	12–20
Arid-climate small commercial buildings	30–40
Temperate/coastal-climate small commercial buildings	>70
Los Angeles commercial buildings	15–65
San Francisco commercial buildings	40–80
Fresno commercial buildings	30–45

Source: E SOURCE, *Space Cooling Technology Atlas*, Sec. 6.3.1.

In a practical sense, it is difficult to measure relative humidity accurately over a long period. For this reason, dry-bulb economizers, which measure temperature alone, are common.

Do not assume a building uses outside air economizing just because dampers, temperature sensors, and controls are installed. Outside air dampers, along with sensors, are prone to malfunctioning. Again, underscoring the importance of the ENERGY STAR Approach, Building Tune-Up is designed to identify and fix equipment problems so that systems such as outside air economizers work properly.

Load Reduction Strategy: Night Precooling

Night precooling, another ventilation control strategy, is an energy-efficient way of cooling your building in lieu of mechanical refrigeration cooling. Night ventilation is an effective means of cooling in regions where nighttime temperature is low and daytime cooling loads are significant (*Passive Solar Journal*, vol. 2, no. 2). This strategy can be considered as a flushing method, whereby cold outdoor air is introduced during the night to flush internally generated heat out of a building.

Night precooling can save significant energy. Studies have shown that cost savings range from 5 percent in Phoenix, Arizona, to 18 percent in Denver, Colorado, for a typical office building. Additionally, peak demand reduction can also be achieved through night precooling. Simulation analyses have shown that precooling a 100,000-sf 3-story building in Sacramento, California, would save up to 12.6 percent in energy and cause a peak demand reduction of 31.3 percent (E SOURCE, *Space Cooling Technology Atlas*, Section 6.3.1).

Load Reduction Strategy: Minimize Kitchen Equipment Loads

When buying kitchen equipment such as refrigerators, buy the most energy-efficient model available in your size. If you have vending machines, they are typically lit continuously, consuming energy 24 hours a day. If possible, put such lighting on timers or replace them with more efficient lights. With some vending machines, it is possible to put the entire machine on a timer.

Load Reduction Strategy: Reduce Domestic Hot Water Heat Loss

Heat loss from domestic hot water tanks occurs 24 hours a day. Reducing heat loss from the tanks with either added insulation or installation of a higher efficiency unit also reduces the load on air-conditioning systems. For electric hot water tanks, an insulation wrap is both easy to install and pays for itself quickly. Another option is point-of-use heaters that have no tank and therefore no standby losses.

Load Reduction Strategy: Window Films

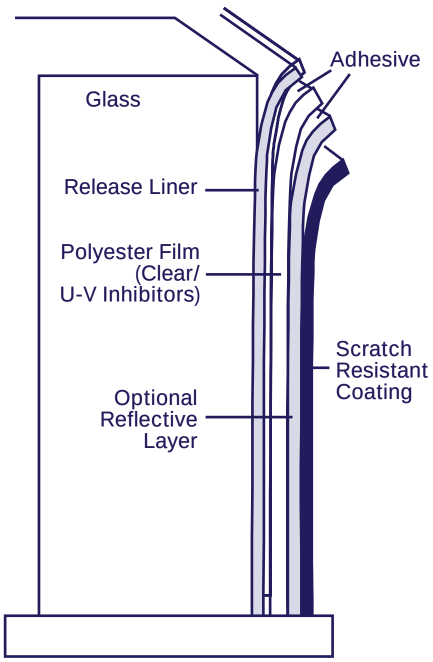
Window films can be retrofitted to existing windows to reduce heat gain due to solar radiation and provide a low-cost cooling load reduction (see Figure 4).

Window films are thin layers of polyester, metallic coatings, and adhesives that save energy by limiting both the amount of solar radiation passing through the windows and the amount of internal heat escaping through windows. They can be applied directly to the interior surfaces of all types of glass and generally last 7 to 12 years.

Typically, in the heating season, more heat escapes from most windows than comes in from the sun (on a 24-hour basis); the extent depends on the local climate and the R-value of the window. Window films can help reduce this costly heat loss by reflecting indoor radiant heat back into the room. In the cooling season, even when drapes and blinds are closed, much of the sun's heat passes through the glass into the room. Window films address this problem by reducing solar heat gain at the window.

In short, window films save energy by reducing radiation and other forms of heat transfer through windows, by allowing better balance in heating and cooling systems and by providing opportunities for HVAC downsizing.

Figure 4: Window Films



Window Films: Cost Effective For Your Building?

Apply the following criteria to your building. The more criteria your building meets, the more profitable window films can be.

- The amount of window space on the building is large compared to the total surface area (that is, greater than 25 percent of the surface area).
- The building is in a sunny location with little natural shade.
- Windows on the south and west sides of the building receive direct sunlight.
- Windows have single-pane glass. (Note: Even buildings with better insulated, double-pane windows may profit from window films.)
- Windows are clear; they have no tint, color, or reflective coating.
- The building is in a geographical area that has many sunny days.

Fan systems and cooling equipment can be downsized following peak cooling load reductions.

There are several economic considerations in regard to window film installations. For old, drafty, single-pane windows, complete window replacement is another option. Although this option is more expensive than window film installation, it may be more appropriate depending on your window condition. It may be most cost effective to install window films only on the south and west sides of the building. Window films typically cost between $1.35 and $3 per square foot, installed. Improperly installed films can, however, bubble, crack, peel, or even cause the glass to crack, so it is worthwhile to buy films with a material and installation guarantee of 5 to 10 years.

Load Reduction Strategy: Window Shading

Other ways to reduce the solar cooling load imposed by windows involve physical shading. Exterior and interior shading are among the best ways to keep the sun's heat out of a building. In warm climates, buildings in sunny areas can benefit greatly from a variety of shading techniques (see Figure 5).

Interior Shading

Venetian blinds and other operable shades are a low-cost and effective solution for keeping out the sun. More sophisticated systems, sometimes even located between two panes of window glazing, automatically open and close shades in response to the cooling load imposed by the sun.

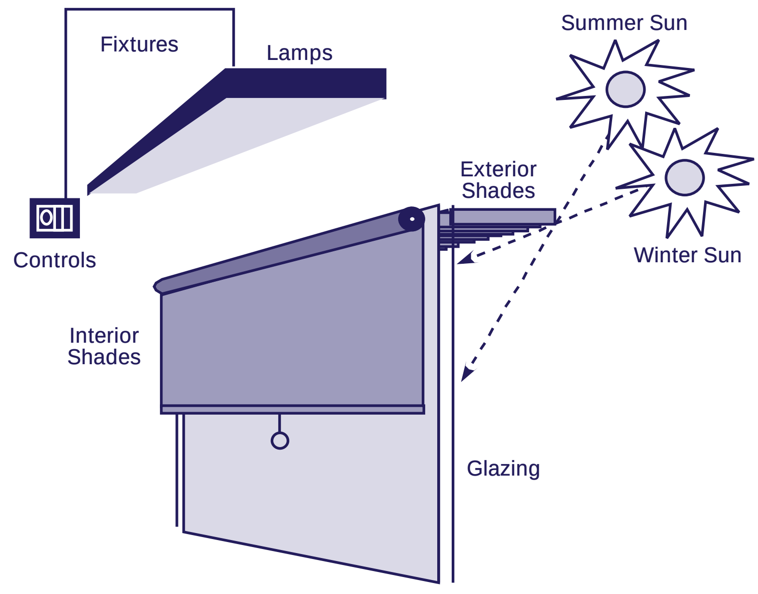
Low emissivity coatings

Low-emissivity (low-e) coatings provide better insulation, while letting in as much solar heat gain as possible. These coatings are now typically offered on many window systems.

Exterior Shading

Properly applied, overhangs and awnings can be particularly beneficial. During winter, when the sun is low in the sky, sunlight is beneficial for heating and lighting the inside of a space while the windows are not shaded. During summer, when the sun is high in the sky, overhangs or awnings keep sunlight off the window.

Figure 5: Shading Strategies



Exterior shading techniques are also an excellent way of reducing glare produced when sunlight strikes glass directly.

Awnings are popular exterior shading devices on low-rise commercial buildings. Fiberglass or metal shade screens are often cost effective for low-rise commercial applications and are capable of reducing solar heat gain up to 80 percent in comparison to unshaded clear glass. Air space between exterior shades and windows helps carry away heat absorbed by the shade before it can be transferred through the window.

Exterior roller blinds are one effective method of exterior shading. Exterior roller blinds are a series of slats, typically horizontally oriented, made of wood, steel, aluminum, or vinyl. Like interior shades, they can be raised or lowered as needed to control the amount of sunlight entering a building space. In warm temperatures during sunny hours, they can be lowered to function as an insulating barrier, limiting incoming sunlight and reducing heat gain. Similarly, they can be raised in cold temperatures during sunny hours for desirable heat gain. Partially raising the blinds allows some daylight and air to enter between the slats. Experimentation has shown that these blinds can improve the R-value of the window area from the standard 0.88 for uncovered single glass to 1.75 with a lowered blind. However, this shading technique can be expensive, and it alters the exterior appearance of a building.

When selecting shading system colors, be sure to remember that light colors are better at reflecting solar radiation. A darker awning may require venting to allow heat dissipation.

Shading With Vegetation

Finally, deciduous trees are also very effective at providing shade: During the winter they are bare, allowing sunlight to pass through, but during summer they shade the building.

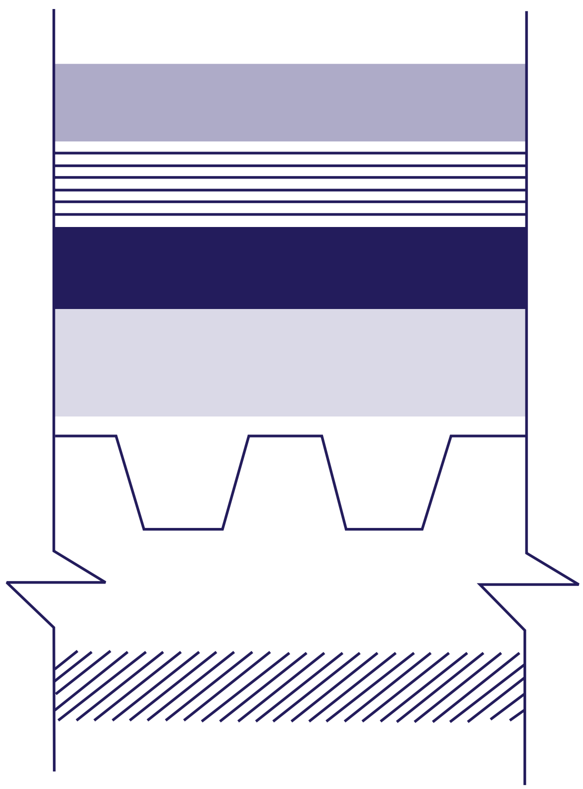
Load Reduction Strategy: Roof Insulation

A significant portion of a building's heat loss and heat gain occurs through its roof. Energy efficiency measures that slow the rate of energy transfer through the roof therefore provide opportunities for significant energy savings. The most effective means of reducing the heat transfer rate through the roof is to maximize R-value by adding thermal insulation.

In buildings undergoing roof replacement, it is always a good idea to incorporate roof insulation as part of the renovation. Rigid board insulation, typically two inches thick, can be applied to the exterior surface of the roof prior to the application of the new roof covering. This technique works well with new roof construction as well. However, it is generally not cost effective to apply insulation to the outside surface of an existing roof unless the roof itself is being replaced.

Where there is an attic or crawlspace below the roof, there are other options. Roof insulation types used in such applications include fiberglass blanket or "batt" insulation; blowing insulation, typically a spray-on urethane or fiberglass foam; or blown-in loose cellulose or fiberglass. In most cases, roof insulation for buildings withvented attic spaces is applied to the attic floor, in the form of either fiberglass batts or blown-in loose insulation.

Figure 6: Roofing Layers



For buildings with unvented attics or no attic, or in buildings where foot traffic might damage attic floor insulation, apply insulation to the inside roof surface, using either rigid board or spray-on foam insulation. Attic floor insulation is also inappropriate in the presence of any type of water pipe in the attic space. Because the insulation reduces the heat flow from the occupied spaces upward to the attic, the attic space is at a lower temperature, increasing the likelihood that your pipes may freeze and burst during the heating season.

In well-insulated buildings, the relative significance of heat loss through uninsulated structural members, particularly those made of metal, increases. This effect reduces the effectiveness of the insulation by as much as 20 percent. It is important to consider insulating these structural members (see Figure 6) as well as the building envelope components, unless, as with flat roofs, the roof insulation is on the exterior of the building.

Load Reduction Strategy: ENERGY STAR *Labeled Roof Products*

A significant portion of a building's heat loss and heat gain occurs through its roof. Energy efficiency measures that slow the rate of energy transfer through the roof therefore provide opportunities for significant energy savings. As with insulation, an effective means of reducing the heat transfer rate through the roof is to minimize the amount of heat conducted through the roof. ENERGY STAR labeled roof products use reflectivity to lower the roof surface temperature by up to 100 °F, thereby decreasing the amount of heat transferred into a building's interior.

Benefits of ENERGY STAR labeled roof products include:

- Downsized A/C equipment. A reflective roof can reduce peak cooling demand by 15%. The home or building owner may be able to purchase a smaller, less-expensive cooling system.
- Extended roof life. Roofs undergo significant expansion and contraction as they heat and cool throughout the day. Heat absorbed by the roof can also accelerate degradation by ultraviolet rays and water. A reflective roof can reduce the amount of thermal shock that occurs on the roof surface and make the roof last longer.
- Reduced Heat Island Effect. Roofs made of non-reflective products cause the temperature of the air passing over them to rise, resulting in an increase in the overall temperature of the area, also known as a "heat island effect." The elevated temperature leads to increased building and vehicle air conditioning demand, increased levels of smog, and the associated increased incidence of heat- and smog-related health problems.

Energy savings from installing ENERGY STAR labeled roof products will depend on the geographic location and climate where it is installed, existing insulation levels in the building, the type of roof it replaces, the type of roof installed, and how well it is kept clean and maintained. In general, cooling energy savings can be as high as 50%. Additionally, a reflective roof can reduce peak cooling demand by 10 to 15%. As a result, building owners may be able to purchase smaller, less expensive HVAC systems.

Additional Strategies

There are many additional strategies for reducing loads. Some are only cost effective, however, when viewed as part of the incremental costs of replacing old equipment for reasons unrelated to energy efficiency. Other technologies are emerging and may become more cost effective in the future.

Load Reduction Strategy: High-Performance Windows

Windows almost always represent the largest source of unwanted heat loss and heat gain in buildings. This is because even the best windows provide less insulation (lower R-value) than the worst walls or roofs, and because windows represent a common source of air leakage. Windows also admit solar radiation. Of course, we neither want nor need to eliminate windows.

While improvements such as films, shading, and weather-stripping have already been discussed, replacing the complete window offers some additional benefit and is economically feasible in some situations, particularly as part of an extensive renovation.

Many window or glazing systems of buildings built in the 1960s and 1970s are beginning to fail. Often, these failing systems are single-pane glass, as found in 68 percent of commercial space and 52 percent of office space in the United States. If your building has windows needing replacement, this presents an excellent opportunity to use the latest in advanced window designs, which offer paybacks in only a few years.

Here are some new technologies to look for:

- **Spectrally selective** glasses can maximize or minimize solar gain and shading depending on the product chosen.
- **New double-glazed systems** with layers of low-e film stretched across the interior air space have become available, which offer R-values as high as 8.
  - Gas filled windows, using argon or krypton gas, minimizes the convection currents within the space, conduction through the gas is reduced, and the overall transfer of heat between the inside and outside is reduced.

Architects and facility planners now have a vast selection of new window types available that not only meet stringent energy performance requirements but also satisfy aesthetic concerns.

Load Reduction Strategy: Energy Recovery Strategies

Heat recovery is one of the most beneficial ways of optimizing energy efficiency during building operations. Exhaust air from HVAC systems is a primary source of useful waste heat. During most of the year, energy is consumed to heat, cool, humidify, or dehumidify the air supply. Exchanging the energy between the outdoor air introduced into the building and the air exhausted from the building reduces the energy required to condition the outdoor air. Several heat recovery technologies are available, including rotary heat wheels, plate and frame heat exchangers, runaround coils, and heat pipes.

Each of these technologies is suited to specific applications. Consult vendors and engineers to determine the best match for your building. Depending on the application and technology type, these systems can recover 50 to 80 percent of the energy used to heat or cool ventilation air brought into the building.

Load Reduction Strategy: Desiccant Dehumidification

As new building codes require more outside air to be circulated into buildings, the amount of humidity that an air-conditioning system must remove has increased substantially. Conventional cooling systems consume more and more energy removing moisture, often overcooling the air below its dew point just to get the water out.

Recently, new desiccant-based cooling systems have emerged on the market. Desiccants are materials that absorb moisture from their surrounding space. Most people know them as small, usually white, packets found in the packaging of electronics and dried foods. Desiccant materials used in building applications can be regenerated. In other words, the moisture is driven out of them by the application of heat, whereupon they can be reused to absorb more water from the air. The heat is generally derived from gas, steam, or waste heat from the building.

The best applications for desiccant cooling systems are buildings with large dehumidification loads, long hours, and those in warm and humid climates—for example, hospitals, swimming pools, or supermarket fresh-produce areas. The cost of gas or waste heat used for regeneration is typically much lower than the cost of electricity used for conventional dehumidification.

Load Reduction Strategy: Building Integrated Photovoltaics

Photovoltaic (PV) panels generate electricity while absorbing solar radiation and reducing solar heat gain through the roof. A newly emerging Building Integrated PV (BIPV) technology is the use of PV roofing materials that can be installed much like traditional shingles or flat roof membranes, and involve little or no unusual engineering design.

Recently, buildings have incorporated PV cells mounted on clear building materials both to generate power and allow some light transmission through the panels to provide daylight to the space below. Such a system was installed at the Olympic Natatorium, built for the 1996 Olympic Games, at Georgia Institute of Technology.

With PV materials becoming available for roofs and walls, as well as other products that allow through some visible light, a large proportion of a building's exterior surface area has the potential to provide power generation of approximately 0.5 to 1 kW peak for every 10 square meters, depending on construction and orientation. In addition to reducing solar heat gain through the shell, BIPV technologies offer the advantage of providing the greatest power generation capacity coincident with the time of day when space-cooling needs are greatest.

Load Reduction Strategy: Daylighting And Light Pipes

Once the most efficient electric lighting sources are implemented, reduce lighting operating hours for additional energy savings. The use of daylight sensors is the first step toward eliminating or reducing electric lighting operation when there is enough available daylight from windows along building perimeters during occupied hours.

It is often possible to shade windows enough to reduce heat gain and glare substantially (see shading discussion above) while still providing enough daylight to eliminate electric light usage for much of the workday. Exterior light shelves can be used to reflect light onto the ceiling of the space without absorbing much solar heat. Lighting in parts of the space away from the window or light source can be increased using reflective surfaces or louvers.

What about interior building spaces, particularly those below the top floor where skylights are not feasible? Emerging and experimental technologies offer the potential to "pipe" light from roof- or wall-mounted collectors to interior spaces that do not have windows. One advantage of piping light is the potential to use either the daylight collector or a high-efficacy light source to light the whole system depending on daylight availability.

Load Reduction Strategy: Solar Windows (Chromogenic Glazings)

Research is currently under way to develop glazings that change automatically in response to changing temperature and/or light level conditions—similar, for example, to sunglasses that darken in sunlight. One technology being investigated is a treatment that turns glass cloudy as temperatures rise. Another technology uses an electrical current to alter the spectral selectivity of the glass. Strategically selected and positioned sensors thus control what the window is doing at any given time. A third effort is focusing on the embedding of thin-film amorphous PV material into glass while retaining light transmission so that the window becomes a miniature electric power plant.

