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HANDBOOK OF ENERGY AUDITS

Eighth Edition



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Energy Audits*

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Preface

As a result of changes in the energy marketplace, the role of energy audits has greatly expanded. There is an increasing need in business and industry to more effectively manage energy use. Reducing utility costs is still one of the most effective and achievable strategies for lowering the operating costs.

Today, many large energy consumers are contracting with energy service providers to implement energy projects. This arrangement necessitates the establishing of baseline energy usage as well as quantification of savings resulting from project implementation. Accurate and complete energy audits are essential as a means to assess and verify a project's success at meeting contracted goals. This book is designed to provide you with the fundamental knowledge you need to evaluate how energy is used in commercial facilities, establish accurate baseline information, and identify where energy consumption can be reduced.

The *Handbook of Energy Audits* will also provide you with all the information you need to establish an energy audit program for your facility. Energy accounting procedures, electrical, mechanical, building and process systems analysis, life cycle costing, and maintenance management are all covered in detail.

This book is a first level energy audit reference for energy engineers as well as non-engineers and others new to the field of energy management. It will guide the reader through the audit process system by system to help them identify and prioritize conservation potential as well as identify several low-cost and no-cost operational and maintenance opportunities. The book provides practical example calculations to help readers understand and apply basic energy calculations to their projects.

By using this text, energy engineers can gain a better understanding of facility energy use and make valuable contributions to on-going efforts to improve energy efficiency.

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Chapter 1

Energy Auditing Basics

Energy audits can mean different things to different individuals. The scope of an energy audit, the complexity of calculations, and the level of economic evaluation are all issues that may be handled differently by each individual auditor and should be defined prior to beginning any audit activities. This chapter will review the various approaches to energy auditing and outline a standard approach to organizing and conducting an energy audit.

An energy audit can be simply defined as a process to evaluate where a building or plant uses energy, and identify opportunities to reduce consumption

There is a direct relationship to the cost of the audit, how much data will be collected and analyzed, and the number of conservation opportunities identified. Thus, a first distinction is made between cost of the audit which determines the type of audit to be performed. The second distinction is made between the type of facility. For example, a building audit may emphasize the building envelope, lighting, heating, and ventilation requirements. On the other hand, an audit of an industrial plant emphasizes the process requirements.

TYPES OF ENERGY AUDITS

Before starting the energy audit, it is helpful to have some idea of the scope of the project and level of effort necessary to meet expectations. There are three basic types or levels of energy audit, any of which may meet your requirements.

The basic audit levels, in order of increasing complexity are:

Level I—The Walk-through Audit

The walk-through audit, as its name implies, is a tour of the facility to visually inspect each of the energy using systems. It will typically include an evaluation of energy consumption data to analyze energy use quantities and patterns as well as provide comparisons to industry aver-

ages or benchmarks for similar facilities. It is the least costly audit but can yield a preliminary estimate of savings potential and provide a list of low-cost savings opportunities through improvements in operational and maintenance practices. The level one audit is also an opportunity to collect information for a more detailed audit later on if the preliminary savings potential appears to warrant an expanded scope of auditing activity.

Level II—Standard Audit

The standard audit goes on to quantify energy uses and losses through a more detailed review and analysis of equipment, systems, and operational characteristics. This analysis may also include some on-site measurement and testing to quantify energy use and efficiency of various systems. Standard energy engineering calculations are used to analyze efficiencies and calculate energy and costs savings based on improvements and changes to each system. The standard audit will also include an economic analysis of recommended conservation measures.

Level III—Computer Simulation

The level three audit will include more detail of energy use by function and a more comprehensive evaluation of energy use patterns. This is accomplished through use of computer simulation software. The auditor will develop a computer simulation of building systems that will account for weather and other variables and predict year-round energy use. The auditor's goal is to build a base for comparison that is consistent with the actual energy consumption of the facility. After this baseline is built, the auditor will then make changes to improve efficiency of various systems and measure the effects compared to the baseline. This method also accounts for interactions between systems to help prevent overestimation of savings. Because of the time involved in collecting detailed equipment information, operational data, and setting up an accurate computer model, this is the most expensive level of energy audit but may be warranted if the facility or systems are more complex in nature.

TYPES OF ENERGY AUDITS AND WHAT THEY TELL YOU

(Ref. Procedures for Commercial Buildings Energy Audits, 2005 ASHRAE)

- The U.S. Green Building Council LEED—Existing Buildings: Operations and Maintenance offers energy credits for completing ASHRAE Level II Energy Audits.

- Energy efficiency experts generally recognize three levels of energy audits, depending on the time and effort spent during the audit and analysis.

Level I—Basic

- Also known as the “one-day” or “walk-through” audit, this approach involves a cursory analysis of energy bills and a brief survey of the building to produce a rough estimate of how efficiently energy is used in the building
- This level of effort will detect at least some of the “low-hanging fruit” and may suggest other options worthy of more study, but should never be viewed as comprehensive.
- Although this option is easiest, it also produces the crudest results, so don’t be tempted into thinking you’re done once you do this much—you’ve really only gotten started.

Level II—Intermediate

- By investing more effort in the building survey and energy analysis, and by adding some system performance testing, this method provides a breakdown of how energy is used in the building as well as a broader range of savings options, including simple capital investments.
- It accounts for the “people factor” and its effect on uncertainty of savings, and also explores maintenance procedures and assesses any impacts savings measures may have on them.
- Many facilities will find this level of analysis to be sufficient.

Level III—Advanced

- Also known as the “investment-grade audit,” this analysis digs into the details of any large capital projects you may be considering as a result of previous, simpler audits.
- Even more detailed data are gathered from field equipment. Extensive test measurements are taken which may include spot measurements and short-term energy monitoring. Possible risks are assessed, and intensive engineering and economic analysis produces reliable estimates of project energy and financial performance with the high confidence needed for major capital projects.

- These audit approaches tend to overlap in practice. All three assess the potential energy savings and initial cost of various energy savings strategies, so in that sense all are similar. The differences are in your confidence that you've truly found all your savings opportunities, the accuracy of the expected savings and initial cost, and how much information you have about the difficulty of the project implementation and the likely persistence of the savings over time. The devil is definitely in the details.
- All level II and level III audits involve collecting general building data (location, size, usage type, energy sources), historical energy use data, and energy systems data (type of equipment in the envelope, lighting, HVAC, service water, etc.) to get a description of the facility. The more detailed the available data are, the more complete this description can be. For example, submetering within a building makes it easy to call out specific end uses or facility areas, and having daily or even hourly consumption data allows you to call out time patterns normally buried within the monthly billing cycle.
- All these data then feed an energy use analysis that lays out how much energy is consumed for each major end use in the building, such as space heating, space cooling, lighting, air distribution, etc. This defines a baseline scenario for future years, is no energy projects are undertaken. A similar analysis can be done with respect to peak energy demand
- If you're serious about saving as much energy cost as possible with the quickest payback time and least hassle, take the time to plan your energy projects right. Perform a good energy audit, and assess its results carefully based on the needs of your facility, whether based on annual savings, initial cost, payback time, synergistic comfort benefits to occupants, or recurring maintenance hassle. The rewards are well worth the work.

The Association of Energy Engineers has developed two certification programs for professionals practicing energy auditing: The Certified Energy Auditor (CEA) Program and the Certified Energy Manager (CEM) Program.

THE CERTIFIED ENERGY AUDITOR (CEA) PROGRAM FOR PROFESSIONAL CERTIFICATION



The Mark of an Energy Professional

In 2006, the Certified Energy Auditor (CEA) and Certified Energy Auditor in Training (CEAIT) certifications were developed and added to the impressive portfolio of certifications offered by the Association of Energy Engineers. Rising energy costs and inefficiency in plants and buildings is continually driving the need for trained and experienced energy auditors. The CEA certification is one that identifies professionals as having the required knowledge and experience needed to succeed in the growing field of energy auditing.

Objectives

- To raise the professional standards of those engaged in energy auditing.
- To improve the practice of energy auditors by encouraging energy auditing in a continuing education program of professional development.
- To identify persons with acceptable knowledge of the principles and practices of energy auditing through completing an examination and fulfilling prescribed standards of performance and conduct.
- To award special recognition to those energy auditing professionals who have demonstrated a high level of competence and ethical fitness in energy auditing.

The Certified Energy Manager (CEM) Program for Professional Certification



When you've earned the right to put the initials "CEM" behind your name, you've distinguished yourself among energy management

professionals. Simply put, the designation CEM, which stands for Certified Energy Manager, recognizes individuals who have demonstrated high levels of experience, competence, proficiency, and ethical fitness in the energy management profession. By attaining the status of CEM, you will be joining an elite group of 6,000 professionals serving industry, business and government throughout the U.S. and in 22 countries abroad. These high-achieving individuals comprise a "Who's Who" in the energy management field.

The Mark of An Energy Professional

Since its inception in 1981, the Certified Energy Manager (CEM®) credential has become widely accepted and used as a measure of professional accomplishment within the energy management field. It has gained industry-wide use as the standard for qualifying energy professionals both in the United States and abroad. It is recognized by the U.S. Department of Energy, the Office of Federal Energy Management Programs (FEMP), and the U.S. Agency for International Development, as well as by numerous state energy offices, major utilities, corporations and energy service companies.

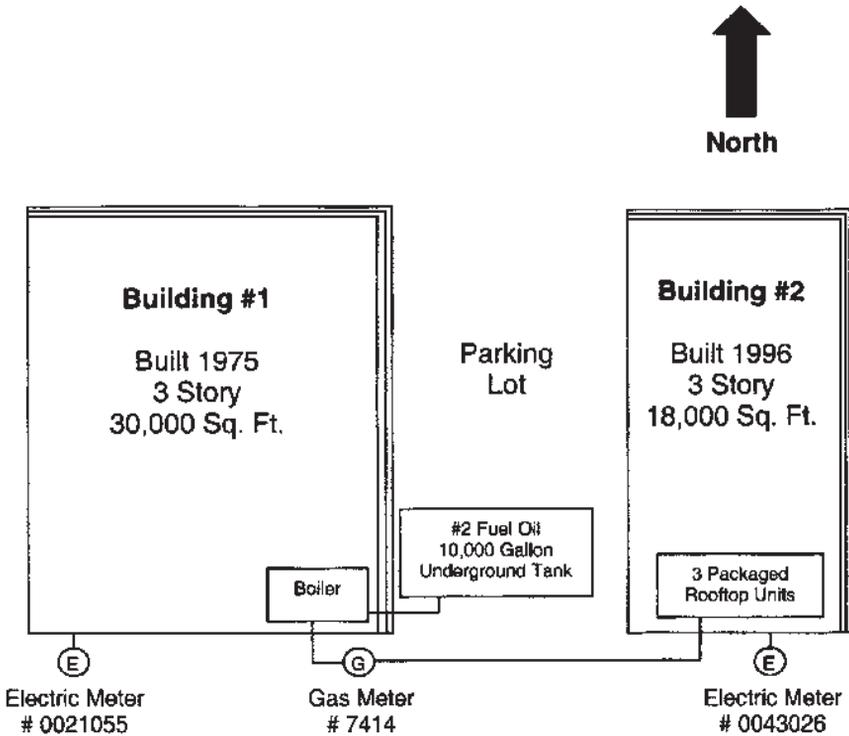
THE AUDIT PROCESS

Once you have established the level of audit to be performed, you can begin collecting information on the structural and mechanical components that affect building energy use, and about the operational characteristics of the facility. Much of this information can and should be collected prior to the actual site-visit. A thorough evaluation of energy use and systems before going on-site will help identify areas of savings potential and help make best use of your on-site time.

An organized approach to auditing will help you collect useful information and reduce the amount of time spent evaluating your facility. By splitting the audit process into three distinct components, *pre-site work*, *the site visit*, and *post-site work*, it becomes easier to allocate your time for each step and leads to a more comprehensive and useful audit report. The following sections describe the tasks associated with each step of the audit process.

PRE-SITE WORK

Pre-site work is important in getting to know basic aspects of the building. This preparation will help ensure the most effective use of your



Site Sketch

on-site time and minimize disruptions to building personnel.

A thorough pre-site review will also reduce the time required to complete the on-site portion of the audit. The pre-site review of building systems and operation should generate a list of specific questions and issues to be discussed during the actual visit to the facility.

Pre-site Tasks

- 1) Collect and review two years of utility energy data. Tabulate and graph the data. Check for seasonal patterns, unusual spikes, and accuracy of the billings. Graphing consumption and cost data makes it easier to understand how each building uses energy. By determining seasonal and base loads, then apportioning energy use among specific building systems such as heating, cooling, lighting and hot water, it becomes easier to identify areas with the greatest savings potential. It's also important to include electric demand kilowatts and demand charges in your evaluation. (See Energy Accounting section for additional information on utility bill analysis.)

Pie charts of energy use and cost by fuel type can offer compelling documentation of overall energy uses and expenses.

- 2) Obtain mechanical, architectural, and electrical drawings and specifications for the original building as well as for any additions or remodeling work that may have been done. Try the local building department or original architect if the owner doesn't have them. If any energy audits or studies have been done in the past, obtain a copy and review them.
- 3) Draw a simple floor plan of the building on 8-1/2 × 11 or 11 × 17 inch paper. Make several copies to use for taking notes during the actual site visit. Use separate copies for noting information on locations of HVAC equipment and controls, heating zones, light levels and other energy related systems.
- 4) Calculate the gross square footage using outside building dimensions multiplied by the number of stories. Substantial areas that are not conditioned and occupied can be subtracted from the gross square footage.
- 5) Use audit data forms to collect, organize and document all pertinent building and equipment data. Audit workbooks containing checklists, equipment schedules, and other forms are available from a variety of sources including ASHRAE and your State Energy Office. You may also find it useful to develop your own forms to meet your specific needs. To save time, fill out as much of the form as possible using the building plans and specifications before starting on-site work.
- 6) Develop a building profile narrative that includes age, occupancy, description, and existing conditions of architectural, mechanical, and electrical systems. Note the major energy consuming equipment or systems.
- 7) Calculate the energy use index (EUI) in Btu/sq ft/year and compare it with EUIs of similar building types using the chart in the energy accounting section. The EUI is calculated by converting annual consumption of all fuels to Btus then dividing by the gross square footage of the building. It can be a good indicator of the relative potential for energy savings. A comparatively low EUI indicates less potential for large energy savings.

While completing your pre-site review, note areas of particular interest and write down any questions you may have in advance. Typical questions may concern lighting type and controls, HVAC zone controls or morning warm-up operation. Other questions may be on maintenance practices for pieces of equipment you've identified which typically require regular servicing.

If you are auditing a building other than one you operate, obtain the data discussed above and confirm your preliminary observations with the building manager or operator by phone prior to your visit. Ask them if they are interested in particular conservation projects or planning changes to the building or its systems. Try to schedule the audit at a time when the systems you want to check are in operation and arrange to have the building operator accompany you during the site visit.

Develop a list of potential energy conservation measures (ECMs) and operation and maintenance (O&M) procedures as you conduct this preliminary research. Your state energy office or local utility companies should be able to provide you with more information on conservation technologies and O&M recommendations. If you do some homework first, you will be better able to discuss energy saving measures with the building manager.

Develop a Site Sketch

Prepare a site sketch of the building or complex which shows the following information:

- Relative location and outline of the building(s).
- Name and building number of each building. (Assign building numbers if none exist.)
- Year of construction of each building and additions.
- Square footage of each building and additions.
- Location, fuel type and I.D. numbers of utility meters.
- Areas served by each utility meter.
- Location of heating and cooling plants and equipment.
- North orientation arrow.

The Site Visit

With pre-site work completed, you should have a basic understanding of the building and its systems. The site visit will be spent inspecting actual systems and answering specific questions from your pre-site review.

Plan to spend at least a full day on-site for each building. The amount of time required will vary depending on the completeness of the pre-site information collected, the complexity of the building and systems, and the need for testing of equipment. Small buildings may take less time. Larger buildings can take two days or more.

Here are some steps to help you conduct an effective audit:

- Have all necessary tools available on site. Try to anticipate basic hand tools and test equipment you will need to perform a thorough inspection. Some basic audit tools you'll want to bring along include:
 - Notebook
 - Calculator
 - Flashlight
 - Tape Measure
 - Pocket Thermometer
 - Light Meter
 - Pocket Knife
 - Camera

A more detailed description of specialized audit instrumentation is included in Chapter 4.

- Prior to touring the facility, sit down with the building manager to review energy consumption profiles and discuss aspects of the facility you aren't able to see such as occupancy schedules, operation and maintenance practices, and future plans that may have an impact on energy consumption.
- Confirm the floor plan on your drawing to the actual building and note major changes. Use copies of the floor plan to note equipment locations such as boilers, chillers, DHW heaters, kitchen appliances, exhaust fans, etc., as well as lighting types, levels, and switching, photo locations, room temperatures, general conditions and other observations.
- Fill out the audit data sheets. Use them to organize your site visit and as a reminder to collect information missing from pre-site documents.
- Look at the systems relating to the ECMs and O&Ms on your preliminary list. Review the application of your recommendations and

note any problems that may affect implementation. Add additional measures to your list as you tour the facility.

- Take pictures as you walk through the building. Include mechanical equipment, lighting, interior workspaces, common areas and halls, and the exterior including the roof. They are useful in documenting existing conditions, discussing problems and issues with colleagues, as well as serving as a reminder of what you inspected. Building managers will find them useful for explaining conservation measures to administrators and building occupants.

POST-SITE WORK

Post-site work is a necessary and important step to ensure the audit will be a useful planning tool. The auditor needs to evaluate the information gathered during the site visit, research possible conservation opportunities, organize the audit into a comprehensive report, and make recommendations on mechanical, structural, operational and maintenance improvements.

Post-site work includes the following steps:

- Immediately after the audit, review and clarify your notes. Complete information you didn't have time to write down during the audit. Use copies of the floor plan to clean up notes for permanent records.
- Review and revise your proposed ECM and O&M lists. Eliminate those measures lacking potential and document why they were eliminated. Conduct preliminary research on potential conservation measures and note conditions that require further evaluation by an engineer or other specialist.
- Process your photos and paste or import pictures on 8-1/2 × 11 inch pages. Number the photographs and note on a floor plan the location where each photo was taken. Identify and add notes under the pictures as needed.
- Organize all charts, graphs, building descriptions, audit data sheets, notes and photos into a 3 ring binder. Energy auditing can be an ongoing process. By keeping all building information in a dedicated binder or file, records can be easily added or updated

and can be very useful to architects and engineers if future work is done on the building.

THE AUDIT REPORT

The general flow of audit activities is to identify all energy systems, evaluate the condition of the systems, analyze the impact of improvements to those systems, and write up an energy audit report. This report explains the existing conditions of the building(s) in terms of the envelope, equipment, lighting, and occupancy, followed by recommendations to improve efficiency through improvements in operation and maintenance items, or O&Ms, and through installation of energy conservation measures, or ECMs.

Effectively communicating audit findings and recommendations increases the chance of action being taken to reduce energy consumption. When preparing the audit report, keep in mind the various audiences that will be using each section and try to customize each section to most effectively reach that audience.

Typical audiences for audit reports include:

- CEO, COO, Administrator, Superintendent
- Facilities and Plant Managers
- CFO, Controller
- Plant Engineer
- Operations and Maintenance Staff

The following outlines the basic components of a well-organized audit report:

I. Executive Summary

The Executive Summary should be a simple, straight forward and to the point explanation of the current situation, recommended improvements, and advantages of taking recommended actions. Include a brief introduction to the facility and describe the purpose of the audit and overall conclusions. An executive may read no further than this one or two-page introduction so make sure that you have expressed very clearly what specific actions you want them to take.

II. Building Information

This section provides a general background of the facility, its mechanical systems, and operational profile. It should include a description of the building envelope, age and construction history, operating schedules, number of employees and occupancy patterns, and a discussion of the operation and maintenance program. It is also useful to include a floor plan, selected photos of the facility and mechanical systems, a description of energy types used in the plant, and a description of the primary mechanical systems and controls.

III. Utility Summary

Energy Accounting information for the last two years is included in this section. Attach selected charts and graphs that were developed for analysis that are easy to understand and demonstrate the overall consumption patterns of the facility. Choose the information for each graph to suit each target audience. For example, actual monthly consumption by fuel type may be of more interest to the engineering and maintenance staff while annual costs or dollar-savings information may be more appropriate for administrative personnel. Pie charts of energy use and cost by fuel type can offer compelling documentation of overall energy uses and expenses.

Include a summary of overall facility benchmarks, energy use indices, and comparisons with industry averages.

You may also want to include a copy of the utility rate schedules and any discussion or evaluation of rate alternatives for which the facility may qualify.

IV. Energy Conservation Measures (ECMs)

Begin this section with a summary list of Energy Conservation Measures that meet the financial criteria established by the facility owner or manager. For each measure, include the measure name, estimated cost, estimated savings, and simple payback in a summary chart. A one or two page description of each energy conservation measure and support calculations should follow this summary chart. Include the ECM description, energy use and savings calculations, and the simple payback, net present value or life cycle cost analysis. It's also a good idea to discuss any assumptions that were made regarding operation or equipment efficiency. ECMs that were considered but fell out of current financial criteria should also be listed and identified as have been evaluated.

V. Operation and Maintenance Measures (O&Ms)

This section will address operational and maintenance issues observed during the site visit. Include descriptions of specific low-cost operational and maintenance items that require attention. Include items that will reduce energy consumption and costs, address existing problems, or improve practices that will help prolong equipment life of systems not being retrofit. It is also useful to the owner to include cost and savings estimates of O&M recommendations.

VI. Appendices

Support material and technical information not included elsewhere in the report can be added to the appendices. Typical information in this section includes, floor plans and site notes as appropriate, photos, audit data forms, motor, equipment, and lighting inventories, and equipment cut sheets of existing or recommended systems.

SUMMARY

When you've completed your audit activities, you should have a good understanding of the primary drivers affecting facility energy use. By identifying the energy consuming components of a building or plant and documenting the existing conditions, conservation opportunities can be identified and prioritized. Set up a meeting with the building or plant manager to go over your report. Discuss your recommendations for conservation actions, methods of funding ECMs. Include training recommendations for building operators and occupants that will improve the operating efficiency of the building as well as training required for maintenance and operation of newly install measures.

Chapter 2

Energy Accounting and Analysis

As previously stated, the overall purpose of the energy audit is to evaluate the efficiency in which the building systems use energy to provide a comfortable work environment. In this evaluation, the energy auditor will typically start at the utility meters to locate all energy sources coming into the facility. The auditor will then identify energy streams for each fuel, quantify those energy streams into discrete functions, evaluate the efficiency of each of those functions, and identify energy & cost savings opportunities.

The first task is to collect and review two years of utility energy data for all fuels. This includes electricity, natural gas, fuel oil and any other delivered fuels. This information is used to analyze operational characteristics, calculate energy benchmarks for comparison to industry averages, estimate savings potential, set an energy reduction target, and establish a baseline to monitor the effectiveness of implemented measures.

Several steps must be taken to ensure you have all the information required to do a thorough and accurate evaluation of energy consumption data.

- Make sure you receive copies of all monthly utility bills and delivered fuel invoices.
- Sort utility bills by building or by meter, and organize them into 12-month blocks using the meter-read dates.
- Locate all meters and sub-meters. If numerous meters are used, it is helpful to clearly label them on a site plan for each building being evaluated.
- Verify that all meter numbers match with those on the account.

- Determine which building or space is being served by each meter.
- Calculate conditioned area (in square feet) for each building.

SPREADSHEET SET-UP

Set up a spreadsheet to enter, sum, calculate benchmarks, and graph utility information. The sample energy accounting form in Figure 2-1 can be used as a template to organize your data. Record energy units (kWh, therms, gallons, etc.), electric demand (kW), and dollars spent for each fuel type. Units of production (number of units, occupied rooms, students, persons served, etc.) can also be included in your analysis if such production is directly related to energy consumption. By analyzing the data, it is possible to identify relationships between energy use and other factors such as occupancy, sales volume, floor area, production rates, and outdoor temperatures.

THE ENERGY USE INDEX

Each energy type will be converted to a common unit (Btus) for comparison and calculation of total energy consumed. The Energy Use Index (EUI) is the most common means of expressing the total energy consumption for each building. The EUI is expressed in Btus/Square Foot/Year and can be used to compare energy consumption relative to similar building types or to track consumption from year to year in the same building.

The EUI is calculated by converting annual consumption of all fuels to Btus then dividing by the gross square footage of the building. It can be a good indicator of the relative potential for energy savings. A comparatively low EUI indicates less potential for large energy savings. Figure 2-2 provides typical ranges for total energy use for a variety of commercial building types.

CONDITIONED AREA

To calculate Btus and dollars per square foot, it is necessary that an accurate assessment of heated area be calculated for each building. This can be done by referring to the dimensions in the blueprints or

Facility Name: _____
 Facility Type: _____
 Electric Utility: _____
 Gas Utility: _____
 Gross Square Footage: _____

Electric Meter # _____ Electric Rate Schedule: _____
 Gas Meter # _____ Gas Rate Schedule: _____

Year:		Electricity						Natural Gas				Totals		Energy Use Index	
Month	# Days In Billing Period	Electric Usage kWh	Electric Demand kW	Electric Cost \$	Electric Unit Cost \$/kWh	Electric MMBtu kWh × .003413	Load Factor $\frac{\text{kWh}}{\text{kW} \times \text{Days} \times 24}$	Gas Usage Therms	Gas Cost \$	Gas Unit Cost \$/Therm	Gas MMBtu Therms/×.10	(A) MMBtu Consumed	(B) Cost of Energy	(C) EUl Btu/Sq.Ft.	(D) Cost \$/Sq.Ft.
Jan															
Feb															
Mar															
Apr															
May															
Jun															
Jul															
Aug															
Sep															
Oct															
Nov															
Dec															
Annual Totals															

Data Entry and Calculations

- A. Transfer consumption and cost information from energy bills to data sheet. Add columns for other fuels as needed.
- B. Convert kWh and therms to MMBtus using the formulas at the top of each column or conversions below.
 (Electric kWh × .003413, Gas Therms × .10, #2 Fuel Oil Gallons × .14, Propane Gallons × .0915)
- C. Calculate Fuel Unit Costs and Electric Load Factor using formulas at top of each column.
- D. Total electric and fuel MMBtus consumed and costs for each month and enter in the TOTALS column.
- E. Total all columns (calculate average for demand, unit cost, and load factor).
- F. Calculate annual Energy Use Index in Btu/Square Foot/Year by multiplying total MMBtu consumed (Column A) by 1,000,000 then divide by the Building Gross Square Footage.

$$\text{Btu/Square Foot/Year} = \text{Column A total} \times 1,000,000 / \text{Building Sq. Ft.}$$
- G. Calculate Dollars per Square Foot by dividing the total cost of energy (Column B) by the Building Square Footage.

$$\text{Dollars/Square Foot/Year} = \text{Column B total} / \text{Building Sq.Ft.}$$

Figure 2-1. Sample Energy Accounting Form

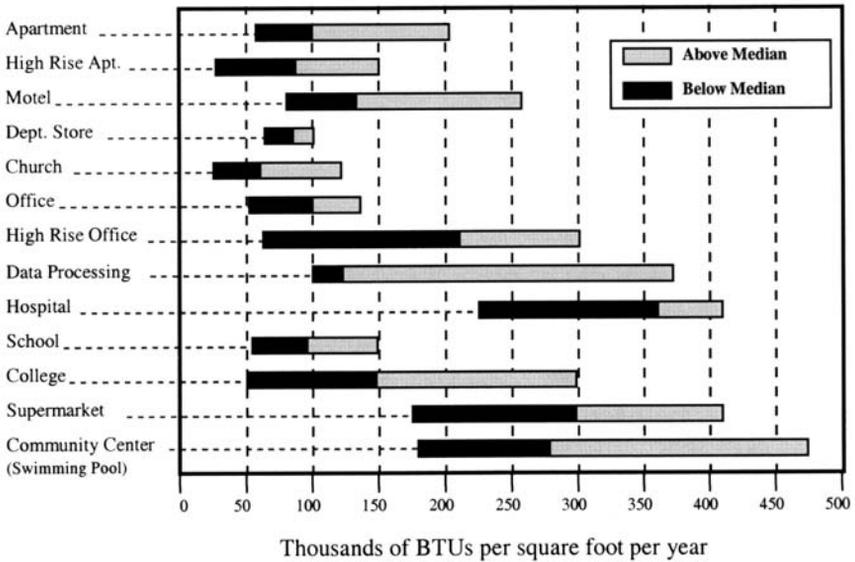


Figure 2-2. Energy Use Index by Building Type

by measuring the outside dimensions of the building (length × width), and multiplying this area by the number of floors. Generally, basement areas and mechanical rooms are not included as conditioned areas unless HVAC equipment is installed and operating.

ELECTRICITY COSTS

Evaluating kWh, kW, and power factor charges separately (Figure 2-3) can be useful in evaluating the impact of demand and power factor penalties on the monthly electric bill. High demand costs can sometimes be lowered by simply rescheduling or alternating run times of particular pieces of equipment. Savings from installation of power factor correction devices often have paybacks less than two years. Although demand and power factor measures save little if any energy, the significant cost savings and relatively short payback periods make them attractive measures to include in the audit analysis.

Electric Demand

Care should be taken to distinguish between billing and actual demand on the utility bill. Actual demand is the figure registered on

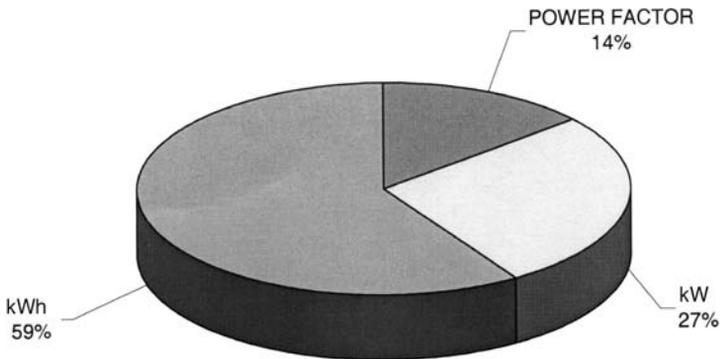


Figure 2-3. Electricity Cost Breakdown

the meter and should be used to evaluate power requirements and load factor of the facility. Billing demand is the amount of demand for which the facility is actually billed. This figure may be different than the actual demand due to various types of rate schedules. Rate schedules that include a ratchet clause, power factor adjustment, or first block of kW at no charge can cause billing and actual demand to be different. A more detailed discussion of utility rate structures is included in chapter 3.

Load Factor

Depending on the facility, the demand charge can be a significant portion, as much as 20 to 40% of the utility bill. The user will get the most electrical energy per dollar if the load is kept constant, thereby minimizing the demand charge. The objective of demand control is to even out the peaks and valleys of consumption by deferring or rescheduling the use of energy during peak periods.

A measure of the electrical efficiency of a facility can be found by calculating the load factor. The load factor is the relationship between electric kWh consumption and kW demand for the same billing period. It is commonly calculated by dividing the monthly kWh consumption by the kW demand multiplied by the number of hours in the billing period. This gives a ratio of average demand to peak demand and is a good indicator of cost savings potential of shifting some electric loads to off peak hours to reduce overall demand.

$$\text{Load Factor} = \frac{\text{kWh} \times \# \text{ Hours}}{\text{Peak kW} \times \# \text{ hours in time period}}$$

If a facility were to consume electricity at a steady rate at the highest demand registered on the demand meter, the load factor would be 1.00 (one), the theoretical maximum. This indicates that the facility does not have any variance in consumption or time of day peaks in demand. Other than installing more efficient electrical equipment, little can be done to reduce demand because this facility is already taking full advantage of the demand for which it is being billed.

A low load factor is a good indication that a facility has demand spikes at some point in the billing period. In this case, action should be taken to identify when the spikes occur and operation of nonessential equipment should be restricted at that time or rescheduled for operation during off peak hours.

The ideal load factor should be as close to 1.00 as possible. However, most facilities don't operate 24 hours a day, so load factors will typically be considerably lower than the theoretical maximum. If a building operates only 12 hours a day, for example, then a load factor of .50 may be the highest possible for that building. The important thing is to monitor the load factor and establish what is normal for each facility and meter, noting any significant changes in the kWh consumption and kW demand ratio.

Many energy management control systems (EMCS) have demand limiting and load shedding capabilities which can help maintain acceptable load factors if properly used.

SIM 2-1

What is the load factor of a continuously operating facility the consumed 800,000 kWh of energy during a 30-day billing period and established a peak demand of 200 kW?

ANSWER

$$\text{Load Factor} = \frac{800,000 \text{ kWh}}{2000 \text{ kW} \times 30 \text{ days} \times 24 \text{ hours/day}} = 0.55$$

Graphs and Reports

Once energy data have been collected and organized, they must be made comprehensible to the energy auditor for analysis purposes as well as those who will be receiving the energy audit report. Creating graphs, tables, and pie charts provide essential information, but in a more visually appealing form than text. Graphing consumption and

cost data makes it easier to see consumption trends and understand how each facility uses energy.

Analyzing Energy Data

Analysis of graphs and consumption data is important in understanding how energy is used at the facility and which factors affect consumption the greatest. This is done by identifying energy using systems in the building and determining how each system operates throughout the year. Some systems will operate all year long while others may only operate during the summer or winter months. Annual energy consumption is then broken into base and seasonal loads and equipment is fit into each category. This helps identify which equipment or systems are most energy intensive so measures can be evaluated which reduce consumption in those areas.

Base Loads

Base loads are the energy-using systems that consume a continuous amount of energy throughout the year. The base load can be established by drawing a horizontal line across a graph of energy consumption or cost at the average point of lowest consumption for each energy type. The base load is that portion of consumption or cost below the line as shown in Figure 2-4. Typical base loads include lighting, office equipment, appliances, domestic hot water, and ventilation. High base loads

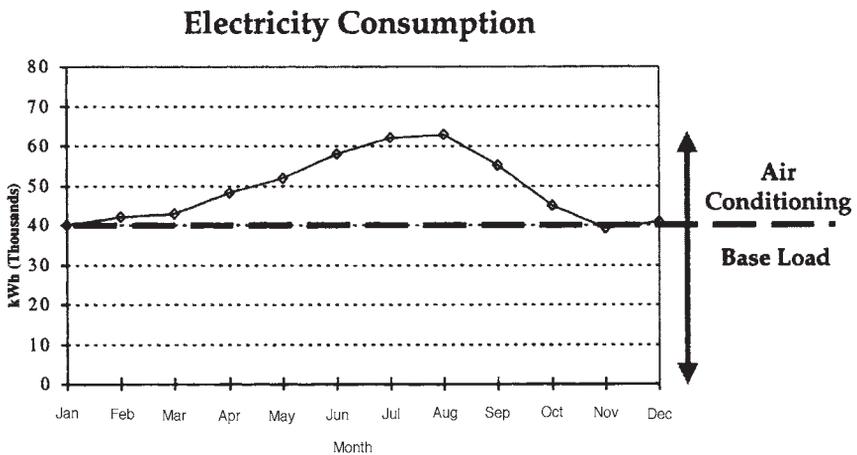


Figure 2-4. Base and Seasonal Loads

indicate conservation efforts should be focused in these areas.

Seasonal Loads

Seasonal loads, such as heating and air conditioning, are identified as the portion of consumption or cost located above the line used to establish base loads on the graph. Seasonal loads can be the result of changes in weather or operation of the building, such as the school season.

High seasonal loads may reveal an opportunity to reduce consumption by making improvements to the heating and air conditioning equipment, temperature controls, the building envelope, or to other systems which are affected by seasonal operation.

Consumption Trends

One of the easiest ways to evaluate consumption data is to watch for upward or downward trends in kWh, demand, natural gas, or costs. This can be done by graphing two or more years of monthly data on one graph or by graphing only the annual totals for several years.

Rolling 12-Month Method

Another useful method for evaluating monthly data is a rolling summary whereby a new 12-month total is calculated each month by dropping the oldest month and adding the newest. A graph of this type will remain a relatively flat line if no significant changes in energy consumption occur. Even though each monthly figure is an annual total, any sudden change is the result of that month's operation. This is good graph for the energy auditor to see the overall consumption trends of the facility. A gradual increase, for example, may indicate that occupancy or production has increased, or that system efficiency is slowly degrading. The graph shown in Figure 2-5 can be a useful evaluation tool as it shows the monthly consumption as well as the rolling annual trend on a separate y-axis. As you can see, it takes 12 months of data to begin charting the annual trend.

INCREASED CONSUMPTION

An increase in annual natural gas consumption can be the result of several factors. Further analysis can determine which of these factors is most likely the cause of the increased consumption.

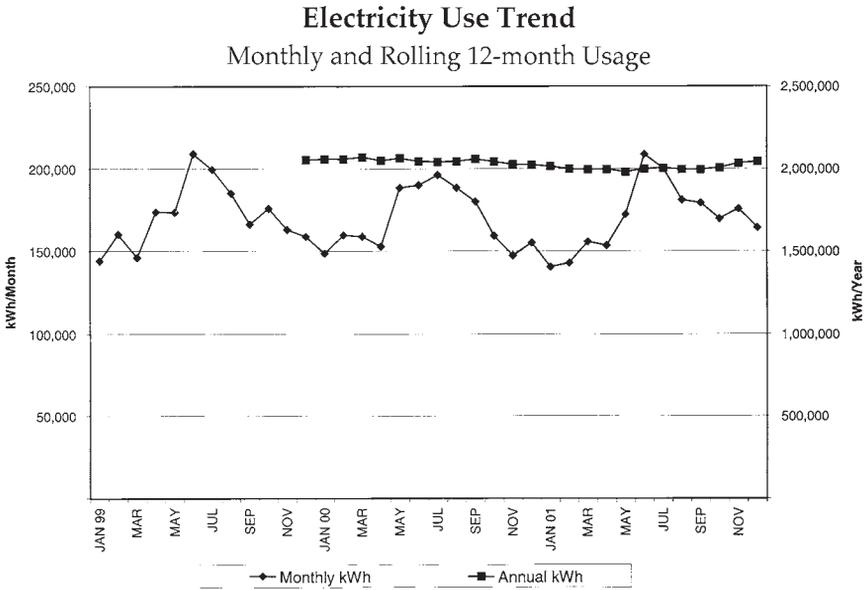


Figure 2-5.