None of these chromogenic technologies is commercially available at this time, but all are showing promise. In just a few years, window technology may indeed be vastly different from today's.

Summary

Other Load Reductions identifies numerous opportunities for further reducing your loads and allowing the installation of smaller, lower first-cost equipment in fan and HVAC Systems. To recap, here are your best savings opportunities:

- Ventilation Upgrades
  - Control ventilation rates to minimum requirements
  - Install air-side cooling economizer cycle
  - Install energy recovery technologies
- Equipment Upgrades
  - Use ENERGY STAR labeled office equipment
- Building Envelope Upgrades
  - Add window films and/or shading
  - Upgrade roof insulation

Next Steps

- Assess your load sources to determine where loads can be reduced.
- Implement upgrades to reduce loads and allow the installation of smaller equipment in fan and HVAC systems.
- If possible, delay the installation of HVAC equipment until all loads can be reduced and the impacts on HVAC systems can be measured directly.

Appendix: History Of Ventilation Requirements

Building codes require minimum ventilation rates. Code requirements have changed significantly over the years in response to the impact of outside air quantities on energy consumption, occupant comfort and health.

The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) has updated its recommended ventilation rates periodically. Prior to 1973, ASHRAE recommended a standard of 15 to 25 cubic feet per minute (cfm) of outside air per person. After the oil crisis of the mid-1970s, a new awareness of the energy costs for treating outside air led to ASHRAE Standard 62-1981.

ASHRAE Standard 62-1981 defined ventilation air requirements and allowable contaminant levels. Striking a compromise between indoor air quality concerns and energy consumption concerns, Standard 62-1981 recommended a minimum of 5 cfm of outside air per person in a nonsmoking environment and 20 to 35 cfm of outside air per person in a smoking environment. At times, the reduction in outside air requirements for nonsmoking spaces led to an increase in indoor air quality complaints. ASHRAE Ventilation Standard 62-1989 required at least 15 cfm of outside air per person (and more for many types of spaces) and a maximum CO_2 concentration of 1,000 ppm.

Partly because of lower ventilation rates set in ASHRAE Standard 62-1981, complaints of discomfort and poor health, phenomena now referred to as Sick Building Syndrome and Building Related Illnesses, increased. This led ASHRAE to raise its ventilation requirements closer to its previous levels. Depending on space use, ASHRAE Standard 62-1989 requires minimum outside ventilation rates of 15 to 25 cfm per occupant. The new standard defines acceptable air quality as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities . . ." Since the 1989 publication of the Standard, several cognizant authorities have determined that tobacco smoke is harmful to human health. These authorities include, among others, the U.S. Environmental Protection Agency, World Health Organization, American Medical Association, American Lung Association, National Institutes of Occupational Safety and Health Administration, and the Office of the U.S. Surgeon General, while smoking lounges still require 60 cfm of outside air per occupant.

The current ASHRAE Ventilation Standard 62-1999 requires at least 15 cfm of outside air per person (and more for many types of spaces) and modifies the criteria for maximum CO_2 concentration to 700 ppm above the outdoor air concentration. In addition, language has been added more clearly describing the CO_2 concentrations as a useful indicator of the concentration of human bioeffluents. Finally, Standard 62-1999 removes references that the ventilation rates (in Table 2 of the Standard) will accommodate a moderate amount of smoking. Please see Standard 62-1999 for further details regarding smoking and ventilation. (Table 1 summarizes the history of ventilation requirements.)

Table 1: Historical Outside Air Requirements

Outside air per person	*cfm*
Industry Standard 1973	15–25
ASHRAE Standard 62-1981	> 5
ASHRAE Standard 62-1989	> 15
ASHRAE Standard 62-1999	>15

With the increased use of chemical-based products, building materials, and furnishings that contribute to indoor pollution, health and comfort complaints, ASHRAE has concurrently tried to address contaminants not produced by occupants in its ventilation requirements. The current Standard 62-1999 allows the user to establish ventilation requirements based on a separate procedure that analyzes specific contaminants.

Fan System Upgrades

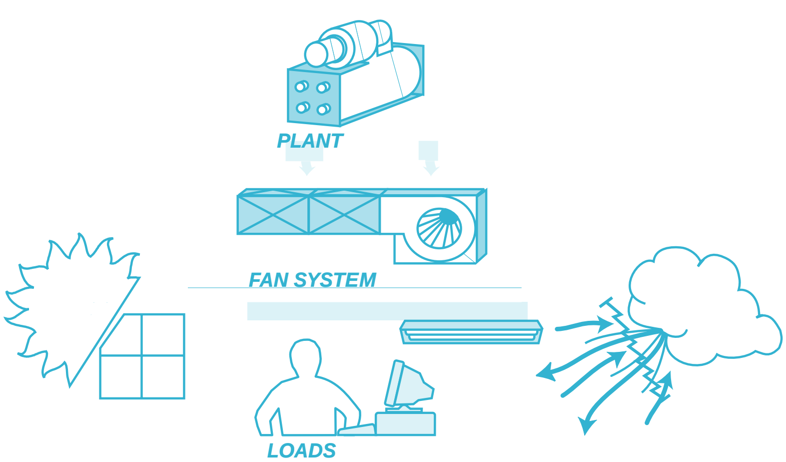
Overview

Fan Systems, also know as air-handling systems, are the conduit for getting conditioned air (heating and cooling) to people occupying a building, and therefore directly impacting occupant comfort. Fan systems can be upgraded and adjusted to optimize the delivery of air in the most energy efficient way.

The heat flow diagram (Figure 1) illustrates how, in Fan System Upgrades, you can take advantage of the load reductions you have realized in other stages of an integrated approach. The resultant opportunities for reducing your air-handling system's energy consumption are now tremendous. Continuing with the integrated approach, you can realize a 50 to 85 percent reduction in fan power consumption.

Fan System Upgrades section will help you identify which components of your fan systems are most inefficient. "Best Ways to Save" and "Take Action", will provide you with checklists for improving the operation of fan systems. "Best Opportunities" and "Additional Considerations" discuss the opportunities for improving energy performance of your fan systems through technology as well as operations. The appendix Fan System Survey provides instructions for recording the loads associated with your fan system.

Figure 1: Heat Flow In Buildings



Heat Flow In Buildings: Building Systems Interactions

Figure 2 shows the interaction of heating, cooling, and electrical loads with the HVAC equipment. Arrows indicate heat flow pathways. Reducing heating, cooling, and electrical loads reduces the demand on HVAC equipment, thus saving energy.

Fan Systems Strategy

- Rightsize your cooling system to match reduced loads.
- Take advantage of improvements in air-handling technology.
- Install equipment that allows for more efficient operation, lower first cost, and lower maintenance costs.

The Best Ways To Save

- Fan system rightsizing
- Variable-speed drives
- Improved controls
- Energy-efficient motors
- Energy-efficient belts

If you are already planning to purchase replacement equipment, installing smaller components is less costly than replacing with larger equipment.

Potential Savings

Potential energy savings from rightsizing, energy-efficient motors, and variable speed drives: 50–85%

Source: *Variable Air Volume Systems: Maximize Energy Efficiency and Profits*, EPA 430-R-95-002.

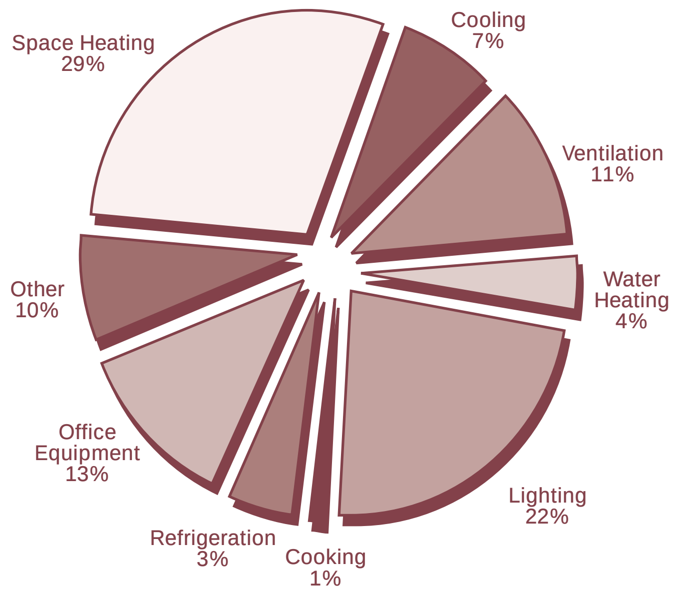
An Easy Target

The fans that move the heated and cooled air through your building constitute eleven percent of the total energy consumed by your facility, as shown in Figure 2. Any reductions in their consumption can result in significant savings for you. A recent EPA study found that almost 60 percent of building fan systems were oversized by at least 10 percent, with an average oversizing of 60 percent. By rightsizing, you can save an average of 50 percent in fan system energy. Moreover, these savings are independent of any other improvements, such as installing energy-efficient motors.

Take Action!

1. Use the Fan System Survey at the end of this chapter to determine the operating characteristics of your current fan system.
2. Enter survey data into a fan system software package to estimate potential savings and economic benefits.
3. Upgrade your fan system and begin saving money and energy, immediately.

Figure 2: Typical Electrical Energy Consumption



Source: U.S. Department of Energy, Energy Information Administration, Energy End Use Intensities in Commercial Buildings, Sept. 1994. DOE/EIA-05555(94)/2.

Air-Handling Components

The major components in an air-handling system (AHS) are fans, coils, ducts, and dampers. These components must function well individually and together in order to ensure efficient operation as well as occupant comfort.

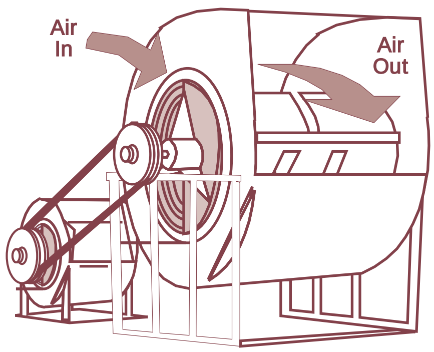
Each component performs a task critical to the proper operation of your system. Fans circulate the air and provide the pressure required to push it through ducts and across heating and /or cooling coils. Ducts convey the conditioned air throughout your building, distributing the air from the AHS to occupants and then returning it to the AHS to be conditioned and circulated again. Dampers control the flow and mix of returned and outside air through the ducts to the various parts of the building.

Fans

Fans are the heart of your building's air-handling system. Like a heart that pumps blood through a body, they distribute throughout the building the conditioned (heated or cooled) air, that your occupants need. There are two main types of fans, centrifugal and axial.

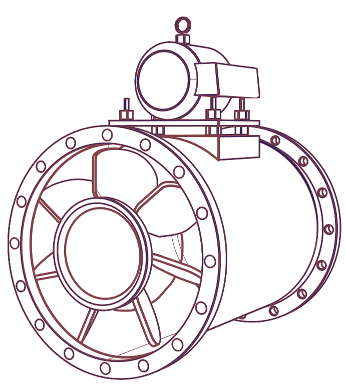
Centrifugal fans (see Figure 3) are by far the most prevalent type of fan used in the HVAC industry today. They are usually cheaper than axial fans and simpler in construction, but generally do not achieve the same efficiency. Centrifugal fans consist of a rotating wheel, or impeller, mounted eccentrically inside a round housing. The impeller is electrically driven by a motor, which is usually connected via a belt drive.

Figure 3: Centrifugal Fan



Axial fans (see Figure 4) consist of a cylindrical housing with the impeller mounted inside along the axis of the housing. In an axial fan, the impeller consists of blades mounted around a central hub similar to an airplane propeller. As with an airplane, the spinning blades force the air through the fan. Typically, axial fans are more efficient than centrifugal fans.

Figure 4: Axial Fan



Axial fan motors can be mounted externally as on a centrifugal fan. They can also be belt driven. However, they are often driven by a motor directly coupled to the impeller mounted within the central hub.

Ducts

Like the arteries and veins in your body, ducts convey the conditioned air from the air handling unit out through the building and return it back to be conditioned again. They are usually constructed of sheet metal, and are insulated.

Ductwork can either be round or rectangular. Rectangular duct is cheaper and more common than round duct, as it is generally easier to route, design, and install. Round duct, on the other hand, uses much less material, as it is the most efficient shape for a given cross-sectional area. It is also naturally stiffer than a rectangular duct having the same cross-sectional area. Round duct also creates less resistance as the air moves through it, reducing fan power requirements.

Duct insulation helps prevent the warming of your chilled air and the cooling of your heated air as it passes through the ducts. Ducts must be properly insulated to prevent excessive energy loss. Commercial building codes typically require 1 inch of insulation for ducts carrying hot or cold air. This requirement varies by jurisdiction, please consult your local energy and / or mechanical codes. Proper choice of insulation can also help reduce the transmission of fan and motor noise from your HVAC system to the working spaces inside your building.

Dampers

Dampers serve to modulate the flow of air through the ducts to the various parts of the building, reducing or increasing the flow of air depending upon conditions. Dampers also serve to regulate the quantities of outside air allowed to enter the air handling unit and mix with return air for ventilation purposes. Dampers can be difficult to maintain and can affect occupant comfort as the space requirements change and as the air-handling system ages.

Air-Handling System Types

Depending on the age and design requirements of your building, you might have one or more of the following systems:

- Constant volume systems
  - Reheat system
  - Dual-duct system
  - Multizone system
- VAV systems

Compared to older systems, current air-handling systems offer much more efficient designs than may have originally been installed in your building. Today's VAV systems can handle changing load requirements by varying the amount of air circulated, as well as regulating the amount of cooled or heated air, to more accurately tailor energy consumption to the actual climate control needs of the building's occupants.

Constant Volume Systems

Constant volume, also referred to as constant air volume, systems are installed in a large number of buildings. The simplest of all the systems discussed, they circulate a constant volume of conditioned air.

Reheat Systems

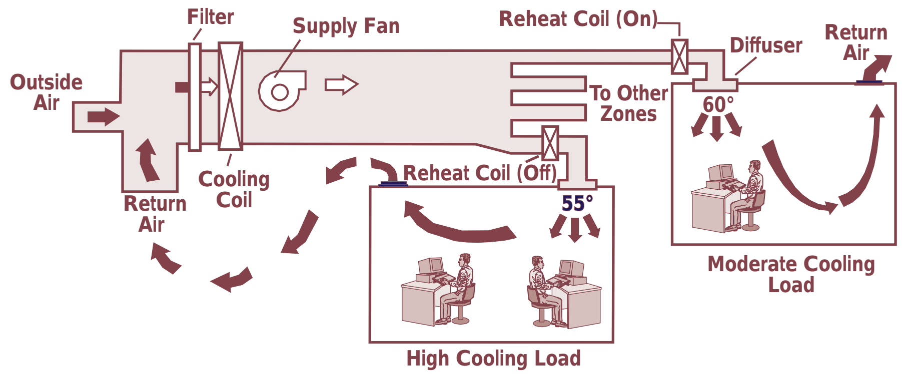
In a reheat system, a constant amount of air is cooled and recirculated (see Figure 5). This amount of air is designed to be able to cool all parts of the building at peak cooling load. To cool at lighter loads or to heat the building, the circulated air, *which is still being cooled*, is reheated before being distributed to the various zones.

Reheat systems are very inefficient because the same air is being cooled and then reheated before it even reaches building occupants.

Dual-Duct Systems

Often found in buildings constructed during the 1960s and 1970s, dual-duct systems are a relatively effective means of maintaining comfort, yet an extremely inefficient method of conditioning air.

Figure 5: Constant Volume System With Reheat



In this example, the room with the moderate cooling load is reheating its air from 55° to 60° F.

Dual-duct systems consist of two independent systems, one warm and one cool, which circulate air in parallel sets of ducts through all sections of the building. Hot and cold air are mixed in local mixing boxes in each zone or room and then fed into that area. Depending on the temperature needs of the area, the mixture of hot and cold air is adjusted until the desired temperature is reached. Unfortunately, with a dual-duct system, you must pay to cool, heat, and circulate a volume of air that is typically much larger than the actual volume required by your building.

Multizone Systems

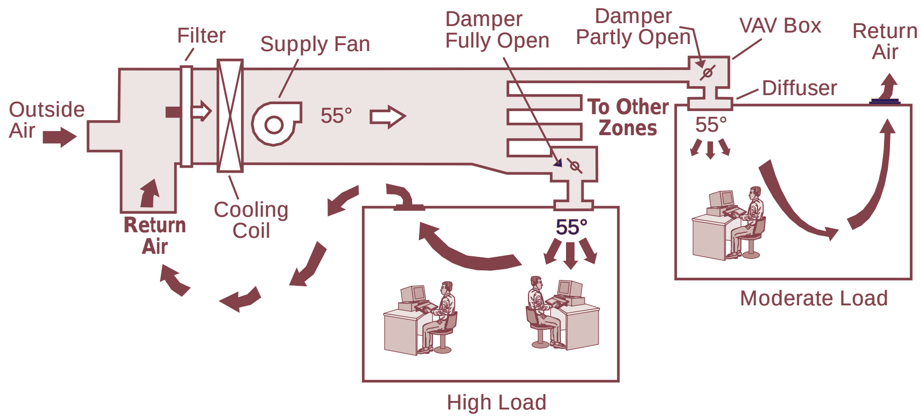
Multizone systems are similar to dual-duct systems in that two streams of hot and cold air are mixed to produce a desired temperature. But, whereas dual-duct systems mix the air in individual boxes located at each area or room, multizone systems mix air in large mixing boxes near the fans. This conditioned air is then fed to each zone, with each zone, depending on its load, receiving air at a different temperature. As with dual-duct and reheat systems, multizone systems are quite inefficient because you must pay to heat and cool air simultaneously.

Variable Air Volume Systems

VAV systems vary the amount of circulated air in response to varying heating or cooling loads. This reduces fan power requirements, which saves energy and costs.

VAV systems work either by opening or closing dampers or by modulating the airflow through VAV fan-powered mixing boxes as loads in various zones of the building change (see Figure 6). If, for example, more cooling in an area is required, the damper to that area is opened wider, increasing the flow of cold air until the desired temperature is reached. Conversely in this same example, if an area is too cool, the damper is slowly closed, reducing the flow of cold air. Used in combination with VSDs, this reduction in flow results in a reduction in the fan power needed, saving energy. Because retrofitting an existing constant volume system to a VAV system allows your system to turn itself down in response to changing demand, it is a popular option for many building owners. Proper conversions to VAV systems include the removal of constant volume dampers and typically reduce fan horsepower requirements by 40 to 60 percent.

Figure 6: VAV System



In a VAV system, dampers control the flow of chilled air to respond to changes in cooling load.

Thermally Powered VAVs

Thermally powered VAV systems, like standard VAV systems, regulate the volume of air that a space (usually a room) receives based upon its temperature.

Thermally powered VAVs are ceiling-mounted diffusers, each with its own damper, that replace standard diffusers. With an internal "thermostat" and a small damper, they enhance the process of reducing airflow to a certain conditioned space when its temperature is below the setpoint and increasing airflow when the temperature in that space is too warm. In addition, thermally powered VAVs are now being produced with individual controls, a feature that provides a level of control comparable to that of a standard VAV system.

Thermally powered VAV systems also:

- Provide more comfort at less cost.
- Are a viable alternative to VAV fan-powered mixing boxes in terms of costs, benefits, and lessened disruption during retrofit construction.

Best Opportunities

Comparison: VAV Systems Vs. Constant Volume Systems

The conversion of your older constant volume reheat, multizone, or dual-duct system to a modern, energy-efficient variable air volume system is a task to be undertaken with serious consideration and expert analysis. This would normally require the services of an engineering firm.

As discussed earlier, VAV systems are more energy-efficient than constant volume systems as VAV systems can reduce airflow in response to decreasing demand. You are also cooling only the amount of air that is required to meet demand, rather than meeting demand by simultaneously heating and cooling large volumes of air.

Are Your Fans Oversized?

If your fans are oversized, fan rightsizing can be profitable. It can be implemented separately or in combination with energy-efficient motors and VSDs. In general, rightsizing with an energy-efficient motor, energy-efficient belts, and a VSD is the best alternative.

Advantages Of A Rightsized System

A rightsized system saves you energy costs; however, there are other advantages to a rightsized system that you might not have thought of:

- *Lower First Costs*

  As the capacity required from your fan system is reduced, your system can be more accurately tailored to the new air flow requirements. By installing smaller, more energy-efficient equipment that meets these requirements, first costs are also reduced.

- *Comfort*

  If your fan system supplies too much air to your occupants, not only are you wasting energy, but you could also be affecting their comfort. Too much air can result in disturbing drafts, increased humidity, and noise.

- *Equipment Life*

  Prolonged operation of an oversized motor with a VSD at very low speeds can reduce the useful life of motors and other equipment. Properly sized, smaller capacity equipment will be more suited to operation at reduced capacities.

Rightsizing Your Fan System

When rightsizing your fan system, the type of system in use—constant volume or VAV—will slightly affect the methods you use.

Regardless of whether you have a constant volume system or a VAV system, when reducing your fan airflows, make sure that you maintain the proper amount of outside air to ensure occupant health and comfort (see Stage Three—Other Load Reductions, Load Sources). Consult your local building codes for information about required outside air quantities.

VAV Systems

While VAV systems are more energy-efficient than constant volume systems, the potential for rightsizing may still exist. Your building engineer may be able to determine if your VAV fans are oversized by using one of three methods: measuring the fan motor current draw (amperage), checking the fan control vanes and dampers, or measuring fan system static pressure.

Measuring Amperage

1. Measure the fan motor amperage. For a VAV system, measure the amperage when your cooling system is operating under a peak load (a hot, humid day, for example).
2. Read the full-load amperage off the motor's nameplate or from the Operations & Maintenance manual.
3. Compare these two numbers. If the measured amperage is lower than 75 percent of the full-load amperage, the motor is oversized.

Checking Vanes and Dampers – Check the position of the fan control vanes or dampers when the cooling system is operating under a peak load (a hot, humid day, for example). If the vanes or dampers are closed more than 20 percent, the fan is oversized.

Measuring Static Pressure

1. Measure the static pressure of the main supply fan system on a hot, humid day. Make sure that all fan vanes and dampers are fully open, and that all VAV boxes are fully open.
2. Compare your static pressure reading with the static pressure setpoint. If the static pressure reading is less than the setpoint and the space in your building is sufficiently comfortable, the setpoint can be adjusted to the lower static pressure.

Constant Volume Systems – If it is not economically feasible to replace your constant volume system with a VAV, rightsizing your constant volume system is generally a profitable choice. However, in determining the potential for rightsizing, your building's engineer is typically limited to just one method—measuring fan system static pressure.

Measuring Static Pressure

1. Measure the main supply fan system static pressure on a hot, humid day. Make sure that all fan vanes and dampers are 100-percent open.
2. If the measured static pressure is greater than the design pressure (found in your building's mechanical drawings), your fan is probably supplying too much air and is a good candidate for rightsizing.

Three Ways To Rightsize – If you have assessed that your VAV or constant volume system is oversized, you can now rightsize it to match your building's actual flow requirements. Rightsizing your fan system can be accomplished by installing larger pulleys (sheaves), adjusting static pressure, and/or replacing the fan's motor with a smaller, energy-efficient motor.

- *Smaller, Energy-Efficient Motors*

  Once you have rightsized the fan flow rate, your existing motor is probably too big for the brake horsepower required. Replace the existing, oversized motor with a smaller, energy-efficient motor that matches the load. For example, rightsizing a 75-hp standard efficiency motor to a 50-hp energy-efficient motor will reduce your motor energy consumption by about 33 percent.

- *Larger Pulleys*

  Replacing an existing belt-driven pulley with a larger one will reduce its speed, saving energy costs. Reducing a fan's speed by 20 percent reduces its energy consumption by 50 percent.

  Note: The new pulley should operate the fan at a reduced speed that matches peak load requirements.

- *Static Pressure Adjustment (VAV Systems Only)*

  Reducing static pressure in your VAV system reduces the fan horsepower consumption. By gradually reducing the static pressure setpoint to a level low enough to keep occupants comfortable, you will reduce energy consumption.

Example: VAV System Static Pressure Reduction

A VAV fan system currently operating at a static pressure of 6 inches of water (gauge) is found to operate satisfactorily at 4 inches. This 33 percent reduction in static pressure with its accompanying reduction in flow will result in an energy savings of approximately 45 percent.

Estimating Potential Savings

You can estimate the expected benefits of rightsizing by collecting data listed in the Fan Survey (see Appendix) and calculating savings from right-sizing your fan systems using a commercially available fan analysis software program.

Project Management Considerations

The first consideration in rightsizing your fan system is to determine which components will be involved in the process. You have the choice of replacing pulleys, adjusting static pressure, installing smaller energy-efficient motors, or a combination of these.

Note: Changes to one of these components will affect the others! Be sure to perform an analysis of the options and their effects on the system before proceeding to ensure an effective reduction.

The engineer verifying the rightsizing potential will need the information you collected in the Fan Survey, as well as the types and efficiencies of the air-handling units, fans, and pulleys in your building.

If your company does not have a qualified engineer on staff, hire a consulting engineering firm to verify your choices.

Once the potential for rightsizing is verified, qualified personnel should implement the changes—a controls technician should adjust static pressure, an electrician should replace motors and drives, and HVAC technicians should replace fan pulleys and belts.

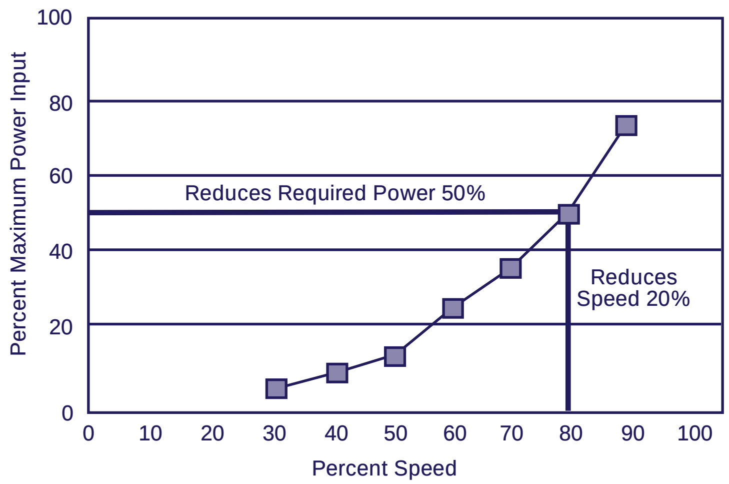
Variable-Speed Drives

Variable-speed drives (VSDs) are an efficient and economical retrofit option and should be considered for all VAV systems. VSDs allow the motor speed of your equipment to vary depending on actual operating conditions, rather than operating at one speed. Varying the speed of your fans allows them to match more closely the actual load required. As indicated in Figure 7, reducing a fan's speed by 20 percent can reduce its energy requirements by nearly 50 percent. Installing a VSD on your fan motor allows the fan to automatically match this reduced capacity, slowing down in response to reduced demand, thereby saving energy.

A VSD is not actually a motor, but rather an electronic device that varies the frequency of the electricity to the motor. It is installed "upstream" of the motor, between the transformer and the motor.

A recent EPA study (*Variable Air Volume Systems Maximize Energy Efficiency and Profits*, EPA 430-R-95-002) showed that VSDs can greatly reduce the energy used by the same fan operating under similar airflow volumes and static pressure conditions. Overall, the study indicated that VSDs provided an average energy savings of 52 percent.

Figure 7: VSDs Reduce Maximum Power Input



Source: Electric Power Research Institute.

VSDs make economic sense when installed on motors that operate many hours per year at fluctuating loads, and especially on larger motors.

Table 1: VSDs: Installed Cost For Various Size Motors

hp	*Installed Cost*
5	$2,975
7.5	$3,400
10	$3,575
15	$4,225
20	$4,925
30	$7,225
40	$8,625
50	$11,100
60	$13,200
75	$17,700
100	$19,400

Source: Adapted from R.S. Means, *Electrical Cost Data*—1997 Edition.

Controls

Modifying the *way* your system operates, not just the system itself or its components, can also save energy. By taking advantage of such concepts as economizer cooling and night precooling, you can significantly reduce your cooling costs.

Optimized Scheduling

An optimum start and stop procedure for your system is a common-sense control philosophy that can result in significant energy savings. Normally, your system is set to automatically turn itself on and off based upon the expected occupant working hours.

For example, your cooling might come on at 6 A.M. and shut off at 7 P.M. Adjusting these times for varying seasons will reduce your energy costs. In the spring and fall seasons, where cooling is required but the peak temperatures are typically lower than the summer temperatures, you can set your system to come on later in the morning and shut off earlier in the day. Of course, you can also shut down your system on weekends.

Pressure Reset

If you have installed a VSD on your fan system, pressure reset is a method by which you can increase your system's energy savings. Pressure and flow are related. Reducing pressure supplied by your fans also reduces the flow supplied, in turn reducing the power required. By reducing the duct pressure level when less air is required, instantaneous fan energy savings of 50 percent can be achieved above and beyond the application of a VSD. The desired setpoint can be found by gradually reducing the fan speed each day until the pressure is as low as possible, but occupant space is still comfortable. It is possible to have two or more pressure settings; for example, one for daytime and one for evening or one for summer and one for winter.

Case Study: Economizer Cooling

The majority of conventional air-handling units are enabled to provide 100-percent outside air. However, at one 200,000-sf office building in a Boston suburb, it was noticed that air conditioning compressors in the rooftop units operated on sunny days even when outside air temperature was as low as 35° F. The reason was that solar-heated interior air had no way to escape from the building, so that the rooftop units, even with outside air dampers wide open, could not provide enough outside air to cool the building without mechanical refrigeration.

The solution was found by installing power exhausts in the rooftop units, which exhausted all indoor air outside when the building was in economizer cooling mode. Roughly 1,000 hours per year were found to have proper conditions for free cooling. After installation of the power exhausts, cooling compressors only operated when outside air temperature was above 55° F. The installation cost $75,000 and paid for itself in under 4 years.

Economizer Cooling

As discussed in Other Load Reductions, air-side economizers consist of a set of dampers, filters, and sometimes a fan on the supply air side of the air-handling system. The damper is controlled so that when outside air is cooler than return air, the outside-air damper opens, allowing the outside air to be drawn into the building. When it is hotter and more humid outside than the return air, the economizer damper closes to its minimum setting, which is the minimum amount of fresh air required according to ASHRAE standards (see Stage Three, Load Sources).

Demand Ventilation

Standard ventilation specifications are based on a certain volume of outside air in cubic feet per minute (cfm). ASHRAE 62-1999 specifies a minimum of 15 cfm per occupant. T1his ventilation level, however, should be understood as an average value to be applied to a whole building. In other words, if your building holds 3,000 people, your air-handling system should provide 15 cfm/person x 3,000 people = 45,000 cfm of outside air. This assumes that the occupants of your building are also equally distributed.

In some areas, such as cafeterias, auditoriums, conference rooms, and gymnasiums, the area could be empty during some portions of the day but full at others to the point that indoor air quality would suffer. For example, in a cafeteria at lunchtime, the air-handling system might not supply enough outside air to meet demand; conversely, for most of the day, the air-handling system is supplying outside air to an area with no people.

The solution to this problem is demand ventilation. By only supplying outside air when and where it is needed, you can ensure proper air quality while not wasting energy supplying the area with outside air during other parts of the day. A popular way to do this is by monitoring the concentration of CO_2 in the area. As mentioned before, CO_2 concentration is a good indicator of an area's population. As more people exhale, the concentration of CO_2 increases. By controlling the quantity of outside air based on a CO_2 setpoint, you can ventilate an area on a demand basis. When CO_2 concentration rises, dampers are opened and more outside air is allowed to flow into the area until the concentration decreases to acceptable levels. Keep in mind that CO_2 concentration rates do not indicate the levels of other potential VOCs contained within the space and that additional ventilation may be required in order to satisfy the acceptable indoor air quality requirements (consult your local building codes for proper ventilation rates).

Energy-Efficient Motors

Depending on their size, typical electrical motors are 75 percent to 95 percent efficient, with larger motors being more efficient than smaller ones. The remaining 5 percent to 25 percent of the wasted power is lost as heat to the surrounding area.

Energy-efficient motors are designed to convert a greater amount of electrical energy into useful work. After completing the other stages, you will have reduced the heating and cooling loads in your building, allowing for the installation of smaller motors that better match the reduced power requirements. By installing motors that are smaller *and* more efficient, you can save further energy costs.

Table 2: Comparison Of Standard Efficiency Motors And Energy-Efficient Motors

(1,800 RPM Totally Enclosed Fan-Cooled Motor)

hp	*Standard-Efficiency Motor*	*Energy-Efficient Motor*
5	83.3	90.2
7.5	85.2	91.7
10	86.0	91.7
15	86.3	93.0
20	88.3	93.6
30	89.5	94.5
40	90.3	94.5
50	91.0	95.0
60	91.7	95.4
75	91.6	95.4
100	92.1	95.4

Note: Older standard-efficiency models have even lower efficiencies than those shown in this table.

Source: Adapted from California Energy Commission, Washington State Energy Office, U.S. Department of Energy, and E Source, *Space Cooling Technology Atlas.*

Economic Benefits

The savings realized by installing energy-efficient motors can be particularly attractive for equipment motors that run most or all of the day and have a higher capacity, such as a fan motor.

Energy-efficient motors achieve their efficiencies from improved internals (windings, stators, etc.). Higher efficiency means less waste heat is generated. While excessive heat shortens motor life over time, less heat prolongs lubricant life. Also, the higher thermal mass of energy-efficient motors allows them to tolerate heat better than standard motors. Altogether, energy-efficient motors generally last longer and require less maintenance than standard motors.

Considerations

Repair (Rewind) Vs. Replacement

Occasionally, like any type of equipment under constant use, motors fail. When they do, many people make the assumption that they should replace the unit immediately rather than repair it. Although it is generally more economical to replace, rather than repair, a failed motor, this is not always the case. Rewinding a failed motor can be more cost effective if one or more of the following situations applies:

- The motor is larger than 125 hp.
- The motor operates less than 2,000 hours per year.
- The failed motor is an energy-efficient motor.

Premium Efficiency Vs. High Efficiency

Many motor manufacturers have three lines of motors—standard efficiency, high efficiency, and premium efficiency. Adding to the confusion, many other manufacturers offer just two lines of motors, calling their standard efficiency motors "high efficiency" and their energy-efficient motors "premium efficiency." Understanding this practice will help you choose the combination of motor efficiency and cost that best suits your specific needs.

Shaft Alignment

In typical fan system configurations, the motor and the fan each have shafts, which are connected with a belt or belts and two pulleys. If the pulley faces are not square with each other, then the belt and shafts are not in alignment. Improperly aligned shafts can not only result in poor efficiency and higher operating costs, but also can lead to premature failure and increased maintenance costs. Whenever you replace or rewind a motor, be sure to pay close attention to the shaft alignment.

Energy-Efficient Belt Drives

Belts are often used to transfer power from the motor to the fan system being driven. Standard V-belt drives can be found in the majority of belt applications. They are the lowest cost option of the belt family. The tradeoff, as usual, is reduced energy efficiency.

- V-belts, when new, can typically achieve efficiencies in the 90 to 95 percent range. A worn belt, however, can considerably reduce the efficiency by slippage caused by slackening and worn grip surfaces.
- Cogged V-belts are similar to standard V-belts, except that the normally flat underside has longitudinal grooves in it, allowing better grip and less slip than standard V-belts. They typically offer a 2 percent to 5 percent efficiency bonus.
- Synchronous belts combine toothed belts with grooved pulleys, minimizing slip and improving efficiency to a range of 97 percent to 99 percent.

Economic Benefits

Drive belts should be a standard replacement part in your building's maintenance program, requiring replacement every few months. Energy-efficient belts can easily be incorporated into your standard maintenance program, and the savings generated greatly outweigh the slight increase in cost per belt.

Additional Considerations

Ventilation Requirements

As discussed in Other Load Reductions, building codes based on standards set by ASHRAE dictate minimum ventilation rates. Code-mandated rates have changed significantly over the years in response to events and new understanding about the impact of outside air, energy consumption, and occupant comfort.

Testing, Adjusting, and Balancing Firms

One issue to consider: After implementing some of the modifications outlined, your HVAC system will most likely exhibit different operating characteristics than before. Normally, the engineer or contractor who performed the work will be responsible for what is called the testing, adjusting, and balancing, or TAB, of the modified or new system. TAB involves analyzing the various flows of air, chilled water, hot water, steam, etc., and ensuring that distribution of heating and cooling throughout the building meets the required specifications as outlined in the contract documents. Recent developments in the building heating and cooling industry have led to the introduction of independent TAB firms. Under contract to the building manager, they serve as a third party to ensure accuracy of the TAB measurements and are worth retaining if further oversight is desired.

Upgrading Of Fan System
JC Penney
Atlanta, GA

The air distribution for one of JC Penney's 155,000-sf stores was provided by five air-handling units located in a penthouse equipment room. Two return fans, also located in the penthouse, vented air from the first and second floors through ductwork and back to the air-handling units. The air-handling units supplied conditioned air through ductwork to diffusers throughout the building. The fans operated at two speeds, high and low, each manually controlled with selector switches as well as on-off automatic-function switches. The fans usually operated at the high-speed setting, although they were cycled occasionally to conserve electricity. In an effort to reduce energy consumption, tests were conducted to determine the airflow from each of the fans while operating at high speed. Data collected indicated that the actual airflow for each air-handling unit was less than the design airflow; therefore the fans were larger than necessary for this facility. The testing also revealed that an accumulation of dirt on the cooling coils in air-handling units 1 and 2 was restricting air flow and wasting fan energy. The QuikFan software developed by EPA was used to estimate the energy savings potential of the various Stage Four upgrade options. Measurements of each fan motor indicated that the maximum load was less than the horsepower rating.

Another potential energy saver was minimization of the outside air brought into the building for ventilation. This air had to be heated or cooled, which required energy. By monitoring carbon dioxide levels in the building it was felt that the air intake could be safely reduced to the minimum quantity necessary.

JC Penney decided to install variable-speed drives on the supply-air and return-air fans in the building to bring the fan capacity nearer the actual load and to install carbon dioxide sensors that would enable the system to minimize the intake of air. The large open areas in the store made it impractical to install variable air volume boxes that control the speed of the fan motors with pressure sensors. Space thermostats were therefore used to regulate fan speeds directly. Before installation of the variable-speed drives, the fans cycled on at maximum electrical consumption and then cycled off regularly. The variable-speed drives eliminated this inefficient constant cycling. Peak power use was therefore less than the maximum, with projected electric demand savings of 36 kW per month.