- 1) Determine THERM/Degree-Day consumed for previous year.
- 2) Multiply by number of degree-days for current year to obtain estimated natural gas consumption.
- 3) If actual consumption is equal to or less than estimated consumption, the increase is due to weather conditions.
- 4) If actual consumption is significantly greater than estimated consumption, factors other than weather are the cause of this increase.
- 5) Determine if new gas-consuming equipment has been installed or if floor space has been added.
- 6) If no new equipment or floor space was added, the increase in consumption is most likely the result of a problem in the heating system. Provide corrective maintenance and continue to monitor monthly consumption.

ENERGY-USING SYSTEMS

After utility use has been broken down by seasonal and base loads, make a list of the major energy-using systems in each facility and estimate when each system is in operation throughout the year. As you

develop your list, think about how each system uses energy and where potential savings may exist. You can add more specific components to the list as you learn more about the plant or building. By determining seasonal and base loads, then apportioning energy use among specific building systems such as heating, cooling, lighting and hot water, it becomes easier to identify areas with the greatest savings potential and target the energy audit activities to those systems. Using the Comparative Energy End Use by System in Table 2-1 will assist you in ranking energy end use based on climate zones. While each individual building must be analyzed separately, studies have shown that similar buildings in similar climates tend to demonstrate recurring patterns of energy use.

COMMERCIAL ENERGY USE PROFILES

The following tables illustrate the variation in use (by %) of different energy functions for several commercial building types. Compare the functions of the audited facility to each of these categories in order to determine which profile the facility will most closely resemble. These tables will serve as a general guideline to help identify major energy consuming systems. Keep in mind that energy use in individual buildings and similar building types in different climates will vary.

IDENTIFYING POTENTIAL MEASURES

Once the end use profiles have been estimated, the auditor will use this information to develop an initial list of potential energy conservation measures (ECMs) and prioritize on-site audit activities. The most common ECMs found in existing commercial buildings typically fall into the following categories.

- Building Operation
- Lighting Systems
- HVAC Systems
- HVAC Distribution Systems
- Energy Management Control Systems
- Building Envelope
- Power Systems
- Water Heating Systems
- Heat Recovery Opportunities
- Renewables—solar, wind, geothermal

Table 2-1. Comparative Energy Use by System

Building Type	Climate Zone	Heating & Ventilation	Cooling & Ventilation	Lighting	Power & Process	Domestic Hot Water
Schools	A	4	3	1	5	2
	B	1	4	2	5	3
	C	1	4	2	5	3
Colleges	A	5	2	1	4	3
	B	1	3	2	5	4
	C	1	5	2	4	3
Office Buildings	A	3	1	2	4	5
	B	1	3	2	4	5
	C	1	3	2	4	5
Commercial Stores	A	3	1	2	4	5
	B	2	3	1	4	5
	C	1	3	2	4	5
Religious Buildings	A	3	2	1	4	5
	B	1	3	2	4	5
	C	1	3	2	4	5
Hospitals	A	4	1	2	5	3
	B	1	3	4	5	2
	C	1	5	3	4	2

Climate Zone A: Fewer than 2500 Degree Days

Climate Zone B: 2500 - 5500 Degree Days

Climate Zone C: 5500 - 9500 Degree Days

Note: Numbers indicate energy consumption relative to each other.

(1) Greatest Consumption

(2) Least Consumption

Source: Guidelines For Energy Savings in Existing Buildings ECM-1

Table 2-2. Energy Use in Office Buildings

<i>Energy Use in Office Buildings</i>	<i>Range (%)</i>	<i>Norm (%)</i>
Space Heating	45-65	50
Air Conditioning	20-30	25
Lighting	15-25	20
Special Functions (elevators/escalator, general power, security lights, domestic hot water, refrigeration, cooking)	5-10	5

Table 2-3. Energy Use in Retail Stores

<i>Energy Use in Retail Stores</i>	<i>Range (%)</i>	<i>Norm (%)</i>
Lighting	40-75	60
HVAC	20-50	30
Special Functions (elevators/escalator, general power, security lights, domestic hot water, refrigeration, cooking)	5-20	10

Table 2-4. Energy Use in Schools

<i>Energy Use in Schools</i>	<i>Range (%)</i>	<i>Norm (%)</i>
HVAC	45-80	65
Lighting	10-20	15
Food Service	5-10	7
Hot Water	2-5	3
Special Functions	0-20	10

Table 2-5. Energy Use in Hospitals

<i>Energy Use in Hospitals</i>	<i>Range (%)</i>	<i>Norm (%)</i>
Environmental Control	40-65	58
Lighting	10-20	15
Laundry	8-15	12
Food Service	5-10	7
Special Functions	5-15	8

Table 2-6. Energy Use in Supermarkets

<i>Energy Use in Supermarkets</i>	<i>Range (%)</i>	<i>Norm (%)</i>
Refrigeration	40-50	45
Lighting	17-24	20
Fans & Anti-Sweat Devices	10-15	12
HVAC	8-14	12
Special Functions	8-12	10

Table 2-7. Energy Use in Apartment Buildings

<i>Energy Use in Apartment Buildings</i>	<i>Range (%)</i>	<i>Norm (%)</i>
Environmental Control	50-80	70
Lighting/Plug Load	10-20	15
Hot Water	2-8	5
Special Functions (laundry, swimming pool, elevators, security lighting)	5-15	10

Table 2-8. Energy Use in Hotels/Motels

<i>Energy Use in Hotels/Motels</i>	<i>Range (%)</i>	<i>Norm (%)</i>
Space Heating	45-70	60
Lighting	5-15	11
Air Conditioning	3-15	10
Refrigeration	0-10	4
Special Functions (laundry, kitchen, restaurant, swimming pool, elevators, security lighting, hot water)	5-20	15

Table 2-9. Energy Use in Restaurants

<i>Energy Use in Restaurants</i>	<i>Table</i>	<i>Fast food</i>
HVAC	32	36
Lighting	8	26
Food Preparation	45	27
Refrigeration	2	6
Sanitation	12	1
Other	1	4

An ECM may be realized either by implementing operation and maintenance (O&M) measures or by incorporating available technologies through the installation of energy conservation measures (ECMs).

Building Operation

An enormous amount of energy is wasted because building equipment is operated improperly or unnecessarily. The amount of heat (sensible and latent) supplied to or extracted from the indoors in order to maintain a comfortable indoor environment is directly proportional to

the difference in temperature and humidity between indoors and outdoors. Consequently, one should lower the heating and raise the cooling temperature setpoints and/or lower the humidification setpoints and raise the dehumidification setpoints to minimize the space conditioning requirements whenever possible.

When the building is not occupied, the building systems should be turned off or their operation reduced to a minimum.

Depending on building operations, the following systems' operating hours can be curtailed during unoccupied periods:

- HVAC systems
- water heating systems
- lighting systems
- escalators and elevators
- other equipment and machinery.

Care must be taken to ensure that any reduction in equipment operating hours has no adverse impact on building operations and systems, safety, or security.

Lighting System

Lighting typically accounts for a significant portion of electrical energy consumed in commercial buildings. Energy is saved and electric demand is reduced by reducing illumination levels, improving lighting system efficiency, curtailing operating hours, and using daylighting.

Reduction of lighting energy can also increase the energy use of building heating and decrease cooling system consumption, since internal heat gains are reduced. However, this heat-of-light is often a relatively expensive method of heating a building. If the building cooling plant is to be replaced, implementation of lighting measures can reduce the required plant size.

HVAC Systems

The HVAC systems in the building are made up of energy conversion equipment, which transforms electrical or chemical energy to thermal energy, and distribution and ventilation systems, which transport the thermal energy and supply fresh outdoor air to the conditioned space.

Energy may be saved in HVAC systems by reducing ventilation requirements; improving the performance of space conditioning equip-

ment such as boilers, furnaces, chillers, air conditioners, and heat pumps; using energy-efficient cooling systems; and reducing the occurrence of reheating or recooling.

HVAC Distribution Systems

HVAC distribution systems transport the heating and cooling fluids (generally air, water, or steam) from the central plants (chillers, boilers, etc.) to the conditioned space. The system is made up of a network of pipes, ducts, fans, pumps, grills, etc. Energy is required by the fans and pumps that transport the working fluids. In addition, thermal energy is lost from the distribution systems, reducing heating or cooling capacity. Conservation opportunities for distribution systems fall into two areas: reduction of energy required to transport fluids, and reduction of energy losses during transport.

Energy Management Control Systems

Energy can be saved by automating the control of energy systems through the use of energy management control systems (EMCS). Rising energy costs and decreasing prices for computers and microprocessors have encouraged the use of energy management and control systems. An EMCS can efficiently control the heating, ventilating, air conditioning, lighting, and other energy-consuming equipment in the building. It selects optimum equipment operating times and setpoints as a function of electrical demand, time, weather conditions, occupancy, and heating and cooling requirements.

The basic control principles for building energy conservation are:

- Operate equipment only when needed
- Eliminate or minimize simultaneous heating and cooling
- Supply heating and cooling according to actual needs
- Supply heating and cooling from the most efficient source

Building Envelope

Energy is saved when the heat exchange between the building and the outside environment is reduced and/or solar and internal heat gains are controlled.

The primary method of reducing heat conduction through ceilings/roofs, walls, and floors is by adding insulation. Installing vapor barriers in ceilings/roofs and walls, caulking utility penetrations, and maintaining door closures and weatherstripping is also effective in reducing infiltration. To control or reduce solar heat gains through the roof or

glazing areas, a reflective surface or film can be used. For glazing areas, the installation of interior or exterior shading and films will also help control solar heat gain. The installation of storm windows, multiple-glazed windows, and low-e glazing will also reduce heat conduction and long-wave radiation through glazing areas.

Power Systems

The inefficient operation of power systems stems mainly from a low power factor. Power factor correction is cost-effective when utility penalties are imposed. Low power factors can be improved with power factor correction devices and high-efficiency motors. Additional energy can be saved by installing energy-efficient transformers and replacing existing motors with smaller and/or higher efficiency motors, or by installing variable-speed motor drives.

The peak power demand can be reduced by load-shedding, cogeneration, or cool storage systems that produce cold water or ice during off-peak hours. Load-shedding may also reduce the total power consumption, as well as the demand. Cogeneration systems will increase the use of on-site energy, but can also replace electricity consumption with less expensive fossil energy. Also, the waste heat from the cogeneration equipment can meet thermal loads. Cool storage systems shift the chiller demand to off-peak periods, reducing on-peak demand.

Evaluation of power management measures requires a determination of the building demand profile. Several weeks of data in 15-minute intervals should be taken with a recording meter. The measurements may have to be taken both in the cooling and heating season. Most electric utilities have interval data available or will provide recording services at a nominal charge.

Water Heating Systems

In general, heating and distribution of hot water consumes less energy than space conditioning and lighting. However, for some cases, such as hospitals, restaurants, kitchens, and laundries, water heating amounts to substantial energy consumption.

Water heating energy is conserved by reducing load requirements, reducing distribution losses, and improving the efficiency of the water heating systems.

Heat Recovery Opportunities

Heat recovery is the reclamation and use of energy that is other-

wise rejected from the building. When applied properly, heat reclaim systems may be used to reduce energy consumption, as well as peak power demand. The effectiveness of a heat reclaim systems for energy conservation depends on the quantity and temperature of the heat available for recovery, as well as the application of the reclaimed heat.

Heat recovery opportunities exist where there is a need to reject heat from a constant supply of high temperature liquid such as air, water, or refrigerant.

Industrial Energy Use

While the energy audit process for a commercial building emphasizes the building envelope, heating and ventilation, air conditioning, and lighting functions, the industrial facility audit must also include process consideration. Figures 2-6 through 2-9 illustrate how energy is used for a typical industrial plant. It is important to account for total consumption, cost, and how energy is used for each commodity such as steam, water, and compressed air, as well as natural gas and electricity. This procedure is required to develop the appropriate energy conservation strategy.

The top portion of Figure 2-6 illustrates how much energy is used by fuel type and its relative percentage. The pie chart below the energy use profile shows how much is spent for each fuel type. Using a pie chart representation can be very helpful in visualizing how energy is being used and how costs are distributed for those fuels.

Figure 2-7 on the other hand shows how much of the energy is used for each function such as lighting, process, building and plant heating, and process ventilation. Pie charts similar to Figure 2-8 should be made for each category such as compressed air, steam, electricity, water, and natural gas.

Nodal flow diagrams, such as the one in Figure 2-9, illustrate an alternative representation for the steam distribution profile. These diagrams can also assist the auditor in explanation of energy flows and efficiency improvement strategies.

INDUSTRIAL AUDIT OPPORTUNITIES

Several audits are required to construct the industrial energy use profile. The first two, the Envelope Audit and the Functional Audit are similar to the audits in commercial buildings but the focus of the

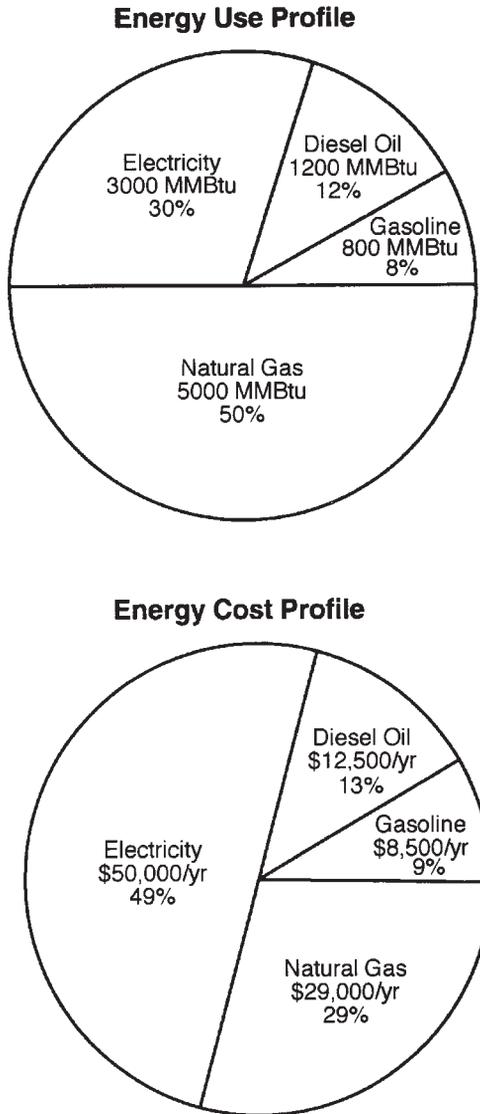


Figure 2-6. Energy Use and Cost Profile

improvements may be vastly different. In an industrial plant, for example, the envelope may not be well insulated but the plant may be very thermally heavy. Adding insulation may hinder the ability to reject excess heat. There may also be substantial ventilation and make-up air requirements in the plant that you would not normally have in a commercial facility.

Energy Distribution Profile

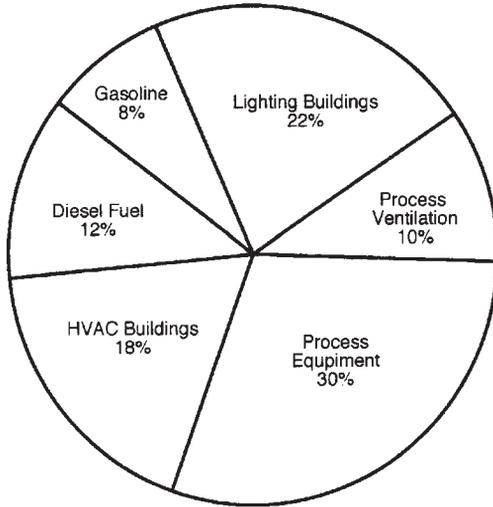


Figure 2-7. Energy Profile by Function

Steam Distribution Profile

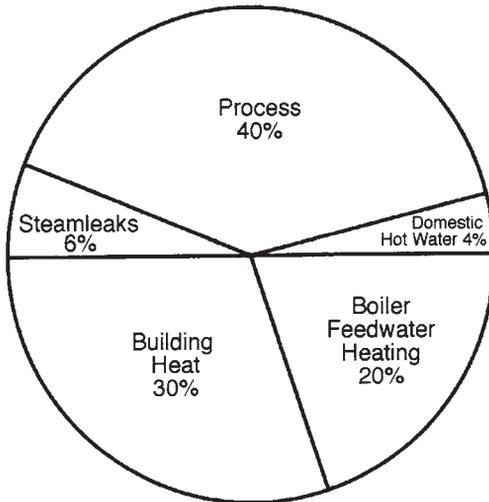


Figure 2-8. Steam Profile by Function

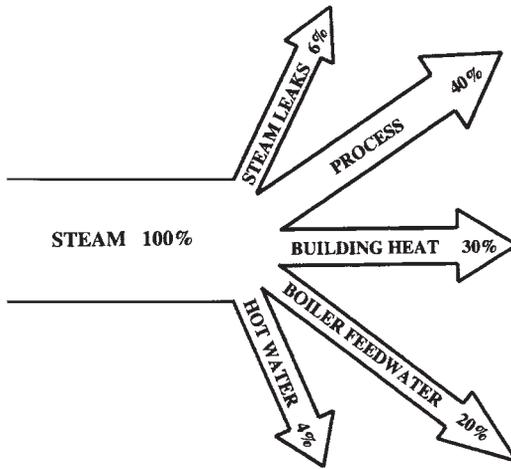


Figure 2-9. Steam Distribution Nodal Diagram

- Envelope Audit—Like the commercial audit, this audit surveys the building envelope for losses and gains due to leaks, building construction, entry and bay doors, glass, lack of insulation, etc.
- Functional Audit—This audit determines the amount of energy required for particular building functions and identifies energy conservation opportunities in office and plant HVAC systems, lighting, domestic hot water, and other building functions similar to commercial buildings.
- Process Audit—This audit determines the amount of energy required for each process function and identifies conservation opportunities in process machinery, heat treatment, furnaces, pumps and motors, conveying systems, and other process loads.
- Utility Audit—This audit analyzes the daily, monthly, or annual usage for each utility including steam, compressed air, process hot water, etc.
- Transportation Audit—This audit determines the amount of energy required for forklifts, trucks, and other vehicles.

INDUSTRIAL ENERGY USE PROFILES

Energy use profiles for several end-users are summarized in the following tables.

Table 2-10. Energy Use in Bakeries

<i>Housekeeping Energy</i>	<i>Percent</i>
Space Heating	21.5
Air Conditioning	1.6
Lighting	1.4
Domestic Hot Water	1.8
TOTAL	26.3
<i>Process Energy</i>	<i>Percent</i>
Baking Ovens	49.0
Pan Washing	10.6
Mixers	4.1
Freezers	3.3
Cooking	2.0
Fryers	1.8
Proof Boxes	1.8
Other Processes	1.1
TOTAL	73.7

Data for a 27,000-square-foot bakery in Washington, D.C.

Table 2-11. Energy Use in Die Casting Plants

<i>Housekeeping Energy</i>	<i>Percent</i>
Space Heating	24
Air Conditioning	2
Lighting	2
Domestic Hot Water	2
TOTAL	30
<i>Process Energy</i>	<i>Percent</i>
Melting Hearth	30
Quiet Pool	20
Molding Machines	10
Air Compressors	5
Other Processes	5
TOTAL	70

Table 2-12. Energy Use in Transportation Terminals

<i>End Use</i>	<i>Range (%)</i>	<i>Norms (%)</i>
Space Heating	50 to 75	60
Air Conditioning	5 to 25	15
Lighting	5 to 25	15
Special Functions Elevators, General Power, Parking, Security Lighting, Hot Water	3 to 20	10

**Table 2-13. Energy Use in Warehouses and Storage Facilities
(Vehicles not Included)**

<i>End Use</i>	<i>Range (%)</i>	<i>Norms (%)*</i>
Space Heating	45 to 80	67
Air Conditioning	3 to 10	6
Lighting	4 to 12	7
Refrigeration	0 to 40	12
Special Functions Elevators, General Power, Parking, Security Lighting, Hot Water	5 to 15	8

*Norms for a warehouse or storage facility are strongly dependent on the products and their specific requirements for temperature and humidity control.

SUMMARY

One of the more important aspects of energy management and conservation is measuring and accounting for energy consumption. An important part of the overall energy auditing program is to be able to measure where you are and determine where you are going. It is vital to establish an energy accounting system at the beginning of the program. This information will be used to evaluate the overall trends of facility energy usage, establish benchmarks to determine a realistic estimate of energy savings potential, disaggregate energy use into discrete functions, and establish a base line to compare post-retrofit energy usage and calculate energy savings.

By gathering and organizing energy consumption data as a part of the auditing process, the auditor can also help establish a system of tracking energy use against production to monitor production efficiency

and answer the kind of questions typically posed by plant engineers and business managers alike such as:

- How much have we saved as a result of energy efficiency improvements?
- If we are conserving energy, why is our total energy consumption increasing?
- If we are conserving energy, why isn't our energy bill decreasing?
- If we have no change in efficiency, why is our consumption changing?
- How much of our energy consumption is due to factors beyond our control, such as weather, legislated environmental controls, etc.?
- How much of our energy consumption is directly related to production?

By addressing questions such as these, the auditor is generating awareness of how energy is consumed and providing information that can lead to energy savings through behavioral changes resulting from this increased understanding.

Chapter 3

Understanding The Utility Bill

Managing energy consumption and controlling energy costs are primary objectives for successful energy management. As a result, it is important to understand energy rates, rate schedules, metering methods, and characteristics of the various fuels used in each facility. Regardless of what type of fuel is used, understanding how energy is billed is fundamental to learning how to control energy use and costs.

Take a look at your gas or electric utility bill. It always tells you how much to pay, when to pay it, and where to send the check. It should also show how much gas or power you used but it may not give you a breakdown of all charges or indicate how the total was derived. The best way to understand these charges is to obtain a copy of the rate schedule that applies to the bill and recalculate the total using consumption information from the bill.

The rate schedule is your guide for determining how the costs are allocated. The rate schedule that applies to your facility is usually identified on the billing statement. Once you understand your utility bill, it may serve as a tool for reducing utility costs as well as using energy more efficiently.

Most gas and electric bills include several different charges. The following represents the typical charges and rate structures you will find in most applications.

ELECTRIC CHARGES

Service Charge

This monthly charge, sometimes called the basic or customer charge, pays for fixed utility costs and are included with every billing. These fixed costs are independent of energy consumption and help

cover a portion of the ongoing costs of service, such as operation and maintenance of the distribution systems, and administrative costs for metering, billing and collections.

Energy Charge

The standard billing unit for electricity is the kilowatt hour or kWh. It is a measure of the intensity or rate of energy use multiplied by the length of time it is used, (kW x hours = kWh). Therefore, the larger the power rating on your electrical equipment, and the longer you use it, the more kWh or energy you consume.

Most all rate schedules include an energy charge per kWh for electricity consumption. The energy charge is based on the total number of units recorded over the billing period, usually about one month. Some utilities charge the same rate for all energy you use, while others charge different rates for different "blocks" of energy. For example, the first 20,000 kWh may be charged at one rate and all additional kWh may be charged at a higher or lower rate. Energy charges may also vary by season depending on the utility's energy resources and peak loads.

Power or Fuel Cost Adjustment

This adjustment corrects for differences between your utility's budgeted and actual energy costs. This allows the utility to adjust for uncertainties, such as rapidly changing fuel costs and availability of generation and supply resources, and pass these extra costs directly through to consumers.

Demand Charge

Electric utilities charge commercial customers based not only on the amount of energy used (kWh) but also on the peak demand (kW) for each month. Demand charges are imposed by the utilities in an effort to be fair to all their commercial customers. The need arises because not all businesses use energy the same way. Some businesses may have a need for high amounts of power for short periods of time while others may require a constant supply of power at a lower level. While both businesses may use the same number of kWh, one requires the utility to have more generating capacity than the other. The demand charge pays for your share of the utility's generation, transmission, and distribution capacity that is standing ready to meet your greatest need.

Demand charges can be a significant portion of the total bill. If you are unable to determine the amount of demand charge from the monthly

utility bill, it's a good idea to recalculate the bill with a rate schedule to determine the actual cost of demand.

Demand is a charge based on your maximum or peak rate of using energy. The term "power" applies to the rate of using energy. Power is measured in kilowatts (kW). One kilowatt is equivalent to 1000 watts, and is the amount of power required to light ten 100 watt light bulbs. Some utilities do not charge small commercial users, with demand less than 30 to 50 kW, for example, for demand.

In order to determine the peak demand during the billing period, the utility establishes short periods of time called the demand interval, typically 15 to 30 minutes. The demand meter continuously records the rate of power draw and averages it over the specified interval period. The *actual demand* is defined as the highest average demand recorded during any one demand interval within the billing period. (See Figure 3-1) The *billing demand* is that portion of the actual demand for which a charge applies. Demand charges may also vary by season.

In addition to these typical charges, other charges may apply:

Ratchet Clause

Some utilities may have clauses in their rate schedules that base your demand charges on a specified percentage of the highest kW usage

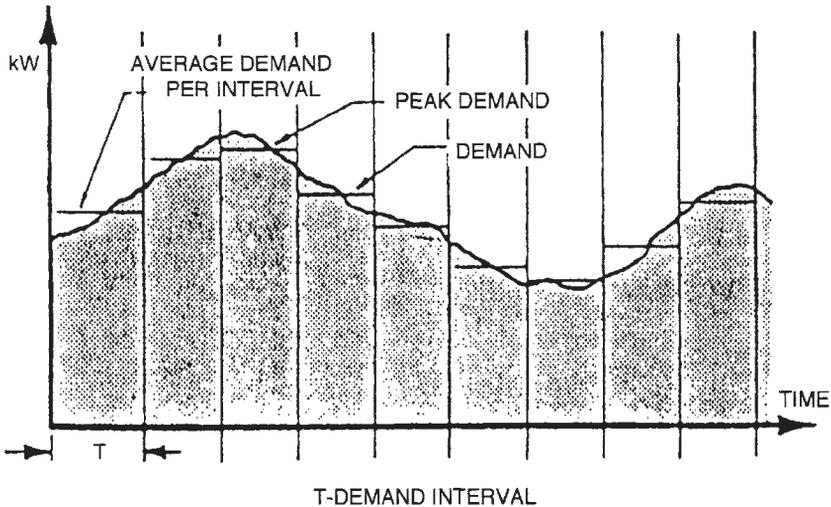


Figure 3-1. Peak Demand

during the preceding 11 months. This can have a potentially significant effect on your utility bill if you have a month or two of high demand, for summer air conditioning for example, and lower demand for the remainder of the year. Those two summer months would establish your demand charges for the entire year and you would be billed at that rate each month whether you reach that kW peak or not. Focusing on reducing demand during those months of highest use would become a top priority for reducing demand charges throughout the year.

Power Factor Charge

Utilities generally assess a penalty for low “power factor” to some larger commercial and industrial customers. The reason is that not all of the power you use registers on the energy and demand meters. Energy (kWh) and demand (kW) meters record the “real” energy use and power that does useful work or makes heat. In addition to energy and demand, “reactive power” is used by induction motors and transformers to excite magnetic fields and causes electrical current to flow partially out of phase. When this occurs, some additional current must be delivered to you that does not register on the energy and demand meters. Excessive reactive power has a negative effect on the utility companies distribution system and can reduce their capacity as well as the capacity within your facility. If you use more than a specified amount of reactive power, measured in “kvar” or kilovolt-amps reactive, your utility company will probably install a separate meter to measure and bill you for the reactive power used.

In general, you can expect a power factor charge if your power factor is less than .95 or 95%. Power factor is billed in a variety of ways including kvar, kvar-hour, by adjustments to your demand charges by increasing billed kW for each percentage your power factor drops below the 95% allowed, or by measuring and billing demand in kVa.

Power factor charges may not be a large part of your utility bill but it is important to be aware of them and take corrective action if the charges become significant. Installing capacitors and high power factor equipment can reduce power factor penalties.

Electric Rate Structures

Each utility has different rate structures or tariffs for different types of users such as residential, small commercial, large commercial, industrial, farm, irrigation and outdoor lighting. There may also be different schedules within each of these user groups depending on capacity, time of day use, or other variables.

Flat Rate

A flat rate, as the name implies, is a single rate which does not vary. Each kWh costs the same, regardless of how much electricity is used or when.

Seasonal Rates

Seasonal rates vary according to the time of year, typically with one rate for summer and another for winter. This type of rate generally reflects seasonal differences in demand and generating costs. When demand increases, generating costs generally increase as well, as less efficient and more costly generating facilities must be used. Utilities who experience their highest demand in summer will generally have a higher summer rate, while winter-peaking utilities may have higher rates in winter. Understanding seasonal differences in rates may enable you to make a more economical choice of heating systems. In areas with low winter rates, electric heating may be quite economical, while in other areas with high winter rates, a fossil fuel system may be a more economical choice.

Tiered or Block Rates

With tiered or block rates, the cost per kWh varies according to how much electricity is used in the billing period. The first "block" of kWh is billed at a certain rate, the next block at a different rate, and so on. In most commercial and industrial cases, the cost per kWh decreases with increased use, although in other cases, where controlling demand is critical, the cost may increase with greater consumption.

Time of Use Rates

Time of use rates help utilities to manage demand for electricity by rewarding off-peak use with lower rates and penalizing peak electric use with higher rates. This means you could have multiple meters measuring energy and demand for various periods throughout the day. One measuring demand during specified "on-peak" hours, such as Monday through Friday from 6 a.m. to 10 p.m., and the other measuring demand during "off-peak" hours, such as nights and weekends. By shifting use of major equipment to off-peak hours, you may be able to cut your electric bills without sacrificing comfort or convenience. The more electric consumption you can shift to off-peak hours, the more you will save.

To save with time of use rates you need to know what times are considered on-peak and off-peak. Generally, nighttime and early morn-

ing hours are considered off-peak, while afternoon hours are considered on-peak. Some utilities have up to four different time periods with different rates assigned to each period.

Other Rate Options

There are also several other rate options that are currently being offered or considered by some electric utilities. “Real-time pricing” uses interactive computer technology to vary rates over time, based on the utility’s cost of generation. By monitoring fluctuations in rates, customers can manage their electric use to take advantage of low rates and minimize use when rates are high. Some utilities also offer “green rates,” which enable customers with environmental concerns to pay a somewhat higher rate to support generation of electricity via solar energy or other environmentally friendly methods.

As the industry moves toward more competition, aggregation of loads, interruptible service, self-generation, and retail wheeling are all potential avenues to reduce costs. It’s a good idea to review all rates available and discuss options with a utility representative.

SIM 3-1

The existing rate structure is as follows:

Demand Charge:

First	25 kW of billing demand	\$4.00 per kW per month
Next	475 kW of billing demand	\$3.50 per kW per month
Next	1000 kW	\$3.25 per kW per month

Energy Charge:

First	2,000 kW-Hrs per month	8¢ per kWh
Next	18,000 kW-Hrs per month	6¢ per kWh
Next	180,000 kW-Hrs per month	4.4¢ per kWh
Etc.		

The new proposed schedule deletes price breaks for usage.

	<i>Billing Months</i> <i>June-September</i>	<i>Billing Months</i> <i>October-May</i>
Demand Charge	\$13.00 per kW/Month	\$5.00 per kW/Month
Energy Charge	5¢ per kWh	3¢ per kWh
Demand charge based on greatest billing demand month.		

Comment on the proposed billing as it would affect an industrial customer who uses 475 kW per hour for 330 hours per month. For the 8 months of winter, demand is 900 kW. For the 4 months of summer, demand is 1200 kW.

ANALYSIS

The proposed rate schedule has two major changes. First, billing demand is on a ratchet basis and discourages peak demand during summer months. The high demand charge encourages the plant to improve the overall load factor. The increased demand charge is partially offset with a lower energy usage rate.

Original Billing

Winter:	First 25 kW	\$100
Demand	Next 475 kW	1,660
	Next 400 kW	1,300
		\$3,060
Summer:		\$4,035
Total Demand:	$8 \times 3060 + 4 \times 4035 = \$40,620$	
Usage Charge:	$475 \text{ kW} \times 330 \text{ Hours} = 156,750 \text{ kWh}$	
	First 2,000 kWh @ 8¢ =	\$ 160
	Next 18,000 kWh @ 6¢ =	1,080
	Next 136,750 kWh @ 4.4¢ =	6,016
		\$7,256

Total Usage: $7256 \times 12 = \$87,072$
Total Charge = \$127,692 or 8.1¢ per kWh

Proposed Billing

Demand:	$1200 \times \$13.00 \times 4 \text{ months} =$	\$ 62,000
	$1200 \times \$ 5.00 \times 8 \text{ months} =$	\$ 48,000
Total Demand:		\$ 110,400
Usage:	$475 \text{ kW} \times 330 \times 5\text{¢} \times 4 =$	\$ 31,350
	$475 \text{ kW} \times 330 \times 3\text{¢} \times 8 =$	\$ 37,620
Total Usage:		\$ 68,970
	Total Charge = \$179,370 or 11.4¢ per kWh or a 40% increase	

Natural Gas Rates

The most common billing unit for natural gas is the therm, which is based on heat content (1 therm = 100,000 Btus). Natural gas is measured

by volume in Ccf (hundred cubic feet) or Mcf (thousand cubic feet). Once the volume is measured by the gas meter, a Btu factor is applied to determine the heat content, in therms, for the natural gas consumed. The Btu factor will vary by month as heat content of natural gas varies due to changes in atmospheric conditions.

Customer Charge

In addition to the unit cost per therm or Ccf, many gas companies also charge a monthly customer charge or service charge. This monthly charge pays for fixed utility costs and are included with every billing. These fixed costs are independent of energy consumption and help cover a portion of the ongoing costs of service, such as operation and maintenance of the distribution systems, and administrative costs for metering, billing and collections.

Energy and Demand

Energy refers to the total amount of natural gas flowing through your meter. Your energy used is measured in therms. Demand refers to the greatest amount of energy you've used in any given day. The gas supplier needs to be able to provide capacity for your energy use at its greatest amount and measures that demand in peak therms per day.

Flat Rate

As with electricity, a flat rate is a single cost per therm or Ccf, regardless of how much gas is used or when.

Seasonal Rates

Many gas utilities also charge different rates in winter and summer. In most cases, the summer rates will be lower, as the demand for natural gas is less during non-heating months.

Tiered or Block Rates

Tiered or block rates vary depending on how much gas is used in the billing period. Gas utilities assign a different unit cost for each "block" of therms or Ccfs. Generally, the unit cost decreases as consumption increases, much like a "volume discount." However, in areas where natural gas is in short supply, the unit cost may increase to discourage excessive use.

Firm Rates

With a firm rate, the customer is assured delivery of natural gas service under all weather conditions. Firm service is ideal for businesses with heating loads that require uninterrupted service.

Interruptible Rates

Customers on interruptible service agree to curtail their natural gas use during peak times when requested by the utility. Customers on interruptible services must operate an alternate fuel system or be willing to shut down operations, during periods of curtailment. In return they pay reduced rates for their natural gas. Failure to interrupt or curtail gas use when requested by the utility will result in a penalty.

Natural Gas Supply from a Third-party Supplier

You purchase gas from a different supplier. You then need a balancing service because the interstate pipelines hold the local accountable for the difference between what your supplier delivers to the local distributor for you and what you actually use (daily imbalances). Gas utilities often label the combination of distribution service with balancing service as “utility transportation service.”

Other Factors

Some gas companies have also implemented a surcharge for customers with “dual fuel” systems, which typically use an electric heat pump as the primary heating system, with a gas furnace as a supplement during very cold weather. Because the customer uses less gas, and only during times of peak demand, the gas companies apply a surcharge to recover some of the cost of serving that customer.

Thermal Values

When working with the wide variety of fuel types available in most commercial facilities, it often becomes necessary to find a way to compare one fuel to another in terms of the cost of energy delivered per unit of fuel. The primary common denominator for all types and sources of energy is the “British thermal unit,” better known as the Btu.

Most utility companies measure natural gas in thousands of cubic feet (Mcf) or hundreds of cubic feet (Ccf) and convert to therms, oil is delivered in gallons or barrels, electricity in kilowatt hours, coal in tons, etc. In order to be of use in an energy conservation study, these various energy sources must be converted to a common unit of Btus.

Once you have established the savings in Btus of an energy conservation measure, those figures must then be converted back into the energy units which appear on the utility bills. Only then can the savings in dollars be calculated. It is necessary, therefore, that the energy manager or consultant become acquainted with the appropriate energy conversion units and factors listed in the chart below.

Natural Gas

1 Cubic Foot	= 950 to 1150 Btu
1 Ccf	= 100 Cubic Feet
1 Therm	= 100,000 Btu
1 Therm	= 1 Ccf or .1 Mcf
1 Mcf	= 1,000 Cubic Feet
1 Mcf	= 10 Therms or 10 Ccf
1 Mcf	~ 1,000,000 Btu

Fuel Oil

Kerosene	= 134,000 Btu/Gallon
Number 2	= 140,000 Btu/Gallon
Number 6	= 152,000 Btu/Gallon

Propane

LPG = 91,600 Btu/Gallon

1 Btu = Heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit at sea level.

Electricity

1 kW	= 1000 Watts
1 kWh	= 3413 Btu

Water

1 Gallon	= 8.33 lbs.
1 Cubic foot	= 7.48 Gallons
1 Ccf	= 748 Gallons

Steam

10 PSIG	= 1000 Btu/lb.
100 PSIG	= 1100 Btu/lb.

Coal

Lignite	= 11,000 Btu/lb.
Bituminous	= 14,000 Btu/lb.
Anthracite	= 13,900 Btu/lb.
Sub-bituminous	= 12,600 Btu/lb.