The total cost of installation of the variable-speed drives and the carbon dioxide sensors was $17,000, which is projected to save 138,833 kWh of electricity at an annual savings of $9,726. The payback for this upgrade of the fan system is 1.75 years, and the internal rate of return is 56.6 percent. JC Penney was therefore able to realize substantial annual savings with a relatively low investment, and the savings continue year after year.

Summary

Fan Systems illustrates the many options that are available to you to save on your building's energy costs. To recap:

- Measure your loads.
- Rightsize your fan system to match actual loads.
- Install rightsized, energy-efficient motors where possible.
- Install VSDs where practical.
- Install energy-efficient belts.
- Investigate options available for improving the control of your fan system.

Next Steps

1. Using the Fan System Survey provided in the Appendix, record information on your various fan systems and measure your loads.
2. Enter this data into a commercial fan sizing software program to estimate what you could save.
3. Using a qualified engineering firm, perform a more detailed assessment of your system to investigate further savings.

Fan System Survey										
Facility Name								Date		
Fan System Information					Motor Information			Operational Information		
Name (ID)	Fan System Type	Operati-ng Schedule	Fan Flow Control	System Duty Cycle	Nameplate Horsepow-er	Efficiency %	Horsepower @ 100% cfm	Installed Capacity	Coil Load @ Peak (tons)	Fan Flow @ Peak (cfm)

HEATING AND COOLING SYSTEM UPGRADES

Overview

Heating and cooling systems are the largest single consumers of energy in buildings. These systems condition the air within a building so that occupants are comfortable. Heating and cooling systems consist mainly of chillers, boilers, cooling towers, and pumps. There are central heating and cooling systems, and unitary systems that combine heating and cooling. Opportunities exist for improvement to both central and unitary systems.

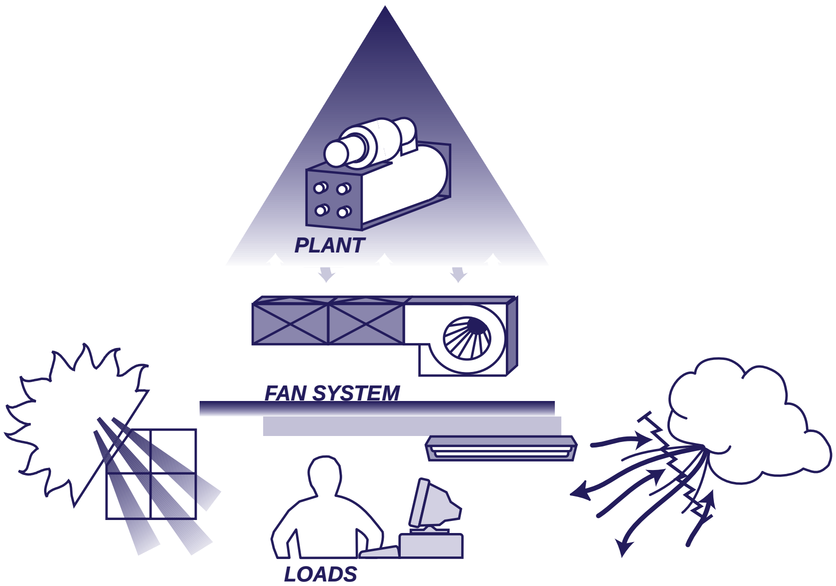
The heat flow diagram (Figure 1) illustrates how, you can capitalize on the heating, cooling, and electrical load reductions you have realized through your upgrades in the other stages of an integrated approach. The cumulative effect of these various load reductions now allows you to install heating and cooling systems that are both more energy efficient and properly sized to accommodate appropriate loads.

Heating and Cooling System Upgrades chapter will help you identify the opportunities for improving the performance of your heating and cooling system based on the type of system that you have in place. "Best Ways to Save" and "Take Action" provide checklists for cooling and heating upgrade opportunities and benefits. The Heating and Cooling Survey Appendix will assist you with evaluating the current condition of your systems and opportunities for improvement.

Heating and Cooling System Strategy

- Measure your heating and cooling loads.
- Rightsize your heating and cooling systems.
- Replace your chillers with new, more energy-efficient, non-chlorofluorocarbon (CFC) models.
- Upgrade your heating and cooling system components.
- Install variable-speed drives (VSDs) on your pumps and cooling tower fans.
- Optimize operation of your heating and cooling systems.

Figure 1: Heat Flow In Buildings



Heat Flow In Buildings: Building Systems Interactions

Figure 2 shows the interaction of heating, cooling, and electrical loads with the HVAC equipment. Arrows indicate heat flow pathways. Reducing heating, cooling, and electrical loads reduces the demand on HVAC equipment, thus saving energy.

The Best Ways To Save

- Cooling System Upgrades
  - – High Efficiency Components
  - – Cooling Tower Improvements
  - – Free Cooling
  - – VSD Pumping
  - – Controls
- Heating System Upgrades
  - – High Efficiency Components
  - – Controls

Table 1: Potential Cooling and Heating Energy Savings

System	*Typical Savings*
Cooling	
Central Chiller	15–35%
Unitary A/C	20–35%
Heating	
Boiler	10–30%
Furnace	5–25%

Adapted from: E SOURCE, *Space Cooling Technology Atlas* and E SOURCE, *Space Heating Technology Atlas*.

Use An Integrated System Approach

The conventional approach to upgrading a heating and cooling system is to address each component of the system individually. However, addressing the interaction between the components using an **integrated system approach** ultimately results in a more energy-efficient system. In addition, compared with assessing components individually, assessing upgrade opportunities for whole systems consumes less time, and therefore less money, in the long term. Heating and cooling system components, particularly in central systems, interact with each other extensively. For example, chillers operate more efficiently if they receive cooler condenser water. However, the cooling tower fans consume more energy to provide cooler condenser water. Optimizing the energy use of the cooling tower/chiller system is one example of using an integrated system approach that can improve your energy performance and save money.

Heating and Cooling System Energy Use

Cooling may use as much as a third of the electricity consumed in a typical building. Heating systems use natural gas or oil as the primary fuel, but may also use electricity. Heating and cooling systems condition the air within a building so that occupants are comfortable. These systems consist mainly of chillers, boilers, cooling towers, and pumps. Cooling systems generally have higher space conditioning capacities than heating systems, because a large portion of the building's heating requirements is supplied by waste heat from the people, lighting, and office equipment. The proper design and operation of these systems can translate into significant savings. If you have followed the steps outlined in the other stages, your cooling load may now be low enough to justify retrofitting or rightsizing your cooling system.

Advantages Of A Rightsized System

In addition to reducing energy consumption and costs, heating and cooling upgrades will:

- Reduce noise.
- Lower first costs for equipment.
- Reduce equipment footprint.
- Eliminate CFCs.
- Optimize equipment operation

Take Action!

1. Measure your existing heating and cooling loads. To begin, see the Heating and Cooling Survey (Appendix). Contact an engineering services firm for the more complex load measurement tasks.

2. Total the reduction in cooling load achieved by your efforts from the previous stages. Calculate the proper size for your chiller. See the Heating and Cooling Survey (Appendix).
3. Use the information from the Heating and Cooling Survey to investigate options for upgrading your chiller plant.
4. Contact vendors and/or an engineering consultant who can recommend specific components and design upgrades for your heating and cooling system.

Central Cooling Systems: Best Opportunities

Cooling systems consist of various components that must work together to operate at highest efficiency while ensuring proper occupant comfort. Improvements to any system must, of course, incorporate improvements to its individual pieces of equipment. However, these changes must be viewed as part of an integrated system approach. To improve your building's overall efficiency, modifications in the design or operation of one set of components will affect, the operation of other equipment within the system.

There are four types of mechanical compression chillers—centrifugal, screw, scroll, and reciprocating, different applications call for different chiller types. Generally, older chillers have efficiencies ranging from 0.8 to 1.0 kW/ton; they often consume approximately twice the energy of newer, more efficient chillers. Today, centrifugal chillers have efficiencies as low as 0.45 kW/ton. Table 2 shows the efficiency ranges in which these chiller technologies.

Eliminating CFCs:
Headache Or Opportunity?

- CFC refrigerant production was phased out by law in 1996. As existing stock of CFCs dwindle and become more expensive, conversion to or replacement with non-CFC chillers is becoming more cost effective.
- Existing, relatively new chillers may be cost effective to retrofit for non-CFC operation.
- Replacing an older chiller with a new, non-CFC chiller is an excellent opportunity to invest in a high efficiency unit. First cost for the installation will be reduced by installing a smaller chiller made possible by the implementation of all upgrade stages.

Chiller Retrofit

If the existing chiller is less than 10 years old, retrofitting the chiller to operate on non-CFC refrigerants at the newly reduced loads will probably be your most profitable option. This postpones investing in a new chiller. When you are replacing refrigerant, use HCFC-123 in place of R-11 and HFC-134a in place of R-12.

Retrofitting may involve replacing orifice plates, impellers, gaskets, or even the compressor. The specifics of the retrofit depend on the type of chiller and its manufacturer. Many manufacturers offer retrofit kits for their chillers. Contact the manufacturer of your chiller to determine its requirements.

Due to their inherent properties, non-CFC refrigerants are not as efficient and thus will affect the chiller efficiency by reducing its cooling tonnage at current or even increased levels of energy consumption. However, the reduced cooling loads obtained through performing a comprehensive upgrade will offset this loss.

Table 2: Common Chiller Types and Efficiencies

Chiller Type	*Size Range (tons)*	*Full-load Efficiency (kW/ton)*
Centrifugal	100–1,500+	0.45–0.68
Screw	40–1,100	
water-cooled		0.56–0.70
air-cooled		1.1–1.3
Reciprocating	1–400	
water-cooled		0.8–1.0
air-cooled		0.97–1.6

Source: E Source, *Space Cooling Technology Atlas.*

CFCs Are On The Way Out

Eighty percent of today's existing chillers are centrifugal chillers that use R-11 as refrigerant. The newer, non-CFC alternative to R-11 is HCFC-123. Some centrifugal chillers use R-12; its non-CFC alternative is HFC-134a. Unitary A/C units typically use R-22, which will be phased out in the future.

Phase-Out Dates	*Refrigerants*	*Action*
1996	R-11, R-12, R-500,HCFC-152A, CFC-114	Production of these refrigerants has stopped. Equipment using these refrigerants is no longer manufactured.
2010	HCFC-22	Manufacture of equipment using this refrigerant has stopped
2020	HCFC-123	Manufacture of equipment using this refrigerant has stopped
2030	HCFC-22	Production of this refrigerant has stopped.
2030	HCFC-123	Production of this refrigerant has stopped.

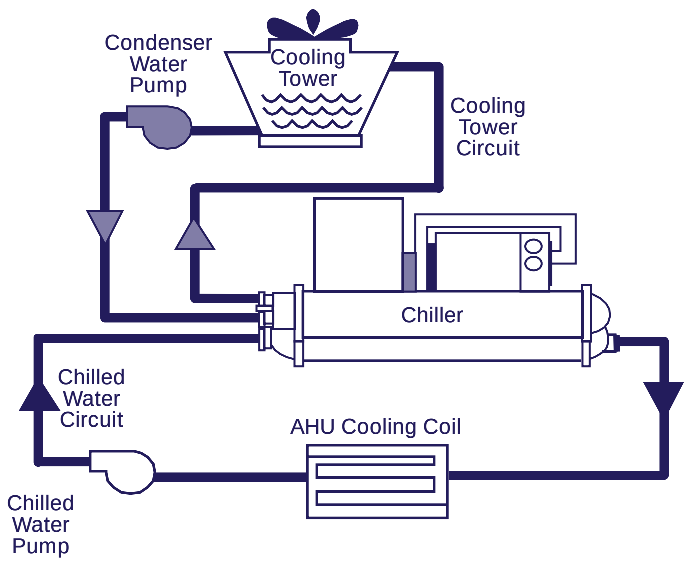
Source: ASHRAE *Fundamentals Handbook, 2001..*

Chiller Rightsizing

Depending on the upgrades implemented in the previous stages, loads on your cooling system (see Figure 2) likely have been reduced by at least 10 percent, and perhaps by as much as 40 percent. Even if you haven't implemented upgrades, design loads and actual building demand rarely match.

Chillers are frequently oversized, and those in poor condition suffer downtime and significantly increased operating and maintenance costs. A new efficient and reliable chiller may be more cost effective. Thus, you may want to consider rightsizing your existing chiller with a new, smaller, energy-efficient one that matches the newly reduced loads and uses compliant non-CFC refrigerants. This option is most profitable when your existing chiller is more than 10 years old.

Figure 2: Typical Water-Cooled Chiller System



When you decide to replace an existing chiller with an energy efficient unit, be sure to evaluate the initial operating and maintenance costs, size, and weight of the new unit. Keep in mind that the energy consumption of a new high efficiency chiller could range from 15 percent to more than 50 percent less than that of the existing chiller.

While the new chiller must be sized for peak loads, be sure that it operates efficiently at part-load conditions, because it is at part load that the chiller operates most of the time. Many chiller manufacturers provide electronic copies of their equipment specifications catalogs on CD-ROM. This information can be used to identify the appropriate chiller for your facility, once you have analyzed the building's peak load profile. An energy services professional or consulting engineer can develop the new peak load profile.

To analyze the profitability of chiller upgrades, you will need to identify the relationship between outdoor air temperature and the cooling load that the chillers must meet. Consult the chiller manufacturer's specifications to prepare a load profile for your building gathered using the Heating and Cooling survey (Appendix).

To evaluate the chiller project, gather data about existing chillers, operating schedules, utility rate schedules, cooling tower parameters, and water reset temperatures for the condenser and evaporator.

Chiller Rightsizing Case Study: An ENERGY STAR Showcase Building

Mobil Corporation's 340,000-sf research and development building in Dallas, Texas, was upgraded over a 1-year period as an ENERGY STAR Showcase Building. The original cooling capac. ity of the building's chiller plant was 1,760 tons. During the first 10 years, the building's cooling load had been projected to increase to 1,805 tons primarily from heat generated by the increasing number of personal computers and related equipment. Prior to the Showcase project, Mobil was planning to replace its three R-11 chillers with larger R-123 chillers, sized to provide the additional cooling capacity. Using the ENERGY STAR Approach, Mobil identified profitable opportunities to reduce the building's cooling loads. Upgrades in the five stages pro. vided a total cooling load reduction of 212 tons—more than enough to eliminate the need for larger chillers.

Existing Cooling Capacity	1,760 tons
Pre-Upgrade Calculated Peak Cooling Load	1,805 tons
Upgrades Implemented	***Reductions***
Lighting retrofit	45 tons
Peak air flow to labs reduced 10 percent	115 tons
ENERGY STAR computers, monitor shutoff devices, window films	38 tons
Variable-speed drives	14 tons
Post-Upgrade Projected Peak Cooling Load	1,593 tons

By committing to ENERGY STAR, Mobil was able to rightsize the three chillers with chillers that were smaller than originally planned. Mobil thus saved money on the first cost of the chillers and is reaping significant energy savings over the life of the chillers. The total cost of the chiller plant upgrades was $641,000. This investment resulted in an annual cost savings of $110,000, an annual energy savings of 10.4 percent, with an internal rate of return of 16.5 percent.

Mobil purchased the chillers before the tune-up and conversion of the return air system for lab spaces. In hindsight, had it waited to purchase the chillers last, as prescribed by the ENERGY STAR Approach, the lab return air conversion and tune-up would have reduced the peak cool. ing load by up to 120 tons and 250 tons respectively.

Mobil's experience in upgrading its R&D facility confirmed one of the basic premises of ENERGY STAR: systematically reducing cooling loads where profitable from tune-ups through fan sys. tems generates opportunities to profitably install rightsized, high efficiency chillers.

Source: *ENERGY STAR Showcase Building Project: Demonstrating Profitable Energy Savings,* EPA 430-R-96-006.

Upgrading Chiller Components

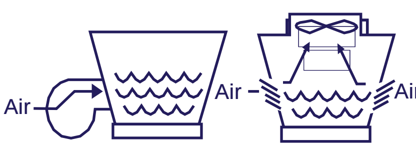
Numerous components of a chiller system can be upgraded to improve system efficiency and increase cooling cost savings.

Cooling Tower Improvements

Central cooling systems generate heat that must be rejected outside the building, a cooling tower is commonly used for this purpose. All cooling towers function as large heat exchangers, transferring heat from the condenser side of the chiller to the outside air by spraying the hot water through a flow of outside air. This flow of outside air is created with centrifugal or axial fans mounted at the lower end of the tower in the **forced-draft tower**.

A more common type of tower, the **induced-draft tower**, utilizes a propeller fan at the top of the tower to pull air up through the tower. The induced-draft tower offers better aerodynamics and is generally more efficient than a forced-draft tower. The forced-draft tower is generally quieter and requires less space than an induced-draft tower, but operates at a lower efficiency. Both forced-draft and induced-draft cooling towers (Figure 3) employ a surface contact medium or fill to increase contact surface and improve the transfer of heat between hot water from the chiller and the outside air.

Figure 3: Cooling Tower Types



Scaling, corrosion, and biological growth all impede tower efficiency and increase maintenance costs from the resultant condenser fouling and loss of heat transfer. Chemical treatment is generally used to mitigate these problems. However, new, non-chemical water treatment technologies, such as ozone generators, magnetic systems, and ultraviolet irradiation, are available. Ozone is a powerful oxidant and biocide that can replace chemicals completely in some cases. Magnetic systems are designed to cause scale-forming minerals to precipitate in a low-temperature area away from heat exchanger surfaces, thus producing non-adherent particles. The precipitated particles can then be removed by blowdown, mechanical means or physical flushing. The effectiveness of a magnetic system can be diminished by a low ratio of dissolved calcium to silica, by the presence of excessive iron in the water, or if it is installed in close proximity to high-voltage power lines.

Two-speed fan motors in combination with fan cycling provide an improvement in control and efficiency over fan cycling alone. **VSDs** provide the most efficient method of control. Cooling tower fans offer similar energy-saving opportunities. Fan power is proportional to the cube of the airflow rate; thus, a reduction of 20 percent in fan airflow (and speed) will correspond to a reduction of 49 percent in fan power.

Free Cooling (Water Side Economizer)

Under the right conditions, free cooling or a water side economizer system can generate significant energy savings. In cooler, drier climates, water side economizers can provide over 75 percent of the cooling requirements; in warmer climates they may provide only 20 percent. Although air side economizers, as discussed in Stages Three and Four, are typically less expensive, you should also consider using a water side economizer.

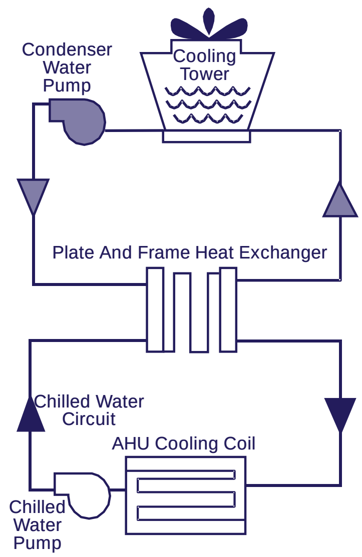
Several methods of free cooling are available. The most common method is a type of **indirect** free cooling that uses a separate heat exchanger, typically of the plate-and-frame type. It allows for a total bypass of the chiller, transferring heat directly from the chilled water circuit to the condenser water loop (see Figure 4).

A less common method is **direct** free cooling, in which the condenser and chilled water circuits are linked directly without the use of a separate heat exchanger. A disadvantage of using direct free cooling is that bacteria present in the cooling tower water system (described above) may contaminate your chilled water circuit. You can, however, install filtration systems or strainers to minimize this risk.

Facilities that require year-round cooling from high sensible heat gains would most likely benefit from direct free cooling. A large computer room or data center cooled with a central chilled water system would be a promising application.

When ambient outdoor conditions are ideal (that is, when the wet-bulb temperature is low enough), the chiller can be shut off and the cooling load may be served exclusively by the cooling tower without the energy-intensive mechanical refrigeration. The resulting reduction in energy consumption can be dramatic.

Figure 4: Indirect Water Side Economizer



Pumping System Upgrades

In buildings that use pumps to transport chilled water or condenser water, an integrated system approach can reduce pumping system energy by 50 percent or more. You can make your pumping systems more energy-efficient by:

- Replacing oversized impellers, pumps, and motors with rightsized pumps and smaller, energy-efficient motors.
- Installing VSDs on pump motors.
- Converting single-loop configurations to primary-secondary loop configurations.

Rightsizing

Rightsizing pumps to accommodate lower maximum loads can result in energy savings of up to 70 percent. The most cost-effective method is often trimming or replacing an oversized impeller in an existing centrifugal pump. When pump rightsizing, maximum design capacity of the new impeller or pump must be greater than the measured maximum load for the system. Be certain that the new motor is an energy-efficient model, sized to meet the maximum load, and recognize that pump motors, like fan motors, come in incremental sizes (5 hp, 7.5 hp, 10 hp, etc.).

Calculate your energy savings from rightsizing by comparing rated energy curves at various loads for old and new pump and motor sizes. Contact the pump manufacturer or an engineering consultant for further assistance.

Variable-Speed Drives

Installation of VSDs will ensure that your pumps are performing at maximum efficiency at part-load conditions. (See page 10 for an example of VSD savings potential.) Similar to the fan systems, the power required to operate a pump motor is proportional to the cube of the speed. For example, in a pump system with a VSD, a load reduction that results in a 10-percent reduction in motor speed reduces energy consumption by 27 percent [$1 - (0.9)^3 = 0.27$].

Estimating Savings From Installing VSDs On Pumps

To estimate the annual energy savings you can gain from installing VSDs on pumps, you will need to estimate run times for all part-load conditions, based either on monitoring or load calculations. Compare the motor horsepower of the existing motor with the motor horsepower of the motor with a VSD installed under the part-load conditions. The difference in horsepower (converted to kW) multiplied by the operating hours for the range of load percentages will give you the expected energy savings in kWh.

Example:

A 30-hp VSD is installed on a chilled-water pump. The existing flow rate is 1,040 gallons per minute (GPM), existing operating hours are 3,300 per year, and the pump's energy consumption is 66,900 kWh per year. The initial cost of the VSD is $7,175.

The VSD reduces average flow to 700 GPM.

Estimated new annual energy consumption:

$(66{,}900)(700 \div 1{,}040)^3$ =
20,400 kWh per year.

Estimated annual energy savings:

(66,900 – 20,400)($0.08/kWh) =
$3,720 per year.

Simple payback =
$7,175 ÷ $3,720 = 1.9 years.

When installing VSDs, be sure to:

- Complete harmonic, power factor, and torsional analyses before installation.
- Conduct a coast-down test to compare mechanical resonance with speed response.
- Ensure that maximum and minimum flow rates through the chiller can be met with chiller pump upgrades.

Single-Loop Conversions

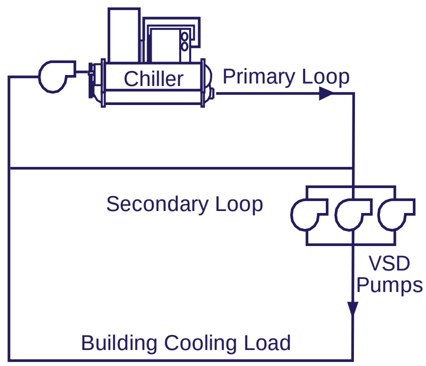
The rated minimum flow for chilled water through the chiller is typically 70 percent of maximum, which also applies to VSD flow reductions. However, a primary-secondary loop configuration, also known as a production-distribution configuration, can allow for greater energy savings without compromising your chiller performance. With the primary-secondary loop configuration (see Figure 5), chillers are equipped with smaller chilled-water pumps, or primary pumps. These are constant-flow pumps that operate with a lower pressure drop than in a single-loop configuration. Variable-flow secondary pumps then distribute the chilled water through your building's end-use air-handling devices and have the capability of reducing their speed at part-load conditions.

When converting from a single-loop configuration to a primary-secondary configuration, be sure to:

- Pipe the lower velocity chiller bypass water on the production side to flow into the higher velocity chilled water return on the distribution side and not vice versa.

- Replace three-way valves at air-handling unit coils with two-way valves.
- Maintain maximum and minimum flow rates through the chiller.

Figure 5: Primary/Secondary Pumping Loop

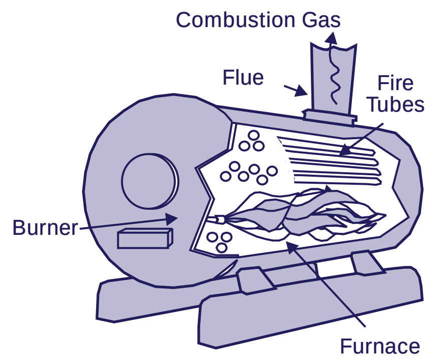


Central Heating Systems: Best Opportunities

Boiler System Upgrades

Approximately 40 percent of all commercial buildings use boilers for space heating (see Figure 6). Of these, roughly 65 percent are gas fired, 28 percent are oil fired, and 7 percent are electric. The combustion efficiency of older boilers is generally between 65 percent and 75 percent, although inefficient boilers can have efficiencies between 40 percent and 60 percent. Energy-efficient gas- or oil-fired boiler systems can have efficiencies between 85 and 95 percent.

Figure 6: Boiler Components



Boiler system energy consumption can be reduced by 10 to 30 percent. Improve your boiler system's efficiency by either:

- Replacing your existing boiler system with a new, rightsized, more energy-efficient boiler system.
- Retrofitting your boiler so that it can perform more efficiently.

Boiler Rightsizing

The best opportunities for energy savings come with replacing an old or inefficient boiler with a more efficient boiler system. Energy-efficient boilers have increased heating surface areas and improved controls for fuel and airflow over the range of load conditions. Before replacing your boiler:

- Determine your building's heating load and rightsize your boiler accordingly.
- Plan to rightsize your boiler with an energy-efficient model.
- Determine the applicability of converting from a single-boiler system to a staged system of smaller, energy-efficient boilers operating in combination.

To determine whether you should replace your boiler system, you need to understand your building's heating load and your existing boiler's efficiency. Calculate the energy savings from replacing a boiler by comparing rated energy consumption at various loads for the old and new boiler systems. Contact the boiler manufacturer or an engineering consultant for further assistance.

Boiler Retrofit

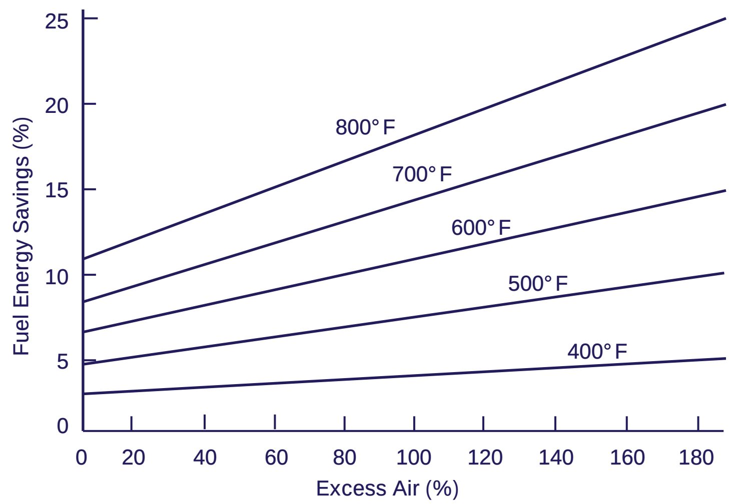
Retrofitting existing boilers can dramatically improve the peak- and part-load efficiency of your boiler and extend the useful life of your heating systems. Your best options include:

- **New Burners**—Efficient burners improve fuel combustion and reduce emissions of nitrogen oxide.
- **Temperature/Pressure Reset—**
  Temperature and pressure reset controls provide significant energy savings by minimizing fuel waste. Reset controls match the supply of steam with the demand for heat instead of supplying steam at a higher pressure than is needed. The system water temperature is reset based on the outdoor temperature. If outdoor temperature increases, the system water temperature is lowered.
- **Boiler Economizer**—A boiler economizer captures waste heat in the exhaust flue gases and uses it to preheat the boiler feedwater. When natural gas fuels the boiler, it is important to maintain the stack temperature at a minimum of 250° F to avoid condensation of the water vapor in the flue gases. The figure below shows the percentage of fuel saved as a function of the percentage of excess air

for different stack temperatures from a gas-fired boiler. For example, with the use of an economizer, a boiler operating at a stack temperature of 500° F and 80 percent excess air would realize a 7 percent fuel savings (see Figure 7).

- **Baffle Inserts**—Baffle inserts induce combustion gases to flow in a turbulent spiral pattern, which increases the efficiency of heat transfer.

Figure 7: Boiler Economizer Fuel Energy Savings



Source: Turner, *Energy Management Handbook*, 2nd ed.

As discussed in Recommissioning, improved operation and maintenance are important parts of your overall strategy and can provide significant energy savings. An annual tune-up, improved water treatment, and a preventative maintenance program can reduce boiler energy waste by as much as 15 percent.

Furnace Upgrades

Furnaces are heating plants that produce heat for the purpose of providing thermal comfort for your building. The heat source can be fuel oil, natural gas, electricity, coal, or wood. The main components of a warm-air furnace are the heat exchanger, fuel burner, blower or fan, controls, and housing.

An integrated system approach can reduce your furnace energy consumption 5 percent to 25 percent. You can make your furnace energy-efficient by:

- Replacing your existing furnace with a new, rightsized, energy-efficient furnace.
- Retrofitting your furnace with additional controls so that it can perform more efficiently.

Furnace Rightsizing

Standard combustion furnaces have a steady-state efficiency of about 80 percent. High efficiency furnaces built with condensing heat exchangers have a steady-state efficiency as high as 94 percent. If your furnace is more than 10 years old, you should:

- Measure your heating loads.
- Evaluate your existing furnace in terms of efficiency and capacity.
- Determine the benefits of installing a new, rightsized energy-efficient model.

Furnace Retrofit

Retrofitting existing furnaces can significantly increase your energy savings. Your best options are to:

- **Install new burners**—Efficient burners improve fuel combustion and reduce emissions of nitrogen oxide.
- **Install two-stage setback controls**—In electrically heated spaces where the temperature is reduced during unoccupied periods, the electric demand needed to bring the space back to its original temperature can be significant. In this case, if your electric rate structure includes demand charges, install a two-stage setback thermostat with staged supplemental heat and a programmable demand limiter to prevent demand peaks in the morning. Consider alternatives to resistance heating to reduce heating costs and overall impact on the environment.

As discussed in Recommissioning, improved operation and maintenance of your systems save energy—often in significant amounts. As with boiler systems, an annual tune-up and a preventative maintenance program are crucial to achieving and sustaining these savings.

Unitary Systems: Best Opportunities

Unitary systems are factory-assembled cooling, or combined heating and cooling, systems. Cabinet- or skid-mounted for easy installation, typical units generally consist of an evaporator, blower, compressor, condenser, and, if a combined system, a heating section. The size of the units ranges from approximately 1.5 to 130 tons.

Typical unitary systems are single-packaged units, split-system packaged units, heat pump systems, and water-source heat pump systems. Compared to central chiller plants, unitary systems do not last as long (only 12 to 15 years) and are less efficient. Unitary systems are generally used in one-, two-, or three-story buildings that have small cooling loads, such as retail spaces, small office buildings, and classrooms.

Generally speaking, it is not feasible to convert a building from packaged units to central chilling. However, it is not always necessary to replace in kind. (See the heat pump and additional strategies sections for conversion options, pages 18 and 19.)

Whether your building uses unitary systems for cooling, heating, or both, you can benefit from an integrated system approach. Depending on the upgrades you have implemented in tune-ups through fan systems, cooling load requirements have probably been reduced between 10 percent and 40 percent.

As with chillers, existing unitary systems are, in many cases, oversized. Likewise, unitary systems that are in poor condition suffer downtime and significantly increased operating and maintenance costs. A new and more reliable unitary system may be more cost effective. If your unitary systems are 10 years old or older, you can realize energy savings by replacing unitary systems with rightsized, energy-efficient models.

Rightsizing

Rightsizing your unitary systems to maximize the benefits of the cooling and heating load reductions can result in significant energy savings. When determining the rightsizing potential of your unitary system, be sure to measure your cooling and heating loads first. By knowing what your cooling and heating loads are, you will be better able to rightsize your new unitary system to meet maximum loads.

To estimate your energy savings from rightsizing, first measure your cooling and heating loads. Then, using the **seasonal energy efficiency ratio** (SEER) for your old and new systems, compare their respective energy consumption. Contact your equipment manufacturer or an engineering consultant for further assistance.

Typically, commercial buildings use unitary systems with cooling capacities greater than 5 tons. In some cases, however, due to space requirements, physical limitations, or small additions, residential-sized unitary systems are used. In these cases, be sure to look for the ENERGY STAR label. The ENERGY STAR label is found on various high efficiency heating, cooling, and control products and can help you differentiate between these and standard efficiency products. To determine what products may meet your needs, visit the ENERGY STAR Web site at http://www.energystar.gov/products/

The information about the technologies listed below will help you better understand your unitary system and recent technological advances that may increase its rightsizing potential.

- Packaged or rooftop units
- Vertical packaged units
- Split-system packaged units
- Air-source heat pumps
- Water-loop heat pump systems

Packaged Or Rooftop Units

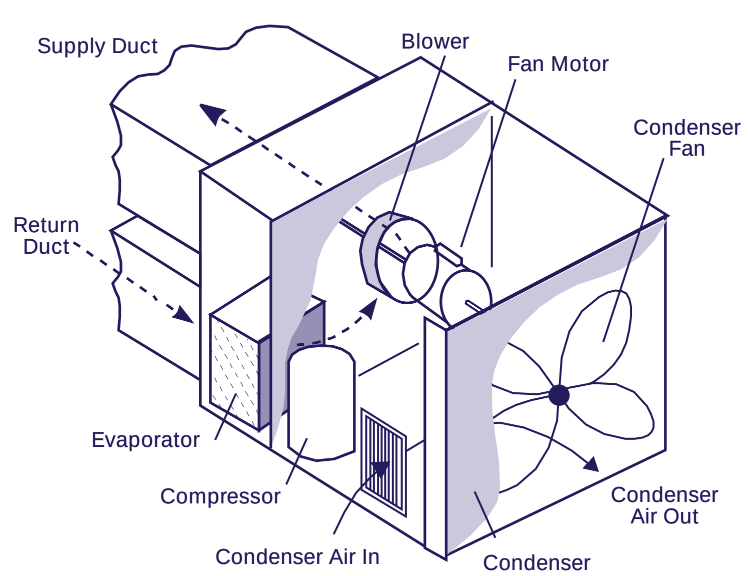
Packaged units are packaged HVAC units that are usually mounted on the roof, freeing up valuable indoor floor space. They can also be installed on a concrete pad at ground level. Because they are self-contained, manufactured units, installation costs are low.

Single-package units consist of a blower section, filter bank, evaporator coil, at least one compressor (larger units typically have multiple compressors to improve load matching), and an air-cooled condenser section (see Figure 8). Units may also come equipped with a heating section.

Heating is accomplished using either natural gas or electricity; however, natural gas is generally less expensive, depending on the region. Heat pump systems can be used in situations where electricity is the only source of energy. Unitary heat pump units typically range in size from 1.5 to 20 tons. Heat pump systems are discussed further below.

As packaged units age and deteriorate, their efficiency often decreases while the need for maintenance increases. Upgrading your packaged units to high efficiency models will result in substantial long-term energy savings.

Figure 8: Self-Contained Packaged AC Unit



In the last 10 to 15 years, manufacturers have made significant improvements to the efficiency of packaged units. The efficiency of heat transfer at both the evaporator and condenser coils has been improved; high efficiency motors are now standard;

and blower and compressor designs have improved in high efficiency packaged units. Scroll compressors are now commonplace on medium-sized (20- to 60-ton) rooftop units. Energy efficiencies of newer units have a SEER in the range of 9.50 to 13.0. It is not uncommon to find older units operating at efficiencies as low as 6.0, and most operate at less than 9.0. Gas-fired heating sections typically have an **annual fuel utilization efficiency** (AFUE) of about 80 percent.

Case Study: Installing High Efficiency Packaged Units Can Cut Energy Costs

For a typical 100,000-sf office building that has 10 standard 25-ton packaged units with a SEER rating of 9 and 80 percent electric heat efficiency, electricity costs would be about $71,300 per year ($53,300 for cooling and $18,000 for heating, at $0.08 per kWh).

Installing a new energy-efficient unit with a cooling energy efficiency rating of 13 would result in cooling mode electricity costs of about $36,900 annually—a savings of $16,400 per year. If the heating component of the system was improved to 90 percent efficiency, the heating savings would be $2,000 per year. The combined annual savings of $18,400 equals a reduction in energy costs of more than 25 percent.

(The cooling units are assumed to operate for 2,000 hours per year, while the heating units are assumed to run for 1,000 hours per year.)

All newer packaged rooftop units are equipped with factory-installed microprocessor controls. These controls make maintaining equipment easier and improve the energy efficiency of both the unit and the overall HVAC system. Control features include temperature setback and on/off scheduling. Large systems have variable air volume capability, as discussed in Fan System Upgrades. Also, most units have an optional communication interface for connection to an EMS system.

Vertical Packaged Units

Other unitary systems, if upgraded to high efficiency systems, offer much the same potential for energy savings. **Vertical packaged units** (see Figure 9), which are a variation on the packaged unit, are typically designed for indoor installation. Most units have a water-cooled condenser, which can be fed from a cooling tower and/or city water. Other components are mounted in the package. Ductwork can be connected to the unit to distribute the air.

Split-System Packaged Units

Split-system packaged units (see Figure 10) have an outdoor pad or rooftop-mounted air-cooled condenser. Refrigerant piping connects the compressor section to an indoor air-handling unit and evaporator coil.

Unless they are heat pump type units, they cannot provide heat to the space. Heating coils can be installed in the air-handling section, particularly if there is a central source of heat such as hot water or steam from a boiler.