Chapter 4

Energy Economics

Having determined possible retrofit options for various pieces of equipment or systems within the facility, it is necessary for to develop some method for evaluating the economic basis or comparing the cost effectiveness of competing investments. A number of methodologies have been developed to provide some uniform methods of comparison. This section will discuss the various methods used to evaluate investments in energy conservation.

SIMPLE PAYBACK

The least complicated of such methods is referred to as the simple payback period. The payback period is the time required to recover the capital investment out of the annual savings. The payback period is determined by dividing the cost of the retrofit measure by the annual energy cost savings, using current fuel prices, to come up with some number of years after which the investment will have supposedly paid for itself. This method ignores all savings beyond the payback years, thus potentially penalizing projects that may have a long service life in favor of those that offer high initial savings relative to the installation cost.

The simple payback period is simply computed as:

$$\text{Simple Payback} = \frac{\text{First Cost}}{\text{Annual Energy Savings}} \quad (4-1)$$

It is the easiest method to use and has the advantage that you do not need to assume any future value factors such as discount rates, inflation and other annual costs during the life of the measure.

Its advantage is in its simplicity both for the analyst and the owner/developer. Its disadvantage is that it does not take into account other important factors which will be discussed in the other evaluation methods.

THE TIME VALUE OF MONEY

Most energy savings proposals require the investment of capital to accomplish them. By investing today in energy conservation, yearly operating dollars over the life of the investment will be saved. A dollar in hand today is more valuable than one to be received at some time in the future. For this reason, a *time value* must be placed on all cash flows into and out of the company.

Money transactions are thought of as a cash flow to or from a company. Investment decisions also take into account alternate investment opportunities and the minimum return on the investment. In order to compute the rate of return on an investment, it is necessary to find the interest rate which equates payments outgoing and incoming, present and future. The method used to find the rate of return is referred to as *discounted cash flow*.

Evaluation methods that use the time value of money include:

- Net Present Value
- Internal Rate of Return
- Equivalent Uniform Annual Costs (EUAC)
- Life Cycle Costing

Time Value of Money Definitions

Present Value (P)—the current value or principal amount.

Future Value (F or S)—the future value of a current investment.

Interest/Discount Rate (i)—the “carrying” charge for the use or investment of funds.

Term of Investment (N)—the number of years the investment is held.

Period (M)—the time schedule at which the interest/discount rate is applied. For simple interest the period is one (1) year.

Annuity (A or R)—a series of equal payments made over the term of an investment.

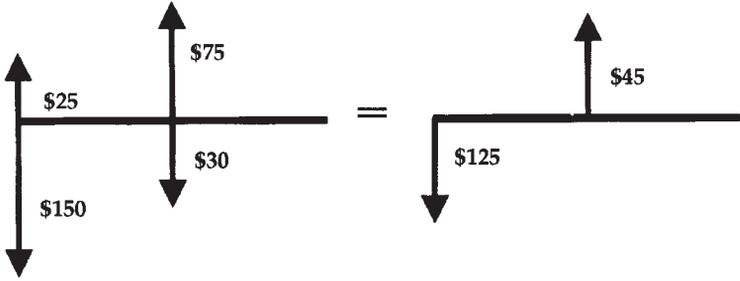
Gradient (G)—an escalating annuity (i.e., one that rises at a uniform rate throughout the term of the investment).

Cash Flow Diagrams

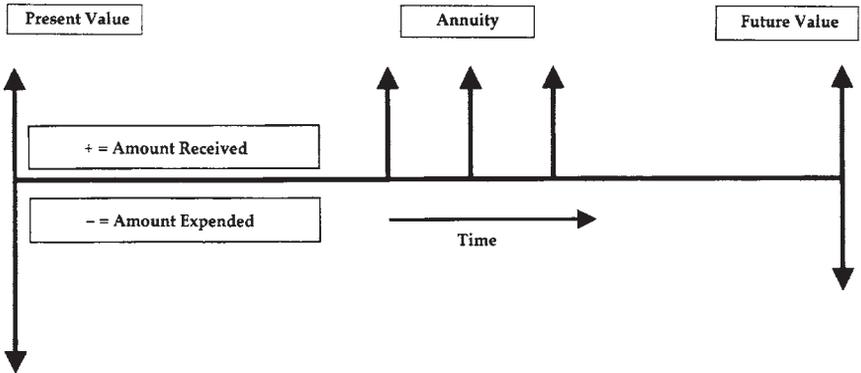
Cash flow diagrams are often used to help visualize the flow of capital throughout the term of an investment or life of an investment in energy efficiency improvements. When drawing a cash flow diagram, the following rules are applied:

- Arrows Always Point Away from the Time Axis
- Arrows Pointing Up Are Income
- Arrows Pointing Down Are Expenses
- Arrows Can Be Summed in the Same Year.

Example:



Present Values, Future Values, and Annuities



Net Present Value

By comparing an original investment to the income and/or expenses that it generates over the life of the investment, you can calculate whether the entire cash flow results in an increase in wealth, or a *positive net present value*.

To determine net present value, convert all expenses and income over the life of a project to a present value using the appropriate table and interest rate. Sum the present values, including the initial investment and determine whether the net present value is positive.

This method is the one used in determining life cycle costs.

Equation for Present Value: $P = A \times (P/A, I, N)$

Internal Rate of Return

By setting the net present value of an investment to zero (the minimum value that would make the investment worthwhile), you can solve the cash flow diagram for the discount rate. If this discount rate is greater than the “hurdle” rate or current interest rate, the investment is sound.

This procedure, like net present value, can be used to compare alternatives. Unlike NPV, though, the mathematics involved in determining IRR is quite complicated and usually requires a computer spreadsheet. Determining IRR is an iterative process requiring guesses and approximations until a satisfactory answer is derived.

Equivalent Uniform Annual Costs (EUAC)

The EUAC is a method used to compare alternatives with different lifetimes. The method is to prepare a cash flow diagram and convert each alternative into a present value. The present value is then converted into an equivalent annual cost (annuity) using the life of the measure and the applicable interest rate.

The alternative with the lowest annual cost is the one to be selected.

Step #1 - Determine Present Value

$$P = A \times (P/A, I, N)$$

Step #2 - Determine EUAC Using Interest and Lifetime of Measure

$$\text{EUAC} = \text{Present Value} \times (A/P, i, N)$$

Life Cycle Costing

A method of evaluating energy conservation options over the life of a system is through life cycle costing. Life cycle costing is used to compare systems over the same lifetime, usually that of the building project.

Life cycle costing has brought about a new emphasis on the comprehensive identification of all costs associated with a system. The most commonly included costs are the initial installed cost, maintenance costs, operating costs including energy, fuel escalation rates, inflation, interest on the investment, salvage value, and other lifetime expenses for the equipment.

These expenses over the life of the facility are multiplied by their present value factor $(1 + i)^n$. The sum of all the present values is called the life cycle cost.

Two factors enter into appraising the life of the system; namely, the expected physical life and the period of obsolescence. The lesser factor is governing time period. The effect of interest can then be calculated by us-

ing one of the several formulas which take into account the time value of money.

When comparing alternative solutions to a particular problem, the system showing the lowest life cycle cost will usually be the first choice (performance requirements are assess as equal in value).

Life cycle costing is a tool in value engineering. Other items, such as installation time, pollution effects, aesthetic considerations, delivery time, and owner preferences will temper the rule of always choosing the system with the lowest life cycle cost. Good overall judgment is still required.

The life cycle cost analysis still contains judgment factors pertaining to interest rates, useful life, and inflation rates. Even with the judgment element, life cycle costing is the most important tool in value engineering, since the results are quantified in terms of dollars.

Life Cycle Cost Spreadsheet

The following is an example of a typical life cycle cost analysis output. A computer spreadsheet can be used easily to prepare this type of analysis.

In the following analysis, two boiler systems are being evaluated to determine the lowest life cycle cost. Alternative A has a first cost of \$80,000, will last for 20 years, and has a salvage value of \$7,000 at the end of its useful life. Alternative B has a first cost of \$35,000 and a useful life of 10 years. Alternative B has no salvage value and will have to be completely replaced in year 11 with the same annual costs. The following table shows additional costs for annual maintenance of each system.

	Alternative A	Alternative B
First Cost	\$80,000	\$35,000
Life	20 Years	10 Years
Salvage Value	\$7,000	\$0
Additional Costs		
Years 1 - 5	\$1,000	\$3,000
Years 6 - 10	\$1,500	\$4,000
Year 10	\$5,000 Burner Replacement	Replace Entire System
Year 11 - 20	\$2,000	

Present Worth Discount Rate = 10%

Alternative A

Year	First & Replacement Cost	Annual Costs	Total Annual Costs	Present Worth Factor (P/F)	Present Worth of Annual Costs	Present Worth Cumulative Costs
0	80000	0	80000	1.00	80000	80000
1	0	1000	1000	0.91	909	80909
2	0	1000	1000	0.83	826	81736
3	0	1000	1000	0.75	751	82487
4	0	1000	1000	0.68	683	83170
5	0	1000	1000	0.62	621	83791
6	0	1500	1500	0.56	847	84637
7	0	1500	1500	0.51	770	85407
8	0	1500	1500	0.47	700	86107
9	0	1500	1500	0.42	636	86743
10	5000	1500	6500	0.39	2506	89249
11	0	2000	2000	0.35	701	89950
12	0	2000	2000	0.32	637	90587
13	0	2000	2000	0.29	579	91167
14	0	2000	2000	0.26	527	91693
15	0	2000	2000	0.24	479	92172
16	0	2000	2000	0.22	435	92607
17	0	2000	2000	0.20	396	93003
18	0	2000	2000	0.18	360	93363
19	0	2000	2000	0.16	327	93690
20	-7000	2000	-5000	0.15	-743	92947
Total	-2000	32500	110500		\$92,947	

Alternative B

Year	First & Replacement Cost	Annual Costs	Total Annual Costs	Present Worth Factor (P/F)	Present Worth of Annual Costs	Present Worth Cumulative Costs
0	35000	0	35000	1.00	35000	35000
1	0	3000	3000	0.91	2727	37727
2	0	3000	3000	0.83	2479	40207
3	0	3000	3000	0.75	2254	42461
4	0	3000	3000	0.68	2049	44510
5	0	3000	3000	0.62	1863	46372
6	0	4000	4000	0.56	2258	48630
7	0	4000	4000	0.51	2053	50683
8	0	4000	4000	0.47	1866	52549
9	0	4000	4000	0.42	1696	54245
10	0	4000	4000	0.39	1542	55787
11	0	35000	35000	0.35	12267	68055
12	0	3000	3000	0.32	956	69011
13	0	3000	3000	0.29	869	69880
14	0	3000	3000	0.26	790	70670
15	0	3000	3000	0.24	718	71388
16	0	3000	3000	0.22	653	72041
17	0	4000	4000	0.20	791	72832
18	0	4000	4000	0.18	719	73552
19	0	4000	4000	0.16	654	74206
20	0	4000	4000	0.15	595	74800
Total	0	101000	136000		\$74,800	

Discounting Factors

To make investment decisions, the energy manager must follow one simple principle: Relate annual cash flows and lump sum deposits to the same cash base. The six factors used for investment decision making simply convert cash from one time base to another. Since each company has various financial objectives, these factors can be used to solve *any* investment problem.

The factors are given the functional notation $(X, Y, \%i, n)$ where X is the desired value, Y is the known value, i is the interest rate, and n is the number of periods, usually expressed in years. The functional symbol is read "X given Y at $i\%$ for n years." The discounting factors convert Y to X under the conditions of constant interest rate compounded for n years.

The six common discounting factors and formulas are given below:

Description	Factor	Formula
Single Payment Compound Amount (Future value of \$1)	$(F/P, i\%, n)$	$(1 + i)^n$
Single Payment Present Worth (Present value of \$1)	$(P/F, i\%, n)$	$\frac{1}{(1 + i)^n}$
Uniform Series Compound Amount (Future value of uniform series of \$1)	$(F/A, i\%, n)$	$\frac{(1 + i)^n \pm 1}{i}$
Sinking Fund Payment (Uniform series whose future value is \$1)	$(A/F, i\%, n)$	$\frac{i}{(1 + i)^n \pm 1}$
Capital Recovery (Uniform series with present value of \$1)	$(A/P, i\%, n)$	$\frac{i(1 + i)^n}{(1 + i)^n \pm 1}$
Uniform Series Present Worth (Present value of uniform series of \$1)	$(P/A, i\%, n)$	$\frac{i(1 + i)^n}{(1 + i)^n \pm 1}$

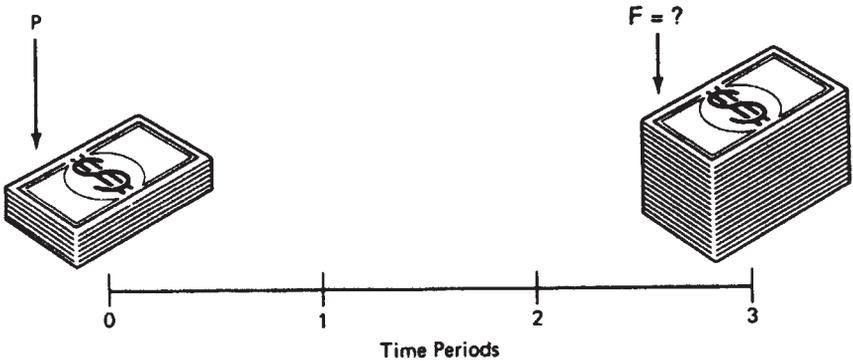


Figure 4-1. Single payment compound amount (F/P).

Single Payment Compound Amount—F/P

Use the F/P factor to determine future amount *F* that present sum *P* will accumulate at *i* percent interest, in *n* years. If *P* (present worth) is known, and *F* (future worth) is to be determined, use Equation 4-2.

$$F = P \times (1 + i)^n \tag{4-2}$$

$$F/P = (1 + i)^n \tag{4-3}$$

The *F/P* can be computed by an interest formula, but usually its value is found by using the interest tables. Interest tables for interest rates of 10 to 50 percent are found at the conclusion of this chapter (Tables 4-1 through 4-8). In predicting future costs, there are many unknowns. For the accuracy of most calculations, interest rates are assumed to be compounded annually unless otherwise specified. Linear interpolation is commonly used to find values not listed in the interest tables.

Tables 4-9 through 4-12 can be used to determine the effect of fuel escalation on the life cycle cost analysis.

Single Payment Present Worth—P/F

The P/F factor is used to determine the present worth, *P*, that a future amount, *F*, will be at interest of *i*-percent, in *n* years. If *F* is known, and *P* is to be determined, then Equation 4-4 is used.

$$P = F \times 1/(1 + i)^n \tag{4-4}$$

$$P/F = \frac{1}{(1 + i)^n} \tag{4-5}$$

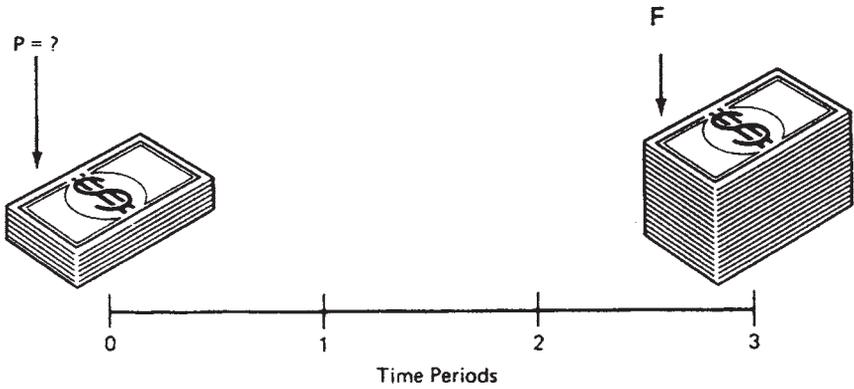


Figure 4-2 Single payment present worth (P/F).

Uniform Series Compound Amount— F/A

The F/A factor is used to determine the amount F that an equal annual payment A will accumulate to in n years at i percent interest. If A (uniform annual payment) is known, and F (the future worth of these payments) is required, then Equation 4-6 is used.

$$F = A \times \frac{(1 + i)^n - 1}{i} \quad (4-6)$$

$$F/A = \frac{(1 + i)^n - 1}{i} \quad (4-7)$$

Uniform Series Present Worth— (P/A)

The P/A factor is used to determine the present amount P that can be paid by equal payments of A (uniform annual payment) at i percent interest, for n years. If A is known, and P is required, then Equation 4-8 is used.

$$P = A \times \frac{(1 + i)^n - 1}{i (1 + i)^n} \quad (4-8)$$

$$P/A = \frac{(1 + i)^n - 1}{i (1 + i)^n} \quad (4-9)$$

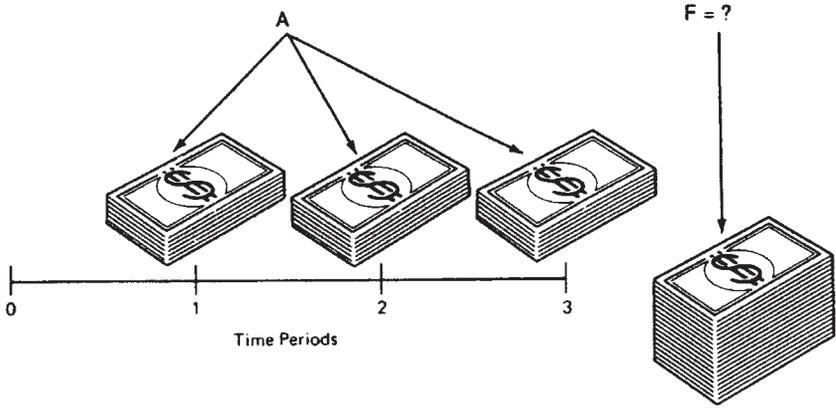


Figure 4-3. Uniform series present worth (F/A).

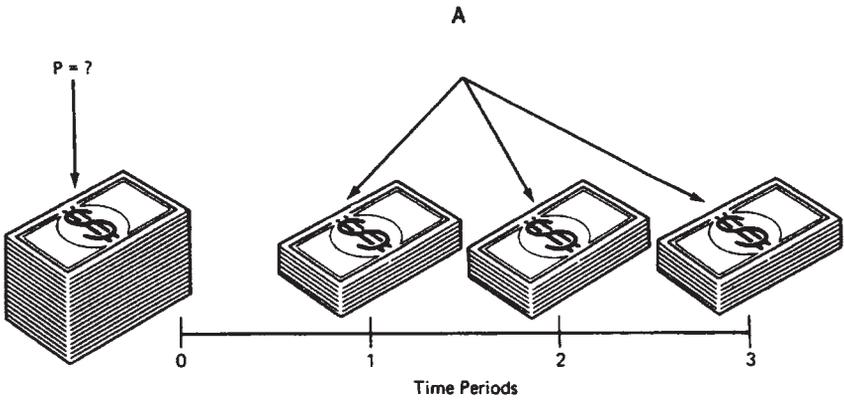


Figure 4-4. Uniform series present worth (P/A).

Capital Recovery—A/P

The A/P factor is used to determine an annual payment *A* required to pay off a present amount *P* at *i* percent interest, for *n* years. If the present sum of money, *P*, spent today is known, and the uniform payment *A* needed to pay back *P* over a stated period of time is required, then Equation 4-10 is used

$$A = P \times \frac{i(1 + i)^n}{(1 + i)^n - 1} \tag{4-10}$$

$$A/P \times \frac{i(1+i)^n}{(1+i)^n - 1} \tag{4-11}$$

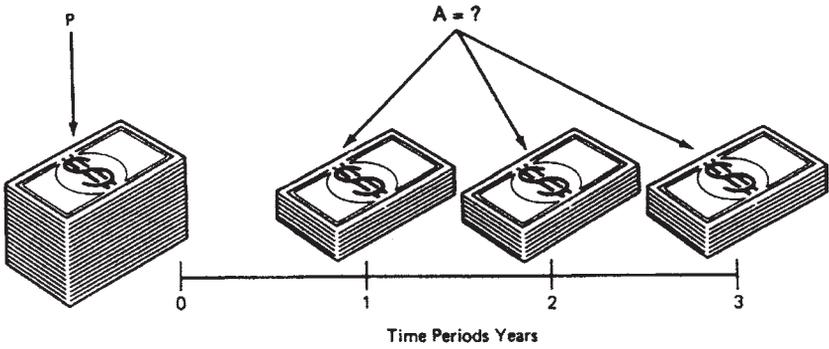


Figure 4-5. Capital recovery (A/P).

Sinking Fund Payment—A/F

The A/F factor is used to determine the equal annual amount *R* that must be invested for *n* years at *i* percent interest in order to accumulate a specified future amount. If *F* (the future worth of a series of annual payments) is known, and *A* (value of those annual payments) is required, then Equation 4-12 is used.

$$A = F \times \frac{i}{(1+i)^n - 1} \tag{4-11}$$

$$A/F = \frac{i}{(1+i)^n - 1} \tag{4-11}$$

Gradient Present Worth—GPW

The GPW factor is used to determine the present amount *P* that can be paid by annual amounts *A'* which escalate at *e* percent, at *i* percent interest, for *n* years. If *A'* is known, and *P* is required, then Equation 4-14 is used. The GPW factor is a relatively new term which has gained in importance due to the impact of inflation.

$$P = A' \times (\text{GPW}) i_n \tag{4-14}$$

$$P/A' = GPW = \frac{\frac{1+e}{1+i} \left[1\tilde{n} \left(\frac{1+e}{1+i} \right)^n \right]}{1\tilde{n} \frac{1+e}{1+i}} \tag{4-15}$$

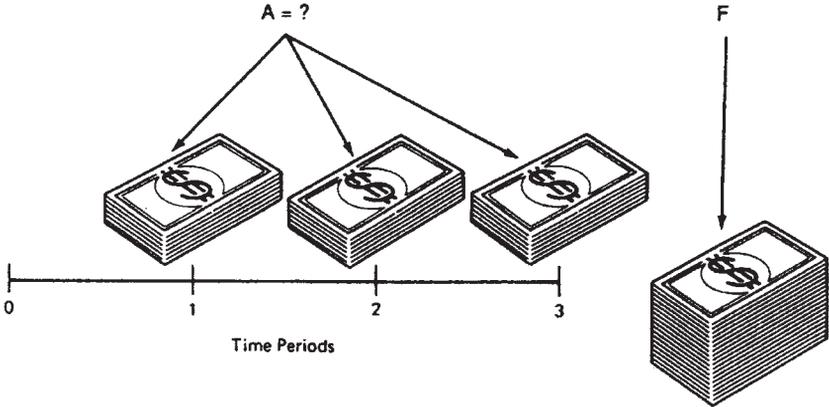


Figure 4-6. Sinking fund payment (A/F).

The three most commonly used methods in life cycle costing are the annual cost, present worth and rate-of-return analysis.

In the present worth method a minimum rate of return (*i*) is stipulated. All future expenditures are converted to present values using the interest factors. The alternative with lowest effective first cost is the most desirable.

A similar procedure is implemented in the annual cost method. The difference is that the first cost is converted to an annual expenditure. The alternative with lowest effective annual cost is the most desirable.

In the rate-of-return method, a trial-and-error procedure is usually required. Interpolation from the interest tables can determine what rate of return (*i*) will give an interest factor which will make the overall cash flow balance. The rate-of-return analysis gives a good indication of the overall ranking of independent alternates.

The effect of escalation in fuel costs can influence greatly the final decision. When an annual cost grows at a steady rate it may be treated as a gradient and the gradient present worth factor can be used.

Special thanks are given to Rudolph R. Yanuck and Dr. Robert Brown for the use of their specially designed interest and escalation tables used in this text.

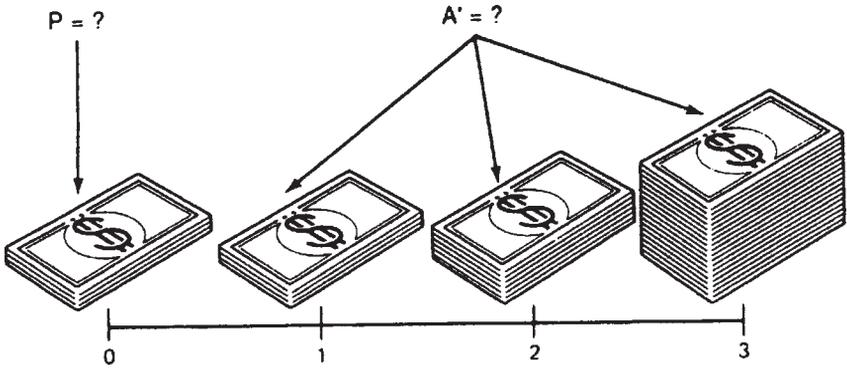


Figure 4-7. Gradient present worth

When life cycle costing is used to compare several alternatives the differences between costs are important. For example, if one alternate forces additional maintenance or an operating expense to occur, then these factors as well as energy costs need to be included. Remember, what was previously spent for the item to be replaced is irrelevant. The only factor to be considered is whether the new cost can be justified based on projected savings over its useful life.

THE JOB SIMULATION EXPERIENCE

Throughout the text you will experience job situations and problems. Each simulation experience is denoted by SIM. The answer will be given below the problem. Cover the answers, then you can "play the game."

SIM 4-1

An evaluation needs to be made to replace all 40-watt fluorescent lamps with a new lamp that saves 12 percent or 4.8 watts and gives the same output. The cost of each lamp is \$2.80.

Assuming a rate of return before taxes of 25 percent is required, can the immediate replacement be justified? Hours of operation are 5800 and the lamp life is two years. Electricity costs 7.0¢/kWh.

ANSWER

$$A = 5800 \times 4.8 \times 0.070 / 1000 = \$1.94$$

$$A/P = 1.94 / 2.80 = .69$$

From Table 4-5 a rate of return of 25 percent is obtained. When analyzing energy conservation measures, never look at what was previously spent or the life remaining. Just determine if the new expenditure will pay for itself.

SIM 4-2

An electrical energy audit indicates electrical motor consumption is 4×10^6 kWh per year. By upgrading the motor spares with high efficiency motors a 10% savings can be realized. The additional cost for these motors is estimated at \$80,000. Assuming an 8¢ per kWh energy charge and 20-year life, is the expenditure justified based on a minimum rate of return of 20% before taxes? Solve the problem using the present worth, annual cost, and rate-of-return methods.

Analysis

	<i>Present Worth Method</i>	
	<i>Alternate 1</i>	<i>Alternate 2</i>
	<i>Present Method</i>	<i>Use High Efficiency Motor Spares</i>
(1) First Cost (P)	—	\$80,000
(2) Annual Cost (A)	$4 \times 10^6 \times .08$ = \$320,000	$.9 \times \$320,000$ = \$288,000
P/A (Table 4-4)	4.87	4.87
(2) A \times 4.87 =	\$1,558,400	\$1,402,560
Present Worth	\$1,558,400	\$1,482,560
(1) + (3)		Choose Alternate with Lowest First Cost

	<i>Annual Cost Method</i>	
	<i>Alternate 1</i>	<i>Alternate 2</i>
(1) First Cost (P)	—	\$80,000
(2) Annual Cost (A)	\$320,000	\$288,000
A/P (Table 4-4)	.2	.2
(3) P \times .2	—	\$16,000
Annual Cost	\$320,000	\$304,000
(2) + (3)		Choose Alternate with Lowest First Cost

Rate of Return Method

$$P = (\$320,000 - \$288,000)$$

$$P/A = \frac{80,000}{32,000} \quad 2.5$$

What value of i will make $P/A = 2.5$? $i = 40\%$ (Table 4-7).

SIM 4-3

Show the effect of 10 percent escalation on the rate of return analysis given the

Energy equipment investment	= \$20,000
After tax savings	= \$ 2,600
Equipment life (n)	= 15 years

ANSWER

Without escalation:

$$\frac{A}{P} = \frac{2,600}{20,000} = 7.69$$

From Table 4-1, the rate of return is 10 percent. With 10 percent escalation assumed:

$$\frac{P}{A} = \frac{20,000}{2,600} = 7.69$$

From Table 4-11, the rate of return is 21 percent.

Thus we see that taking into account a modest escalation rate can dramatically affect the justification of the project.

MAKING DECISIONS FOR ALTERNATE INVESTMENTS

There are several methods for determining which energy conservation alternative is the most economical. Probably the most familiar and trusted method is the annual cost method.

When evaluating replacement of processes or equipment *do not* consider what was previously spent. The decision will be based on whether the new process or equipment proves to save substantially enough in operating costs to justify the expenditure.

Equation 4-16 is used to convert the lump sum investment P into the annual cost. In the case where the asset has a value after the end of its useful life, the annual cost becomes:

$$AC = (P - L) A/P + iL \tag{4-16}$$

where

AC is the annual cost

L is the net sum of money that can be realized for a piece of equipment, over and above its removal cost, when it is returned at the end of the service life. L is referred to as the salvage value.

As a practical point, the salvage value is usually small and can be neglected, considering the accuracy of future costs. The annual cost technique can be implemented by using the following format:

	Alternate 1	Alternate 2
1. First cost (P)		
2. Estimated life (n)		
3. Estimated salvage value at end of life (L)		
4. Annual disbursements, including energy costs & maintenance (E)		
5. Minimum acceptable return before taxes (i)		
6. A/P n, i		
7. $(P - L) * A/P$		
8. Li		
9. $AC = (P - L) * A/P + Li + E$		

Choose alternate with lowest AC

The alternative with the lowest annual cost is the desired choice.

SIM 4-4

A new water line must be constructed from an existing pumping station to a reservoir. Estimates of construction and pumping costs for each pipe size have been made.

Pipe Size	Estimated Construction Costs	Cost/Hour for Pumping
8"	\$80,000	\$4.00
10"	\$100,000	\$3.00
12"	\$160,000	\$1.50

The annual cost is based on a 16-year life and a desired return on investment, before taxes of 10 percent. Which is the most economical pipe size for pumping 4000 hours/year?

ANSWER

	8" Pipe	10" Pipe	12" Pipe
<i>P</i>	\$80,000	\$100,000	\$160,000
<i>n</i>	16	16	16
<i>E</i>	16,000	12,000	6,000
<i>i</i>	10%	10%	10%
$A/P = 0.127$	—	—	—
$(P - L) A/P$	10,160	12,700	20,320
<i>Li</i>	—	—	—
AC	\$26,160	\$24,700 (Choice)	\$26,320

DEPRECIATION, TAXES, AND THE TAX CREDIT

Depreciation

Depreciation affects the “accounting procedure” for determining profits and losses and the income tax of a company. In other words, for tax purposes the expenditure for an asset such as a pump or motor cannot be fully expensed in its first year. The original investment must be charged off for tax purposes over the useful life of the asset. A company usually wishes to expense an item as quickly as possible.

The Internal Revenue Service allows several methods for determining the annual depreciation rate.

Straight-Line Depreciation. The simplest method is referred to as a straight-line depreciation and is defined as:

$$D = \frac{P - L}{n} \tag{4-17}$$

where

- D* is the annual depreciation rate
- L* is the value of equipment at the end of its useful life, commonly referred to as salvage value
- n* is the life of the equipment, which is determined by Internal Revenue Service guidelines
- P* is the initial expenditure.

Sum-of-Years Digits. Another method is referred to as the sum-of-years digits. In this method the depreciation rate is determined by finding the sum of digits using the following formula,

$$N = n \frac{(n + 1)}{2} \quad (4-18)$$

where n is the life of equipment.

Each year's depreciation rate is determined as follows.

$$\text{First year} \quad D = \frac{n}{N} (P - \bar{n} L) \quad (4-19)$$

$$\text{Second year} \quad D = \frac{n - \bar{n} + 1}{N} (P - \bar{n} L) \quad (4-20)$$

$$n \text{ year} \quad D = \frac{1}{N} (P - \bar{n} L) \quad (4-21)$$

Declining-Balance Depreciation. The declining-balance method allows for larger depreciation charges in the early years which is sometimes referred to as fast write-off.

The rate is calculated by taking a constant percentage of the declining undepreciated balance. The most common method used to calculate the declining balance is to predetermine the depreciation rate. Under certain circumstances a rate equal to 200 percent of the straight-line depreciation rate may be used. Under other circumstances the rate is limited to 1-1/2 or 1/4 times as great as straight-line depreciation. In this method the salvage value or undepreciated book value is established once the depreciation rate is pre-established.

To calculate the undepreciated book value, Equation 4-22 used.

$$D = 1 - \bar{n} \left(\frac{L}{P} \right)^{1/N} \quad (4-22)$$

where

- D is the annual depreciation rate
- L is the salvage value
- P is the first cost.

The Tax Reform Act of 1986 (hereafter referred to as the "Act") represented true tax reform, as it made sweeping changes in many basic federal tax code provisions for both individuals and corporations. The Act has had significant impact on financing for cogeneration, alternative energy and energy efficiency transactions, due to substantial modifica-

tions in provisions concerning depreciation, investment and energy tax credits, tax-exempt financing, tax rates, the corporate minimum tax and tax shelters generally.

The Act lengthened the recovery periods for most depreciable assets. The Act also repealed the 10 percent investment tax credit ("ITC") for property placed in service on or after January 1, 1986, subject to the transition rules.

Tax Considerations

Tax-deductible expenses such as maintenance, energy, operating costs, insurance, and property taxes reduce the income subject to taxes.

For the after-tax life cycle analysis and payback analysis the actual incurred and annual savings is given as follows.

$$AS = (1 - I)E + ID \quad (4-23)$$

where

AS is the yearly annual after-tax savings (excluding effect of tax credit)

E is the yearly annual energy savings (difference between original expenses and expenses after modification)

D is the annual depreciation rate is the income tax bracket.

I is the income tax bracket

Equation 4-23 takes into account that the yearly annual energy savings is partially offset by additional taxes which must be paid due to reduced operating expenses. On the other hand, the depreciation allowance reduces taxes directly.

After-Tax Analysis

To compute a rate of return which accounts for taxes, depreciation, escalation, and tax credits, a cash-flow analysis is usually required. This method analyzes all transactions including first and operating costs. To determine the after-tax rate of return a trial and error or computer analysis is required.

All money is converted to the present assuming an interest rate. The summation of all present dollars should equal zero when the correct interest rate is selected, as illustrated in Figure 4-8.

This analysis can be made assuming a fuel escalation rate by using the gradient present worth interest of the present worth factor.

Year	1 Investment	2 Tax Credit	3 After Tax Savings (AS)	4 Single Payment Present Worth Factor	(2+3) × 4 Present Worth
0	-P				-P
1		+TC	AS	P/F ₁	+P ₁
2			AS	P/F ₂	P ₂
3			AS	P/F ₃	P ₃
4			AS	P/F ₄	P ₄
Total					$\frac{P_4}{\Sigma P}$

$AS = (1 - I) E + ID$
 Trial and Error Solution:
 Correct i when $\Sigma P = 0$

Figure 4-8. Cash flow rate of return analysis.

SIM 4-5

Develop a set of curves that indicate the capital that can be invested to give a rate of return of 15 percent after taxes for each \$1000 saved for the following conditions.

1. The effect of escalation is not considered.
2. A 5 percent fuel escalation is considered.
3. A 10 percent fuel escalation is considered.
4. A 14 percent fuel escalation is considered.
5. A 20 percent fuel escalation is considered.

Calculate for 5-, 10-, 15-, 20-year life.

Assume straight-line depreciation over useful life, 34 percent income tax bracket, and no tax credit.

ANSWER $AS = (1 - I) E + ID$

$$I = 0.34, \quad E = \$1000$$

$$AS = 660 + \frac{0.34P}{N}$$

Thus, the after-tax savings (AS) are comprised of two components. The first component is a uniform series of \$660 escalating at e percent/year. The second component is a uniform series of 0.34 P/N.

Each component is treated individually and converted to present day values using the GPW factor and the P/A factor, respectively. The sum of these two present worth factors must equal P. In the case of no escalation, the formula is:

$$P = 660 * PA + \frac{0.34P}{N} * P/A$$

In the case of escalation:

$$P = 660 GPW + \frac{0.34P}{N} * P/A$$

Since there is only one unknown, the formulas can be readily solved. The results are indicated below.

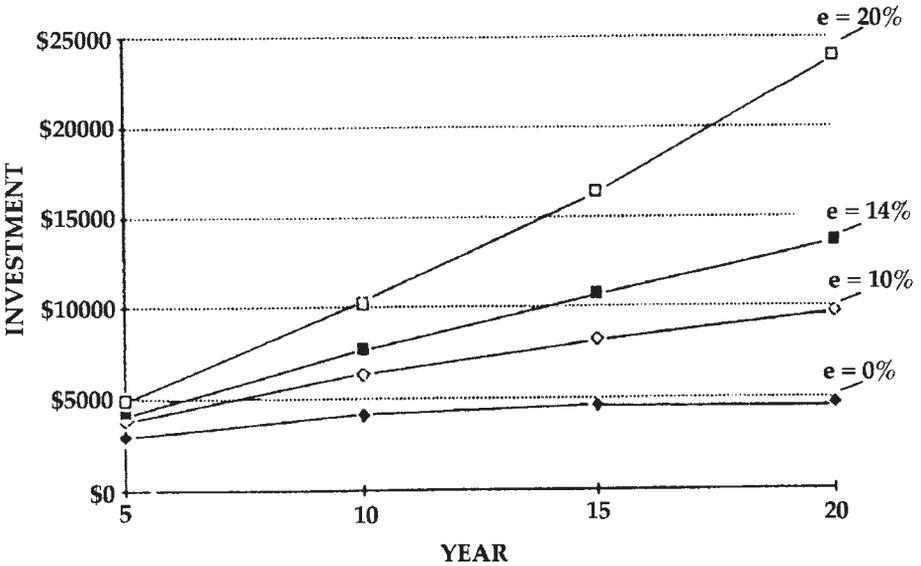
	N = 5	N = 10	N = 15	N = 20
	\$P	\$P	\$P	\$P
e = 0	2869	4000	4459	4648
e = 10%	3753	6292	8165	9618
e = 14%	4170	7598	10,676	13,567
e = 20%	4871	10,146	16,353	23,918

Figure 4-9 illustrates the effects of escalation. This figure can be used as a quick way to determine after-tax economics of energy utilization expenditures.