Figure 9: Vertical Packaged Units

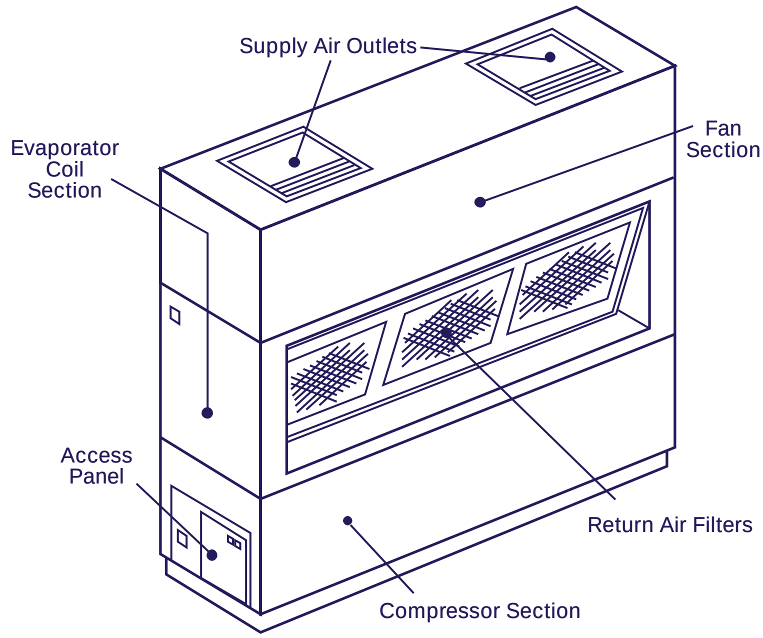
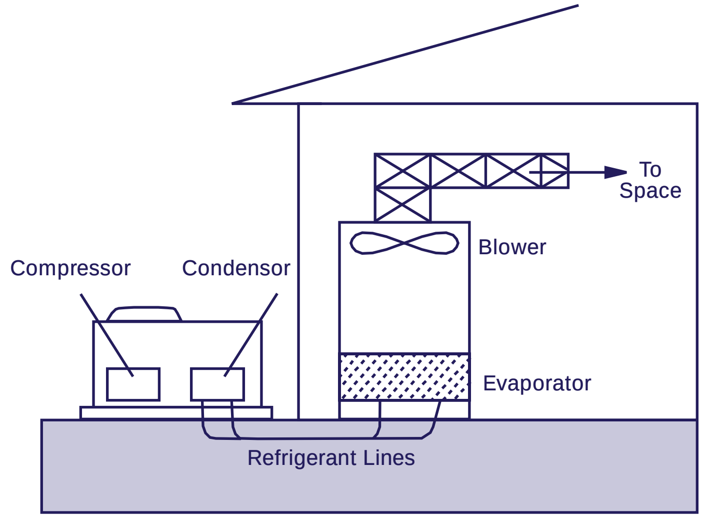


Figure 10: Split-System Packaged Units



Air-Source Heat PumpsK

Air-source heat pump systems are typically rooftop units, packaged either. complete or as split systems. During cooling mode, the unit operates as a typical air-. conditioning system. During heating mode, the cooling system is reversed completely. to extract heat from the outside air and to provide it to the space. The size of. unitary heat pump systems ranges from approximately 1.5 tons to 20 tons. In some. cases, existing packaged cooling units with electric resistance heat can be upgraded to. heat pumps for improved energy efficiency..

Heat pump applications are best suited to relatively warm climates, such as the. Southeastern United States, and to areas where the availability of natural gas for. heating is low. . When temperatures are low, the **coefficient of performance** (COP). of the heat pump falls dramatically. A 7.5-ton rooftop heat pump unit that has a. high-temperature COP of 3.0 can have a low-temperature COP of 2.0 or less.. Moreover, when the temperature drops further, heat pumps require supplemental. heat, typically electric resistance; thus, effective heating efficiencies become even. lower. More recently, dual-fuel heat pumps have become available in areas where. natural gas can be used as the supplemental heating source..

Split-package heat pumps are designed with an air-handling unit located inside the. conditioned space, and both the condenser and compressor are packaged in units for. outdoor installation on a pad or on the roof..

Due to their improved annual efficiency, air-source heat pumps are good candidates. for replacing packaged cooling units with electric-resistance heating coils..

Water-Loop Heat Pump SystemsK

Water-loop, or water-source, **heat pump systems** use water instead of air to. transfer heat. In an air-to-air heat pump system, heat is removed from indoor air and. rejected to outside air during the cooling cycle. The reverse happens during the. heating cycle. However, in a water-loop heat pump, water replaces the outdoor air as. the source or sink for heat, depending on the cycle in use..

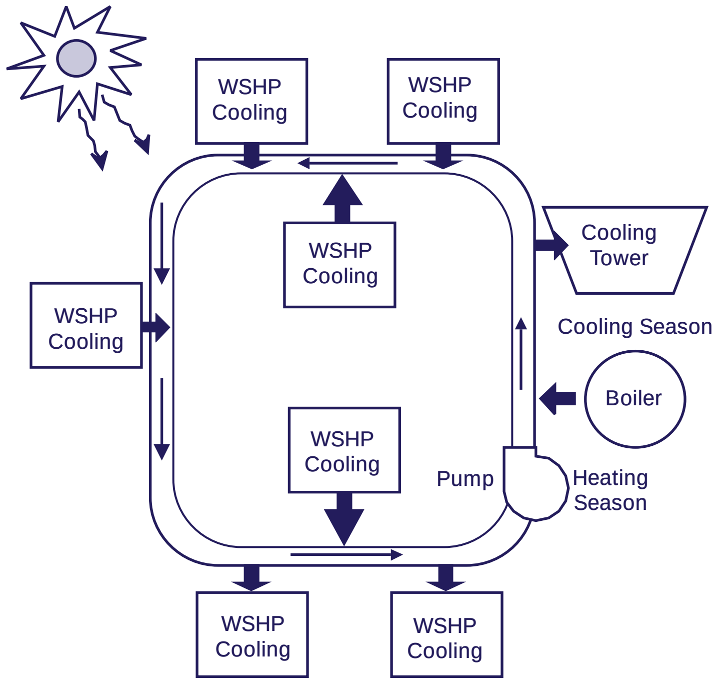
In hot weather, a cooling tower removes heat from the water loop; in cooler weather,. a central boiler heats the water..

As shown in Figure 11, water-loop heat pump systems allow for simultaneous heating. and cooling by multiple separate and distinct units, and thus increase individual. comfort. Furthermore, recovering heat from cooled areas and recycling it into other. areas adds to the system's efficiency..

The size of water-source heat pumps ranges from approximately 0.5 tons to 25 tons.. Efficiencies of water-source units are generally higher than their air-to-air. counterparts, where a SEER of 11.0 and COP of 3.8 to 4.0 are not uncommon..

High efficiency water-source heat pumps have a SEER as high as 14.0 to 15.0 and a COP as high as 4.4.

Figure 11: Water-Loop Heat Pump System



Additional Strategies: Best Opportunities

In addition to the strategies outlined in previous sections, other worthwhile technological strategies warrant further attention for some applications. Whether or not these strategies are viable for your building depends upon various conditions (for example, size, location, types of business onsite, utility rate structures). These strategies include the following:

Heating and Cooling Strategies

- Geothermal heat pumps
- District heating and cooling
- Radiant heating and cooling

Cooling Strategies

- Cool storage.
- High temperature difference distribution.
- Evaporative cooling.
- Non-electric cooling.

Geothermal Heat Pumps

An additional strategy for improving the efficiency of your HVAC equipment is the geothermal heat pump. Geothermal heat pumps take advantage of the natural heat stored underground to provide space conditioning heating, cooling, and humidity control. Rather than converting chemical energy to heat, as in a furnace, geothermal heat pumps work by moving heat. During the heating season, a geothermal heat pump can move heat taken from the ground and apply it to a building. In the cooling season, this process is reversed, as the building's excess heat is moved back to the ground to provide air conditioning. (See *A Short Primer and Environmental Guidance for Geothermal Heat Pumps*, EPA 430-K-97-007, available from 1-888-STAR YES).

Due to the relative stability of ground temperature, geothermal heat pump systems are inherently more efficient than air-source heat pumps, which rely on outside air as the medium which receives heat from the heat pump or from which heat is extracted by the heat pump. Geothermal heat pump systems provide the highest efficiencies in both cooling and heating seasons, as well as in heating water.

Information on geothermal heat pump systems is available from the ENERGY STAR Web site at http://www.energystar.gov/products/, under the Heating and Cooling for your home. For additional information, visit the Geothermal Heat Pump Consortium Web site at http://www.ghpc.org/home.htm.

District Heating and Cooling

District cooling is a shift in the generation location of chilled water from inside a facility to a local chilled-water producer. As a district cooling customer, your facility would purchase chilled water from a generation plant just as you purchase power from a local utility company. Chilled-water plants supply water to a number of customers within the plant district territory, usually encompassing a radius of three to five city blocks.

There are several advantages to district cooling:

- Most district cooling plants are modern facilities that use energy-efficient generation methods.
- The need for buildings to own and use refrigerants is eliminated along with refrigerant compliance responsibilities, handling regulations, rising replacement costs, and capacity-loss issues.
- Ice can be generated at off-peak hours (when utility demand and rates are lowest) and used at peak cooling periods to supplement chilled-water production, yielding a lower chilled-water temperature. This lower temperature means that high temperature-difference distribution may be viable, as discussed below.

- •0Chilled water can be purchased without the expense of installing, operating, or maintaining one's own chiller.

This strategy is applicable for some facilities in cities, campuses, or industrial parks. District heating and cooling eliminates central heating and/or cooling equipment. Also, because district cooling suppliers use modern, non-CFC chillers, CFC chiller equipment in your building can be retired.

Radiant Heating And Cooling

Radiant heating and cooling, also called hydronic heating and cooling, differs from standard HVAC design in that it uses water distribution instead of air distribution to meet a building's heating and cooling needs.

In a radiant cooling system, cold water is pumped through special panels or grids of tubing mounted in the walls, ceilings, or floors. These panels absorb heat from the building and bring it back to the HVAC plant to be removed from the building.

As discussed in load reductions and fan systems, the amount of outdoor air required to ventilate your building is actually much smaller than the amount of air that must be circulated through cooling coils to handle cooling load. Radiant systems cool the space directly, reducing your ventilation system to the size required to bring in outside air. This requirement is about 20 percent of the total air recirculation capacity of the average building. As water has a much higher capacity to store heat or cold than air, a much smaller volume of water can be circulated, further reducing costs. Radiant cooling can supply the same cooling capacity as other systems but at levels of energy consumption that are typically about 75 percent of those for air-based systems.

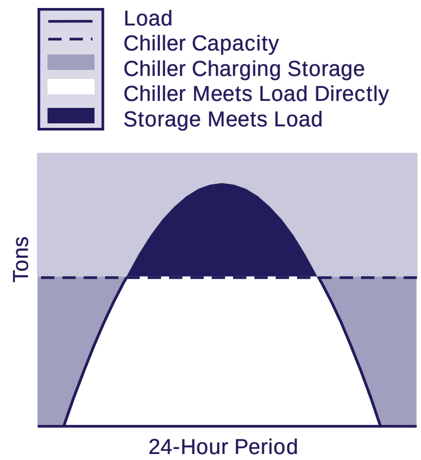
Cool Storage

Cool storage is a means of using less expensive off-peak power to produce cooling for the building. Cool storage is based upon the principle that a storage medium can be cooled while chiller operating cost is low, and the storage can be discharged when chiller operating cost is high. Furthermore, chillers tend to be most economical to operate at night, when building cooling loads are low, electric rates may be lower, and lower outdoor temperatures allow the chiller to reject heat more efficiently. Cooling energy is stored in tanks of water, ice and water, or water circulating around chemical modules that freeze and thaw. This last system, as well as an ice-based system, has the advantage of taking up less space than chilled-water storage because the freezing process can naturally store much more "cold" in a given volume.

Generally, the most cost effective type of cool-storage design and operating strategy is the partial-storage system shown in Figure 12. A partial storage system reduces a building's maximum electrical demand by shifting a portion of the cooling load from daytime to nighttime. The total chiller capacity required for the building is also less than that of a standard system.

The cost effectiveness of cool-storage systems varies considerably depending on the specific application. However, high electric-utility peak-demand charges, which generally coincide with the peak cooling period in the afternoon, and a time-of-use rate with a low nighttime kWh charge are factors that make it favorable to shift cooling equipment operation away from the utility peak period. A cool storage system is most cost effective when its capital cost is viewed as an incremental cost compared to replacing or constructing a new chilled-water system.

Figure 12: Partial-Storage Strategy



Source: E SOURCE, *Commercial Space Cooling Technology Atlas.*

High Temperature-Difference Distribution

Designing or modifying the chilled water distribution system to have a lower supply temperature and a higher return temperature than normal provides more cooling capacity for the same amount of chilled water flow. Increasing the difference between the supply and return temperatures by a certain percentage reduces the required water flow by the same percentage. Such a reduction in chilled-water flow can substantially reduce required pumping energy.

Because a chiller operates less efficiently as it supplies colder chilled water, high temperature-difference distribution systems are most appropriate when combined with cool-storage systems, as discussed above. To reduce the required tank size, cool-storage tanks containing ice or water are generally at lower-than-standard supply temperature.

High temperature difference distribution systems are most cost effective in new construction, because reduced chilled water flow requirements reduce the capital cost of pumps, piping, and heat exchangers.

Evaporative Cooling

The process of evaporating water or another fluid absorbs heat, just as a kettle must be heated before the water must boil. This is the basis for many types of mechanical cooling. A much simpler and more economical variation can be used in some climates. Cooling is produced by passing a flow of dry air over a wet surface. As the water evaporates from the surface, the air stream is cooled. Although evaporative cooling systems are most effective in dry climates, where the air has a large capacity to absorb evaporating water, they can also be used elsewhere to reduce the annual cooling load on mechanical refrigeration equipment.

There are both direct and indirect types of evaporative coolers and systems used in conjunction with mechanical refrigeration. Direct evaporation systems evaporate water directly into the supply air stream, whereas indirect systems cool one air stream that in turn cools the supply air stream through a heat exchanger. Although indirect systems are more costly, they avoid increasing the humidity of supply air. Evaporative cooling can also be used to precool air to reduce the load on a mechanical refrigeration system. Mechanical refrigeration can be used to increase the evaporative cooling capacity by cooling the water used for evaporation.

Compared with standard unitary air-conditioning equipment, indirect evaporative coolers have been shown to use 70 percent less electricity seasonally. While evaporative cooling equipment generally offers reduced cooling capacity compared to mechanical refrigeration, indirect evaporative precooling can supply half of the annual cooling load in many areas (ASHRAE, 1999, *Applications Handbook*, Chapter 50).

Nonelectric Cooling

While the most common cooling plants use an electric motor to drive a refrigerant compressor, there are nonelectric alternatives, such as engine-driven, steam turbine1 driven, and absorption chillers. While nonelectric cooling systems are often less expensive to operate, their first cost is higher than that of electric systems, and they come with increased equipment size and maintenance costs.

Gas engine-driven chillers are a cost-effective option for producing chilled water in areas where gas rates are lower than electric rates. Gas engine-driven chillers are much like electric chillers, except that they contain an engine rather than a motor. Where there is a need for heating during the cooling season, heat recovery from both the exhaust and cooling water can improve the efficiency of these systems. Gas engine-driven chillers have average operating COPs of 1.7 to 1.9. If heat recovery from the exhaust and water jacket are implemented, their efficiency can increase to 2.3 COP. While the efficiency of gas engine-driven chillers is much lower than that of electric chillers, total fuel use and pollution emissions can be comparable when considering electric power plant operations. The centrifugal or screw chiller driven by the engine uses an HCFC or HFC refrigerant, much like an electric chiller.

Absorption chillers do not use the vapor compression cycle that most mechanical refrigeration uses; instead, they are "driven" by heat, not by a mechanical drive input. Moreover, they use water as a refrigerant in conjunction with lithium bromide as the absorption chemical (or ammonia and water) such that there is no ozone-depletion potential from the system. Although the system has fewer moving parts than a centrifugal chiller, it is technically complex.

There are single- and double-effect absorption systems, and they may be fired directly with a gas burner or indirectly with steam generated by separate equipment. Single-effect systems have a COP of 0.5 to 0.7. Double-effect systems are more efficient, with a COP of 1.0 to 1.1. Triple-effect absorbers are also under development and promise still better efficiency. In addition, chiller-heaters, which use absorption technology to provide cooling, heating, or both cooling and heating as required, are available.

Steam turbines can be used to drive centrifugal compressors. The chilled medium is usually water or brine, with a halogenated hydrocarbon refrigerant. Other refrigerants such as ammonia, butane, or propane are also used in industrial processes.

Summary

This section has described numerous opportunities for optimizing both the size and efficiency of your building's heating and cooling systems. Before undertaking any of these strategies, you should measure your building's heating and cooling loads. Having done so, retrofit or rightsize your heating and cooling equipment based on the load reductions implemented in tune-ups through fan systems.

To find the most efficient equipment for your building's cooling and heating systems, consult the American Council for an Energy-Efficient Economy's (ACEEE's) *Guide To Energy-Efficient Commercial Equipment, 2nd edition*.

Next Steps

Measure your cooling and heating loads and complete the Heating and Cooling Survey at the end of this document.

Cooling Systems

- Estimate your savings by conducting a Heating and Cooling survey and working with an engineer (on-staff or consultant) to calculate savings potential.
- Rightsize your cooling system to take advantage of load reductions.
- 0Eliminate CFC refrigerants from your chiller system by retrofitting or replacing your chiller.
- 0Older chillers represent an investment opportunity. Install new high efficiency chillers to reduce operating costs and match equipment size to cooling load.

- Improve cooling towers and install VSD controls with rightsized pumps.
- Implement cooling system efficiency strategies such as free cooling.

Heating Systems

•0Replace older boilers and furnaces or upgrade components and controls of existing units.

Unitary Systems

- Replace older unitary equipment with high efficiency equivalents or heat pumps.

Additional Strategies

•0When evaluating your upgrade options, assess whether your building's specific characteristics lend themselves to:

– Geothermal heat pumps

– District heating and cooling

– Radiant heating and cooling

– Cool storage

– High temperature-difference distribution

– Evaporative cooling

– Nonelectric cooling

Appendix: Heating and Cooling Survey

Measure Heating and Cooling Loads To Rightsize Systems

This survey will familiarize you with the condition of your heating and cooling systems and enable you to determine whether your heating and cooling equipment needs replacing with rightsized, energy-efficient equipment.

To prepare to rightsize your heating and cooling systems, compile basic information and measurements about the systems and your facility. Next, calculate the required cooling and heating loads for your building.

To get started, recruit a survey team including a building engineer, HVAC technician, boiler operator, and electrician. You will need to evaluate your available staff resources and staff capabilities. If you do not have the means of taking these measurements, you may want to contact an independent ***testing, adjusting and balancing*** (TAB) firm or seek outside engineering services.

Before You Begin

You will need the following items to complete your survey:

- The latest specifications for the heating and cooling equipment in your building.
- The TAB report for your building's pumping systems.
- "As built" mechanical drawings.
- Operations and maintenance manuals for the boiler, chiller, or unitary system equipment.
- The system logs showing hot and chilled water supply and chilled-water return temperatures and flow rates (if you have an energy management system).
- A data logger (note: for unitary systems only).
- A calculator.

Chiller Systems Survey

Collect the following information:

Chiller Type
(choose one)

- ☐ Air-cooled centrifugal
- ☐ Water-cooled centrifugal
- ☐ Reciprocating
- ☐ Helical rotary/screw
- ☐ Steam absorption
- ☐ Hot-water absorption
- ☐ Direct-fired absorption
- ☐ Engine-driven

Manufacturer ____

Type of Refrigerant ___________________________________

Age ____

Efficiency (kW/ton) ___________________________________

Size or Capacity (in tons) ______________________________
(12,000 Btu/hr = 1 ton)

Calculate the maximum cooling load for your building using the following procedure:
What is the maximum cooling load for the building (in tons)? This load will be compared with the chiller capacity recorded above. To determine maximum cooling load, take the following measurements in the afternoon on a typical hot summer day to capture peak load effects on your system. *Note: An energy management system may also log these measurements.*

- Temperature of the chilled-water supply (CHWS). A temperature gauge should be found on the pipe at the chiller's supply outlet.
- Temperature of the chilled-water return (CHWR). A temperature gauge should be found on the pipe at the chiller's return inlet.
- Flow rate (GPM) of the chilled water supply. A flow rate gauge should be found on the supply pipe. If a gauge is not available, the design flowrate from as-built drawings may be used.