SIM 4-6

It is desired to have an after-tax savings of 15 percent. Calculate the investment that can be justified if it is assumed that the fuel rate escalation should not be considered and the annual energy savings is \$2000 with an equipment economic life of 15 years.

Calculate the investment that can be justified in the above example, assuming a fuel rate escalation of 14%.



Note: Maximum investment in order to attain a 15% after-tax rate of return on investment for annual savings of \$1000.

Figure 4-9. Effects of Escalation on investment requirements.

ANSWER

From Figure 4-9, for each \$1000 energy savings, an investment of \$4400 is justified or \$8800 for a \$2000 savings when no fuel increase is accounted for.

With a 14 percent fuel escalation rate an investment of \$10,600 is justified for each \$1000 energy savings, thus \$21,200 can be justified for \$2000 savings. Thus, a much higher expenditure is economically justifiable and will yield the same after-tax rate of return of 15 percent when a fuel escalation of 14 percent is considered.

IMPACT OF FUEL INFLATION ON LIFE CYCLE COSTING

As illustrated by problem 4-5 a modest estimate of fuel inflation as a major impact on improving the rate of return on investment of the project. The problem facing the energy engineer is how to forecast what the future of energy costs will be. All too often no fuel inflation is

considered because of the difficulty of projecting the future. In making projections the following guidelines may be helpful:

- Is there a rate increase that can be forecast based on new nuclear generating capacity?
- What has been the historical rate increase for the facility? Even with fluctuations there are likely to be trends to follow.
- What events on a national or international level would impact on your costs? New state taxes, new production quotas by OPEC and other factors affecting your fuel prices.
- What do the experts say? Energy economists, forecasting services, and your local utility projections all should be taken into account.

SUMMARY OF LIFE-CYCLE COSTING

In determining which interest formula to use, the following procedure may be helpful. First, put the symbols in two rows, one above the other as below:

$$\frac{\text{PAF (unknown)}}{\text{PAF (known)}}$$

The top represents the unknown values, and the bottom line represents the known. From information you have and desire, simply circle one of each line, and you have the correct factor.

For example, if you want to determine the annual saving "A" required when the cost of the energy device "P" is known, circle P on the bottom and A on the top. The factor A/P or capital recovery is required for this example. Table 4-13 summarizes the cash analysis for interest formulas.

Table 4-13. Cash Analysis for Interest Formulas

<u>GIVEN</u>	<u>FIND</u>	<u>USE</u>
P	F	F/P
F	P	P/F
A	F	F/A
F	A	A/F
P	A	A/P
A	P	P/A

Table 4-1. 10% Interest factors.

Period <i>n</i>	Single- payment compound- amount F/P	Single- payment present- worth P/F	Uniform series compound- amount F/A	Sinking-fund payment A/F	Capital recovery A/P	Uniform- series present- worth P/A
	Future value of \$1 $(1+i)^n$	Present value of \$1 $\frac{1}{(1+i)^n}$	Future value of uniform series of \$1 $(1+i)^n \pm 1$ <i>i</i>	Uniform series whose future value is \$1 $\frac{i}{(1+i)^n \pm 1}$	Uniform series with present value of \$1 $\frac{i(1+i)^n}{(1+i)^n \pm 1}$	Present value of uniform series of \$1 $\frac{i(1+i)^n}{(1+i)^n \pm 1}$
1	1.100	0.9091	1.000	1.00000	1.10000	0.909
2	1.210	0.8264	2.100	0.47619	0.57619	1.736
3	1.331	0.7513	3.310	0.30211	0.40211	2.487
4	1.464	0.6830	4.641	0.21547	0.31147	3.170
5	1.611	0.6209	6.105	0.16380	0.26380	3.791
6	1.772	0.5645	7.716	0.12961	0.22961	4.355
7	1.949	0.5132	9.487	0.10541	0.20541	4.868
8	2.144	0.4665	11.436	0.08744	0.18744	5.335
9	2.358	0.4241	13.579	0.07364	0.17364	5.759
10	2.594	0.3855	15.937	0.06275	0.16275	6.144
11	2.853	0.3505	18.531	0.05396	0.15396	6.495
12	3.138	0.3186	21.384	0.04676	0.14676	6.814
13	3.452	0.2897	24.523	0.04078	0.14078	7.103
14	3.797	0.2633	27.975	0.03575	0.13575	7.367
15	4.177	0.2394	31.772	0.03147	0.13147	7.606
16	4.595	0.2176	35.950	0.02782	0.12782	7.824
17	5.054	0.1978	40.545	0.02466	0.12466	8.022
18	5.560	0.1799	45.599	0.02193	0.12193	8.201
19	6.116	0.1635	51.159	0.01955	0.11955	8.365
20	6.727	0.1486	57.275	0.01746	0.11746	8.514
21	7.400	0.1351	64.002	0.01562	0.11562	8.649
22	8.140	0.1228	71.403	0.01401	0.11401	8.772
23	8.954	0.1117	79.543	0.01257	0.11257	8.883
24	9.850	0.1015	88.497	0.01130	0.11130	8.985
25	10.835	0.0923	98.347	0.01017	0.11017	9.077
26	11.918	0.0839	109.182	0.00916	0.10916	9.161
27	13.110	0.0763	121.100	0.00826	0.10826	9.237
28	14.421	0.0693	134.210	0.00745	0.10745	9.307
29	15.863	0.0630	148.631	0.00673	0.10673	9.370
30	17.449	0.0673	164.494	0.00608	0.10608	9.427
35	28.102	0.0356	271.024	0.00369	0.10369	9.644
40	45.259	0.0221	442.593	0.00226	0.10226	9.779
45	72.890	0.0137	718.905	0.00139	0.10139	9.863
50	117.391	0.0085	1163.909	0.00086	0.10086	9.915
55	189.059	0.0053	1880.591	0.00053	0.10053	9.947
60	304.482	0.0033	3034.816	0.00033	0.10033	9.967
65	490.371	0.0020	4893.707	0.00020	0.10020	9.980
70	789.747	0.0013	7887.470	0.00013	0.10013	9.987
75	1271.895	0.0008	12708.954	0.00008	0.10008	9.992
80	2048.400	0.0005	20474.002	0.00005	0.10005	9.995
85	3298.969	0.0003	32979.690	0.00003	0.10003	9.997
90	5313.023	0.0002	53120.226	0.00002	0.10002	9.998
95	8556.676	0.0001	85556.760	0.00001	0.10001	9.999

Table 4-2. 12% Interest factors.

Period <i>n</i>	Single- payment compound- amount F/P	Single- payment present- worth P/F	Uniform series compound- amount F/A	Sinking-fund payment A/F	Capital recovery A/P	Uniform- series present- worth P/A
	Future value of \$1	Present value of \$1	Future value of uniform series of \$1	Uniform series whose future value is \$1	Uniform series with present value of \$1	Present value of uniform series of \$1
	$(1+i)^n$	$\frac{1}{(1+i)^n}$	$\frac{(1+i)^n \pm 1}{i}$	$\frac{i}{(1+i)^n \pm 1}$	$\frac{i(1+i)^n}{(1+i)^n \pm 1}$	$\frac{(1+i)^n \pm 1}{i(1+i)^n}$
1	1.120	0.8929	1.000	1.00000	1.12000	0.893
2	1.254	0.7972	2.120	0.47170	0.59170	1.690
3	1.405	0.7118	3.374	0.29635	0.41635	2.402
4	1.574	0.6355	4.779	0.20923	0.32923	3.037
5	1.762	0.5674	6.353	0.15741	0.27741	3.605
6	1.974	0.5066	8.115	0.12323	0.24323	4.111
7	2.211	0.4523	10.089	0.09912	0.21912	4.564
8	2.476	0.4039	12.300	0.08130	0.20130	4.968
9	2.773	0.3606	14.776	0.06768	0.18768	5.328
10	3.106	0.3220	17.549	0.05698	0.17698	5.650
11	3.479	0.2875	20.655	0.04842	0.16842	5.938
12	3.896	0.2567	24.133	0.04144	0.16144	6.194
13	4.363	0.2292	28.029	0.03568	0.15568	6.424
14	4.887	0.2046	32.393	0.03087	0.15087	6.628
15	5.474	0.1827	37.280	0.02682	0.14682	6.811
16	6.130	0.1631	42.753	0.02339	0.14339	6.974
17	6.866	0.1456	48.884	0.02046	0.14046	7.120
18	7.690	0.1300	55.750	0.01794	0.13794	7.250
19	8.613	0.1161	63.440	0.01576	0.13576	7.366
20	9.646	0.1037	72.052	0.01388	0.13388	7.469
21	10.804	0.0926	81.699	0.01224	0.13224	7.562
22	12.100	0.0826	92.503	0.01081	0.13081	7.645
23	13.552	0.0738	104.603	0.00956	0.12956	7.718
24	15.179	0.0659	118.155	0.00846	0.12846	7.784
25	17.000	0.0588	133.334	0.00750	0.12750	7.843
26	19.040	0.0525	150.334	0.00665	0.12665	7.896
27	21.325	0.0469	169.374	0.00590	0.12590	7.943
28	23.884	0.0419	190.699	0.00524	0.12524	7.984
29	26.750	0.0374	214.583	0.00466	0.12466	8.022
30	29.960	0.0334	241.333	0.00414	0.12414	8.055
35	52.800	0.0189	431.663	0.00232	0.12232	8.176
40	93.051	0.0107	767.091	0.00130	0.12130	8.244
45	163.988	0.0061	1358.230	0.00074	0.12074	8.283
50	289.002	0.0035	2400.018	0.00042	0.12042	8.304
55	509.321	0.0020	4236.005	0.00024	0.12024	8.317
60	897.597	0.0011	7471.641	0.00013	0.12013	8.324
65	1581.872	0.0006	13173.937	0.00008	0.12008	8.328
70	2787.800	0.0004	23223.332	0.00004	0.12004	8.330
75	4913.056	0.0002	40933.799	0.00002	0.12002	8.332
80	8658.483	0.0001	72145.692	0.00001	0.12001	8.332

Table 4-3. 15% Interest factors.

Period <i>n</i>	Single-payment compound-amount F/P	Single-payment present-worth P/F	Uniform series compound-amount F/A	Sinking-fund payment A/F	Capital recovery A/P	Uniform-series present-worth P/A
	Future value of \$1	Present value of \$1	Future value of uniform series of \$1	Uniform series whose future value is \$1	Uniform series with present value of \$1	Present value of uniform series of \$1
	$(1 + i)^n$	$\frac{1}{(1 + i)^n}$	$\frac{(1 + i)^n \pm 1}{i}$	$\frac{i}{(1 + i)^n \pm 1}$	$\frac{i(1 + i)^n}{(1 + i)^n \pm 1}$	$\frac{(1 + i)^n \pm 1}{i(1 + i)^n}$
1	1.150	0.8696	1.000	1.00000	1.15000	0.870
2	1.322	0.7561	2.150	0.46512	0.61512	1.626
3	1.521	0.6575	3.472	0.28798	0.43798	2.283
4	1.749	0.5718	4.993	0.20027	0.35027	2.855
5	2.011	0.4972	6.742	0.14832	0.29832	3.352
6	2.313	0.4323	8.754	0.11424	0.26424	3.784
7	2.660	0.3759	11.067	0.09036	0.24036	4.160
8	3.059	0.3269	13.727	0.07285	0.22285	4.487
9	3.518	0.2843	16.786	0.05957	0.20957	4.772
10	4.046	0.2472	20.304	0.04925	0.19925	5.019
11	4.652	0.2149	24.349	0.04107	0.19107	5.234
12	5.350	0.1869	29.002	0.03448	0.18448	5.421
13	6.153	0.1625	34.352	0.02911	0.17911	5.583
14	7.076	0.1413	40.505	0.02469	0.17469	5.724
15	8.137	0.1229	47.580	0.02102	0.17102	5.847
16	9.358	0.1069	55.717	0.01795	0.16795	5.954
17	10.761	0.0929	65.075	0.01537	0.16537	6.047
18	12.375	0.0808	75.836	0.01319	0.16319	6.128
19	14.232	0.0703	88.212	0.01134	0.16134	6.198
20	16.367	0.0611	102.444	0.00976	0.15976	6.259
21	18.822	0.0531	118.810	0.00842	0.15842	6.312
22	21.645	0.0462	137.632	0.00727	0.15727	6.359
23	24.891	0.0402	159.276	0.00628	0.15628	6.399
24	28.625	0.0349	194.168	0.00543	0.15543	6.434
25	32.919	0.0304	212.793	0.00470	0.15470	6.464
26	37.857	0.0264	245.712	0.00407	0.15407	6.491
27	43.535	0.0230	283.569	0.00353	0.15353	6.514
28	50.066	0.0200	327.104	0.00306	0.15306	6.534
29	57.575	0.0174	377.170	0.00265	0.15265	6.551
30	66.212	0.0151	434.745	0.00230	0.15230	6.566
35	133.176	0.0075	881.170	0.00113	0.15113	6.617
40	267.864	0.0037	1779.090	0.00056	0.15056	6.642
45	538.769	0.0019	3585.128	0.00028	0.15028	6.654
50	1083.657	0.0009	7217.716	0.00014	0.15014	6.661
55	2179.622	0.0005	14524.148	0.00007	0.15007	6.664
60	4383.999	0.0002	29219.992	0.00003	0.15003	6.665
65	8817.787	0.0001	58778.583	0.00002	0.15002	6.666

Table 4-4. 20% Interest factors.

Period n	Single- payment compound- amount F/P	Single- payment present- worth P/F	Uniform series compound- amount F/A	Sinking-fund payment A/F	Capital recovery A/P	Uniform- series present- worth P/A
	Future value of \$1 $(1+i)^n$	Present value of \$1 $\frac{1}{(1+i)^n}$	Future value of uniform series of \$1 $\frac{(1+i)^n \pm 1}{i}$	Uniform series whose future value is \$1 $\frac{i}{(1+i)^n \pm 1}$	Uniform series with present value of \$1 $\frac{i(1+i)^n}{(1+i)^n \pm 1}$	Present value of uniform series of \$1 $\frac{(1+i)^n \pm 1}{i(1+i)^n}$
1	1.200	0.8333	1.000	1.00000	1.20000	0.833
2	1.440	0.6944	2.200	0.45455	0.65455	1.528
3	1.728	0.5787	3.640	0.27473	0.47473	2.106
4	2.074	0.4823	5.368	0.18629	0.38629	2.589
5	2.488	0.4019	7.442	0.13438	0.33438	2.991
6	2.986	0.3349	9.930	0.10071	0.30071	3.326
7	3.583	0.2791	12.916	0.07742	0.27742	3.605
8	4.300	0.2326	16.499	0.06061	0.26061	3.837
9	5.160	0.1938	20.799	0.04808	0.24808	4.031
10	6.192	0.1615	25.959	0.03852	0.23852	4.192
11	7.430	0.1346	32.150	0.03110	0.23110	4.327
12	8.916	0.1122	39.581	0.02526	0.22526	4.439
13	10.699	0.0935	48.497	0.02062	0.22062	4.533
14	12.839	0.0779	59.196	0.01689	0.21689	4.611
15	15.407	0.0649	72.035	0.01388	0.21388	4.675
16	18.488	0.0541	87.442	0.01144	0.21144	4.730
17	22.186	0.0451	105.931	0.00944	0.20944	4.775
18	26.623	0.0376	128.117	0.00781	0.20781	4.812
19	31.948	0.0313	154.740	0.00646	0.20646	4.843
20	38.338	0.0261	186.688	0.00536	0.20536	4.870
21	46.005	0.0217	225.026	0.00444	0.20444	4.891
22	55.206	0.0181	271.031	0.00369	0.20369	4.909
23	66.247	0.0151	326.237	0.00307	0.20307	4.925
24	79.497	0.0126	392.484	0.00255	0.20255	4.937
25	95.396	0.0105	471.981	0.00212	0.20212	4.948
26	114.475	0.0087	567.377	0.00176	0.20176	4.956
27	137.371	0.0073	681.853	0.00147	0.20147	4.964
28	164.845	0.0061	819.223	0.00122	0.20122	4.970
29	197.814	0.0051	984.068	0.00102	0.20102	4.975
30	237.376	0.0042	1181.882	0.00085	0.20085	4.979
35	590.668	0.0017	2948.341	0.00034	0.20034	4.992
40	1469.772	0.0007	7343.858	0.00014	0.20014	4.997
45	3657.262	0.0003	18281.310	0.00005	0.20005	4.999
50	9100.438	0.0001	45497.191	0.00002	0.20002	4.999

Table 4-5. 25% Interest factors.

Period <i>n</i>	Single-payment compound-amount F/P	Single-payment present-worth P/F	Uniform series compound-amount F/A	Sinking-fund payment A/F	Capital recovery A/P	Uniform-series present-worth P/A
	Future value of \$1	Present value of \$1	Future value of uniform series of \$1	Uniform series whose future value is \$1	Uniform series with present value of \$1	Present value of uniform series of \$1
	$(1 + i)^n$	$\frac{1}{(1 + i)^n}$	$\frac{(1 + i)^n \pm 1}{i}$	$\frac{i}{(1 + i)^n \pm 1}$	$\frac{i(1 + i)^n}{(1 + i)^n \pm 1}$	$\frac{(1 + i)^n \pm 1}{i(1 + i)^n}$
1	1.250	0.8000	1.000	1.00000	1.25000	0.800
2	1.562	0.6400	2.250	0.44444	0.69444	1.440
3	1.953	0.5120	3.812	0.26230	0.51230	1.952
4	2.441	0.4096	5.766	0.17344	0.42344	2.362
5	3.052	0.3277	8.207	0.12185	0.37185	2.689
6	3.815	0.2621	11.259	0.08882	0.33882	2.951
7	4.768	0.2097	15.073	0.06634	0.31634	3.161
8	5.960	0.1678	19.842	0.05040	0.30040	3.329
9	7.451	0.1342	25.802	0.03876	0.28876	3.463
10	9.313	0.1074	33.253	0.03007	0.28007	3.571
11	11.642	0.0859	42.566	0.02349	0.27349	3.656
12	14.552	0.0687	54.208	0.01845	0.26845	3.725
13	18.190	0.0550	68.760	0.01454	0.26454	3.780
14	22.737	0.0440	86.949	0.01150	0.26150	3.824
15	28.422	0.0352	109.687	0.00912	0.25912	3.859
16	35.527	0.0281	138.109	0.00724	0.25724	3.887
17	44.409	0.0225	173.636	0.00576	0.25576	3.910
18	55.511	0.0180	218.045	0.00459	0.25459	3.928
19	69.389	0.0144	273.556	0.00366	0.25366	3.942
20	86.736	0.0115	342.945	0.00292	0.25292	3.954
21	108.420	0.0092	429.681	0.00233	0.25233	3.963
22	135.525	0.0074	538.101	0.00186	0.25186	3.970
23	169.407	0.0059	673.626	0.00148	0.25148	3.976
24	211.758	0.0047	843.033	0.00119	0.25119	3.981
25	264.698	0.0038	1054.791	0.00095	0.25095	3.985
26	330.872	0.0030	1319.489	0.00076	0.25076	3.988
27	413.590	0.0024	1650.361	0.00061	0.25061	3.990
28	516.988	0.0019	2063.952	0.00048	0.25048	3.992
29	646.235	0.0015	2580.939	0.00039	0.25039	3.994
30	807.794	0.0012	3227.174	0.00031	0.25031	3.995
35	2465.190	0.0004	9856.761	0.00010	0.25010	3.998
40	7523.164	0.0001	30088.655	0.00003	0.25003	3.999

Table 4-6. 30% Interest factors.

Period <i>n</i>	Single- payment compound- amount F/P	Single- payment present- worth P/F	Uniform series compound- amount F/A	Sinking-fund payment A/F	Capital recovery A/P	Uniform- series present- worth P/A
	Future value of \$1 $(1+i)^n$	Present value of \$1 $\frac{1}{(1+i)^n}$	Future value of uniform series of \$1 $(1+i)^n \pm 1$ i	Uniform series whose future value is \$1 i $(1+i)^n \pm 1$	Uniform series with present value of \$1 $i(1+i)^n$ $(1+i)^n \pm 1$	Present value of uniform series of \$1 $(1+i)^n \pm 1$ $i(1+i)^n$
1	1.300	0.7692	1.000	1.00000	1.30000	0.769
2	1.690	0.5917	2.300	0.43478	0.73478	1.361
3	2.197	0.4552	3.990	0.25063	0.55063	1.816
4	2.856	0.3501	6.187	0.16163	0.46163	2.166
5	3.713	0.2693	9.043	0.11058	0.41058	2.436
6	4.827	0.2072	12.756	0.07839	0.37839	2.643
7	6.275	0.1594	17.583	0.05687	0.35687	2.802
8	8.157	0.1226	23.858	0.04192	0.34192	2.925
9	10.604	0.0943	32.015	0.03124	0.33124	3.019
10	13.786	0.0725	42.619	0.02346	0.32346	3.092
11	17.922	0.0558	56.405	0.01773	0.31773	3.147
12	23.298	0.0429	74.327	0.01345	0.31345	3.190
13	30.288	0.0330	97.625	0.01024	0.31024	3.223
14	39.374	0.0254	127.913	0.00782	0.30782	3.249
15	51.186	0.0195	167.286	0.00598	0.30598	3.268
16	66.542	0.0150	218.472	0.00458	0.30458	3.283
17	86.504	0.0116	285.014	0.00351	0.30351	3.295
18	112.455	0.0089	371.518	0.00269	0.30269	3.304
19	146.192	0.0068	483.973	0.00207	0.30207	3.311
20	190.050	0.0053	630.165	0.00159	0.30159	3.316
21	247.065	0.0040	820.215	0.00122	0.30122	3.320
22	321.194	0.0031	1067.280	0.00094	0.30094	3.323
23	417.539	0.0024	1388.464	0.00072	0.30072	3.325
24	542.801	0.0018	1806.003	0.00055	0.30055	3.327
25	705.641	0.0014	2348.803	0.00043	0.30043	3.329
26	917.333	0.0011	3054.444	0.00033	0.30033	3.330
27	1192.533	0.0008	3971.778	0.00025	0.30025	3.331
28	1550.293	0.0006	5164.311	0.00019	0.30019	3.331
29	2015.381	0.0005	6714.604	0.00015	0.30015	3.332
30	2619.996	0.0004	8729.985	0.00011	0.30011	3.332
35	9727.8060	0.0001	32422.868	0.00003	0.30003	3.333

Table 4-7. 40% Interest factors.

Period <i>n</i>	Single-payment compound-amount F/P	Single-payment present-worth P/F	Uniform series compound-amount F/A	Sinking-fund payment A/F	Capital recovery A/P	Uniform-series present-worth P/A
	Future value of \$1 $(1 + i)^n$	Present value of \$1 $\frac{1}{(1 + i)^n}$	Future value of uniform series of \$1 $\frac{(1 + i)^n \pm 1}{i}$	Uniform series whose future value is \$1 $\frac{i}{(1 + i)^n \pm 1}$	Uniform series with present value of \$1 $\frac{i(1 + i)^n}{(1 + i)^n \pm 1}$	Present value of uniform series of \$1 $\frac{(1 + i)^n \pm 1}{i(1 + i)^n}$
1	1.400	0.7143	1.000	1.00000	1.40000	0.714
2	1.960	0.5102	2.400	0.41667	0.81667	1.224
3	2.744	0.3644	4.360	0.22936	0.62936	1.589
4	3.842	0.2603	7.104	0.14077	0.54077	1.849
5	5.378	0.1859	10.946	0.09136	0.49136	2.035
6	7.530	0.1328	16.324	0.06126	0.46126	2.168
7	10.541	0.0949	23.853	0.04192	0.44192	2.263
8	14.758	0.0678	34.395	0.02907	0.42907	2.331
9	20.661	0.0484	49.153	0.02034	0.42034	2.379
10	28.925	0.0346	69.814	0.01432	0.41432	2.414
11	40.496	0.0247	98.739	0.01013	0.41013	2.438
12	56.694	0.0176	139.235	0.00718	0.40718	2.456
13	79.371	0.0126	195.929	0.00510	0.40510	2.469
14	111.120	0.0090	275.300	0.00363	0.40363	2.478
15	155.568	0.0064	386.420	0.00259	0.40259	2.484
16	217.795	0.0046	541.988	0.00185	0.40185	2.489
17	304.913	0.0033	759.784	0.00132	0.40132	2.492
18	426.879	0.0023	1064.697	0.00094	0.40094	2.494
19	597.630	0.0017	1491.576	0.00067	0.40067	2.496
20	836.683	0.0012	2089.206	0.00048	0.40048	2.497
21	1171.356	0.0009	2925.889	0.00034	0.40034	2.498
22	1639.898	0.0006	4097.245	0.00024	0.40024	2.498
23	2295.857	0.0004	5737.142	0.00017	0.40017	2.499
24	3214.200	0.0003	8032.999	0.00012	0.40012	2.499
25	4499.880	0.0002	11247.199	0.00009	0.40009	2.499
26	6299.831	0.0002	15747.079	0.00006	0.40006	2.500
27	8819.764	0.0001	22046.910	0.00005	0.40005	2.500

Table 4-8. 50% Interest factors.

Period	Single-payment compound-amount F/P	Single-payment present-worth P/F	Uniform series compound-amount F/A	Sinking-fund payment A/F	Capital recovery A/P	Uniform-series present-worth P/A
<i>n</i>	Future value of \$1	Present value of \$1	Future value of uniform series of \$1	Uniform series whose future value is \$1	Uniform series with present value of \$1	Present value of uniform series of \$1
	$(1 + i)^n$	$\frac{1}{(1 + i)^n}$	$\frac{(1 + i)^n \pm 1}{i}$	$\frac{i}{(1 + i)^n \pm 1}$	$\frac{i(1 + i)^n}{(1 + i)^n \pm 1}$	$\frac{(1 + i)^n \pm 1}{i(1 + i)^n}$
1	1.500	0.6667	1.000	1.00000	1.50000	0.667
2	2.250	0.4444	2.500	0.40000	0.90000	1.111
3	3.375	0.2963	4.750	0.21053	0.71053	1.407
4	5.062	0.1975	8.125	0.12308	0.62308	1.605
5	7.594	0.1317	13.188	0.07583	0.57583	1.737
6	11.391	0.0878	20.781	0.04812	0.54812	1.824
7	17.086	0.0585	32.172	0.03108	0.53108	1.883
8	25.629	0.0390	49.258	0.02030	0.52030	1.922
9	38.443	0.0260	74.887	0.01335	0.51335	1.948
10	57.665	0.0173	113.330	0.00882	0.50882	1.965
11	86.498	0.0116	170.995	0.00585	0.50585	1.977
12	129.746	0.0077	257.493	0.00388	0.50388	1.985
13	194.620	0.0051	387.239	0.00258	0.50258	1.990
14	291.929	0.0034	581.859	0.00172	0.50172	1.993
15	437.894	0.0023	873.788	0.00114	0.50114	1.995
16	656.841	0.0015	1311.682	0.00076	0.50076	1.997
17	985.261	0.0010	1968.523	0.00051	0.50051	1.998
18	1477.892	0.0007	2953.784	0.00034	0.50034	1.999
19	2216.838	0.0005	4431.676	0.00023	0.50023	1.999
20	3325.257	0.0003	6648.513	0.00015	0.50015	1.999
21	4987.885	0.0002	9973.770	0.00010	0.50010	2.000
22	7481.828	0.0001	14961.655	0.00007	0.50007	2.000

Table 4-9. Five-year escalation table.

Present Worth of a Series of Escalating Payments Compounded Annually Discount-Escalation Factors for $n = 5$ Years						
Discount Rate	Annual Escalation Rate					
	0.10	0.12	0.14	0.16	0.18	0.20
0.10	5.000000	5.279234	5.572605	5.880105	6.202627	6.540569
0.11	4.866862	5.136200	5.420152	5.717603	6.029313	6.355882
0.12	4.738562	5.000000	5.274242	5.561868	5.863289	6.179066
0.13	4.615647	4.869164	5.133876	5.412404	5.704137	6.009541
0.14	4.497670	4.742953	5.000000	5.269208	5.551563	5.847029
0.15	4.384494	4.622149	4.871228	5.131703	5.404955	5.691165
0.16	4.275647	4.505953	4.747390	5.000000	5.264441	5.541511
0.17	4.171042	4.394428	4.628438	4.873699	5.129353	5.397964
0.18	4.070432	4.287089	4.513947	4.751566	5.000000	5.259749
0.19	3.973684	4.183921	4.403996	4.634350	4.875619	5.126925
0.20	3.880510	4.084577	4.298207	4.521178	4.755725	5.000000
0.21	3.790801	3.989001	4.196400	4.413341	4.640260	4.877689
0.22	3.704368	3.896891	4.098287	4.308947	4.529298	4.759649
0.23	3.621094	3.808179	4.003835	4.208479	4.422339	4.645864
0.24	3.540773	3.722628	3.912807	4.111612	4.319417	4.536517
0.25	3.463301	3.640161	3.825008	4.018249	4.220158	4.431144
0.26	3.388553	3.560586	3.740376	3.928286	4.124553	4.329514
0.27	3.316408	3.483803	3.658706	3.841442	4.032275	4.231583
0.28	3.246718	3.409649	3.579870	3.757639	3.943295	4.137057
0.29	3.179393	3.338051	3.503722	3.676771	3.857370	4.045902
0.30	3.114338	3.268861	3.430201	3.598653	3.774459	3.957921
0.31	3.051452	3.201978	3.359143	3.523171	3.694328	3.872901
0.32	2.990618	3.137327	3.290436	3.450224	3.616936	3.790808
0.33	2.939764	3.074780	3.224015	3.379722	3.542100	3.711472
0.34	2.874812	3.014281	3.159770	3.311524	3.469775	3.634758

Table 4-10. Ten-year escalation table.

Present Worth of a Series of Escalating Payments Compounded Annually Discount-Escalation Factors for $n = 10$ Years						
Discount Rate	Annual Escalation Rate					
	0.10	0.12	0.14	0.16	0.18	0.20
0.10	10.000000	11.056250	12.234870	13.548650	15.013550	16.646080
0.11	9.518405	10.508020	11.613440	12.844310	14.215140	15.741560
0.12	9.068870	10.000000	11.036530	12.190470	13.474590	14.903510
0.13	8.650280	9.526666	10.498990	11.582430	12.786980	14.125780
0.14	8.259741	9.084209	10.000000	11.017130	12.147890	13.403480
0.15	7.895187	8.672058	9.534301	10.490510	11.552670	12.731900
0.16	7.554141	8.286779	9.099380	10.000000	10.998720	12.106600
0.17	7.234974	7.926784	8.693151	9.542653	10.481740	11.524400
0.18	6.935890	7.589595	8.312960	9.113885	10.000000	10.980620
0.19	6.655455	7.273785	7.957330	8.713262	9.549790	10.472990
0.20	6.392080	6.977461	7.624072	8.338518	9.128122	10.000000
0.21	6.144593	6.699373	7.311519	7.987156	8.733109	9.557141
0.22	5.911755	6.437922	7.017915	7.657542	8.363208	9.141752
0.23	5.692557	6.192047	6.742093	7.348193	8.015993	8.752133
0.24	5.485921	5.960481	6.482632	7.057347	7.690163	8.387045
0.25	5.290990	5.742294	6.238276	6.783767	7.383800	8.044173
0.26	5.106956	5.536463	6.008083	6.526298	7.095769	7.721807
0.27	4.933045	5.342146	5.790929	6.283557	6.824442	7.418647
0.28	4.768518	5.158489	5.585917	6.054608	6.568835	7.133100
0.29	4.612762	4.984826	5.392166	5.838531	6.327682	6.864109
0.30	4.465205	4.820429	5.209000	5.634354	6.100129	6.610435
0.31	4.325286	4.664669	5.035615	5.441257	5.885058	6.370867
0.32	4.192478	4.517015	4.871346	5.258512	5.681746	6.144601
0.33	4.066339	4.376884	4.715648	5.085461	5.489304	5.930659
0.34	3.946452	4.243845	4.567942	4.921409	5.307107	5.728189

Table 4-11. Fifteen-year escalation table.

Present Worth of a Series of Escalating Payments Compounded Annually Discount-Escalation Factors for $n = 15$ years						
Discount Rate	Annual Escalation Rate					
	0.10	0.12	0.14	0.16	0.18	0.20
0.10	15.000000	17.377880	20.199780	23.549540	27.529640	32.259620
0.11	13.964150	16.126230	18.690120	21.727370	25.328490	29.601330
0.12	13.026090	15.000000	17.332040	20.090360	23.355070	27.221890
0.13	12.177030	13.981710	16.105770	18.616160	21.581750	25.087260
0.14	11.406510	13.057790	15.000000	17.287320	19.985530	23.169060
0.15	10.706220	12.220570	13.998120	16.086500	18.545150	21.442230
0.16	10.068030	11.459170	13.088900	15.000000	17.244580	19.884420
0.17	9.485654	10.766180	12.262790	14.015480	16.066830	18.477610
0.18	8.953083	10.133630	11.510270	13.118840	15.000000	17.203010
0.19	8.465335	9.555676	10.824310	12.303300	14.030830	16.047480
0.20	8.017635	9.026333	10.197550	11.560150	13.148090	15.000000
0.21	7.606115	8.540965	9.623969	10.881130	12.343120	14.046400
0.22	7.227109	8.094845	9.097863	10.259820	11.608480	13.176250
0.23	6.877548	7.684317	8.614813	9.690559	10.936240	12.381480
0.24	6.554501	7.305762	8.170423	9.167798	10.320590	11.655310
0.25	6.255518	6.956243	7.760848	8.687104	9.755424	10.990130
0.26	5.978393	6.632936	7.382943	8.244519	9.236152	10.379760
0.27	5.721101	6.333429	7.033547	7.836080	8.757889	9.819020
0.28	5.481814	6.055485	6.710042	7.458700	8.316982	9.302823
0.29	5.258970	5.797236	6.410005	7.109541	7.909701	8.827153
0.30	5.051153	5.556882	6.131433	6.785917	7.533113	8.388091
0.31	4.857052	5.332839	5.872303	6.485500	7.184156	7.982019
0.32	4.675478	5.123753	5.630905	6.206250	6.860492	7.606122
0.33	4.505413	4.928297	5.405771	5.946343	6.559743	7.257569
0.34	4.345926	4.745399	5.195502	5.704048	6.280019	6.933897

Table 4-12. Twenty-year escalation table.

Present Worth of a Series of Escalating Payments Compounded Annually Discount-Escalation Factors for $n = 20$ Years						
Discount Rate	Annual Escalation Rate					
	0.10	0.12	0.14	0.16	0.18	0.20
0.10	20.000000	24.295450	29.722090	36.592170	45.308970	56.383330
0.11	18.213210	22.002090	26.776150	32.799710	40.417480	50.067940
0.12	16.642370	20.000000	24.210030	29.505400	36.181240	44.614710
0.13	15.259850	18.243100	21.964990	26.634490	32.502270	39.891400
0.14	14.038630	16.694830	20.000000	24.127100	29.298170	35.789680
0.15	12.957040	15.329770	18.271200	21.929940	26.498510	32.218060
0.16	11.995640	14.121040	16.746150	20.000000	24.047720	29.098950
0.17	11.138940	13.048560	15.397670	18.300390	21.894660	26.369210
0.18	10.373120	12.093400	14.201180	16.795710	20.000000	23.970940
0.19	9.686791	11.240870	13.137510	15.463070	18.326720	21.860120
0.20	9.069737	10.477430	12.188860	14.279470	16.844020	20.000000
0.21	8.513605	9.792256	11.340570	13.224610	15.527270	18.353210
0.22	8.010912	9.175267	10.579620	12.282120	14.355520	16.890730
0.23	7.555427	8.618459	9.895583	11.438060	13.309280	15.589300
0.24	7.141531	8.114476	9.278916	10.679810	12.373300	14.429370
0.25	6.764528	7.657278	8.721467	9.997057	11.533310	13.392180
0.26	6.420316	7.241402	8.216490	9.380883	10.778020	12.462340
0.27	6.105252	6.862203	7.757722	8.823063	10.096710	11.626890
0.28	5.816151	6.515563	7.339966	8.316995	9.480940	10.874120
0.29	5.550301	6.198027	6.958601	7.856833	8.922847	10.194520
0.30	5.305312	5.906440	6.609778	7.437339	8.416060	9.579437
0.31	5.079039	5.638064	6.289875	7.054007	7.954518	9.021190
0.32	4.869585	5.390575	5.995840	6.702967	7.533406	8.513612
0.33	4.675331	5.161809	5.725066	6.380829	7.148198	8.050965
0.34	4.494838	4.949990	5.475180	6.084525	6.795200	7.628322

EQUIPMENT LIFE

To estimate equipment lifefor life cycle cost analysis, Table 4-14 can be used.