Chilled Water System
Measurements

Temperature of CHWS ____________

Temperature of CHWR ____________

Flow rate (GPM) of CHWS ________

Now, using the measurements, do the following calculations:

CHWR – CHWS = ΔT:

ΔT x 500 x (GPM ÷ 12,000) =
Load (in tons):

Load x 1.1 = Maximum Cooling Load

How much of your existing chiller capacity does your building currently need? To answer this, do the following calculation:

Maximum Cooling Load ÷
Chiller Capacity =
Percentage of Chiller Capacity Needed

If the required capacity of the chiller is 30 percent less than the installed capacity of your existing chiller, you should seriously consider replacing the chiller. The efficiency of the chiller decreases sharply below 70 percent loading. Also, remember that the chiller is operating most of the time at part-load conditions with your newly reduced loads, which increases your rightsizing potential even further.

Boiler Systems Survey

Collect the following information:

Heating Plant Type	Central hot water boiler
Manufacturer	___________________
Fuel (gas, oil, electric)	______________
Age	______________________________
Efficiency (percent)	_______________
Size or Capacity *(in MBtu/hr)*	___________________

Calculate the maximum heating load for your building using the following procedure: What is the maximum heating load for the building (in MBtu/hr)? This load will be compared with the heating system capacity recorded above. To determine maximum heating load, take the following measurements in the morning on a typical cold winter day to capture peak load effects on your system. *Note: An energy management system may also log these measurements*. The following procedure is tailored to typical central hot water boiler systems.

- Temperature of the hot water supply (HWS). A temperature gauge should be found on the pipe at the boiler's supply outlet.

- Temperature of the hot water return (HWR). A temperature gauge should be found on the pipe at the boiler's return inlet.
- Flow rate (GPM) of the hot water supply. A flow rate gauge should be found on the supply pipe. If a gauge is not available, the design flow rate from as-built drawings may be used.

Boiler System Measurements

Temperature of HWS ____________
Temperature of HWR ___________
Flow rate (GPM) of HWS _________

Now, using the measurements, do the following calculations:

HWR – HWS = ΔT

ΔT x 500 x GPM/1,000 = Load
(in MBtu/hr)

Load x 1.1 = Maximum Heating Load

How much of your existing boiler capacity does your building currently need?

Maximum Heating Load ÷
Heating Plant Capacity =
Percentage of Heating Capacity Needed

For other types of heating systems, there are other ways of measuring maximum heating load.

- For systems such as forced-air furnaces and heat pumps that respond to thermostats by cycling on and off, a simple runtime meter will show how much of the time the unit cycles on. Supply-temperature data logged every few minutes by an EMCS or other data logger can also be analyzed to determine how much of the time the unit is cycled on. The percentage of heating capacity needed is the time the unit operates divided by the total time during a high heating load period.
- Measuring steam boiler loading is similar, but more complicated than for a hot water boiler. Instead of the water flow rate, the steam flow rate must be measured. Instead of multiplying a temperature difference by a factor accounting for the heat content of each GPM, the temperature and pressure properties of the supply steam must be recorded from gauges on the supply line and used to determine the heat content of each pound of steam using a steam table.

Other strategies for measuring heating loads include:

- Periodic gas meter readings.
- Oil tank gauge readings or oil deliveries.
- On/off cycle times for systems that operate intermittently.

Unitary Systems Survey

Collect the following information for each type of unit installed in your building:

Boiler System Measurements

Unitary System Type *(choose one)*☐	☐ Packaged rooftop unit ☐ Split system ☐ Vertical packaged unit ☐ Heat pump

Manufacturer ____

Htg Fuel (gas, oil, elec.) _______________________________

Unit Age ____

Cooling Efficiency (%) ________________________________

Heating Efficiency (%) ________________________________

Size or Capacity (cooling) ______________________________
(in tons)

Size or Capacity (heating) ______________________________
(in MBtu/hr)

Calculate the maximum cooling and heating loads for your building using the following steps:

What are the maximum heating and cooling loads for the building (in MBtu/hr)? These loads will be compared with the cooling and heating capacities recorded above. To determine maximum heating or cooling load use the procedure described in the heating section for small systems that cycle on and off.

Time cycled on ÷ Total time = Percentage of Capacity Needed

A data logger can be used to determine how much of the time the unit is cycled on.

GLOSSARY

Recommissioning

air side systems
Equipment used to heat, cool, and transport air within building HVAC systems.

ASHRAE
American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

balancing
Process of measuring and adjusting equipment to obtain desired flows. Applies to both air side and water side systems.

boiler
Pressure vessel designed to transfer heat (produced by combustion) or electric resistance to a fluid. In most boilers, the fluid is water in the form of liquid or steam.

British thermal unit (Btu)
A unit of energy equivalent to the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

Btu
See *British thermal unit.*

calibration
Process of adjusting equipment to ensure that operation is within design parameters.

carbon monoxide
Colorless, odorless, poisonous gas formed during incomplete combustion of fuel.

central plant
Centrally located equipment that satisfies a building's cooling and heating loads.

CFCs
See *chlorofluorocarbons.*

cfm
Cubic feet per minute.

chiller
Mechanical device that generates cold liquid, which is circulated through cooling coils to cool the air supplied to a building.

chlorofluorocarbons
Chemical compounds consisting of carbon, hydrogen, chlorine, and fluorine, once used widely as aerosol propellants and refrigerants. Believed to deplete the atmospheric ozone layer.

coil, condenser
A heat exchanger used to condense refrigerant from a gas to a liquid.

coil, cooling
Heat exchanger used to cool air under forced convection with or without dehumidification. May consist of a single coil section or several coil sections assembled into a bank.

coil, fan
A device that combines a heat exchanger and a fan in a single unit that conditions air by forced convection.

coil, heating
Heat exchanger that heats air under forced convection. May consist of a single coil section or several coil sections assembled into a bank.

combustion air
Air that supplies the oxygen required to burn fuel.

commissioning
The quality assurance process that ensures design intent is met for new facilities or major rehabilitation.

condenser
Heat exchanger in a refrigeration system that expels building heat absorbed in the evaporator.

conditioned air
Air that serves a space and that has had its temperature and/or humidity altered to meet design specifications.

controls
An instrument or set of instructions for operating or regulating building systems.

control, pneumatic
A control that utilizes air pressure to vary equipment operation.

control, set back
The practice of reducing the thermostat setpoint during unoccupied times.

cooling tower
Device that dissipates heat from water-cooled systems through a combination of heat and mass transfer, whereby the water to be cooled is distributed in the tower and exposed to circulated ambient air.

cycling
The noncontinuous operation of equipment.

dampers
Single- or multiple-blade devices, either manually or automatically opened or closed, that control the flow of air.

demand charges
Fees levied by a utility company for electric demand.

demand, electric
Electrical power delivered to a system at a given time or averaged over a designated period. Expressed in kilowatts.

diffuser, HVAC
A device that distributes conditioned air to a space.

diffuser, lighting
A device that distributes light produced by lamps into a space.

efficiency
Ratio of power output to input.

energy management system (EMS)
The control system that monitors the environment and energy usage in a building and alters equipment operation to conserve energy while providing occupant comfort.

envelope, building
The outer shell of a building, including walls, roof, windows, and doors.

evaporator
Heat exchanger in a refrigeration system that absorbs heat from chilled water or building air, thus reducing the supply temperature.

fouling
The buildup of a film that reduces heat transfer.

heat exchanger
A device that transfers heat from one fluid to another.

humidistat
A device that responds to humidity changes and controls equipment by seeking a setpoint.

HVAC
Heating, ventilating, and air-conditioning.

kilowatt (kW)
Unit of power equal to 1,000 watts.

kilowatt-hour (kWh)
Unit of electric consumption equal to the work done by 1 kilowatt acting for 1 hour.

kW
See *kilowatt*.

kWh
See *kilowatt-hour*.

load
The demand upon the operating resources of a system. In the case of energy loads in buildings, the word generally refers to heating, cooling, and electrical (or demand) loads.

maintenance
An ongoing process to ensure equipment operates at peak performance.

occupancy sensor
A device that detects heat (passive infrared) or a shift in the frequency of reflected ultrasonic sound waves, to control operation of lights or equipment accordingly.

off-peak
Refers to a utility rate schedule that designates the time of day when energy and demand costs are typically less expensive.

on-peak
Refers to a utility rate schedule that designates the time of day when energy and demand costs are typically more expensive.

packaged unit
A self-contained HVAC unit that provides heating and/or cooling to a building space.

part-load
Condition when equipment operates at less than full capacity to meet the demand placed upon it.

part-load performance
Equipment efficiency at less than full capacity.

pressure drop
The loss in pressure experienced by flowing water or air due to friction and obstructions.

radiator
Device that provides warmth to a space through radiant or convective heat provided by either steam or hot water.

recommissioning
Recommissioning ensures system functionality. It is an inclusive and systematic process intended not only to optimize how equipment and systems operate, but also to optimize how the *systems function together*.

refrigerant
Substance, such as *CFCs*, HCFCs, HFCs, air, ammonia, water, or carbon dioxide, used to provide cooling by evaporation and condensation.

reset, chilled water
The practice of increasing chilled water temperature to obtain higher chiller efficiency.

reset, condenser water
The practice of decreasing condenser water temperature to obtain higher chiller efficiency.

rooftop unit
Air-handling equipment such as *packaged units* located on the roof.

scaling
See *fouling*.

schedule
A control sequence that turns equipment on and off.

setpoint
Desired temperature, humidity, or pressure in a space, duct, etc.

shell, building
See *envelope, building*.

space
The distinct area to which conditioned air is delivered.

steam trap
A device that separates air and condensed water from steam.

TAB
See *testing, adjusting, and balancing*.

testing, adjusting, and balancing (TAB)
The process of adjusting HVAC system components to supply air and water flows at design or revised specifications.

thermostat
A device that responds to temperature changes and controls equipment by seeking a setpoint accordingly.

ton
Unit of cooling capacity equal to 12,000 Btu/hr.

tubes, condenser
Heat exchanger tubes through which condenser water is pumped to allow heat transfer between the condenser water and the refrigerant.

tubes, evaporator
Heat exchanger tubes through which chilled water is pumped to allow heat transfer between the chilled water and the refrigerant.

tune-up, building
The purposeful sequence of maintenance and operational improvements, undertaken at a specific point in time, designed to reduce energy use, heating loads, and cooling loads of existing facilities.

variable air volume (VAV)
A type of air-handling system that provides air at a constant temperature and varies the air quantity to each zone to match the variation in room load.

VAV
See *variable air volume*.

water side systems
Equipment used to heat, cool, and transport water to building HVAC systems.

Lighting

---

ballast
Power-regulating device that modifies input voltage and controls current to provide the electrical conditions necessary to start and operate gaseous discharge lamps.

carbon dioxide
Colorless, odorless, incombustible gas formed during respiration, combustion, and organic decomposition. Increasing amounts of carbon dioxide in the atmosphere are believed to contribute to the global warming phenomenon.

CERCLA
Comprehensive Environmental Response, Compensation and Liability Act (1980) an EPA regulation. Also known as the Superfund law.

color rendering index (CRI)
A measure ranging from 0 to 100 of the accuracy with which a light source renders different colors in comparison to natural light, which has a measure of 100.

controls
An instrument or set of instructions for operating or regulating building systems.

CRI
See *color rendering index*.

cycling
The noncontinuous operation of equipment.

deadband
A setting in the lighting control that provides a time delay, signaling the lights to switch off only if the light level is somewhat *above* the setting, or on only if the level is somewhat *below* the setting.

DEHP
Di (2-ethylhexyl) phthalate, an insulator used to replace PCBs in ballast capacitors starting in 1979. DEHP is listed as a hazardous waste in its pure form, but, according to *RCRA*, it is no longer considered hazardous once used in a lighting ballast.

demand charges
Fees levied by a utility company for electric demand.

demand, electric
Electrical power delivered to a system at a given time or averaged over a designated period. Expressed in kilowatts.

diffuser, HVAC
A device that distributes conditioned air to a space.

diffuser, lighting
A device that distributes light produced by lamps into a space.

efficacy
The ratio of lamp lumen output to total lamp power input expressed in lumens per watt.

efficiency
Ratio of power output to power input.

EMS
See *energy management system.*

energy management system (EMS)
The control system that monitors the environment and energy usage in a building and alters equipment operation to conserve energy while providing occupant comfort.

footcandle (fc)
Unit of illuminance equal to 1 lumen per square foot.

heat gain
The rate at which heat enters or is generated within a space at a given instant.

HID
High-intensity discharge.

HVAC
Heating, ventilating, and air-conditioning.

IAQ
Indoor air quality.

IES
Illuminating Engineering Society.

illuminance
Commonly called light level, the light intensity arriving on a surface measured in footcandles.

internal rate of return (IRR)
Compound interest rate at which the total discounted benefits equal total discounted costs for a particular investment.

IRR
See *internal rate of return.*

kilowatt (kW)
Unit of power equal to 1,000 watts.

kilowatt-hour (kWh)
Unit of electric consumption equal to the work done by 1 kilowatt acting for 1 hour.

kW
See *kilowatt*.

kWh
See *kilowatt-hour*.

load
The demand upon the operating resources of a system. In the case of energy loads in buildings, the word generally refers to heating, cooling, and electrical (or demand) loads.

lumen
Unit measurement of the rate at which a light source produces light per unit time.

luminaire
Complete lighting unit, consisting of one or more lamps together with a housing, the optical components to distribute the light from the lamps, and the electrical components (ballast, starters, etc.) necessary to operate the lamps.

luminance
Commonly referred to as brightness, the light leaving a surface measured in footlamberts. It considers both *illuminance* on the surface and reflectance of the surface.

luminance ratio
The ratio between the *luminances* of any two areas in the visual field. This is a measure of the uniformity of luminance.

maintenance
An ongoing process to ensure equipment operates at peak performance.

nitrogen oxides
Chemical compounds that contain nitrogen and oxygen. They react with volatile organic compounds in the presence of heat and sunlight to form ozone and are a major precursor to acid rain.

occupancy sensor
A device that detects heat (passive infrared) or a shift in the frequency of reflected ultrasonic sound waves, to control operation of lights or equipment accordingly.

packaged unit
A self-contained HVAC unit that provides heating and/or cooling to a building space.

payback
See *payback, simple*.

payback, simple
Also known as *payback*. Measurement of the elapsed time between an initial investment and the point at which accumulated savings are sufficient to offset the initial investment.

PCB
Polychlorinated biphenyl. A substance used as an insulator in the capacitor of fluorescent and HID magnetic ballasts prior to 1970. PCBs have been labeled as carcinogenic and can cause skin, liver, and reproductive disorders.

photocell
A device that responds electrically to the presence of light.

power factor
Ratio of real power to total apparent power.

power quality
The degree to which voltage and current wave forms conform to a sinusoidal shape and are in synchronous phase with one another. Poor power quality can have negative impacts on electrical equipment.

RCRA
Resource Conservation and Recovery Act, an EPA Regulation.

reflector
A device installed in *luminaires* used to direct light from a source via specular or diffuse reflection.

rightsizing
The process of correctly sizing equipment to the peak load.

rooftop unit
Air-handling equipment such as *packaged units* located on the roof.

schedule
A control sequence that turns equipment on and off.

sulfur dioxide
A heavy, colorless, pungent air pollutant formed primarily by the combustion of fossil fuels such as coal. It is a respiratory irritant and a precursor to the formation of acid rain.

VCP
See *visual comfort probability*.

visual comfort probability (VCP)
A rating given to lighting systems expressed as the percentage of people who will find light output acceptable in terms of glare due to direct light from luminaires.

voltage, volts
International system unit of electric potential or the amount of electrical flow, also referred to as electromotive force.

Supplemental Load Reductions

AHU
See *air-handling unit.*

air-handling unit (AHU)
Equipment used to distribute conditioned air to a space. Includes heating and cooling coils, fans, ducts, and filters.

air side systems
Equipment used to heat, cool, and transport air within building HVAC systems.

ASHRAE
American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

balancing
Process of measuring and adjusting equipment to obtain desired flows. Applies to both air side and water side systems.

ballast
Power-regulating device that modifies input voltage and controls current to provide the electrical conditions necessary to start and operate gaseous discharge lamps.

British thermal unit (Btu)
A unit of energy equivalent to the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

Btu
See *British thermal unit*.

calibration
Process of adjusting equipment to ensure that operation is within design parameters.

carbon dioxide
Colorless, odorless, incombustible gas formed during respiration, combustion, and organic decomposition. Increasing amounts of carbon dioxide in the atmosphere are believed to contribute to the global warming phenomenon.

CFCs
See *chlorofluorocarbons*.

cfm
Cubic feet per minute.

chiller
Mechanical device that generates cold liquid, which is circulated through cooling coils to cool the air supplied to a building.

chlorofluorocarbons
Chemical compounds consisting of carbon, hydrogen, chlorine, and fluorine, once used widely as aerosol propellants and refrigerants. Believed to cause depletion of the atmospheric ozone layer.

coil, condenser
A heat exchanger used to condense refrigerant from a gas to a liquid.

coil, cooling
Heat exchanger used to cool air under forced convection, with or without dehumidification. May consist of a single coil section or several coil sections assembled into a bank.

coil, fan
A device that combines a heat exchanger and a fan in a single unit that conditions air by forced convection.

coil, heating
Heat exchanger that heats air under forced convection. May consist of a single coil section or several coil sections assembled into a bank.

controls
An instrument or set of instructions for operating or regulating building systems.

dampers
Single- or multiple-blade devices, either manually or automatically opened or closed, that control the flow of air.

DEHP
Di (2-ethylhexyl) phthalate, an insulator used to replace PCBs in ballast capacitors starting in 1979. DEHP is listed as a hazardous waste in its pure form, but, according to RCRA, it is no longer considered hazardous once used in a lighting ballast.

demand charges
Fees levied by a utility company for electric demand.

demand, electric
Electrical power delivered to a system at a given time or averaged over a designated period. Expressed in kilowatts.

demand ventilation
Method of controlling the amount of outdoor air intake based on carbon dioxide levels in a space.

desiccant
A material that absorbs moisture from its surrounding environment.

domestic hot water
All hot water consumed in a building that is used for purposes other than heating a space.

efficacy
The ratio of lamp lumen output to total lamp power input expressed in lumens per watt.

efficiency
Ratio of power output to power input.

ENERGY STAR label
EPA's trademark symbolizing excellence in energy efficiency.

envelope, building
The outer shell of a building, including walls, roof, windows, and doors.

exhaust air
Air removed from a building and not reused.

glazing
Glass set or made to be set in frames.

glazing system
A configuration of materials with a transparent or translucent element designed to admit sunlight.

GPM
Gallons per minute. A measure of water flow rate.

heat exchanger
A device that transfers heat from one fluid to another.

heat, latent
The heat required to change the state of matter from a liquid to gas or gas to liquid.

heat pump
Heat pump utilize the vapor compression refrigeration cycle the same that a DX unit or chiller does. The difference is that a heat pump can reverse the direction of heat flow which naturally flows from warmer to cooler areas.

heat, sensible
The heat required to change temperature without changing state of matter. This temperature change can occur by exposure to radiation, friction between two objects, chemical reaction, or contact with a hotter object.

hp
Horsepower. A unit of mechanical power.

HVAC
Heating, ventilating, and air-conditioning.