Table 4-14. Equipment Service Life Statistics

Equipment Item	Mean	Median	Model(s)	Percentiles		
				25%	75%	N
UNITARY EQUIPMENT						
Room Air Conditioners						
(window or through-the-wall)	10	10	10	5	10	38
Unitary Air Conditioners						
1. Air-cooled—residential (single package or split system)	14	15	15	8	20	29
2. Air cooled—commercial/industrial (single package—through-the-wall or split system)	15	15	15	10	20	40
3. Water cooled—electric	16	15	15-20	10	20	17
Unitary Heat Pumps						
1. Air source—residential	11	10	10	10	12.5	12
2. Air source—commercial/industrial (single package or split system)	15	15	15	11	15	13
3. Water source—comm./industrial	13	13	10	10	20	8
Computer Room Conditioners	18	15	15	15	20	23
ROOF TOP HVAC SYSTEMS						
Single Zone Heating, ventilating and cooling or cooling only	15	15	15	10	20	30
Multizone Heating, ventilating and cooling or cooling only	16	15	15	10	20	25

(Continued)

Equipment Item	Mean	Median	Model(s)	Percentiles		
				25%	75%	N
HEATING EQUIPMENT						
Boilers						
1. Steam —steel watertube	30	26	40	20	40	30
—steel firetube	24	25	25	20	30	14
—cast iron	30	30	30	20	35	12
2. Hot water —steel watertube	24	23	20	20	27	12
—steel firetube	23	24	30	17	30	16
—cast iron	30	30	30	20	40	13
3. Electric	14	15	15	7	17	9
Burners						
Gas—forced and natural and oil-forced	22	20	20	17	27	58
Furnaces						
Gas or oil	18	20	20	12	20	35
Unit Heaters						
Gas or electric	14	13	10	10	20	28
Hotwater or steam	23	20	20	20	30	30
Radiant Heaters and Panels						
Electric heaters	11	10	10	5	25	6
Hot water or steam panels	26	25	20-25	20	30	7
AIR HANDLING AND TREATINGEQUIPMENT						
Terminal Units						
1. Induction units	26	20	20	20	30	16
2. Fan coil	21	20	20	16	22	28
3. Diffusors, grilles and registers	35	27	20	20	50	26
4. Double duct mixing boxes— constant or variable air volume	21	20	20	15	30	20
5. Variable air volume (VAV) boxes single duct	24	20	20	20	30	7
Air Washers	20	17	30	10	30	6
Humidifiers	18	15	10	10	20	23
Ductwork	35	30	50	24	50	31

(Continued)

Equipment Item	Mean	Median	Model(s)	Percentiles		
				25%	75%	N
Dampers including actuators	15	20	20	15	30	20
Fans (supply or exhaust)						
1. Centrifugal—forward curve or backward inclined	27	25	20	20	40	43
2. Axial flow	23	20	20	10	30	16
3. Wall-mounted—propeller type	17	15	20	10	20	15
4. Ventilating—roof mounted	17	20	20	10	20	22
HEAT EXCHANGERS						
Coils						
1. DX	22	20	20	15	27	21
2. Water or steam	24	20	20	20	30	49
3. Electric	15	15	10-15-20	10	20	9
Shell and Tube	25	24	20	20	30	20
COOLING EQUIPMENT						
Reciprocating Compressors	18	20	20	12	20	7
Chillers —packaged—reciprocating	19	20	20	15	20	34
—centrifugal	25	23	20	20	30	28
—absorption	24	23	20	20	30	16
HEAT REJECTION EQUIPMENT						
Cooling Tower —metal—galvanized	18	20	20	10	20	33
—wood	22	20	20	15	27	25
—ceramic	33	34	20	20	5	6
Air-cooled Condenser	20	20	20	15	25	27
Evaporative Condenser	18	20	20	15	20	13
GENERAL COMPONENTS						
Insulation						
1. Preformed—block, molded, etc.	27	20	20	20	30	43
2. Blankets, batts	29	24	20	20	40	23
Pumps						
1. Circulating, base-mounted	19	20	20	13	24	37
2. Circulating, pipe-mounted	12	10	10-15	6	15	28
3. Sump and well	15	10	30	6	30	25

(Continued)

Equipment Item	Mean	Median	Model(s)	Percentiles		
				25%	75%	N
4. Condensate and receiver	18	15	15	10	25	25
Engines, Turbines, Motors						
1. Reciprocating engine	19	20	20	20	20	12
2. Turbines—steam	30	30	40	24	30	13
3. Electric motors	18	18	20	13	20	24
Motor Starters—across line or magnetic	19	17	20	10	30	34
Transformers						
Dry type or oil-filled	31	30	30	20	40	49
Controls and instrumentation						
1. Pneumatic	21	20	20	15	24	34
2. Electrical	17	16	20	10	20	24
3. Electronic	15	15	10-15	10	20	16
4. Automated (computer) building control systems	22	20	20-25	10	25	8
Valve Actuators						
1. Electric	16	14	10-20-30	5	25	18
2. Hydraulic	15	15	20	5	24	8
3. Pneumatic	18	20	20	10	25	26
4. Self-contained	14	10	5-20	5	24	9

Chapter 5

Survey Instrumentation

To accomplish an energy audit survey, it is necessary to clarify energy uses and losses. This chapter illustrates various types of instruments that can aid in the energy audit survey.

GENERAL AUDIT INSTRUMENTATION

Light Level Meter

It takes very little to conduct a lighting system audit. A light level meter is used to measure the amount of light, in foot-candles, that falls on a surface. Light meters are hand-held, battery operated, and light-weight and are meant to be used as field instruments to survey levels of illumination.

To get accurate measurements, take light measurements where the visual tasks are actually performed, such as on a work surface or desktop. Care must be taken to get a representative sample of measurements throughout the space as well as not to cast a shadow over the sensor while taking measurements.

The primary focus of the energy audit is on the quantity of light but there are many qualitative issues that the auditor may have to note depending on the application. While the auditor determines the specifications for energy efficiency, the final design of the retrofit is often best left to a professional lighting designer.

Datalogging light level meters are also available to record variations in light levels over time. Light meters used to measure lighting levels in the home, office, restaurant, school, etc. differ from conventional photographic meters in that light meters relate to the way the human eye sees light, while photographic exposure meters relate to the way film “sees” light.

Data Loggers

Data loggers are fast becoming the tools of choice among performance contractors, service technicians and engineers responsible for diagnosing and evaluating HVAC systems and monitoring energy efficiency and usage. These inexpensive tools are being used in many industries from federal and state energy and weatherization agencies and larger performance contracting companies to smaller service companies and independent technicians, in both residential and commercial applications.

Data loggers can be used to monitor and record building and system conditions, unattended, on a 24-hour, around-the-clock basis. This allows for a more complete and accurate picture of the target system's overall performance, than a simple "spot check" would provide.

The data loggers shown in Figure 5-1 are small, stand-alone, battery-powered devices that are equipped with a microprocessor, memory for data storage and sensor(s). They are used to monitor and record measurements of temperature, relative humidity, indoor air quality, light intensity and hours of operation, motor and equipment run times, voltage, amperage, and events over extended periods of time.

Data loggers with external input capabilities, as shown in Figure 5-2, can gather data from external probes and amp clamps as well as existing transducers, sensors and gauges. Data loggers interface with a personal computer or laptop and operate through software designed to activate the logger and view/analyze the collected data.



Figure 5-1. On/Off status data loggers for lighting and motor applications. Photos courtesy of Onset Computer Corporation.



Figure 5-2. Data logger with external split core AC current sensor. Photos courtesy of Onset Computer Corporation.

Problem areas and unexpected condition changes can be “captured” and stored by the data logger for future study and evaluation. Because of their small size and inexpensive cost, data loggers can be placed in areas where the installation of permanent, hard-wired digital systems would be difficult and expensive.

Temperature and Humidity

Monitoring and recording temperature and humidity can also provide information on HVAC system operation and overall comfort levels in the area under investigation. Plotting changes in temperature for several days can reveal setback periods, amount of setback, and temperature ranges during occupied periods. Wide fluctuations in temperature during occupied periods can indicate HVAC system or control problems. Temperature and humidity values can be plotted on a psychrometric chart to compare with ASHRAE comfort zone conditions. Many of the dataloggers previously discussed include temperature and humidity sensors.

CARBON DIOXIDE (CO₂)

Carbon dioxide is exhaled by building occupants and can be used to provide a more accurate accounting of occupancy periods and patterns than just relying on posted business hours or interviews with building personnel. Outdoor ambient concentrations of CO₂ are typically

in the 250 to 350 parts per million (ppm) range. By measuring and recording CO₂ levels over time, concentrations above ambient conditions can be used to determine when the area is actually occupied. A CO₂ sensor used in conjunction with a data logger, as shown in Figure 5-3, can be used to record and document ventilation system effectiveness due to changes in occupancy.

Carbon dioxide can also be used to evaluate ventilation rates in the area being monitored. Concentrations of CO₂ can be used to determine the ventilation rate in CFM/person and compared to ventilation standards (ASHRAE 62-2004). CO₂ levels above 1000 ppm can indicate that the ventilation rate is probably inadequate. CO₂ levels that remain near outdoor ambient levels throughout the day may indicate that there is excess ventilation.

It is important to test ventilation rates in a variety of locations throughout the building rather than making assumptions on a building average basis. Locations where CO₂ measurements were recorded should be noted on a floor plan and used for analysis with other field data.

Chemical Smoke

Having a convenient source of chemical or silica smoke can be extremely useful when performing HVAC and building envelope audits. Smoke can be useful for evaluating air flow patterns, identifying which are supply and return air grills, testing for short circuiting between air supply and return grilles, and locating sources of infiltration in the building envelope.

Evaluating pressure relationships between rooms and zones using chemical smoke is often very enlightening in understanding how HVAC systems are actually performing and interacting with exhaust fans, doors and operable windows, and other zones.

In the building envelope,

Figure 5-3. Carbon dioxide and temperature monitor with data logger. Photo courtesy of Telaire



smoke is used to find the source and direction of air movement. An auditor can learn airflow sources and direction by watching a small amount of smoke that is shot into cracks and holes, drains, around ceiling tiles, doors and windows, and around envelope penetrations for pipes, electrical conduit, and ductwork. The sources of airflow show possible air infiltration routes.

There are two main types of smoke available for the small quantities required by the energy auditor, chemical smoke and silica powder.

Chemical smoke is generated when titanium tetrachloride mixes with air. It produces a dense and persistent white smoke which is ideal for air leak detection. Chemical smoke kits, such as the one pictured in Figure 5-4, include all the items necessary to generate chemical smoke. The titanium tetrachloride comes in glass vials which are typically opened and poured into a Teflon bottle filled with cotton or fiberglass insulation. To generate smoke, you simply remove the bottle cap and squeeze the bottle. The smoke puffer will last for several months and can be easily recharged. One word of caution, use the chemical smoke in moderation. The smoke generated by titanium tetrachloride is corrosive and can potentially set off smoke detectors if over used.

Silica powder smoke products provide an inexpensive method of generating swirling smoke. This is a great product for air balancing and testing of all high, medium, and low-pressure ductwork systems. When the bottle is squeezed this powder is released in the air forming powder smoke. The smoke emitted is non-toxic and has the same density as air, so that it is possible to observe true air movements without the complicating factor of having to allow for the natural rise or fall of the smoke.

TEMPERATURE MEASUREMENTS

To maximize system performance, knowledge of the temperature of a fluid, surface, etc. is essential. Measuring temperature of pipes, ducts, diffusers, and other equipment is a great way to locate unwanted heat losses or gains and evaluate if systems and equipment are operating properly. Several types of temperature devices are described in this section.

Thermometer

There are many types of thermometers that can be used in an energy audit. The choice of what to use is usually dictated by cost, durability, and application. For air-conditioning, ventilation, and hot-water



Figure 5-4. Chemical smoke kit.
Photo courtesy of E. Vernon Hill,
Incorporated.

service applications (temperature ranges 50°F to 250°F) a multipurpose portable battery-operated thermometer is used. A variety of probes and thermocouples are available to measure liquid, air, or surface temperatures. For boiler and oven stacks, (1000°F) a dial thermometer is typically used. Thermocouples are used for measurements above 1000°F.

No matter what sort of indicating instrument is employed, the thermocouple used should be carefully selected to match the application and properly positioned if a representative temperature is to be measured.

Figure 5-5 illustrates a common digital temperature measuring device.



Infrared Thermometers

Lightweight, compact, and easy to use, noncontact infrared thermometers can safely measure hot, hazardous, or hard-to-reach materials



Figure 5-5. Dual Input Digital Thermometer and General Purpose Air/Surface Probe. Photo Reproduced with Permission of Fluke Corporation

without touching, contaminating, or damaging the material’s surface.

When selecting a hand-held infrared thermometer, keep in mind the temperature range of the intended use and the distance you will be measuring from. Temperature sensitivity ranges are typically available from -25 to 1400°F. Optics are given in a ratio such as 6:1 or 10:1 indicating the distance where a spot size will be 1 foot in diameter. A ration of 10:1, for example, means that from a distance of 10 feet, the sensor will be reading an area 1 foot in diameter. The further the distance from the target, the larger the spot size will be. This is important to keep in mind to assure accuracy of temperatures you are using in energy calculations. You will want to measure only the target and not include surrounding walls or equipment.

Psychrometer

A psychrometer is an instrument which measures relative humidity based on the relation of the dry-bulb temperature and the wet-bulb temperature. Relative humidity is of prime importance in HVAC and drying operations. Recording psychrometers are also available and are often included in temperature datalogger functions.

Surface Pyrometer

Surface pyrometers are instruments which measure the temperature of surfaces. They are somewhat more complex than other temperature instruments because their probe must make intimate contact with the surface being measured. Surface pyrometers are of immense help in assessing heat losses through walls and can also be useful in testing steam traps. They may be divided into two classes: low-temperature (up to 250°F) and high-temperature (up to 600 to 700°F). The low-temperature unit is usually part of a multipurpose thermometer kit. The high-temperature unit is more specialized, but needed for evaluating fired units and general steam service.

Noncontact infrared thermometers are also suitable for this type of work and can be used where the target surfaces are visible but not physically accessible.

MEASURING BUILDING LOSSES

Infrared energy is an invisible part of the electromagnetic spectrum. It exists naturally and can be measured by remote heat-sensing equipment. Lightweight portable infrared systems are available to help determine energy losses. Since IR detection and measurement equipment have gained increased importance in the energy audit process, a summary of the fundamentals are reviewed in this section.

The infrared thermal imaging system is a closed circuit TV unit that is sensitive to the infrared light that the human eye cannot see. Based on the principle that all objects emit infrared radiation proportional to their temperature, variations in surface temperature as small as .1 degrees centigrade can be detected under ideal conditions.

The infrared thermal imaging system, or infrared scanner, produces a TV signal that can be displayed on a TV monitor or recorded on videotape for future review and analysis. A photograph of an infrared view is called a thermogram. On a thermogram, variations in temperature can be seen as lighter or darker areas. Usually the brighter an object appears, the higher its relative temperature.

Though objects emit infrared radiation proportional to their temperature, objects made of different types of materials emit infrared radiation at different rates. This property is called *emissivity*.

Infrared light, like visible light, can be reflected off a surface. The degree to which a surface will reflect light is called its *reflectance*.

When viewing a building with an infrared scanner, two components are viewed: one component is being emitted by the building surface, the other is infrared light emanating from some other sources being reflected from the building surface into the scanner lens.

An object's emissivity and reflectance must both be accounted for when interpreting any information obtained using an infrared sensing device. The introduction of these two complicating factors in the interpretation of infrared data should dispel the notion that conclusions derived from such data are absolute. Only through repeated infrared observation, careful observational technique, accurate data reduction, and informed interpretation by several individuals can valid conclusions be made.

*An obvious question to ask is,
what types of heat loss can this infrared scanner see?*

Any areas that are warmer than their surroundings stand out plainly. Windows, warm foundations, and open windows are obvious examples. Warm exhaust vents, wall and roof areas with wet insulation, poorly insulated steam pipes, warm rooms, and uninsulated structural beams built into walls are other less obvious examples that can be seen from the outside of a building. Any place that warm air is leaking to the outside can be detected. Examples here are gaps around unweather-stripped windows and doors, cracks in walls and foundations, leaking intake and exhaust vents, or joints where two wings of a building meet.

Apparently overly warm areas of a building detected during an infrared scan can have reasonable explanations once investigated. For example, one large room in a building may show as being very warm compared to all other surrounding rooms. This may be a biology laboratory where several large freezers are located. The excess heat emanates from the refrigeration equipment, not from any flaw in the heating system design, its operation, or any structural defect.

The results of an infrared scan may suggest a refinement in a building's operation and maintenance program that will result in energy savings. For example, leaking intake and exhaust vents may indicate that the vent dampers should be adjusted more often to ensure that they are closing tightly. Operation and maintenance procedures can usually be implemented with greater ease and lower cost than most retrofit measures and pay for themselves quickly with energy savings.

Once legitimate areas of high heat loss are known, retrofit measures can be compared on a benefit/cost basis and a prioritized list of

projects can be established. Infrared scanning is well suited to maintain quality control on energy conservation retrofit work once it has been performed. The results from a follow-up scan can be compared to those of the original scan to ensure that heat loss has been decreased.

Before a newly constructed building is occupied, an infrared scan may locate areas of heat loss that the building contractors could remedy before the owner assumed full responsibility for the building. By scanning the new building, long-term energy retrofitting costs as well as energy savings could be realized. This infrared record would also establish a standard for comparing future scans.

Infrared scanning may be based on a simple physical principle, but its final usefulness results from multiple levels of review and complex data analysis. The resulting suggestions for changes in operation and maintenance and energy retrofitting should be considered along with other suggestions for improving the overall energy efficiency of a building on a benefit/cost basis.

APPLICATIONS OF IR THERMOGRAPHY

In addition to detecting building energy losses, IR thermography has been used for other applications, listed in Table 5.1

Table 5-1. Applications of IR Thermography

Inspection of power transmission equipment
Water leakage into building roof insulation
Checking for poor building insulation
Detection of thermal pollution in rivers and lakes
Studying costing uniformity on webs
Inspecting cooling coils for plugged tubes
Spotting plugs and air locks in condenser tubes
Controlling paper calendaring operations
Studying the behavior of thermal sealing equipment
Investigating ultrasonic sealers and sealing operations
Inspection of electronic circuits
Hot injection molding problems
Studying the behavior of heating and cooling devices
Detection of plugged furnace tubes

- Examination of consumer products for hot spots
 - Spotting defects in laminated materials
 - Finding leaks in buried steam line
 - Inspection of heavy machinery bearings
 - Study of stresses due to thermal gradients in a component
 - Detection of defects such as voids and inclusions in castings
-

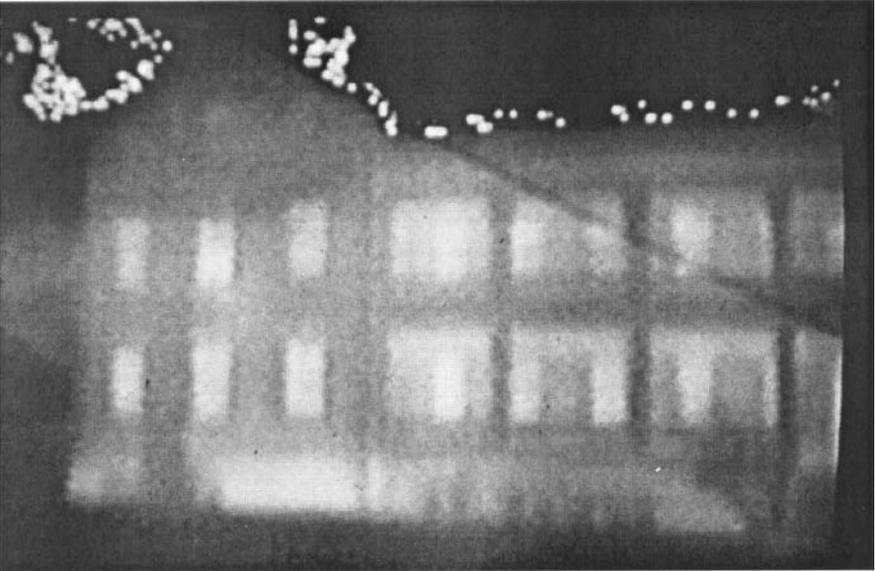


Figure 5-6. An infrared scan of the building envelope reveals substantial heat losses through the roof, windows, and foundation. Several companies offer scanning equipment for sale as well as scanning services for periodic system checks and troubleshooting.

INFRARED RADIATION AND ITS MEASUREMENT

The electromagnetic spectrum is shown in Figure 5-7.

MEASURING ELECTRICAL SYSTEM PERFORMANCE

The ammeter, voltmeter, and wattmeter, and power factor meter are usually required to do an electrical survey. These instruments are described below.

Ammeter and Voltmeter

To measure electrical currents, ammeters are used. For most audits alternating currents are measured. Ammeters used in audits are portable and are designed to be easily attached and removed.

Figure 5-8 illustrates a typical meter and accessories which can be used for current or voltage measurements. Notice the meter illustrated in Figure 5-9 can be clamped around the conductors to measure current.

There are many brands and styles of snap-on ammeters commonly available that can read up to 1000 amperes continuously. This range can be extended to 4000 amperes continuously for some models with an accessory step-down current transformer.

The snap-on ammeters can be either indicating or recording with a printout. After attachment, the recording ammeter can keep recording current variations for as long as a full month on one roll of recording paper. This allows studying current variations in a conductor for extended periods without constant operator attention.

The ammeter supplies a direct measurement of electrical current which is one of the parameters needed to calculate electrical energy. The second parameter required to calculate energy is voltage, and it is measured by a voltmeter.

Several types of electrical meters can read the voltage or current. A voltmeter measures the difference in electrical potential between two points in an electrical circuit.

In series with the probes are the galvanometer and a fixed resistance (which determine the voltage scale). The current through this fixed resistance circuit is then proportional to the voltage and the galvanometer deflects in proportion to the voltage.

The voltage drops measured in many instances are fairly constant and need only be performed once. If there are appreciable fluctuations, additional readings or the use of a recording voltmeter may be indicated.

Most voltages measured in practice are under 600 volts and there are many portable voltmeter/ammeter clamp-ons available for this and lower ranges.

Wattmeter, Power Factor, and Power Quality Meters

The portable wattmeter can be used to indicate by direct reading electrical energy in watts, It can also be calculated by measuring voltage, current and the angle between them (power factor angle).

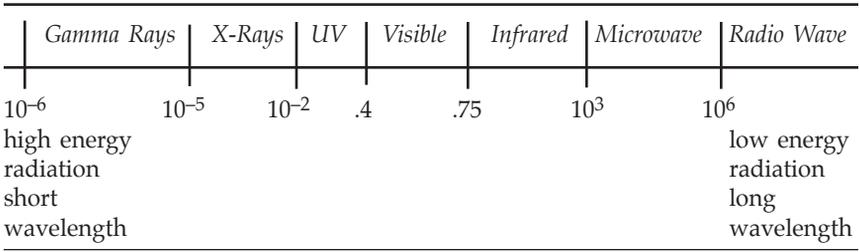


Figure 5-7. Electromagnetic Spectrum

The visible portion of the spectrum runs from .4 to .75 micrometers (μm). The infrared or thermal radiation begins at this point and extends to approximately 1000 μm . Objects such as people, plants, or buildings will emit radiation with wavelengths around 10 μm .

Infrared instruments are required to detect and measure the thermal radiation. To calibrate the instrument a special "black body" radiator is used. A black body radiator absorbs all the radiation, that impinges on it and has an absorbing efficiency or emissivity of 1.

The accuracy of temperature measurements by infrared instruments depends on the three processes which are responsible for an object acting like a black body. These processes—absorbed, reflected, and transmitted radiation—are responsible for the total radiation reaching an infrared scanner.

The real temperature of the object is dependent only upon its emitted radiation.

Corrections to apparent temperatures are made by knowing the emissivity of an object at a specified temperature.

The heart of the infrared instrument is the infrared detector. The detector absorbs infrared energy and converts it into electrical voltage or current. The two principal types of detectors are the thermal and photo type. The thermal detector generally requires a given period of time to develop an image on photographic film. The photo detectors are more sensitive and have a higher response time. Television-like displays on a cathode ray tube permit studies of dynamic thermal events on moving objects in real time.

There are various ways of displaying signals produced by infrared detectors. One way is by use of an isotherm contour. The lightest areas of the picture represent the warmest areas of the subject and the darkest areas represent the coolest portions. These instruments can show thermal variations of less than .1°C and can cover a range of -30°C to over 2000°C.

The isotherm can be calibrated by means of a black body radiator so that a specific temperature is known. The scanner can then be moved and the temperatures of the various parts of the subject can be made.



Figure 5-8. Digital Multimeter with AC/DC Current Clamp Accessory. Photo Reproduced with Permission of Fluke Corporation

Figure 5-9. AC Current Clamp Meter. Photo Reproduced with Permission of Fluke Corporation

The basic wattmeter consists of three voltage probes and a snap-on current coil which feeds the wattmeter movement.

The typical operating limits are 300 kilowatts, 650 volts, and 600 amperes. It can be used on both one- and three-phase circuits.

The portable power factor meter is primarily a three-phase instrument. One of its three voltage probes is attached to each conductor phase and a snap-on jaw is placed about one of the phases. By disconnecting the wattmeter circuitry, it will directly read the power factor of the circuit to which it is attached.



It can measure power factor over a range of 1.0 leading to 1.0 lagging with “ampacities” up to 1500 amperes at 600 volts. This range covers the large bulk of the applications found in light industry and commerce.

The power factor is a basic parameter whose value must be known to calculate electric energy usage. Diagnostically it is a useful instrument to determine the sources of poor power factor and harmonic distortion in a facility.

Digital read-outs of energy usage in both kWh and kW demand or in dollars and cents, including instantaneous usage, accumulated usage, projected usage for a particular billing period, alarms when over-target levels desired for usage, and control-outputs for load-shedding and cycling are possible.

Continuous displays or intermittent alternating displays are available at the touch of a button of any information needed such as the cost of operating a production machine for one shift, one hour or one week.

A typical power quality analyzer is illustrated in Figure 5-10.

MEASURING COMBUSTION SYSTEMS

To maximize combustion efficiency, it is necessary to know the composition of the flue gas. By obtaining a good air-fuel ration, substantial energy can be saved.

Combustion Testing

Combustion testing consists of determining the concentrations of the products of combustion in a stack gas. The products of combustion usually consid-



Figure 5-10. Power Quality Analyzer. Photo Reproduced with Permission of Fluke Corporation

ered are carbon dioxide (CO₂), carbon monoxide (CO). Oxygen (O₂) is also tested to assure proper excess air levels.

The typical ranges of concentrations are:

- CO₂ : 0 - 20%
- O₂ : 0 - 21%
- CO : 0 - .05%

The CO₂ or O₂ content along with the knowledge of flue gas temperature and fuel type allow the flue gas loss to be determined off standard charts. Good combustion usually means high carbon dioxide (CO₂), low oxygen (O₂), and little or no trace of carbon monoxide (CO).

The Orsat Apparatus

The definitive test for these constituents is an Orsat apparatus. This test consists of taking a measured volume of stack gas and measuring successive volumes after intimate contact with selective absorbing solutions. A solution of caustic potash is used to absorb the carbon dioxide, a mixture of pyrogallol acid, caustic potash and water is used to absorb the oxygen, and a solution of cuprous chloride is used to remove the carbon monoxide. The reduction in volume after each absorption is the measure of each constituent.

The Orsat has a number of disadvantages. The main ones are that it requires considerable time to set up and use and its operator must have a good degree of dexterity and be in constant practice. It is also not particularly accurate at detecting very low concentrations.

Instead of an Orsat, there are portable and easy to use absorbing instruments which can quickly determine the concentrations of the constituents of interest on an individual basis. Setup and operating times are minimal and just about anyone can learn to use them.

Gas Analyzers

The Gas analyzer in Figure 5-11 is the Fyrite type. Fyrite gas analyzers are available for either CO₂ or O₂ analysis, and each model is produced in three scale ranges. All six instruments are similar in appearance and size, but differ in important construction details, as well as in the absorbing fluids. Each model, therefore, is suitable only for the particular gas analysis or scale range for which it has been manufactured. Accuracy is within $\pm 1/2\%$ CO₂ or O₂.

Fyrite absorbing fluid is selective in the chemical absorption of



Figure 5-11. Gas Analyzer. Photo courtesy of Bacharach Instrument Company

carbon dioxide or oxygen, respectively. Therefore, the Fyrite’s accuracy, which is well within the range required for industrial and professional applications, does not depend upon complicated sequential test procedures. In addition, Fyrite readings are unaffected by the presence of most background gases in the sample.

This device has been around a long time, and due to its simplicity, is still often used in energy audits today. It is recommended that the auditor take three readings and average the readings to get the best result.

Portable Electronic Combustion Analyzer

The portable combustion analyzer (PCA) shown in Figure 5-12 is the perfect tool for energy auditors as well as furnace and boiler service technicians who need to determine carbon monoxide (CO) safety and combustion efficiency in combustion applications. Residential and commercial furnaces, hot water heaters and boilers are just a few typical applications.

The PCA directly measures and displays flue gas oxygen level,

Figure 5-12. Portable Combustion Analyzer. Photo courtesy of Bacharach Instrument Company

primary and stack temperatures, draft, differential pressure, NO_x and CO . Simultaneously, the instrument calculates and displays combustion efficiency, excess air, CO_2 , NO_x -Ref. O_2 and CO air free.

The PCA shown will allow the user to store up to 100 tests, customize each combustion test with customer information, generate a personalized printout, and download all of this information to a personal computer for record keeping and trend analysis.

Draft Gauge

The draft gauge is used to measure pressure. It can be the pocket type or an inclined manometer which is often included in boiler test kits (Figure 5-13).

Smoke Tester

To measure combustion completeness, the smoke detector is used (Figure 5-13). Smoke is unburned carbon which wastes fuel, causes air pollution, and foul heat exchanger surfaces. To use the instrument, a measured volume of flue gas is drawn through a paper filter with the probe. The resulting smoke spot is then compared visually with a standard scale and a measure of smoke density is determined.

Combustion Efficiency & Environmental Analyzer

The combustion and efficiency and environmental analyzer shown in Figure 5-14 is ideal for professionals concerned about combustion efficiency, environmental compliance, or both. It enables plant maintenance engineers and managers, industrial boiler/furnace service technicians, energy coordinators, compliance officers, environmental auditors and safety managers to ensure that industrial equipment is burning effi-



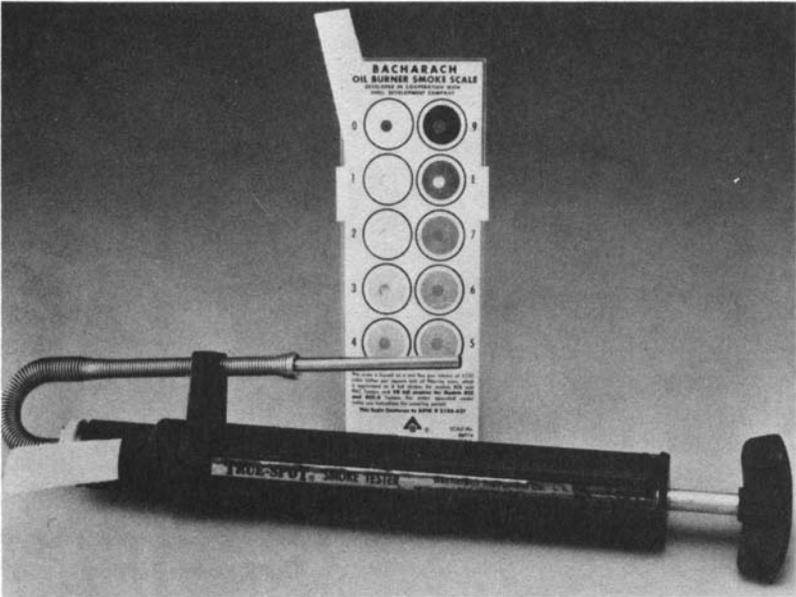
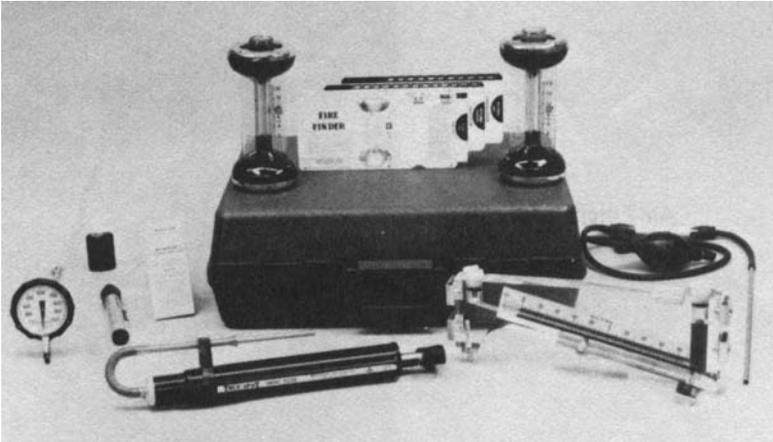


Figure 5-13. Boiler Test Kit (above) and Smoke Tester (below). (Photographs courtesy of Bacharach Instrument Company).

ciently while environmental regulations are being met.

The combustion analyzer measures oxygen, carbon monoxide, nitric oxide, nitrogen dioxide and sulfur dioxide, as well as combustibles, temperature and draft. It also calculates combustion efficiency, excess air, carbon dioxide, NO_x (nitrogen oxides) and pollution units.

The unit also takes continuous samplings of furnaces, boilers and



Figure 5-14. Combustion Efficiency & Environmental Analyzer. Photo courtesy of Bacharach Instrument Company

other industrial combustion equipment for up to eight hours and generates combustion and environmental measurements and calculations. Stored test records can be downloaded to a personal computer and stored as a text file, which can then be opened in a spreadsheet program for analysis.

MEASURING HEATING VENTILATION AND AIR CONDITIONING (HVAC) SYSTEM PERFORMANCE

Air Velocity Measurement

Table 5-2 summarizes velocity devices commonly used in HVAC applications. The following suggests the preference, suitability, and approximate costs of particular equipment.

- **Smoke pellets**—limited use but very low cost. Considered to be useful if engineering staff has experience in handling.

Table 5-2. Air Velocity Measurement Devices

Device/Meter	Application	Range in FPM	Accuracy	Limitations
Smoke pellet or airborne solid tracer	Low air velocities in room —directional	5-50	10%-20%	Useful in tracing air movement in
Anemometer—deflecting vane type	Air velocities in rooms, grill outlets—directional	30-24,000	5%	Not suitable for duct air measurement—requires periodic calibration
Anemometer—revolving vane type	Moderate air velocities in ducts, rooms	100- 3,000	5%-20%	Subject to error variations in velocities—easily damaged. Frequent calibration required.
Pitot tube	Standard instrument for duct velocity measurement	180-10,000 600-10,000 10,000 and up	1%-5%	Accuracy falls at low air flows.
Impact tube (side wall) meter kits	High velocity—small tube and variable direction	120-10,000 600-10,000 10,000 and up	1%-5%	Accuracy related to constant static pressure across stream section
Heated thermocouple anemometer	Air velocities in ducts low velocities	10-2,000	3%-20%	Accuracy of some meters bad at
Hot wire anemometer	(a) Low air velocities in rooms, ducts, etc. (b) High air velocity (c) Transient velocities and turbulences	1-1,000 Up to 60,000	1%-20% 1%-10%	Requires frequent calibration. Complex to use and very costly.

- **Anemometer** (deflecting vane)—good indication of air movement with acceptable order of accuracy. Considered useful. (Approx. \$50).
- **Anemometer** (revolving vane)—good indicator of air movement with acceptable accuracy. However easily subject to damage. Considered useful. (Approx. \$ 100).
- **Pitot tube**—a standard air measurement device with good levels of accuracy. Considered essential. Can be purchased in various lengths—12" about \$20, 48" about \$35. Must be used with a monometer. These vary considerably in cost but could be in the order of \$20 to \$60.
- **Impact tube**—usually packaged air flow meter kits, complete with various jets for testing ducts, grills, open areas, etc. These units are convenient to use and of sufficient accuracy. The costs vary around \$150 to \$300 and therefore this order of cost could only be justified for a large system.
- **Heated thermocouple**—these units are sensitive, accurate, but costly. A typical cost would be about \$500 and can only be justified for regular use in a large plant.
- **Hot wire anemometer**—not recommended. Too costly and too complex.

Temperature Measurement

Table 5-3 summarizes common devices used for measuring temperature in HVAC applications. The temperature devices most commonly used are as follows:

The averaging style of air flow meter shown in Figure 5-16 allows the user to traverse large grilles and ducts in one sweep and to have the average value displayed automatically, thereby saving on operator time and inconvenience of manual calculations.

- **Glass thermometers**—considered to be the most useful of temperature measuring instruments—accurate, convenient, but fragile. Cost runs from \$5 each for 12"-long mercury in glass. Engineers should have a selection of various ranges.

Table 5-3. Temperature Measurement

<i>Device/Meter</i>	<i>Application</i>	<i>Range in °F</i>	<i>Accuracy °F</i>	<i>Limitation</i>
Glass stem thermometers	Temperature of gas, air, and liquids by contact		Less than	In gas and air, glass is affected by radiation. Also likely to break.
Mercury In glass		-38 to 575	0.1 to 10	
Alcohol in glass		-100 to 1000	0.1 to 10	
Pentane in glass		-200 to 70	0.1 to 10	
Zena or quartz mercury		-38 to 1000	0.1 to 10	
Resistance thermometers				
Platinum resistance	Precision remote readings	-320 to 1800	0.02 to 5	High cost — accuracy affected by radiation
Nickel resistance	Remote readings	-150 to 300	0.03	
Thermistors	Remote readings	up to 600	0.1	
Thermocouples				
Pt-Pt-Rh thermocouples	Standard for thermocouples	500 to 3000	0.1 to 5	Highest system
Chrome Alumel “	General testing hi-temps	up to 2000	0.1 to 15	Less accurate than above
Iron Constantan “)		up to 1500	0.1 to 15	Subject to oxidation
Copper “)	Same as above but for	“	“	“ “ “
Chromel “)	lower readings	up to 700	0.1 to 15	“ “ “
Bimetallic thermometers	For approximate temperature	0 to 1000	—	Extensive time lag, not for remote use, unreliable
Pressure-bulb thermometers				
Gas filled		-200 to 1000	2	Usually Permanent Installations. Requires careful fixing and setting
Vapor filled	Suitable for remote reading	20 to 500	2	
Liquid filled		-50 to 2100	2	
Optical Pyrometers	Hi-Intensity, narrow spectrum band radiation	1500 and up	15	Limited to combustion setting
Radiation pyrometers	Hi-intensity, total high temperature radiation	Any	—	Relatively costly, easy to use, quite accurate
Indicating Crayons	Approximate surface temp.	125 to 900	±1%	Easy to use, low cost

Figure 5-15. Air Velocity Meter. By reading air velocity, air volume flow and air stream temperature directly, highly accurate, and instant assessments of airflow conditions are immediately possible. Photo courtesy of Bacharach Instrument Company



Figure 5-16. Averaging Air Velocity Meter. Photo courtesy of Bacharach Instrument Company



- **Resistance thermometers**—considered to be very useful for A/C testing. Accuracy is good, reliable and convenient to use. Suitable units can be purchased from \$150 up, some with a selection of several temperature ranges.
- **Thermocouples**—similar to resistance thermocouple, but do not require battery power source. Chrome-Alum or iron types are the most useful and have satisfactory accuracy and repeatability. Costs start from \$50 and range up.
- **Bimetallic thermometers**—considered unsuitable.
- **Pressure bulb thermometers**—more suitable for permanent installation. Accurate and reasonable in cost— \$40 up.
- **Optical pyrometers**—only suitable for furnace settings and therefore limited in use. Cost from \$300 up.
- **Radiation pyrometers**—limited in use for A/C work and costs from \$500 up.
- **Indicating crayons**—limited in use and not considered suitable for A/C testing- costs around \$ /2crayon.
- **Thermographs**—use for recording room or space temperature and gives a chart indicating variations over a 12- or 168-hour period. Reasonably accurate. Low cost at around \$30 to \$60. (Spring wound drive.)