IAQ
Indoor air quality.

infiltration
Air that leaks into a building through the building shell.

kilowatt (kW)
Unit of power equal to 1,000 watts.

kilowatt-hour (kWh)
Unit of electric consumption equal to the work done by 1 kilowatt acting for 1 hour.

kW
See *kilowatt*.

kWh
See *kilowatt-hour*.

load
The demand upon the operating resources of a system. In the case of energy loads in buildings, the word generally refers to heating, cooling, and electrical (or demand) loads.

maintenance
An ongoing process to ensure equipment operates at peak performance.

nitrogen oxides
Chemical compounds that contain nitrogen and oxygen. They react with volatile organic compounds in the presence of heat and sunlight to form ozone and are a major precursor to acid rain.

occupancy sensor
A device that detects heat (passive infrared) or a shift in the frequency of reflected ultrasonic sound waves, to control operation of lights or equipment accordingly.

payback
See *payback, simple*.

payback, simple
Also known as *payback*. Measurement of the elapsed time between an initial investment and the point at which accumulated savings are sufficient to offset the initial investment.

PPM
Parts per million. A unit of concentration.

roof curb
A raised and reinforced area on a roof for mounting equipment.

setpoint
Desired temperature, humidity, or pressure in a space, duct, etc.

shell, building
See *envelope, building*.

space
The distinct area to which conditioned air is delivered.

timeclock
The control device used to turn equipment on and off at set times of the day.

ton
Unit of cooling capacity equal to 12,000 Btu/hr.

transformer
A device that reduces the incoming line voltage, usually to a standard level, so that it may be used to operate electrical equipment in a building.

tune-up, building
The purposeful sequence of maintenance and operational improvements, undertaken at a specific point in time, designed to reduce
energy use, heating loads, and cooling loads
of existing facilities.

W/sf
Watts per square foot.

Fans

AHU
See *air-handling unit.*

air-handling unit (AHU)
Equipment used to distribute conditioned air to a space. Includes heating and cooling coils, fans, ducts, and filters.

air side systems
Equipment used to heat, cool, and transport air within building HVAC systems.

ASHRAE
American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

balancing
Process of measuring and adjusting equipment to obtain desired flows. Applies to both air side and water side systems.

boiler
Pressure vessel designed to transfer heat produced by combustion or electric resistance to a fluid. In most boilers, the fluid is water in the form of liquid or steam.

British thermal unit (Btu)
A unit of energy equivalent to the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

Btu
See *British thermal unit.*

CAV
See *constant volume.*

CFCs
See *chlorofluorocarbons.*

cfm
Cubic feet per minute.

chiller
Mechanical device that generates cold liquid, which is circulated through cooling coils to cool the air supplied to a building.

chlorofluorocarbons
Chemical compounds consisting of carbon, hydrogen, chlorine, and fluorine, once used widely as aerosol propellants and refrigerants. Believed to cause depletion of the atmospheric ozone layer.

coefficient of performance (COP)
A measure of efficiency in which a higher value designates a more efficient system.

coil, condenser
A heat exchanger used to condense refrigerant from a gas to a liquid.

coil, cooling
Heat exchanger used to cool air under forced convection, with or without dehumidification. May consist of a single coil section or several coil sections assembled into a bank.

coil, fan
A device that combines a heat exchanger and a fan in a single unit that conditions air by forced convection.

coil, heating
Heat exchanger that heats air under forced convection. May consist of a single coil section or several coil sections assembled into a bank.

condenser
Heat exchanger used to expel building heat absorbed in the evaporator of a refrigeration system.

conditioned air
Air that serves a space that has had its temperature and/or humidity altered to meet design specifications.

constant volume (CAV, constant air volume)
Type of air-handling system that supplies the conditioned space at a constant air flow and modulate heating and cooling by varying the air temperature.

controls
An instrument or set of instructions for operating or regulating building systems.

cooling tower
Device that dissipates heat from water-cooled systems through a combination of heat and mass transfer, whereby the water to be cooled is distributed in the tower and exposed to circulated ambient air.

COP
See *coefficient of performance*.

cycling
The noncontinuous operation of equipment.

demand charges
Fees levied by a utility company for electric demand.

demand, electric
Electrical power delivered to a system at a given time or averaged over a designated period. Expressed in kilowatts.

downsizing
Process of reducing the size (capacity) of equipment so that it operates efficiently at design load conditions.

ductwork
The distribution system for air in HVAC systems. It is usually made of sheet metal or fiberglass.

efficiency
Ratio of power output to power input.

EMS
See *energy management system.*

energy management system (EMS)
The control system that monitors the environment and energy usage in a building and alters equipment operation to conserve energy while providing occupant comfort.

evaporator
Heat exchanger in a refrigeration system that absorbs heat from chilled water or building air, thus reducing the supply temperature.

fouling
The buildup of a film that reduces heat transfer.

gasket
Material used to seal a joint against leakage.

GPM
Gallons per minute. A measure of water flow rate.

heat exchanger
A device that transfers heat from one fluid to another.

heat, latent
The heat required to change the state of matter from a liquid to gas or gas to liquid.

heat pump
Heat pump utilize the vapor compression refrigeration cycle the same that a DX unit or chiller does. The difference is that a heat pump can reverse the direction of heat flow which naturally flows from warmer to cooler areas.

heat, sensible
The heat required to change temperature without changing state of matter. This temperature change can occur by exposure to radiation, friction between two objects, chemical reaction, or contact with a hotter object.

hp
Horsepower. A unit of mechanical power.

HVAC
Heating, ventilating, and air-conditioning.

impeller
The rotating element of a fan or pump used to circulate the air or water.

internal rate of return (IRR)
Compound interest rate at which the total discounted benefits become equal to total discounted costs for a particular investment.

IRR
See *internal rate of return.*

kilowatt (kW)
Unit of power equal to 1,000 watts.

kilowatt-hour (kWh)
Unit of electric consumption equal to the work done by 1 kilowatt acting for 1 hour.

kW
See *kilowatt.*

kWh
See *kilowatt-hour*.

load
The demand upon the operating resources of a system. In the case of energy loads in buildings, the word generally refers to heating, cooling, and electrical (or demand) loads.

maintenance
An ongoing process to ensure equipment operates at peak performance.

meter
A device used to measure and display or record data.

nitrogen oxides
Chemical compounds that contain nitrogen and oxygen. They react with volatile organic compounds in the presence of heat and sunlight to form ozone and are a major precursor to acid rain.

off-peak
Refers to a utility rate schedule that designates the time of day when energy and demand costs are typically less expensive.

on-peak
Refers to a utility rate schedule that designates the time of day when energy and demand costs are typically more expensive.

packaged unit
A self-contained HVAC unit that provides heating and/or cooling to a building space.

part-load
Condition when equipment operates at less than full capacity to meet the demand placed upon it.

payback
See *payback, simple*.

payback, simple
Also known as *payback*. Measurement of the elapsed time between an initial investment and the point at which accumulated savings are sufficient to offset the initial investment.

power factor
Ratio of real power to total apparent power.

pressure drop
The loss in pressure experienced by flowing water or air due to friction and obstructions.

refrigerant
Substance, such as *CFCs*, HCFCs, HFCs, air, ammonia, water, or carbon dioxide, used to provide cooling by evaporation and condensation.

reset, chilled water
The practice of increasing chilled water temperature to obtain higher chiller efficiency.

reset, condenser water
The practice of decreasing condenser water temperature to obtain higher chiller efficiency.

rightsizing
The process of correctly sizing equipment to operate efficiently at design load conditions.

rooftop unit
Air-handling equipment such as *packaged units* located on the roof.

scaling
See *fouling*.

schedule
A control sequence that turns equipment on and off.

seasonal energy-efficiency ratio (SEER)
Cooling capacity (Btu/hr) divided by total input power (watts) requirement where both are seasonal averages.

SEER
See *seasonal energy-efficiency ratio*.

sheave
(Pronounced shiv.) Pulley.

space
The distinct area to which conditioned air is delivered.

thermostat
A device that responds to temperature changes and controls equipment by seeking a setpoint accordingly.

timeclock
The control device used to turn equipment on and off at set times of the day.

ton
Unit of cooling capacity equal to 12,000 Btu/hr.

tune-up, building
The purposeful sequence of maintenance and operational improvements, undertaken at a specific point in time, designed to reduce energy use, heating loads, and cooling loads of existing facilities.

variable air volume (VAV)
A type of air-handling system that provides air at a constant temperature and varies the air quantity to each zone to match the variation in room load.

VAV
See *variable air volume*.

VSD
See *variable-speed drive*.

variable-speed drive (VSD)
A device used to adjust the speed of an AC motor to match load requirements.

Heating and Cooling

AHU
See *air-handling unit*.

air-handling unit (AHU)
Equipment used to distribute conditioned air to a space. Includes heating and cooling coils, fans, ducts, and filters.

air side systems
Equipment used to heat, cool, and transport air within building HVAC systems.

ARI
Air-Conditioning and Refrigeration Institute.

ASHRAE
American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

ASME
American Society of Mechanical Engineers.

boiler
Pressure vessel designed to transfer heat produced by combustion or electric resistance to a fluid. In most boilers, the fluid is usually water in the form of liquid or steam.

calibration
Process of adjusting equipment to ensure that operation is within design parameters.

carbon dioxide
Colorless, odorless, incombustible gas formed during respiration, combustion, and organic decomposition. Increasing amounts of carbon dioxide in the atmosphere are believed to contribute to the global warming phenomenon.

CAV
See *constant volume*.

CFCs
See *chlorofluorocarbons*.

chiller
Mechanical device that generates cold liquid, which is circulated through cooling coils to cool the air supplied to a building.

chlorofluorocarbons
Chemical compounds consisting of carbon, hydrogen, chlorine, and fluorine, once used widely as aerosol propellants and refrigerants. Believed to cause depletion of the atmospheric ozone layer.

coefficient of performance (COP)
A measure of efficiency in which a higher value designates a more efficient system. For example, Chiller efficiency measured in Btu output (cooling) divided by Btu input (electric power), measured at full or part load.

coil, condenser
A heat exchanger used to condense refrigerant from a gas to a liquid.

coil, cooling
Heat exchanger used to cool air under forced convection, with or without dehumidification. May consist of a single coil section or several coil sections assembled into a bank.

coil, heating
Heat exchanger that heats air under forced convection. May consist of a single coil section or several coil sections assembled into a bank.

condenser
Heat exchanger used to expel building heat absorbed in the evaporator of a refrigeration system.

constant volume (CAV, constant air volume).
Type of air-handling system that supplies the conditioned space at a constant air flow and modulate heating and cooling by varying the air temperature.

controls
An instrument or set of instructions for operating or regulating building systems.

cooling tower
Device that dissipates heat from water-cooled systems through a combination of heat and mass transfer, whereby the water to be cooled is distributed in the tower and exposed to circulated ambient air.

COP
See *coefficient of performance.*

dampers
Single- or multiple-blade devices, either manually or automatically opened or closed, that control the flow of air.

demand charges
Fees levied by a utility company for electric demand.

direct expansion system
Cooling system in which the refrigerant runs in the cooling coil to cool the air directly; that is, there is no water loop between the refrigerant and the air to be cooled.

downsizing
Process of reducing the size (capacity) of equipment so that it operates efficiently at design load conditions.

EER
Energy Efficiency Ratio. Cooling capacity (Btu/hr) divided by total input power (watts) requirement.

efficiency
Ratio of power output to power input.

EMS
See *energy management system.*

energy management system (EMS)
The control system that monitors the environment and energy usage in a building and alters equipment operation to conserve energy while providing occupant comfort.

fan, cooling tower
Fans that are used to draw air through the cooling tower to carry away water vapor.

gasket
Material used to seal a joint against leakage.

GPM
Gallons per minute. A measure of water flow rate.

heat-exchange area
Area where heat is transferred from one medium to another.

heat pump
Heat pump utilize the vapor compression refrigeration cycle the same that a DX unit or chiller does. The difference is that a heat pump can reverse the direction of heat flow which naturally flows from warmer to cooler areas.

HVAC
Heating, ventilating, and air-conditioning.

IEEE
Institute of Electrical and Electronic Engineers.

internal rate of return (IRR)
Compound interest rate at which the total discounted benefits become equal to total discounted costs for a particular investment.

IRR
See *internal rate of return.*

kilowatt (kW)
Unit of power equal to 1,000 watts.

kilowatt-hour (kWh)
Unit of electric consumption equal to the work done by one kilowatt acting for one hour.

kW
See *kilowatt.*

KWh
See *kilowatt-hour.*

load, cooling
Cooling (typically measured in Btu/hr or
tons) required to maintain an indoor design temperature.

part-load conditions
Time when equipment is operating at less than design loads; represents the majority of the time equipment is operating.

payback
See *payback, simple.*

payback, simple
Also known as *payback*. Measurement of the elapsed time between an initial investment and the point at which accumulated savings are sufficient to offset the initial investment.

peak (cooling) load
Maximum cooling required to maintain an indoor design temperature under the most adverse summertime outdoor air conditions.

pump, chilled-water
Device that circulates chilled water.

pump, condenser-water
Device that circulates condenser water.

refrigerant
Substance, such as *CFCs*, HCFCs, HFCs, air, ammonia, water, or carbon dioxide, used to provide cooling by evaporation and condensation.

seasonal energy-efficiency ratio (SEER)
Cooling capacity (Btu/hr) divided by total input power (watts) requirement where both are seasonal averages.

SEER
See *seasonal energy-efficiency ratio.*

setpoint
Desired temperature, humidity, or pressure in a space, duct, etc.

space
The distinct area to which conditioned air is delivered.

strainer screen
Filtering device used in water side systems to protect equipment from dirt, rust, and other particles.

TAB
See *testing, adjusting, and balancing*.

ton
Unit of cooling capacity equal to 12,000 Btu/hr.

variable air volume (VAV)
A type of air-handling system that provides air at a constant temperature and varies the air quantity to each zone to match the variation in room load.

variable-speed drive (VSD)
A device used to adjust the speed of an AC motor to match load requirements.

VAV
See *variable air volume.*

VSD
See *variable speed drive.*

water side systems
Equipment used to supply heating and cooling for air side systems. Includes pumps, chillers, boilers, and other devices.

Bibliography Organized By Chapter

Recommissioning

American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. (ASHRAE). *Fundamentals Handbook*. Atlanta: ASHRAE, 2001.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. *HVAC Applications Handbook*. Atlanta: ASHRAE, 1995.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. *HVAC Applications Handbook*. Atlanta: ASHRAE, 1996.

E Source. *Commissioning Existing Buildings. Technical Update*. Boulder: E Source, 1997.

E Source. *Space Cooling Atlas*.
Boulder: E Source, 1997.

E Source. *Space Heating Atlas*.
Boulder: E Source, 1996.

Turner, Wayne C. *Energy Management Handbook*. 2nd ed.
Lilburn, GA: The Fairmont Press Inc., 1993.

US Environmental Protection Agency Energy Star program. 430-B-97-002.
Financing Your Energy-Efficiency Upgrade. Washington, DC: GPO, 1997.

US Environmental Protection Agency Energy Star program. 430-R-97-004.
Introducing Your Company's Newest Profit Center. Washington, DC: GPO, 1997.
US Department of Energy - Energy Information Administration Office of Energy Markets and End Use. DOE/EIA-0625(95) *A Look at Commercial Buildings in 1995: Characteristics, Energy Consumption, and Energy Ex*Lighting

E Source. *Lighting Technology Atlas*.
Boulder: E Source, 1994.

Electric Power Research Institute. *Lighting Bulletin*, no. 6. April 1994.

Illuminating Engineering Society of North America. *Lighting Handbook: Reference & Application*, 8th ed. New York: Illuminating Engineering Society of North America, 1993.

Illuminating Engineering Society of North America. *Lighting Handbook: Reference & Application*, 9th ed. New York: Illuminating Engineering Society of North America, 2000.

Illuminating Engineering Society of North America. *The Advanced Lighting Guidelines:2001 Edition*. White Salmon, Washington: New Buildings Institute, Inc., 2001.

National Electrical Manufacturers Association. *The Management of Spent Electric Lamps Containing Mercury*. Washington, DC: National Electrical Manufacturers Association, 1992.

US Department of Energy. *Commercial Building Energy Consumption Survey*.
Washington, DC: GPO, 1994.

US Environmental Protection Agency. 430-B-95-004. *Lighting Waste Disposal*.
Washington, DC: GPO, 1997.

US Environmental Protection Agency. 430-B-95-008. *Lighting Upgrade Technologies.* Washington, DC: GPO, 1997.
Electric Power Research Institute, Inc. , Electric Power Research Institute, Inc. , Office Complexes Guidebook., Boulder: E4 Incorporated, 1997.

Portland Energy Conservation, Inc. (PECI) and Oak Ridge national Laboratory (ORNL). ORNL/TM-1999/34. A Practical Guide for Commissioning Existing Buildings. Portland: PECI, Oak Ridge, ORNL, 1999.

Fans

ASHRAE. *HVAC Systems and Equipment Handbook*. Atlanta: ASHRAE, 2000.

ASHRAE. *HVAC Applications Handbook*. Atlanta: ASHRAE, 1999.

Bonneville Power Administration. *Adjustable Speed Drive Guide Book*. Olympia, WA: Bonneville Power Administration, 1992.

California Energy Commission. *Guide to Preparing Feasibility Studies for Energy Efficiency Projects*. P400-00-002. Sacramento, CA: California Energy Commission, 2000.

Englander, S.L. and L.K. Norford. "Saving Fan Energy in VAV Systems, Part 1: Analysis of a Variable Speed Retrofit," *ASHRAE Transactions* 1992a: 98.

Englander, S.L. and L.K. Norford. "Saving Fan Energy in VAV Systems, Part 2: Supply Fan Control for Static Pressurization Minimization Using DDC Zone Feedback," *ASHRAE Transactions* 1992b: 98.

Lorenzetti, D., and L.K. Norford. "Measured Energy Consumption of Variable Air Volume Fans under Inlet Vane and Variable Speed Drive Control," *ASHRAE Transactions* 1992.

Washington State Energy Office. Motor Master software program. Olympia, WA: 1993.

Heating and Cooling

ACEEE. *Guide To Energy-Efficient Commercial Equipment, 2nd edition*. Washington, DC: The American Council For An Energy-Efficient Economy, 2000.

ASHRAE. *HVAC Applications Handbook*. Atlanta: ASHRAE, 1999.

ASHRAE. *HVAC Systems And Equipment Handbook*. Atlanta: ASHRAE, 2000.

Cleaver Brooks. *The Boiler Book, Systems Fundamentals*. Milwaukee, WI: Cleaver Brooks Division, Aqua-Chem, Inc., 1995.

E Source. *Commercial Space Cooling Technology Atlas*. Boulder, CO: E Source, 1997.

E Source. *Space Heating Technology Atlas*. Boulder, CO: E Source, 1996.

Turner, Wayne C. *Energy Management Handbook*. 2nd ed. Lilburn, GA: The Fairmont Press Inc., 1993.

US Environmental Protection Agency. Energy Star Web site: www.energystar.go/products.

penditures. Washington, DC: 1998.Inc., 1993.

Supplemental Loads

ASHRAE Journal, Sept., 1991.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. ASHRAE Standard 62-81. Atlanta: ASHRAE, 1981.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. ASHRAE Standard 62-1989. Atlanta: ASHRAE, 1989.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. ASHRAE Standard 62-1999. Atlanta: ASHRAE, 1999.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. *Fundamentals Handbook*. Atlanta: ASHRAE, 1993.

US Environmental Protection Agency ENERGY STAR labeled products. www.energystar.gov/products.

E Source. *Space Cooling Technology Atlas.* Boulder, CO: E Source, 1995.

Means, R.S. Building Construction Cost Data. Kingston, MA: R.S. Means Company, Inc., 1996.