**Pressure Measurement
(absolute and differential)**

Table 5-4 illustrates common devices used for measuring pressure in HVAC applications. Accuracy, range, application, and limitations are discussed in relation to HVAC work.

- Absolute pressure manometer
 - Diaphragm
 - Barometer (Hg manometer)
- } not really suited to HVAC test work
- **Micro manometer**—not usually portable, but suitable for fixed measurement of pressure differentials across filter, coils, etc. Cost around \$30 and up.

Table 5-4. Pressure Measurement

<i>Device/Meter</i>	<i>Application</i>	<i>Range in FPM</i>	<i>Accuracy</i>	<i>Limitations</i>
Absolute pressure manometer	Moderately low absolute pressure	0 + 30" Hg	2-5%	Not direct reading
Diaphragm gauge	"	0.1 – 70 mm Hg	0.05 mm Hg	Direct reading
Barometer (Hg manometer)	Atmospheric pressure	—	0.001 to 0.01	Not very portable
Micromanometer	Very low pressure differential	0 to 6" H ₂ O	0.0005 to 0.0001 H ₂ O	Not easily portable, hard to use with pulsating pressures
Draft gauges	Moderately low pressure differential	0 to 10" H ₂ O	0.05 H ₂ O	Must be leveled carefully
Manometer	Medium pressure differential	0 to 100 H ₂ O	0.05 H ₂ O	Compensation for liquid density
Swing Vane gauge	Moderate low pressure differential	0 to 0.5 H ₂ O	5%	Generally used at atmospheric pressure only
Bourdon tube	Medium to high pressure differential. Usually to atmospheric	Any	0.05 to 5%	Subject to damage due to overpressure shock
Pressure transducers	Remote reading—responds to rapid change	0.05 to 50,000 psig	0.1 to 0.5%	Require electronic amplified and readout equipment

- **Draft gauges**—can be portable and used for either direct pressure or pressure differential. From \$30 up.
- **Manometers**—can be portable. Used for direct pressure reading and with Pitot tubes for air flows. Very useful. Costs from \$20 up.
- **Swing Vane gauges**—can be portable. Usually used for air flow. Costs about \$30.
- **Bourdon tube gauges**—very useful for measuring all forms of system fluid pressures from 5 psi up. Costs vary greatly from \$10 up. Special types for refrigeration plants.

Humidity Measurement

The data given below indicate the types of instruments available for humidity measurement. The following indicates equipment suitable for HVAC applications.

- **Psychrometers**—basically these are wet and dry bulb thermometers. They can be fixed on a portable stand or mounted in a frame with a handle for revolving in air. Costs are low (\$10 to \$30) and are convenient to use.
- **Dewpoint Hygrometers**—not considered suitable for HVAC test work.
- **Dimensional change**—device usually consists of a “hair” which changes in length proportionally with humidity changes. Not usually portable, fragile, and only suitable for limited temperature and humidity ranges.
- **Electrical conductivity**—can be compact and portable but of a higher cost (from \$200 up). Very convenient to use.
- **Electrolytic**—as above. But for very low temperature ranges. Therefore unsuitable for HVAC test work.
- **Gravimeter**—Not suitable.

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Chapter 6

The Building Envelope Audit

The building envelope consists of those elements of a building that enclose conditioned spaces through which thermal energy may be transferred. Energy is saved when the heat exchange between the building and the outside environment is reduced and solar and internal heat gains are controlled. Note that many building envelope ECOs have long payback periods; the best time to improve the building envelope is at the initial design stage.

The building envelope audit generally requires gathering the following data:

1. Building characteristics and construction
 - Building orientation
 - Glazing orientation and cooling zones
 - Building floor, wall, and ceiling construction details
2. Window and door characteristics
 - Frame type
 - Window and door area
 - Estimated % of gross wall area
 - Single or double glazing, u-value
 - Glazing coatings
 - Operable windows
 - Alignment of operable windows
 - Cracked or broken panes
 - Weather-stripping condition
 - Daylighting
 - Skylights
3. Insulation status
 - Type, thickness and location of the existing insulation
 - Age and condition of the roof
 - Color of the roof membrane

- Damaged or wet insulation
- Insulation voids

BUILDING DYNAMICS

The building experiences heat gains and heat losses depending on whether the cooling or heating system is present, as illustrated in Figures 6-1 and 6-2. Only when the total season is considered in conjunction with lighting and heating, ventilation and air-conditioning (HVAC) can the energy choice be decided.

Many of the audits discussed in this chapter apply the principle of reducing the heat load or gain of the building. Thus the internal HVAC load would decrease. A caution should be made that without a detailed engineering analysis, a computer simulation, an oversimplification may lead to a wrong conclusion. The weather data for your area and the effect of the total system should not be overlooked.

In order to use the methods described in this chapter, weather data in Chapter 15, Table 15-1 and Figures 15-1 through 15-5 can be used. Figure 15-14 illustrates an energy audit form for a building that may be modified to suit your particular needs.

SIM 6 4

Comment on the effect to the overall heat balance by adding skylights to the roof.

ANALYSIS

The effect of adding skylights will influence the overall energy balance in several ways.

1. The illumination from skylights will decrease the need for lighting systems. As an example a building with 6% coverage with skylights may receive ample illumination to turn off the lighting systems most daylight hours.
2. The solar heat gain factor is increased and if the building is air-conditioned more tons and more energy are required.
3. The excess solar heat gain during the winter months may decrease heating loads.

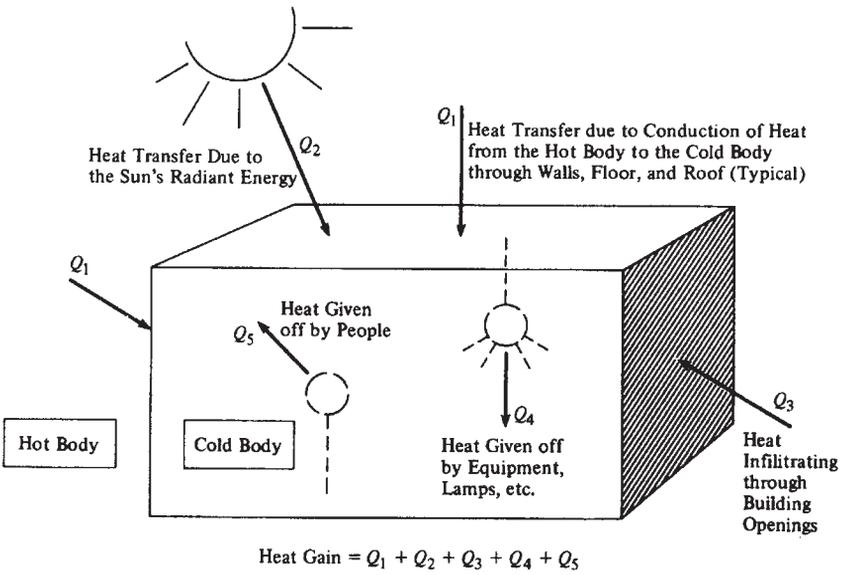


Figure 6-1. Heat Gain of a Building

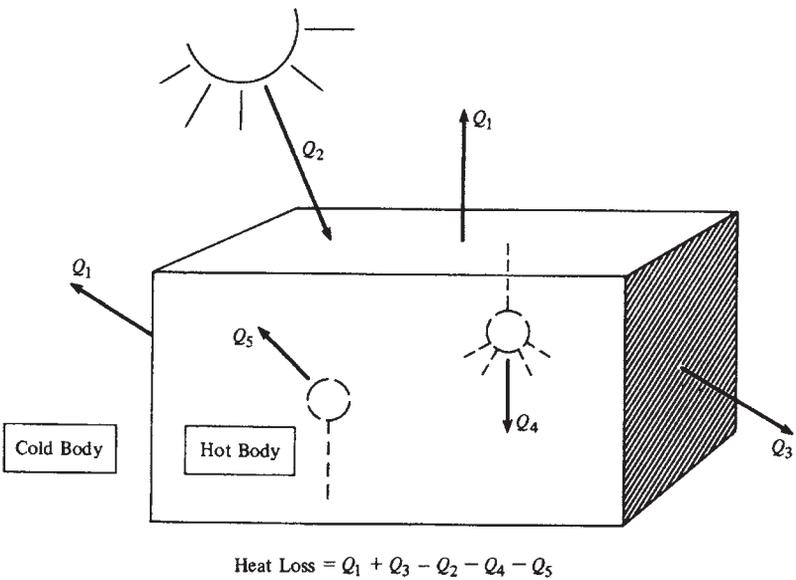


Figure 6-2. Heat Loss of a Building

A detailed handbook, *Skylight Handbook—Design Guidelines*, is available from American Architectural Manufacturers Association, www.aamanet.org.

BUILDING CHARACTERISTICS AND CONSTRUCTION

The envelope audit should record for each space the size, physical characteristics, Hours of operation and function. The assorted materials of construction, windows, doors, holes, percentage glass, etc. should also be recorded.

INFILTRATION

Leakage or infiltration of air into a building is similar to the effect of additional ventilation. Unlike ventilation it cannot be controlled or turned off at night. It is the result of cracks, openings around windows and doors, and access openings. Infiltration is also induced into the building to replace exhaust air unless the HVAC balances the exhaust. Wind velocity increases infiltration and stack effects are potential problems.

A handy formula which relates ventilation or infiltration rates to heat flow is Formula 6-1.

$$Q = 1.08 \times \text{cfm} \times \Delta T \quad (6-1)$$

Where:

- Q is heat removal, Btu/Hr
- cfm is ventilation or infiltration rate, cubic feet per minute
- ΔT is the allowable heat rise.

Heat losses and gains from openings can significantly waste energy. All openings should be noted in the BSEA. Figure 6-3 illustrates the effect of the door size and time opened on the average annual heat loss. The graph is based upon a six-month heating season (mid-October to mid-April) and an average wind velocity of 4 mph. It is assumed that the heated building is maintained at 65°F. To adjust Figure 6-3 for different conditions use Formula 6-2.

$$Q = Q_1 \times \frac{d}{5} \times \frac{65 + T}{13} \tag{6-2}$$

Where:

Q is the adjusted heat loss, Btu/year

Q₁ is the heat loss from Figure 6-3

d is the days of operation

T is the average ambient temperature during the heating season, °F.

If the space were air-conditioned there would be an additional savings during the cooling season.

To reduce heat loss for operating doors, the installation of vinyl strips (see Figure 6-4) is sometimes used. This type of strip is approximately 90% efficient in reducing heat losses. The problem in using the strip is obtaining operator acceptance. Operators may feel these strips

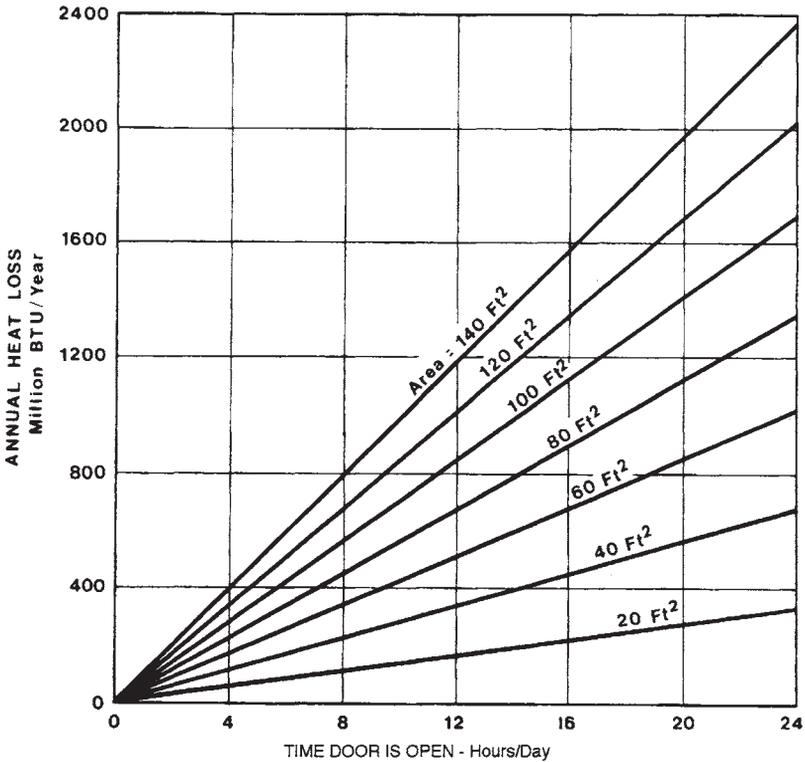


Figure 6-3. Annual Heat Loss from Doors. (Source: Georgia Tech Experiment Station)



Figure 6-4. Installation of Vinyl Strips on Forklift Door. (Photograph courtesy of MetalGlas Products, Inc.)

interfere with operations or cause a safety problem since vision through the access way is reduced.

An alternate method to reduce infiltration losses through access doors is to provide an air curtain.

SIM 6-2

An energy audit of a building indicated that the warehouse is maintained at 65°F during winter and has three 10 ft × 10 ft forklift doors. The warehouse is used 24 hours, 6 days per week, and the doors are open 8 hours per day. The average ambient temperature during the heating season is 48°F. Comment on adding vinyl strips (installed cost \$2,000) which are 90% efficient, given the cost of heating fuel is \$4/million Btu with a boiler efficiency of .65.

ANALYSIS

From Figure 6-3, $Q = 600 \times 10^{12}$ Btu/Year

$$\text{Therefore } Q = 600 \times 10^6 \times \frac{6}{5} \times \frac{65 \pm 48}{13} = 941 \text{ million Btu/yr per door}$$

$$Q = 3 \times .9 \times 941 \times \$4/\text{million Btu} + 65 = \$15.635$$

Since the payback period before taxes is less than one year, the investment seems justified.

To estimate infiltration through windows Table 6-1 and Figure 6-5 may be used. These data also include another estimating tool for determining infiltration through doors.

To compute the energy saved based on reducing the infiltration rates, Figure 6-6 and 6-7 are used for the heating and cooling seasons respectively.

SIM 6-3

An energy audit survey indicates 300 windows, poorly fitted wood sash, in a building which are not weather-stripped. Comment on the savings for weather-stripping given the following:

- Data: Window size 54" × 96"
- Degree-days = 8,000
- Cost of heating = \$4/10⁶ Btu

Table 6-1. Infiltration Through Windows and Doors—Winter*
15 mph wind velocity[†]

DOUBLE HUNG WINDOWS ON WINDWARD SIDE[§]

DESCRIPTION	CFM PER SQ FT AREA					
	.Small - 30" × 72"			Large - 54 - × 96		
	No W-Strip	W-Strip	Storm Sash	No W-Strip	W-Strip	Storm Sash
Average Wood Sash	.85	.52	.42	.53	.33	.26
Poorly Fitted Wood Sash	2.4	.74	1.2	1.52	.47	.74
Metal Sash	1.60	.69	.80	1.01	.44	.50

NOTE: W-Strip denotes weatherstrip.

CASEMENT TYPE WINDOWS ON WINDWARD SIDE[§]

DESCRIPTION	CFM PER SQ FT AREA									
	Percent Ventilated Area									
	0%	25%	33%	40%	45%	50%	60%	66%	75%	100%
Rolled Section-Steel Sash										
Industrial Pivoted	.65	1.44	—	1.98	—	—	—	2.9	—	5.2
Architectural Projected	—	.78	—	—	—	1.1	1.48	—	—	—
Residential	—	—	.56	—	—	.98	—	—	—	1.26
Heavy Projected	—	—	—	—	.45	—	—	.63	.78	—
Hollow Metal—Vertically Pivoted	54	1.19	—	1.64	—	—	—	2.4	—	4.3

DOORS ON ONE OR ADJACENT WINDWARD SIDES[§]

DESCRIPTION	CFM PER SQ FT AREA [¶]				
	Infrequent Use	Average Use			
		1&2 Story Building	Tall Building (ft)		
			50	100	200
Revolving Door	1.6	10.5	12.6	14.2	17.3
Glass Door—(3/16" Crack)	9.0	30.0	36.0	40.5	49.5
Wood Door 3'7"	2.0	13.0	15.5	17.5	21.5
Small Factory Door	1.5	13.0			
Garage & Shipping Room Door	4.0	9.0			
Ramp Garage Door	4.0	13.5			

* All values are based on the wind blowing directly at the window or door. When the prevailing wind direction is oblique to the windows or doors, multiply the above values by 0.60 and use the total window and door area on the windward side(s).

† Based on a wind velocity at 15 mph. For design wind velocities different from the base, multiply the table values by the ratio of velocities.

§ Stack effect in tall buildings may also cause infiltration on the leeward side. To evaluate this, determine the equivalent velocity (V_e) and subtract the design velocity (V). The equivalent velocity is:

$$V_e = \sqrt{V^2 \pm 1.75a} \text{ (upper section)}$$

$$V_e = \sqrt{V^2 \pm 1.75b} \text{ (lower section)}$$

Where a and b are the distances above and below the mid-height of the building, respectively, in ft.

Multiply the table values by the ratio $(V_e - V)/15$ for doors and one-half of the windows on the leeward side of the building. (Use values under "1 & 2 Story Building" for doors on leeward side of tall buildings.)

¶ Doors on opposite sides increase the above values 25%. Vestibules may decrease the infiltration as much as 30% when door usage is light. If door usage is heavy, the vestibule is of little value in reducing infiltration. Heat added to the vestibule will help maintain room temperature near the door.

One-half the windows face the wind at any one time
 Hours of occupation = 5760
 Wet-Bulb Degree-hours = 2,000 greater than 66°F
 Wind velocity summer 10 mph
 Refrigeration consumption = .8 kW/Ton-Hr
 Electric rate = 5¢ kWh
 Hours of operation = 72
 Indoor temperature winter 68°F
 RH summer 50%
 Boiler efficiency = .65

ANALYSIS

$$\text{Areas of windows} = \frac{56 \times 96}{144} = 36 \text{ ft}^2 \text{ per window}$$

Coefficients from Table 6-1

With No Weather-stripping 1.5 2

With Weather-stripping .47

Infiltration before = $36 \times 300/2 \times 1.52 = 8208 \text{ cfm}$

Infiltration after weather-stripping = $36 \times 300/2 \times .47 = 2538 \text{ cfm}$

Savings with weather-stripping = $8208 - 2538 = 5670$

From Figure 6-6 $Q = 100 \times 10^6 \text{ Btu/Year}/1000 \text{ cfm}$

Savings during winter = $5.67 \times 100 \times 10^6 \times \$4/10^6 / .65 = \$3489$

From Figure 6-7 $Q = 10 \times 10^6 \text{ Btu/Year}/1000 \text{ cfm}$

Savings during summer (at 10 mph wind velocity)

$$\begin{aligned} \text{Savings summer} &= 5.67 \times 10 \times 10^6 / 12,000 \times \\ &.8 \times .05 \times 10 / 15 = \$125.00 \end{aligned}$$

Total savings = \$3614 per year

Reducing Infiltration

In addition to weather-stripping, several key areas should not be overlooked in reducing infiltration losses.

Vertical shafts, such as stairwells, should be isolated as illustrated in Figure 6-8. Always check with fire codes before modifying building egress.

Poor quality outdoor air dampers are another source of excess infiltration. Dampers of this nature do not allow for accurate control and positive closure. Replacement with good quality opposed-blade dampers with seals at the blade edges and ends will reduce infiltration losses. (See Figure 6-9.)

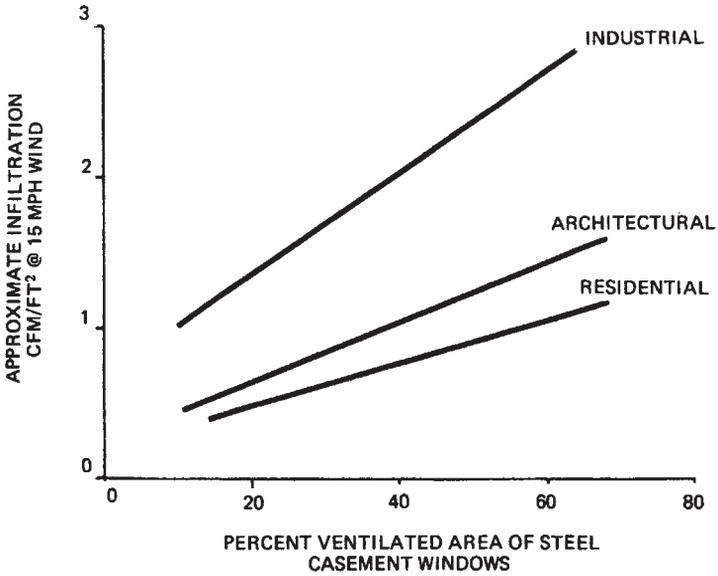
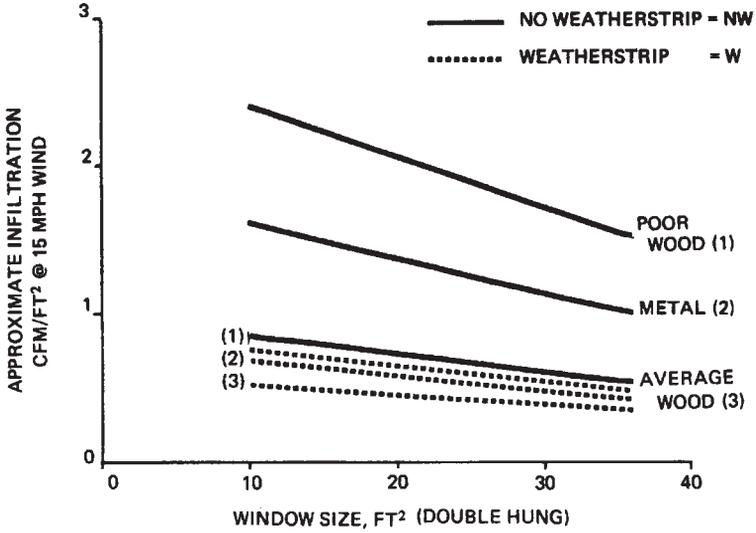


Figure 6-5. Infiltration Through Windows and Door -Winter. (Source: Instructions For Energy Auditors, Vol. II)

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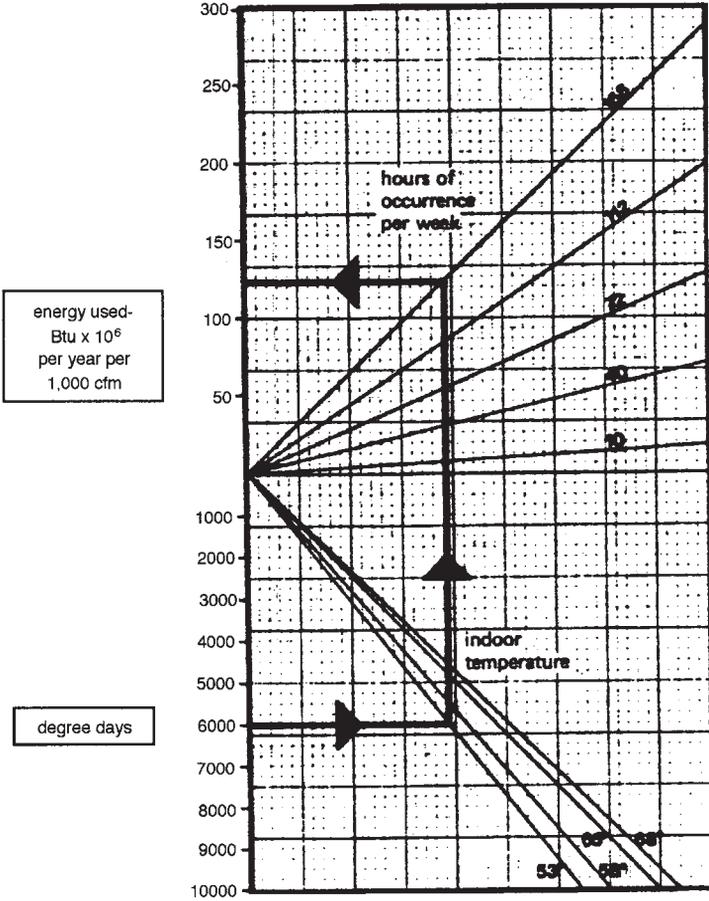


Figure 6-6. Yearly Energy Used Per 1,000 cfm Outdoor Air (Source: Guidelines For Saving Energy in Existing Buildings—Building Owners and Operators Manual, ECM-1)

Energy used is a function of the number of degree days, indoor temperature and the number of hours that temperature is maintained and is expressed as the energy used per 1000 cfm of air conditioned.

The energy used per year was determined as follows:

$$\text{Btu/yr} = (1000 \text{ cfm}) (\text{Degree Days/yr}) (24 \text{ hr/day } 1.08)^*$$

Since degree days are base 65F, the other temperatures in the lower section of the figure are directly proportional to the 65F line. The upper section proportions the hours of system operation with 168 hr/wk being 100%.

*1.08 is a factor which incorporates specific heat, specific volume, and time.

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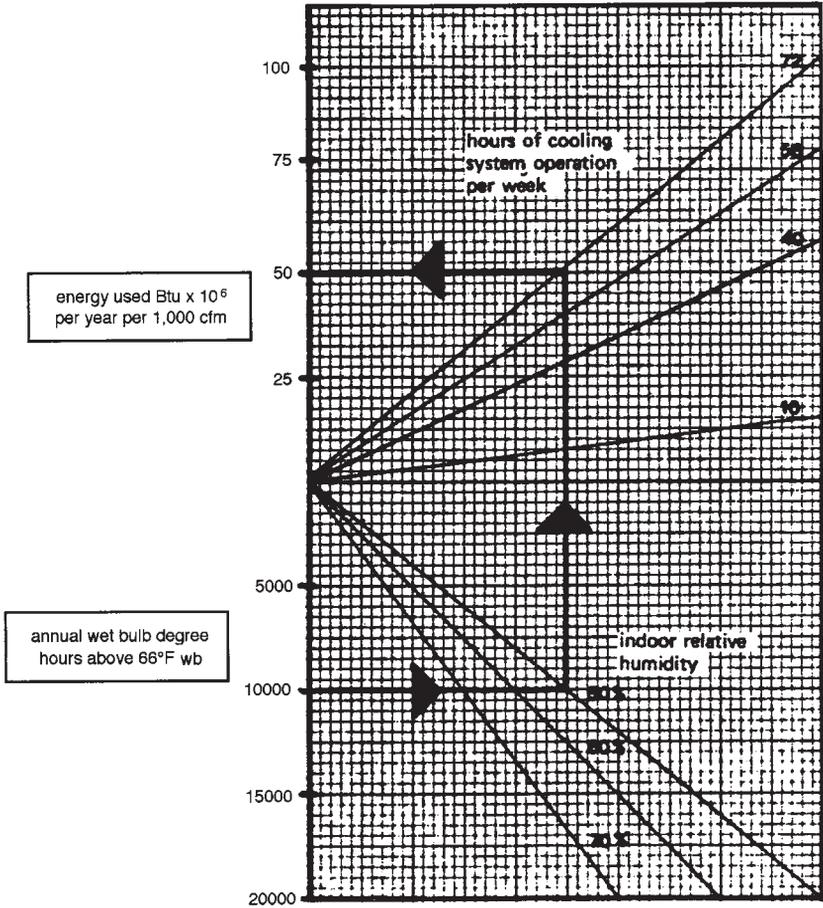
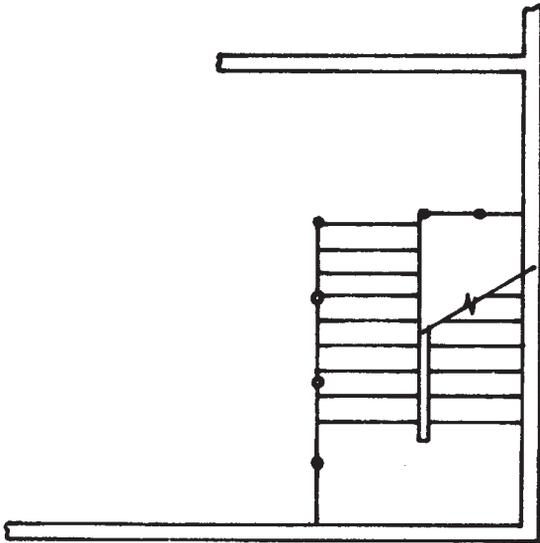


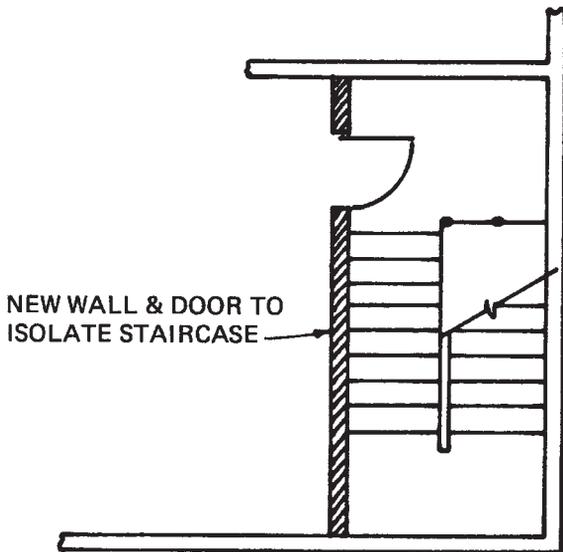
Figure 6-7. Yearly Energy Used Per 1,000 CFM to Maintain Various Humidity Conditions (Source: Guidelines For Saving Energy in Existing Buildings—Building Owners and Operators Manual, ECM-1)

WE degree hours based on 12 Mos/Yr, 8 Hr/Day

Energy used is a function of the WB degree hours above the base of 66F, the RH maintained the No. of hours of controlled humidity. The base RH is 50% which is approximately 78F DB, 66F WB. The figure expresses the energy used per 1000 cfm of air conditioned or dehumidified.

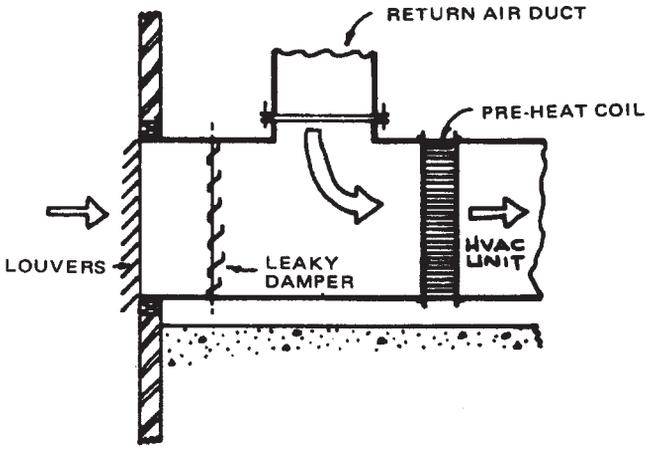


BEFORE

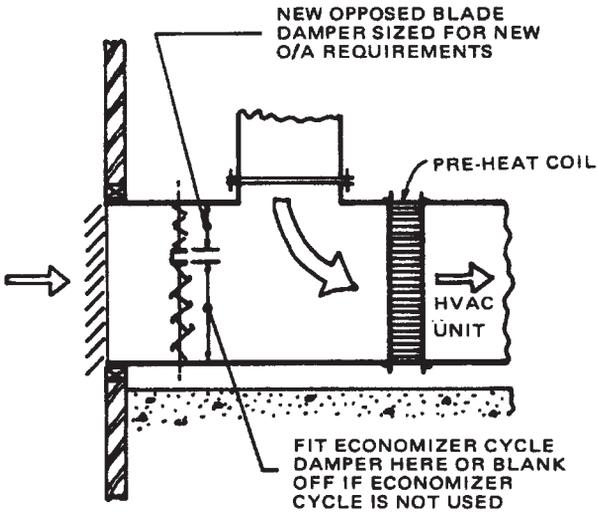


AFTER

Figure 6-8.



BEFORE



AFTER

Figure 6-9.

The third area is to check exhaust hoods such as those used in kitchens and process equipment. Large open hoods are usually required to maintain a satisfactory capture velocity to remove fumes, smoke, etc. These hoods remove large volumes of air. The air is made up through the HVAC system which heats it up in winter and cools and dehumidifies it in summer. Several areas should be checked to reduce infiltration from hoods.

- Minimum capture velocity to remove contaminants.
- Reducing exhaust air by filterizing fitting baffles or a false hood inside existing hood. (See Figure 6-10.)

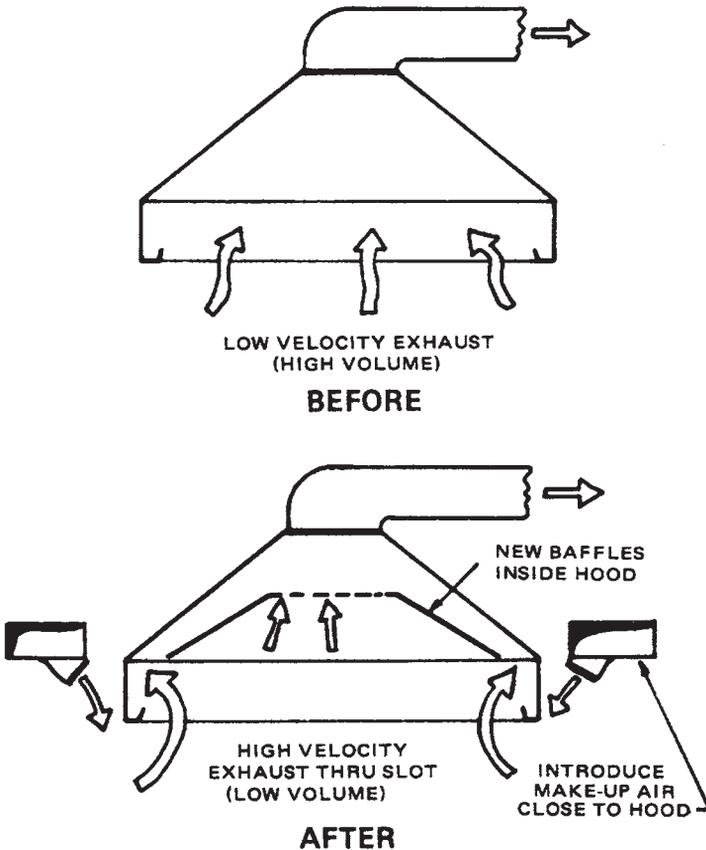


Figure 6-10.

- Installing a separate make-up air system for hoods. The hood make-up air system would consist of a fan drawing in outdoor air and passing through a heating coil to temper air.

HEAT FLOW DUE TO CONDUCTION

When a temperature gradient exists on either side of a wall, a flow of heat from hot side to cold side occurs. The flow of heat is defined by Formula 6-3.

$$Q = k/d \cdot A \cdot \Delta T \tag{6-3}$$

$$U=k/d= 1/R$$

Where:

- Q is the rate of flow Btuh
- d is the thickness of the material in inches
- A is the area of the wall, ft²
- ΔT is the temperature difference, °F
- U is the conductance of the material-Btu/hr/sq ft/F
- k is the conductivity of the material
- R is the resistance of the material.

Resistance of material in series are additive. Thus the importance of insulation is that it increases the R factor, which in turn reduces the heat flow.

Complete tables for conductors and resistances of various building materials can be found in the ASHRAE Guide and Data Book.

HEAT FLOW DUE TO RADIATION

When analyzing a building the conductive portion and radiant portion of heat flow should be treated independently.

Radiation is the transfer of radiant energy from a source to a receiver, The radiation from the source (sun) is partially absorbed by the receiver and partially reflected. The radiation absorbed depends upon its surface emissivity, area, and temperature, as expressed by Formula 6-4.

$$Q = \epsilon \sigma A T^4 \tag{6-4}$$

Where:

- Q = rate of heat, flow by radiation, Btu/hr

- e = emissivity of a body, which is defined as the rate of energy radiated by the actual body. $\epsilon = 1$ for a block body.
 σ = Stephen Boltzman's Constant, 1.71×10^{-9} Btu/ft² • hr • T⁴
 A = surface area of body in square feet.

In addition the radiant energy causes a greater skin temperature to exist on horizontal surfaces such as the roof. The effect is to cause a greater equivalent ΔT which increases the conductive heat flow. Radiant energy flow through roofs and glass should be investigated since it can significantly increase the heat gain of the building. Radiant energy, on the other hand, reduces HVAC requirements during the heating season.

ENERGY AUDITS OF ROOFS

The handy tables and graphs presented in this section are based on the "sunset" program developed for the ECM-2 Manual. The program was based on internal heat gains of 12 Btu/square feet/hour when occupied, 10% average outdoor air ventilation when occupied, and one-half air change per hour continuous infiltration. For significantly different conditions an individual computer run should be made using one of the programs listed in Chapter 5.

A summary of heat losses and heat gains for twelve cities is illustrated in Figures 6-11 and 6-12 respectively. The cumulative values shown take into account both conductive and radiant contributions. Thus a dark covered roof will reduce the heat loss during the winter but increases the heat gain in the summer. Usually the cooling load dictates the color of the roof.

To reduce the HVAC load the U-Factor of the roof is increased by adding insulation.

Estimates of savings can be made by using Figures 6-13, 6-14, and 6-15. The figures take into account both radiant effect and the greater ΔT which occurs due to radiant energy. For cooling load considerations the color of the roof is important. Light color roofs, or adding a surface layer of white pebbles or gravel, are sometimes used. (Care should be taken on existing buildings that structural bearing capacity is not exceeded.)

In addition the roof temperature can be lowered by utilizing a roof spray. (Care should be taken that proper drainage and structural considerations are taken into account.)

Solar radiation data are illustrated in Figure 15-1, Chapter 15.

YEARLY HEAT LOSS/SQUARE FOOT THROUGH ROOF

City	Latitude	Solar Radiation Langley's	Degree-Days	Heat Loss through Roof Btu/Ft ² Year			
				U=0.19		U=0.12	
				a=0.3	a=0.8	a=0.3	a=0.8
Minneapolis	45°N	325	8,382	35,250	30,967	21,330	18,642
Denver	40°N	425	6,283	26,794	22,483	16,226	13,496
Concord, NH	43°N	300	7,000	32,462	27,678	19,649	16,625
Chicago	42°N	350	6,155	27,489	23,590	16,633	14,190
St. Louis	39°N	375	4,900	20,975	17,438	12,692	10,457
New York	41°N	350	4,871	21,325	17,325	12,911	10,416
San Francisco	38°N	410	3,015	10,551	8,091	6,381	4,784
Atlanta	34°N	390	2,983	12,601	9,841	7,619	5,832
Los Angeles	34°N	470	2,061	4,632	3,696	2,790	2,142
Phoenix	33°N	520	1,765	5,791	4,723	3,487	12,756
Houston	30°N	430	1,600	6,045	4,796	3,616	2,778
Miami	26°N	451	141	259	130	139	55

a is the absorption coefficient of the building material
a = .3 (White)
a = .5 (Light colors such as yellow, green, etc.)
a = .8 (Dark colors)

Figure 6-11. Heat Losses for Roofs. (Source: Guidelines For Saving Energy in Existing Buildings-Engineers, Architects and Operators Manual, ECM-2)

YEARLY HEAT LOSS/SQUARE FOOT THROUGH ROOF

City	Latitude	Solar Radiation Langley's	Degree-Days	Heat Loss through Roof Btu/Ft ² Year			
				U=0.19		U=0.12	
				a=0.3	a=0.8	a=0.3	a=0.8
Minneapolis	45°N	325	2,500	2,008	8,139	1,119	4,728
Concord, NH	43°N	300	1,750	1,892	7,379	1,043	4,257
Denver	40°N	425	4,055	2,458	9,859	1,348	5,680
Chicago	42°N	350	3,100	2,104	7,918	1,185	4,620
St. Louis	39°N	375	6,400	4,059	12,075	2,326	7,131
New York	41°N	350	3,000	2,696	9,274	1,534	5,465
San Francisco	38°N	410	3,000	566	5,914	265	3,354
Atlanta	34°N	390	9,400	4,354	14,060	2,482	8,276
Los Angeles	34°N	470	2,000	1,733	10,025	921	5,759
Phoenix	33°N	520	24,448	12,149	24,385	7,258	14,649
Houston	30°N	430	11,500	7,255	20,931	4,176	12,369
Miami	26°N	451	10,771	9,009	24,594	5,315	14,716

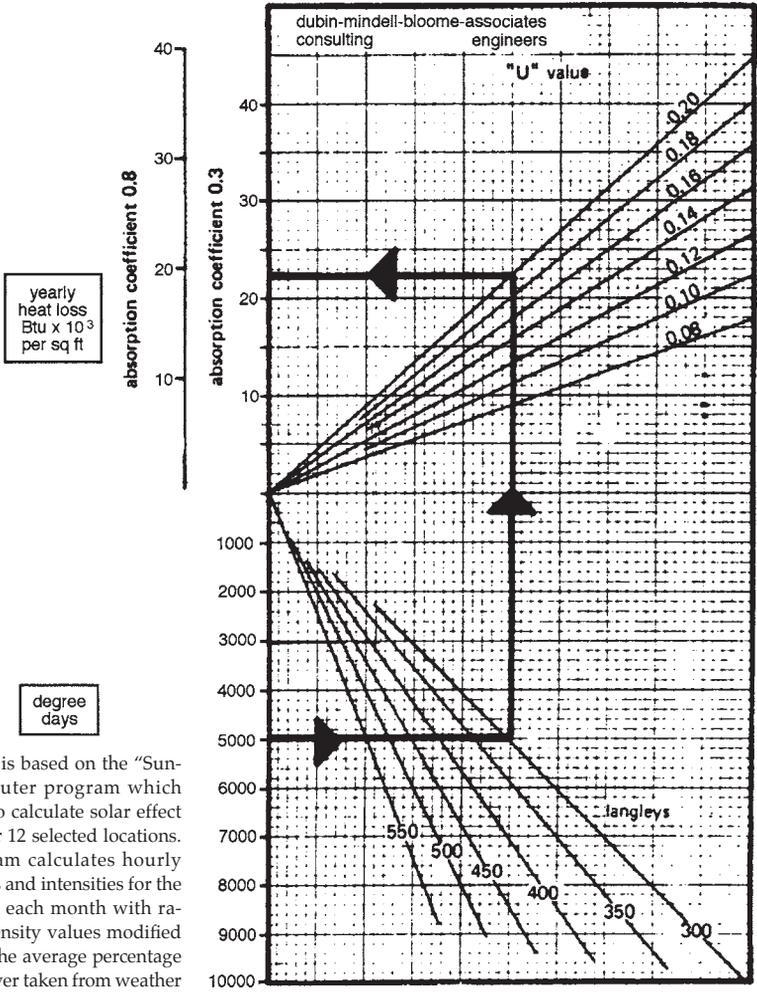
a is the absorption coefficient of the building material

a = .3 (White)

a = .5 (Light colors such as yellow, green, etc.)

a = .8 (Dark colors)

Figure 6-12. Heat Gains for Roofs (Source: Guidelines For Saving Energy in Existing Buildings-Engineers, Architects and Operators Manual, ECM-2)



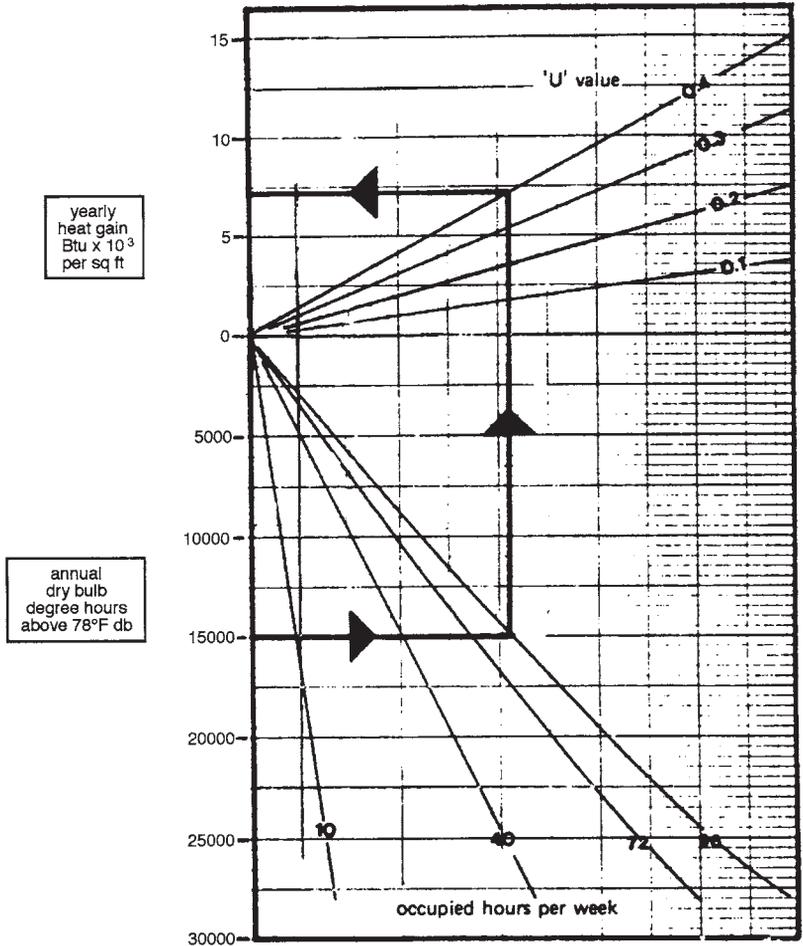
This figure is based on the "Sun-set" Computer program which was used to calculate solar effect on roofs for 12 selected locations. The program calculates hourly solar angles and intensities for the 21st day of each month with radiation intensity values modified hourly by the average percentage of cloud cover taken from weather records. Heat losses are based on a 68F indoor temperature.

The solar effect on a roof was calculated using sol-air temperature and the heat entering or leaving a space was calculated using the equivalent temperature difference. Roof mass ranged from 25-35 lbs/ft² and thermal lag averaged 3-1/2 hours. Additional assumptions were: (1) Total internal heat gain of 12 Btu/ft². (2) Outdoor air ventilation rate of 10%. (3) Infiltration rate of 1.2 air change per hour. Daily totals were then summed for the number of days in each month to arrive at monthly heat losses. The length of the heating season for each location considered was determined from weather data and characteristic operating periods. Yearly heat losses were derived by summing monthly totals for the length of the cooling season.

Absorption coefficients and U values were varied and summarized for the 12 locations. The data were then plotted and extrapolated to include the entire range of degree days.

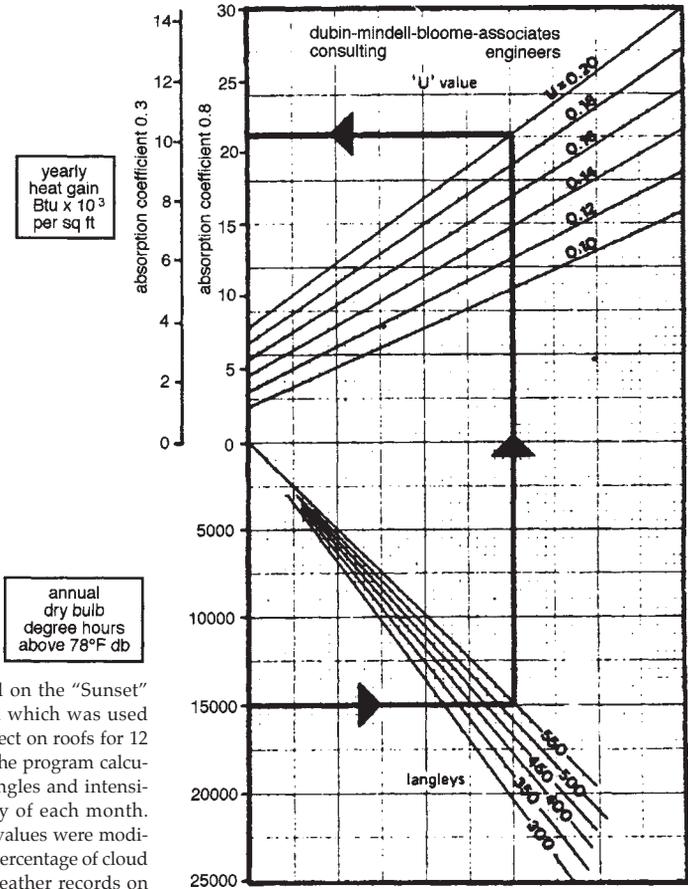
Figure 6-13. Yearly Heat Loss Through Roof. (Source: Guidelines For Saving Energy in Existing Buildings—Engineers, Architects and Operators Manual, ECM-2)

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This figure is based on degree hours with a base of 56 hours/week. The figure is based on the formula: Q (Heat Gain)/yr = Degree Hours/yr \times 'U' Value. The major portion of degree hours occur between 10 a.m. and 3 p.m. Hence for occupancies between 10 and 56 hrs/wk, the degree hour distribution can be assumed to be linear. However, for occupancies greater than 56 hrs/wk the degree hour distribution becomes nonlinear, particularly in locations with greater than 15,000 degree hours. This is reflected by the curves for 72 and 96 hr/wk occupancies.

Figure 6-14. Yearly Conduction Heat Gain Through Walls, Roofs and Floors (Source: Guidelines For Saving Energy in Existing Buildings—Engineers, Architects and Operators Manual, ECM-2)



This figure is based on the "Sunset" Computer program which was used to calculate solar effect on roofs for 12 selected locations. The program calculates hourly solar angles and intensities for the 21st day of each month. Radiation intensity values were modified by the average percentage of cloud cover taken from weather records on an hourly basis. Heat gains are based on a 78F indoor temperature.

The solar effect on a roof was calculated using sol-air temperature and the heat entering or leaving a space was calculated with the equivalent temperature difference. Roof mass ranged from 25-35 lbs/ft² and thermal lag averaged 3-1/2 hours. During the cooling season, internal gains, ventilation, infiltration and conduction through the building skin create a cooling load. Additional load caused by heat gain through the roof was calculated for each day. Daily totals were then summed for the number of days in each month to arrive at monthly heat gains. The length of the cooling season for each location considered was determined from weather data and characteristic operating periods. Yearly heat gains were derived by summing monthly totals for the length of the cooling season.

Absorption coefficients and U values were varied and summarized for the 12 locations. Gains included both the solar and conduction components of heat gain. Values of the conduction heat gain component through roofs were deducted from the total heat gains to derive the solar component. The solar component was then plotted and extrapolated to include the entire range of degree hours.

Figure 6-15. Yearly Heat Loss Through Roof. (Source: Guidelines For Saving Energy in Existing Buildings—Engineers, Architects and Operators Manual, ECM-2)

COMPUTER SERVICES

Most manufacturers of roof insulation and window treatments offer computer simulations to estimate savings as a result of using their products. These programs are usually available at no cost through authorized distributors and contractors.

For information concerning insulation products and services call the nearest authorized distributor or contact:

North American Insulation Manufacturers Assoc.
44 Canal Center Plaza, Suite 310
Alexandria, VA 22314
www.naima.org

Manufacturers such as 3M offer computer load simulations for their products. For information concerning window treatments, contact the manufacturers listed in the next section.

SIM 6-4

An energy audit of the roof indicates the following:

Area	20,000 square feet
Present "R" value	8
(Estimation based on insulation thickness and type)	
Degree-Days (winter)	3,000
Occupied hrs/week	40
D.B. Degree-Hours above 78°F	9,400
Fuel cost	\$5/10 ⁶ Btu
Boiler efficiency	.65
Electric rate	6¢ per kWh
Air-condition requirement	.8 kW/Ton-Hr
Roof Absorption	.3
Solar radiation	390 Langleys

It is proposed that additional insulation of R=13 should be installed.

Comment on the potential savings.

ANALYSIS

$$R_T = R_1 + R_2 = 8 + 13 = 21$$

$$U_{\text{Before}} = 1/8 = .125$$

$$U_{\text{After}} = 1/21 = .047$$

Savings

Winter

From Figure 6-13

$$Q_{\text{Before}} = 7 \text{ Btu} \times 10^3 \text{ per square feet}$$

$$Q_{\text{After}} = 2 \text{ Btu} \times 10^3 \text{ per square feet}$$

$$\text{Savings} = (7-2) \times 10^3 \times 20 \times 10^3 \times 5/10^6 / .65 = \$769$$

Summer

Conduction

From Figure 6-14

$$Q_{\text{Before}} = 1 \times 10^3 \text{ Btu/sq ft/yr}$$

$$Q_{\text{After}} = .4 \times 10^3 \text{ Btu/sq ft/yr}$$

$$\text{Savings} = (1 - .4) \times 10^3 \times 20,000 = 12,000 \times 10^3 \text{ Btu/Yr}$$

Radiation

From Figure 6-15

$$Q_{\text{Before}} = 8.5 \times 10^3 \text{ Btu/sq ft/yr}$$

$$Q_{\text{After}} = 2.5 \times 10^3 \text{ Btu/sq ft/yr}$$

$$\text{Savings} = (8.5-2.5) \times 10^3 \text{ Btu/sq ft/yr} \times 20,000$$

$$120,000 \times 10^3 \text{ Btu/r}$$

$$\text{Savings} = \frac{120,000 + 12,000}{12,000} \times 10^3 \times .8 \times .06 = \$528/\text{yr}$$

Total Savings = \$1297/year.

Figure 6-16 illustrates typical insulation conductance values recommended based on degree-day data.

THE GLASS AUDIT

Conduction Considerations

Glass traditionally has poor conductance qualities and accounts for significant heat gains due to radiant energy.

To estimate savings as a result of changing glass types, Figures 6-17

INSULATION VALUE FOR HEAT FLOW THROUGH OPAQUE AREAS OF ROOFS AND CEILINGS	
Heating Season Degree-Days	U value (Btu/hr/sq ft/°F)
1-1000	0.12
1001 -2000	0.08
2001 and above	0.05
INSULATION VALUE FOR HEAT FLOW THROUGH OPAQUE EXTERIOR WALLS FOR HEATED AREAS	
Heating Seasons Degree-Days	U value (Btu/hr/sq ft)°F)
0-1000	0.30
1001 -2500	0.25
2500-5000	0.20
5000-8000	0.15
Cooling Season—The recommended U value of insulation for heat flow through exterior roofs, ceilings, and walls should be less than 0.15 Btu/hr/sq ft/°F.	

Figure 6-16. Insulation Conductance Values for Roofs and Walls (Source: Instructions For Energy Auditors)

through 6-22 can be used. Figures 6-19 and 6-20 illustrate the heat loss and gain due to conduction for winter and summer respectively. Figures 6-21 and 6-22 can be used to calculate the radiant heat gain during summer.

To decrease losses due to conductance either the glass needs to be replaced, modified, or an external thermal blanket added. Descriptions of window treatments are discussed at the end of the chapter.

SOLAR RADIATION CONSIDERATIONS

In addition to heat flow due to conduction, a significant heat flow occurs through glass due to the sun's radiant energy. The radiant energy will decrease heating requirements during the winter time but greatly increase the air-conditioning load during the cooling season.

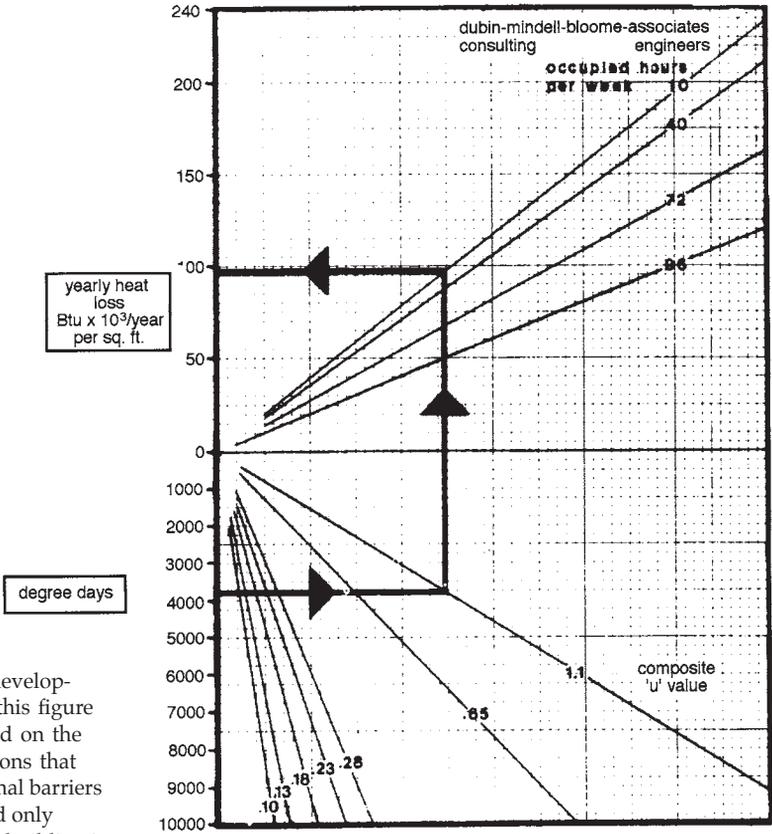
City	Latitude	Solar Radiation Langley's	Degree- Days	Heat Loss Through Roof Btu/Ft ² Year					
				North		East & West		South	
				Single	Double	Single	Double	Single	Double
Minneapolis	45°N	325	8,382	187,362	94,419	161,707	84,936	140,428	74,865
Concord, NH	43°N	300	7,000	158,770	83,861	136,073	73,303	122,144	67,586
Denver	40°N	425	6,283	136,452	70,449	117,487	62,437	109,365	59,481
Chicago	42°N	350	6,155	147,252	75,196	126,838	65,810	110,035	58,632
St. Louis	39°N	375	4,900	109,915	56,054	94,205	49,355	84,399	45,398
New York	41°N	350	4,871	109,672	54,986	93,700	48,611	82,769	44,580
San Francisco	38°N	410	3,015	49,600	25,649	43,866	23,704	41,691	23,239
Atlanta	34°N	390	2,983	63,509	31,992	55,155	28,801	51,837	28,092
Los Angeles	34°N	470	2,061	21,059	11,532	19,487	10,954	19,485	10,989
Phoenix	33°N	520	1,765	25,951	14,381	22,381	12,885	22,488	12,810
Houston	30°N	430	1,600	33,599	17,939	30,744	17,053	30,200	16,861
Miami	26°N	451	141	1,404	742	1,345	742	1,345	742

Figure 6-17. Yearly Heat Loss/Square Foot of Single Glazing and Double Glazing (Source: Guideline For Saving Energy in Existing Buildings-Engineers, Architects and Operators Manual, ECM-2)

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City	Latitude	Solar Radiation Langley's	D.B. Degree- Hours Above 78°F	Heat Loss Through Roof Btu/Ft ² Year					
				North		East & West		South	
				Single	Double	Single	Double	Single	Double
Minneapolis	45°N	325	2,500	36,579	33,089	98,158	88,200	82,597	70,729
Concord, NH	43°N	300	1,750	33,481	30,080	91,684	82,263	88,609	76,517
Denver	40°N	425	4,055	44,764	39,762	122,038	108,918	100,594	85,571
Chicago	42°N	350	3,100	35,595	31,303	93,692	83,199	87,017	74,497
St. Louis	39°N	375	6,400	55,242	45,648	130,018	112,368	103,606	85,221
New York	41°N	350	3,000	40,883	35,645	109,750	97,253	118,454	102,435
San Francisco	38°N	410	3,000	29,373	28,375	88,699	81,514	73,087	64,169
Atlanta	34°N	390-	- 9,400	69,559	50,580	147,654	129,391	106,163	87,991
Los Angeles	34°N	470	2,000	47,912	43,264	126,055	112,869	112,234	97,284
Phoenix	33°N	520	24,448	137,771	97,565	242,586	191,040	211,603	131,558
Houston	30°N	430	11,500	88,334	72,474	213,739	184,459	188,718	156,842
Miami	26°N	451	10,771	98,496	79,392	237,763	203,356	215,382	179,376

Figure 6-18. Yearly Heat Gain/Square Foot of Single Glazing and Double Glazing (Source: Guidelines For Saving Energy in Existing Buildings-Engineers, Architects and Operators Manual, ECM-2)



NOTE

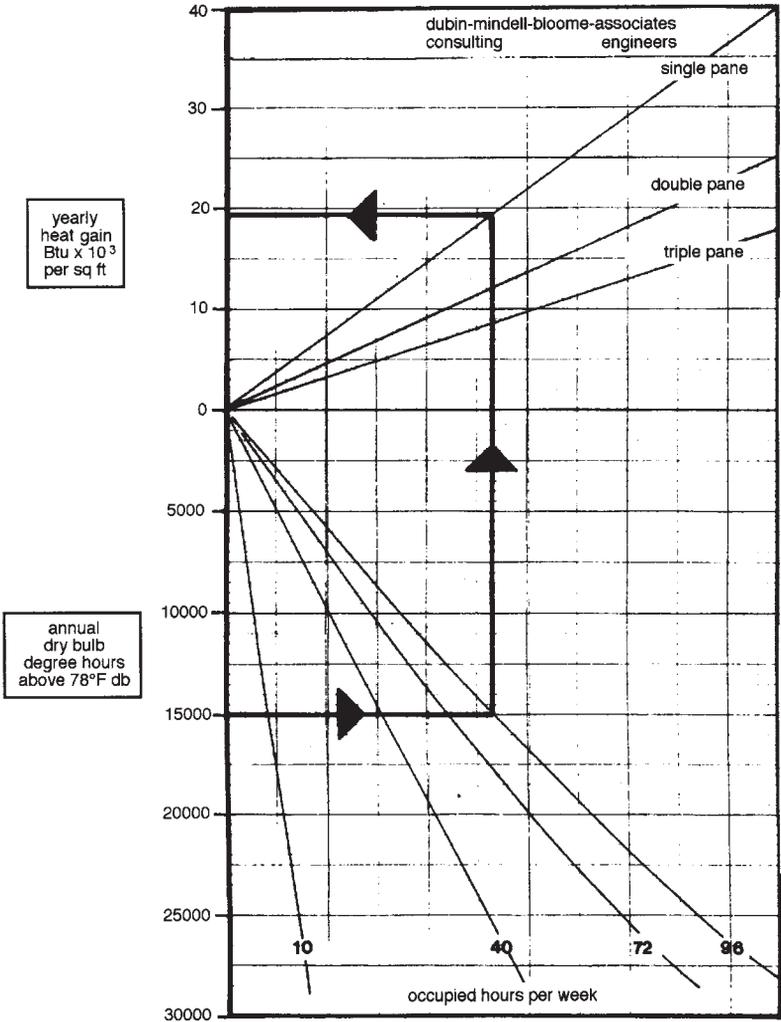
The development of this figure was based on the assumptions that
 1. Thermal barriers are closed only when the building is unoccupied
 2. The average degree-day distribution is 25% during the daytime and 75% during nighttime.

The number of degree days occurring when the thermal barriers are closed (adjusted degree-days - DD_A) were determined from the characteristic occupancy periods shown in the figure. This can be expressed as a fraction of the total degree-days (DD_T) by the relationship:

$$DD_A = 0.25DD_T \left(\frac{\text{unoccupied daytime hours/week}}{\text{total daytime hours/week}} \right) + 0.75DD_T \left(\frac{\text{unoccupied nighttime hours/week}}{\text{total nighttime hours/week}} \right)$$

Yearly heat losses can then be determined by: Q (heat loss/yr) = $DD_A \times U$ value $\times 24$

Figure 6-19. Yearly Heat Loss for Windows with Thermal Barriers. (Source: Guidelines For Saving Energy in Existing Buildings-Engineers, Architects and Operators Manual, ECM-2)



NOTE:

The figure is based on the formula: Q (heat gain)/yr = degree hours/yr \times U value. U values assumed were 1.1 for single pane, 0.65 for double pane and 0.47 for triple pane. The major portion of degree hours occur between 10 a.m. and 3 p.m. Hence, for occupancies between 10 and 56 hours/week, the degree hour distribution can be assumed to be linear. However, for occupancies greater than 56 hours/week the degree hour distribution becomes nonlinear, particularly in locations with greater than 15,000 degree hours. This is reflected by the curves for 72 and 96 hour/week occupancies.

Figure 6-20. Yearly Conduction Heat Gain Through Windows. (Source: Guidelines For Saving Energy in Existing Buildings-Engineers, Architects and Operators Manual, ECM-2)

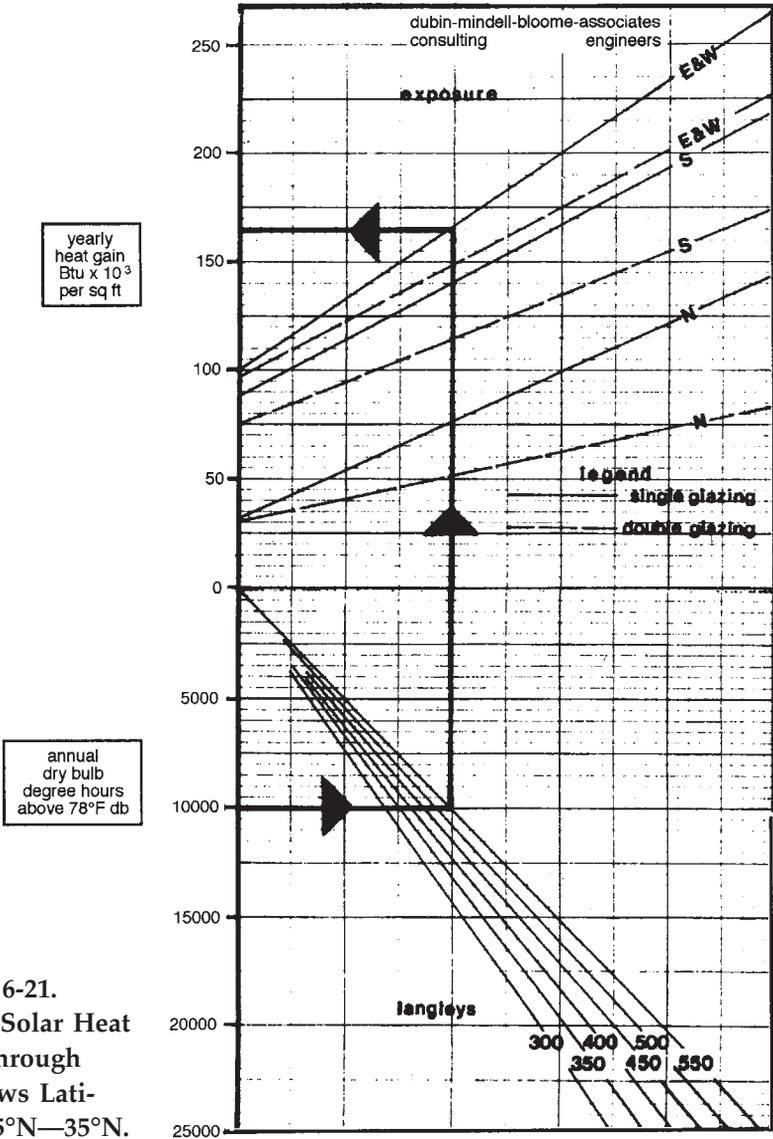


Figure 6-21. Yearly Solar Heat Gain through Windows Latitude 25°N—35°N.

NOTES FOR FIGURES 6-21 AND 6-22

These figures are based on the "Sunset" Computer program which was used to calculate solar effect on windows for 12 locations. The program calculates hourly solar angles and intensities for the 21st day of each month. Radiation intensity values were modified by the average percentage of cloud cover taken from weather records on an hourly basis. Heat gains are based on a 78°F indoor temperature. During the cooling season, internal gains, ventilation, infiltration and conduction through the building can create a cooling load. The additional load caused by heat gain through the windows was calculated for each day.

(Continued on next page)

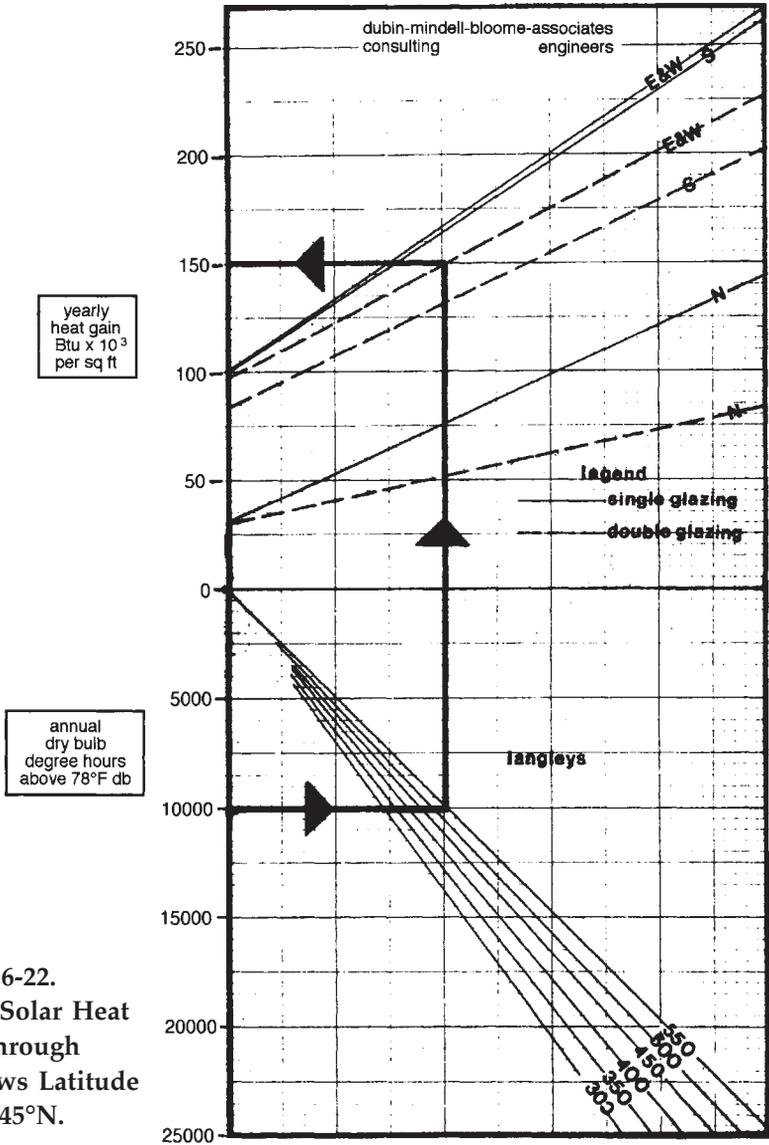


Figure 6-22. Yearly Solar Heat Gain through Windows Latitude 35°N—45°N.

Daily totals were then summed for the number of days in each month to arrive at monthly heat gains. The length of the cooling season for each location considered was determined from weather data and characteristic operating periods. Yearly heat gains were derived by summing monthly totals for the length of the cooling season. Gains are based purely on the solar component. The solar component was then plotted and extrapolated to include the entire range of degree hours. The heat gains assume that the windows are subjected to direct sunshine. If shaded, gains should be read from the north exposure line. The accuracy of the graph diminishes for location with less than 5,000 degree hours.

To reduce solar loads, several common devices are used.

- Roller shades (least expensive)
- Reflective polyester film
- Venetian blinds
- Vertical louver blinds
- External louvered screens
- Tinted or reflective glass (most expensive)

Descriptions of window treatments are discussed at the end of this chapter.

To determine the energy saved from shading devices, Figures 6-21 and 6-22 can be used. Occupancy for these figures is based on 5 days/week, 12 hours/day. If space is occupied differently, prorate the results. The savings for window treatments is estimated by multiplying the annual heat gain by the shading coefficient of the window treatment.

WINDOW TREATMENTS

Several types of window treatments to reduce losses have become available. This section describes some of the products on the market based on information supplied by manufacturers. No claims are made concerning the validity or completeness described. The summary is based on "Windows For Energy Efficient Buildings" as prepared by the Lawrence Berkeley Laboratory for U.S. DOE.

Window treatment manufacturers offer a wide variety of "free programs" to help in evaluation of their products,

Solar Control

Solar Control Films

A range of tinted and reflective polyester films are available to adhere to inner window surfaces to provide solar control for existing clear glazing. Films are typically two- or three-layer laminates composed of metalized, transparent and/or tinted layers. Films are available with a wide range of solar and visible light transmittance values, resulting in shading coefficients as low as 0.24. Most films are adhered with precoated pressure sensitive adhesives. Reflective films will reduce winter U values by about 20%. (Note that a new solar control film, which provides a U value of 0.68, is described in the

thermal barriers section below. Films adhered to glass improve the shatter resistance of glazing and reduce transmission, thus reducing fading of furnishings.

Fiber Glass Solar Control Screens

Solar control screen provides sun and glare control as well as some reduction in winter heat loss. Screens are woven from vinyl-coated glass strands and are available in a variety of colors. Depending on color and weave, shading coefficients of 0.3-0.5 are achieved. Screens are durable, maintenance free, and provide impact resistance. They are usually applied on the exterior of windows and may (1) be attached to mounting rails and stretched over windows, (2) mounted in rigid frames and installed over windows, or (3) made into roller shades which can be retracted and stored as desired. Names of local distributors, installers, and retailers may be obtained by writing to major fabric manufacturers.

Motorized Window Shading System

A variety of plastic and fabric shades is available for use with a motorized window shading system. Reversible motor is located within the shade tube roller and contains a brake mechanism to stop and hold in any position. Motor controls may be gauged and operated locally or from a master station. Automatic photoelectric controls are available that (1) monitor sun intensity and angle and adjust shade position to provide solar control and (2) employ an internal light sensor and provide a preset level of internal ambient light.

Exterior Sun Control Louvers

Operable external horizontal and vertical louver systems are offered for a variety of building sun control applications. Louvers are hinged together and can be rotated in unison to provide the desired degree of shading for any sun position. Operation may be manual or electric; electrical operation may be initiated by manual switches, time clock, or sun sensors. Louvers may be closed to reduce night thermal losses. Sun control elements are available in several basic shapes and in a wide range of sizes.

External Venetian Blinds

Externally mounted, all weather, venetian blinds may be manually operated from within a building or electrically operated and controlled by means of automatic sun sensors, time controls, manual switches, etc.

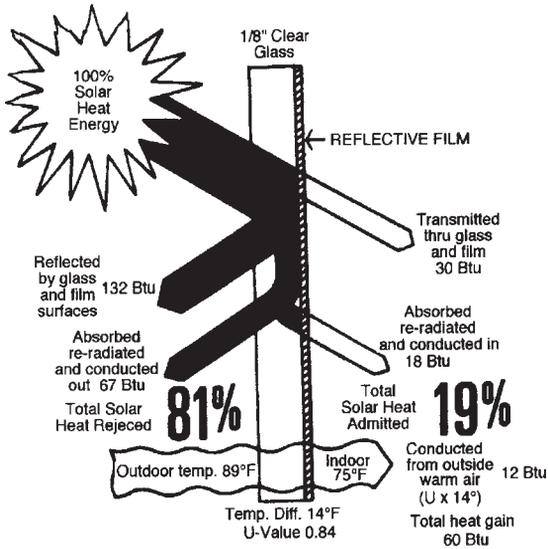


Figure 6-23. Application of Window Film. (Photograph courtesy of 3M Company)

Aluminum slats are held in position with side guides and controlled by weatherproof lifting tapes. Slats can be tilted to modulate solar gain, closed completely, or restricted to admit full light and heat. Blinds have been in use in Europe for many years and have been tested for resistance to storms and high winds.

Adjustable Louvered Windows

Windows incorporating adjustable external louvered shading devices. Louvers are extruded aluminum or redwood, 3 to 5 inches wide, and are manually controlled. Louvers may be specified on double-hung, hinged, or louvered-glass windows. When open, the louvers provide control of solar gain and glare; when closed, they provide privacy and security.

Solar Shutters

The shutter is composed of an array of aluminum slats set at 45° or 22-1/2° from the vertical to block direct sunlight. Shutters are designed for external application and may be mounted vertically in front of window or projected outward from the bottom of the window. Other rolling and hinged shutters are stored beside the window and roll or swing into place for sun control, privacy, or security.

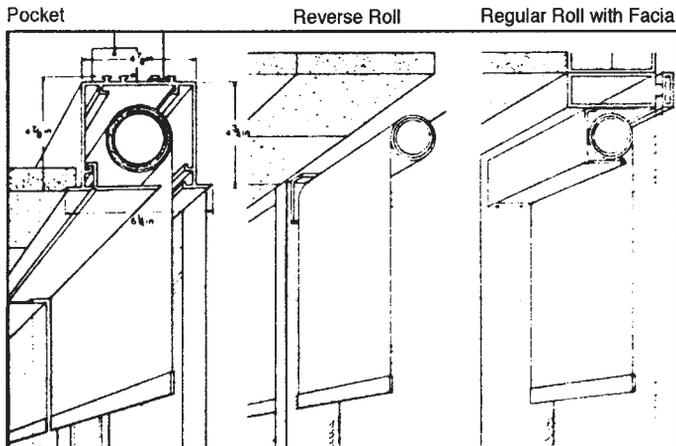


Figure 6-24. Motorized Shade System

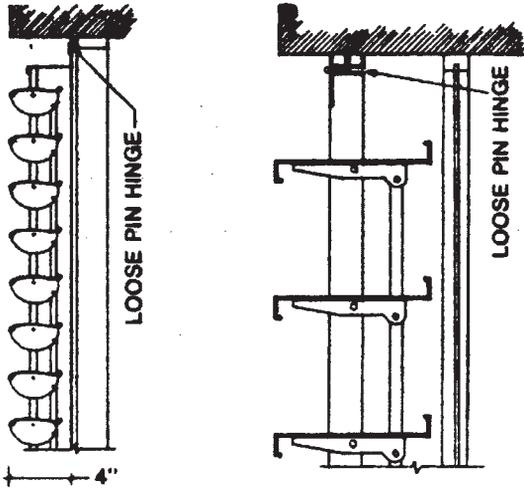


Figure 6-25. Mounting of External Louvers

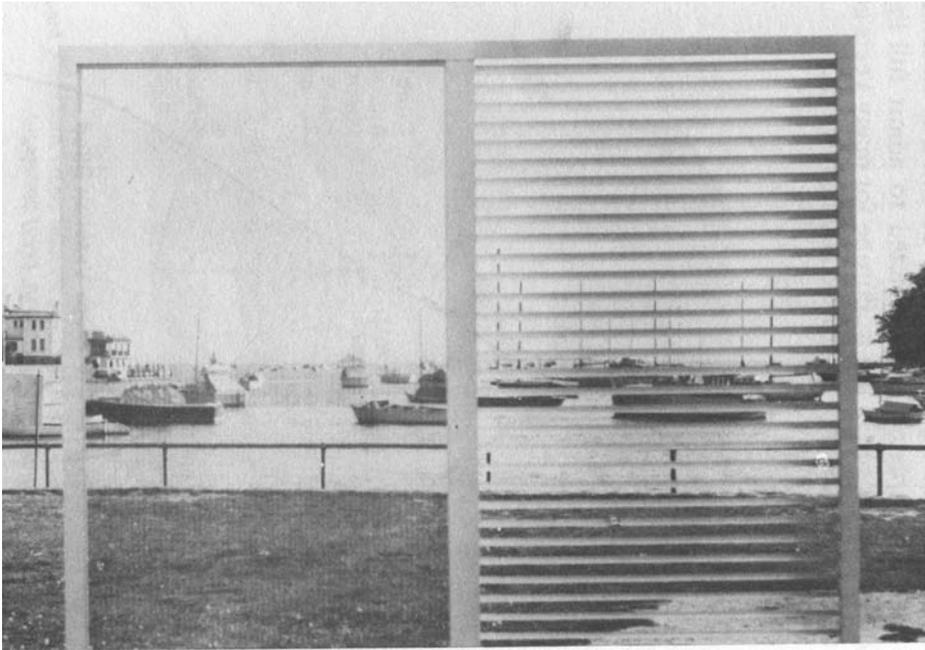


Figure 6-26. Installation of Louvered Solar Screens

Greenwich Harbor, Greenwich, Connecticut, is seen through a louvered solar screen at left and through 34 conventional venetian blind louvers on the right. The two panels are otherwise identical, having the same slat angle and ratio of louver width to louver spacing.

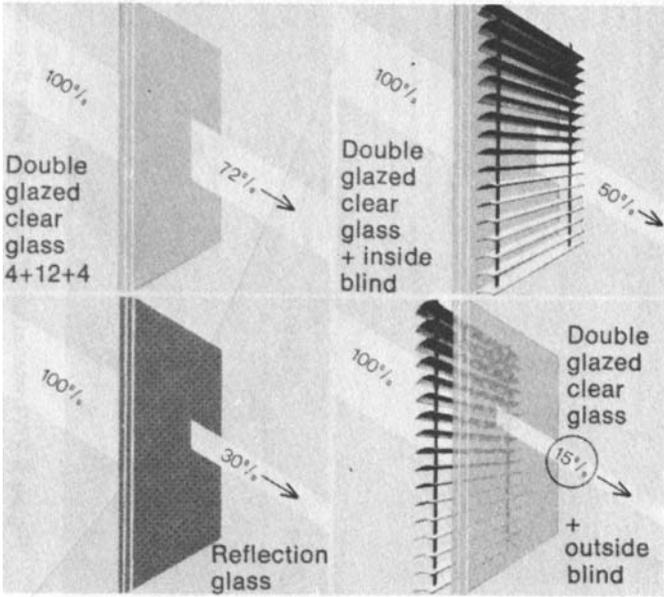


Figure 6-27. Exterior "L"—Type Venetian Blind

Thermal Barriers

Multilayer, Roll-Up Insulating Window Shade

A multilayer window shade which stores in compact roll and utilizes spacers to separate the aluminized plastic layers in the deployed position, thereby creating a series of dead air spaces. Five-layer shade combined with insulated glass provides R8 thermal resistance. Figure 6-28 illustrates a thermal window shade.

Insulating Window Shade

ThermoShade thermal barrier is a roll-up shade composed of hollow, lens-shaped, rigid white PVC slats with virtually no air leakage through connecting joints. Side tracking system reduces window infiltration. Designed for interior installation and manual or automatic operation. When added to a window, the roll-up insulating shade provides R4.5 for single-glazed window or R5.5 for double-glazed window. Quilt is composed of fabric outer surfaces and two polyester fiberfill layers sandwiched around a reflective vapor barrier. Quilt layers are ultrasonically welded. Shade edges are enclosed in a side track to reduce infiltration.

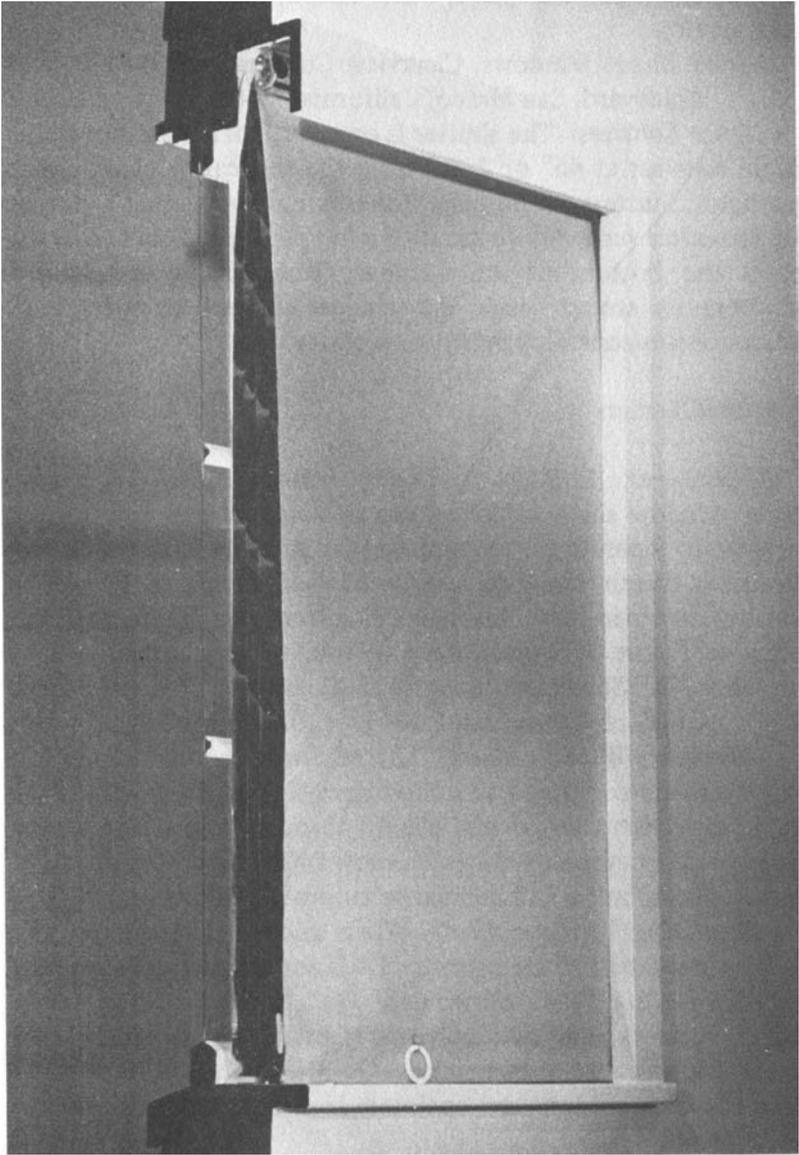
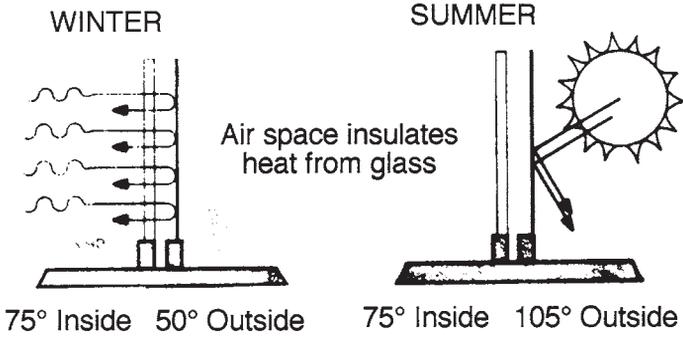


Figure 6-28. Thermal Window Shade Installation

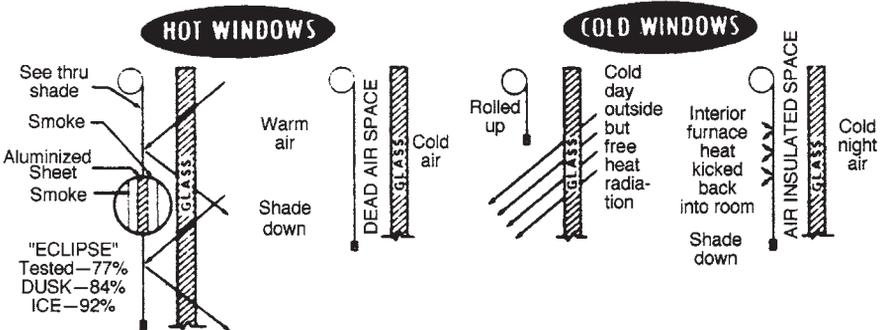
Reflective, Perforated Solar Control Laminate

Laminate of metalized weatherable polyester film and black vinyl which is then perforated with 225 holes/in², providing 36% open area. Available in a variety of metalized and nonmetalized colors, the shading coefficients vary from 0.30 to 0.35 for externally mounted screens and 0.37 to 0.45 for the material adhered to the inner glass surface. The laminate is typically mounted in aluminum screen frames which are hung externally, several inches from the window; it can also be utilized in a roll-up form. Some reduction in winter U value can be expected with external applications.



Semi-Transparent Window Shades

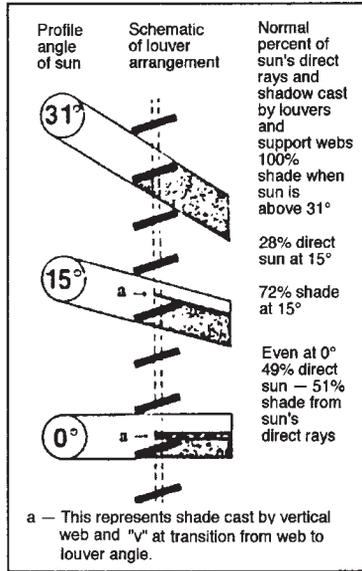
Roll-up window shades made from a variety of tinted or reflective solar control film laminates. These shades provide most of the benefits of solar control film applied directly to glass but provide additional flexibility and may be retracted on overcast days or when solar gain is desired. Shades available with spring operated and gravity (cord and reel) operated rollers as well as motorized options.



Shading coefficients as low as 0.13 are achieved and a tight fitting shade provides an additional air space and thus reduced U-value.

Louvered Metal Solar Screens

Solar screen consists of an array of tiny louvers which are formed from a sheet of thin aluminum. The louvered aluminum sheet is then installed in conventional screen frames and may be mounted against a window in place of a regular insect screen or mounted away from the building to provide free air circulation around the window. View to the outside is maintained while substantially reducing solar gain. Available in a light green or black finish with shading coefficients of 0.21 or 0.15, respectively.

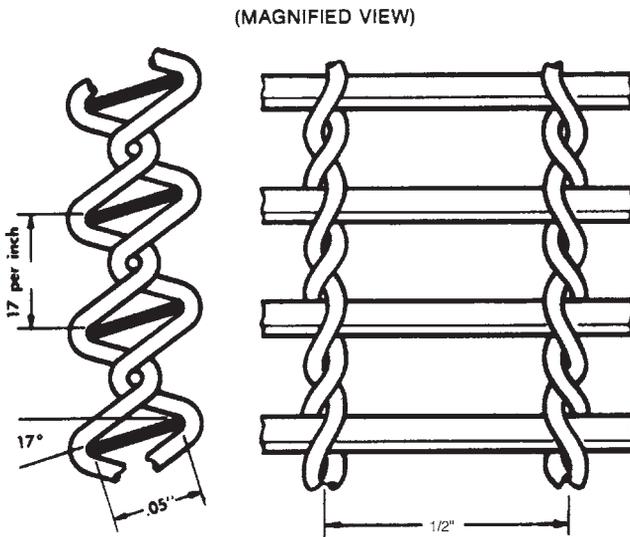


Operable External Louver Blinds

Solar control louver blinds, mounted on the building exterior, can be controlled manually or automatically by sun and wind sensors. Slats can be tilted to modulate light, closed completely, or retracted to admit full light and heat. Developed and used extensively in Europe, they provide summer sun control, control of natural light, and reduction of winter heat loss.

Louvered Metal Solar Screens

Solar screen consists of an array of tiny fixed horizontal louvers



which are woven in place. Louvers are tilted at 17° to provide sun control. Screen material is set in metal frames which may be permanently installed in a variety of configurations or designed for removal. Installed screens have considerable wind and impact resistance. Standard product (17 louvers/inch) has a shading coefficient of 0.23; low sun angle variant (23 louvers/inch) has a shading coefficient of 0.15. Modest reductions in winter U value have been measured.

A comparison of visibility with the louvered screens against conventional venetian blinds is illustrated in Figure 6-26.

Insulating Solar Control Film

A modified solar control film designed to be adhered to the interior of windows provides conventional solar control function and has greatly improved insulating properties. Film emissivity is 0.23-0.25 resulting in a U-value of 0.68 Btu/ft² hr-°F under winter conditions, compared to 0.87 for conventional solar control films and 1.1 for typical single-glazed windows.

Interior Storm Window

Low cost, do-it-yourself interior storm window with a rigid plastic glazing panel. Glazing panel may be removed for cleaning or summer storage. Reduces infiltration losses as well as conductive/convective heat transfer.

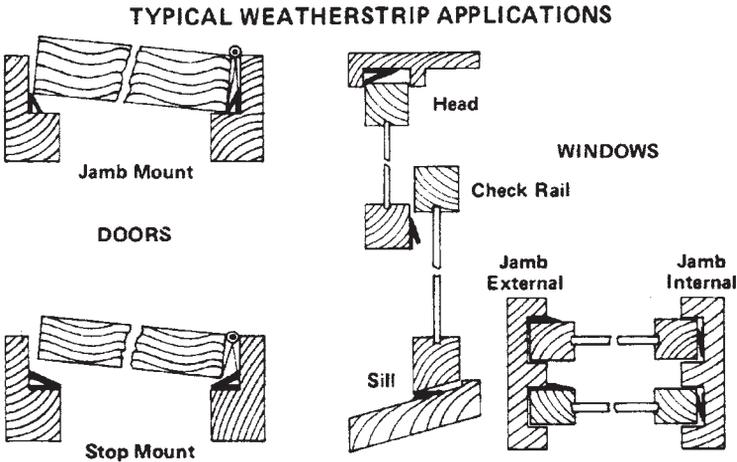
Retrofit Insulating Glass System

Single glazing is converted to double glazing by attaching an extra pane of glass with neoprene sealant. A desiccant-filled aluminum spacer absorbs moisture between the panes. An electric resistance wire embedded in the neoprene is heated with a special power source. This hermetically seals the window. New molding can then be applied if desired.

Infiltration

Weather-strip Tape

A polypropylene film scored along its centerline so that it can be easily formed into a "V" shape. It has a pressure sensitive adhesive on one leg of the "V" for application to seal cracks around doors and windows. On an average fitting, double-hung window it will reduce infiltration by over 70%. It can be applied to rough or smooth surfaces.



PASSIVE SOLAR BUILDING DESIGNS

A passive solar system is defined as one in which thermal energy flows by natural means. Examples of solar building design include:

- Solar greenhouses which are built on the south side of buildings. These can produce 60-100% of heating and cooling requirements.
- Underground buildings which use ground temperature to provide year-round temperature requirements.

- Enhanced natural ventilation through solar chimneys or use of “Trombe wall.”

In these examples and others passive systems accomplish work (heating and cooling) by natural means such as gravity flows, thermosiphons, etc.

To study how the building reacts to loads, its storage effect, etc. computer simulations are many times used. One such system is described below:

PEGFIX—predicts auxiliary heat demand and excess heat available in a space with user-defined maximum and minimum air temperatures. The program is directly useful in sizing and specifying system components and auxiliary equipment. Results stored by *PEGFIX* are: total auxiliary heating load, excess heat available, maximum fan rate required to remove excess heat, and maximum hourly auxiliary load.

PEGFLOAT—predicts hourly temperatures of air and storage mass in a space without auxiliary heat input or removal of excess heat. Its purpose is to evaluate temperature excursions in a 100% solar-dependent operating mode. This program can examine non-south glazing orientations with user-specified hourly values for insulation. *PEGFLOAT* automatically stores maximum and minimum air and storage temperatures of the system modeled.

Both programs require few user-defined inputs regarding the building design and local weather: heat loss coefficients; effective thermal capacity and storage surface area; solar energy available, fraction to storage and fraction to air; average outdoor temperature and daily range. Programs differentiate day and night heat loss values, and can automatically proportion day-long insulation. Each can be run through a 24-hour day, without user interaction, in five to nine minutes. Hourly values of air and storage temperatures, and auxiliary or excess heat, can be displayed without interrupting program execution. Optional hourly display does not affect data storage.

REDUCING STRATIFIED AIR

As indicated in this chapter both the HVAC and building envelope considerations must be considered. An example of this system approach

occurs when heat stratification near ceilings is reduced.

One way of reducing air temperatures near ceilings during the heating season is to use a circulation fan.

The result of reducing ceiling temperature is a reduction in conduction and exhaust losses.

SIM 6-5

Comment on reducing the stratified air temperature from 90°F to 75°F during the heating season.

U = .1

Area = 20,000 square feet

Assume an outside temperature of 15°F and exhaust cfm of 20,000.

ANALYSIS

A handy formula to relate heat loss from cfm exhausts is:

$$Q = 1.08 \text{ Btu Min./Hr, Ft}^3, F \times \Delta T$$

Before change

$$Q_{\text{conduction}} = U A \Delta T = .1 \times 20,000 \times 75 = 150,000 \text{ Btu/h}$$

$$Q_{\text{cfm}} = 1.08 \times 20,000 \times 75$$

$$= 1,620,000 \text{ Btu/h}$$

$$QT = 1,770,000 \text{ Btu/h}$$

After change in stratification temperature

$$Q_c = .1 \times 20,000 \times 60 = 120,000 \text{ Btu/h}$$

$$Q_{\text{cfm}} = 1.08 \times 20,000 \times 60$$

$$= 1,296,000 \text{ Btu/h}$$

$$QT = 1,416,000 \text{ Btu/h}$$

$$\begin{aligned} \% \text{ savings} - \text{heating season} &= 100 - 1,416,000 / 1,770,000 \times 100 = \\ 20\% \times 100 &= 20\% \end{aligned}$$

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Chapter 7

The Electrical System Audit

*T*he electrical consumption in most commercial facilities can easily account for 50 to 75% of the total utility costs. Because of this, special attention must be paid to evaluating electrical consuming equipment and systems within the facility. Electrical energy and costs are saved by managing demand loads, reducing run hours, improving equipment efficiency, and maintaining distribution systems.

A thorough knowledge of how electricity is used in a facility can be invaluable to the electrical system audit. The evaluation should include an electric demand profile for the building.

At a minimum, several weeks of data in 15-minute intervals should be taken with a recording meter. The measurements may have to be taken both in the cooling and heating season. Most electric utilities either have this data available for their customers or can provide this service at a nominal charge. In addition, many energy management control systems have demand recording capability which can be used for interval analysis.

The electrical system audit typically includes gathering the following data:

- Lighting system survey
- Motor inventory and loads
- Power factor and demand

Typical information gathering forms are illustrated in Chapter 15, Figures 15-15 through 15-18.

LIGHTING SYSTEM AUDIT

Lighting accounts for a significant portion of electrical energy consumed in a building. Energy is saved in the lighting system by reducing illumination levels, improving lighting system efficiency, curtailing

operating hours, and by taking advantage of available daylighting.

To perform the lighting audit, the following steps are required:

1. Assess what you have:
 - Room Classification—office, warehouse, storage, etc.
 - Room Characteristics—height, width, length, color and condition of surfaces.
 - Fixture Characteristics—lamp type, number of fixtures, condition of luminaries, methods of control, fixture mounting height, ballast and lamp wattage.
2. Evaluate Lighting Levels and Lighting Quality
 - Measure foot-candles using light meter.
 - Sketch luminaire types and layout in room or area.
 - Check for excessive glare and contrast.
 - Talk to users about lighting levels, controls, and quality.
 - Compare foot-candle measurements to IES recommendations for the task performed.
3. Estimate Electrical Consumption
 - Calculate Total Watts (watts/fixture \times # of fixtures/1000 = Existing kW)
 - Calculate Power Density (kW \times 1000/square foot = watts/square foot)
 - Compare Existing Power Density to Code of Design Guidelines
 - Estimate of Annual Hours of Use
 - Estimate Annual Lighting Energy Cost (Existing kW \times annual hours \times \$/kWh = \$/year)
4. Calculate Energy Savings
 - Determine new total kW after retrofit.
 - Determine change in annual operating hours if lighting controls are changed.
 - Calculate energy savings (kW before—kW after) \times hours of operation = kWh
 - Calculate energy cost savings (kWh \times \$/kWh = annual cost savings)

Reduction of lighting energy can also increase the energy use of building heating and decrease cooling system consumption, since internal

heat gains are reduced. This heat-of-light is often a relatively expensive method of heating a building and can be done more efficiently with the heating system. The lighting calculations should indicate if adjustments for heating and cooling loads have been made. Approximate adjustments for heating and cooling load changes can be made as follows:

- Building heated only—Decrease energy savings by 20%
- Building heated and air conditioned—Increase savings by 20%

If the building cooling plant or HVAC system is to be replaced, implementation of lighting improvements done in conjunction with the replacement can reduce the required plant size.

LIGHTING EFFICIENCY

Lighting Basics

By understanding the basics of lighting design, several ways to improve the efficiency of lighting systems will become apparent.

There are two common lighting methods used. One is called the lumen method, while the other is the point-by-point method. The lumen method assumes an equal foot-candle level throughout the area. This method is used frequently by lighting designers since it is simplest; however, it wastes energy, since it is the light “at the task” which must be maintained and not the light in the surrounding areas. The point-by-point method calculates the lighting requirements for the task in question.

The point-by-point method makes use of the inverse-square law, which states that the illuminance at a point on a surface perpendicular to the light ray is equal to the luminous intensity of the source at that point divided by the square of the distance between the source and the point of calculation, as illustrated in Formula 7-1.

$$E = \frac{I}{D^2} \tag{7-1}$$

Where

E = Illuminance in foot-candles

I = Luminous intensity in candelas

D = Distance in feet between the source and the point of calculation.

If the surface is not perpendicular to the light ray, the appropriate trigonometric functions must be applied to account for the deviation.

Lumen Method

A foot-candle is the illuminance on a surface of one square foot in area having a uniformly distributed flux of one lumen. From this definition, the lumen method is developed and illustrated by Formula 7-2.

$$N = \frac{F_1 \times A}{Lu \times L_1 \times L_2 \times Cu} \quad (7-2)$$

Where

- N is the number of lamps required.
- F_1 is the required foot-candle level at the task. A foot-candle is a measure of illumination; one standard candle power measured one foot away.
- A is the area of the room in square feet.
- Lu is the lumen output per lamp. A lumen is a measure of lamp intensity: its value is found in the manufacturer's catalogue.
- Cu is the coefficient of utilization. It represents the ratio of the lumens reaching the working plane to the total lumens generated by the lamp. The coefficient of utilization makes allowances for light absorbed or reflected by walls, ceilings, and the fixture itself. Its values are found in the manufacturer's catalogue.
- L_1 is the lamp depreciation factor. It takes into account that the lamp lumen depreciates with time. Its value is found in the manufacturer's catalogue.
- L_2 is the luminaire (fixture) dirt depreciation factor. It takes into account the effect of dirt on a luminaire and varies with type of luminaire and the atmosphere in which it is operated.

The lumen method formula illustrates several ways lighting efficiency can be improved.

Faced with the desire to reduce their energy use,* lighting consumers have four options: i) reduce light levels, ii) purchase more efficient equipment, iii) provide light when needed at the task at the required level, and iv) add control and reduce lighting loads automatically. The multitude of equipment options to meet one or more of the above needs permits the consumer and the lighting designer-engineer to consider the

*Source: *Lighting Systems Research*, R.R. Verderber.

trade-offs between the initial and operating costs based upon product performance (life, efficacy, color, glare, and color rendering).

Some definitions and terms used in the field of lighting will be presented to help consumers evaluate and select lighting products best suiting their needs. Then, some state-of-the-art advances will be characterized so that their benefits and limitations are explicit.

LIGHTING TERMINOLOGY

Efficacy—Is the amount of visible light (lumens) produced for the amount of power (watts) expended. It is a measure of the efficiency of a process but is a term used in place of efficiency when the input (W) has different units than the output (lm) and expressed in lm/W.

Color Temperature—A measure of the color of a light source relative to a black body at a particular temperature expressed in degrees Kelvin (OK). Incandescents have a low color temperature (~2800°K) and have a red-yellowish tone; daylight has a high color temperature (~6000°K) and appears bluish. Today, the phosphors used in fluorescent lamps can be blended to provide any desired color temperature in the range from 2800°K to 6000°K.

Color Rendering—A parameter that describes how a light source renders a set of colored surfaces with respect to a black body light source at the same color temperature. The color rendering index (CRI) runs from 0 to 100. It depends upon the specific wavelengths of which the light is composed. A black body has a continuous spectrum and contains all of the colors in the visible spectrum. Fluorescent lamps and high intensity discharge lamps (HID) have a spectrum rich in certain colors and devoid in others. For example, a light source that is rich in blues and low in reds could appear white, but when reflected from a substance, it would make red materials appear faded. The same material would appear different when viewed with an incandescent lamp, which has a spectrum that is rich in red.

LIGHT SOURCES*

Figure 7-1, indicates the general lamp efficiency ranges for the generic families of lamps most commonly used for both general and

* Source: *Selection Criteria for Lighting Energy Management*, Roger L. Knott.

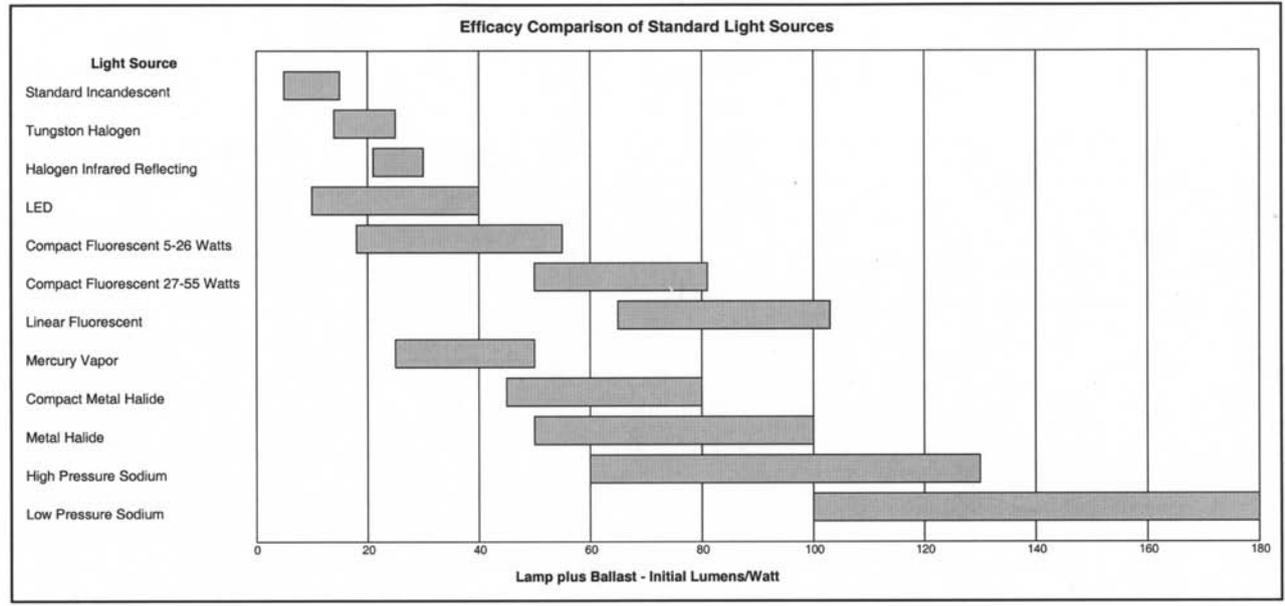


Figure 7-1

supplementary lighting systems. Each of these sources is discussed briefly here. It is important to realize that in the case of fluorescent and high intensity discharge lamps, the figures quoted for “lamp efficacy” are for the lamp only and do not include the associated ballast losses. To obtain the total system efficiency, ballast input watts must be used rather than lamp watts to obtain an overall system lumen per watt figure. This will be discussed in more detail in a later section.

Incandescent lamps have the lowest lamp efficacies of the commonly used lamps. This would lead to the accepted conclusion that incandescent lamps should generally not be used for large area, general lighting systems where a more efficient source could serve satisfactorily. However, this does not mean that incandescent lamps should never be used. There are many applications where the size, convenience, easy control, color rendering, and relatively low cost of incandescent lamps are suitable for a specific application.

General service incandescent lamps do not have good lumen maintenance throughout their lifetime. This is the result of the tungsten’s evaporation off the filament during heating as it deposits on the bulb wall, thus darkening the bulb and reducing the lamp lumen output.

Efficient Types of Incandescents for Limited Use

Attempts to increase the efficiency of incandescent lighting while maintaining good color rendition have led to the manufacture of a number of energy-saving incandescent lamps for limited residential use.

Tungsten Halogen

These lamps vary from the standard incandescent by the addition of halogen gases to the bulb. Halogen gases keep the glass bulb from darkening by preventing the filament’s evaporation, thereby increasing lifetime up to four times that of a standard bulb. The lumen-per-watt rating is approximately the same for both types of incandescents, but tungsten halogen lamps average 94% efficiency throughout their extended lifetime, offering significant energy and operating cost savings. However, tungsten halogen lamps require special fixtures, and during operation the surface of the bulb reaches very high temperatures, so they are not commonly used in the home.

Reflector or R-Lamps

Reflector lamps are incandescents with an interior coating of aluminum that directs the light to the front of the bulb. Certain incandescent

light fixtures, such as recessed or directional fixtures, trap light inside. Reflector lamps project a cone of light out of the fixture and into the room, so that more light is delivered where it is needed. In these fixtures, a 50-watt reflector bulb will provide better lighting and use less energy when substituted for a 100-watt standard incandescent bulb.

Reflector lamps are an appropriate choice for task lighting (because they directly illuminate a work area) and for accent lighting. Reflector lamps are available in 25, 30, 50, 75, and 150 watts. While they have a lower initial efficiency (lumens per watt) than regular incandescents, they direct light more effectively, so that more light is actually delivered than with regular incandescents. (See Figure 7-2.)

PAR Lamps

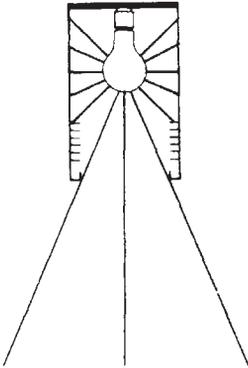
Parabolic aluminized reflector (PAR) lamps are reflector lamps with a lens of heavy, durable glass, which makes them an appropriate choice for outdoor flood and spot lighting. They are available in 75, 150, and 250 watts. They have longer lifetimes with less depreciation than standard incandescents.

ER Lamps

Ellipsoidal reflector (ER) lamps are ideally suited for recessed fixtures, because the beam of light produced is focused two inches ahead of the lamp to reduce the amount of light trapped in the fixture. In a directional fixture, a 75-watt ellipsoidal reflector lamp delivers more light than a 150-watt R-lamp. (See Figure 7-2.)

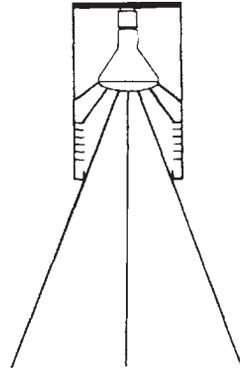
Mercury vapor lamps find limited use in today's lighting systems because fluorescent and other high intensity discharge (HID) sources have surpassed them in both lamp efficacy and system efficiency. Typical ratings for mercury vapor lamps range from about 25 to 50 lumens per watt. The primary advantages of mercury lamps are a good range of color, availability, in sizes as low as 30 watts, long life and relatively low cost. However, fluorescent systems are available today which can do many of the jobs mercury used to do and they do it more efficiently. There are still places for mercury vapor lamps in lighting design, but they are becoming fewer as technology advances in fluorescent and higher efficacy HID sources.

Fluorescent lamps have made dramatic advances in the last 10 years. From the introduction of reduced wattage lamps in the mid-



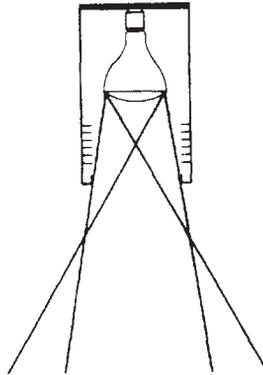
Standard Incandescent

A high percentage of light output is trapped in fixture



R-Lamp

An aluminum coating directs light out of the fixture



ER Lamp

The beam is focused 2 inches ahead of the lamp, so that very little light is trapped in the fixture

Figure 7-2. Comparison of Incandescent Lamps

1970s, to the marketing of several styles of low wattage, compact lamps recently, there has been a steady parade of new products. T-12 lamps are now generally considered obsolete and should be replaced. T-8 lamps are generally considered the industry standard and T-5 lamps represent the next generation. Lamp efficacy now ranges from about 65 lumens per watt to over 90 lumens per watt. The range of colors

is more complete than mercury vapor, and lamp manufacturers have made significant progress in developing fluorescent and metal halide lamps which have much more consistent color rendering properties allowing greater flexibility in mixing these two sources without creating disturbing color mismatches. The compact fluorescent lamps open up a whole new market for fluorescent sources. These lamps permit design of much smaller luminaries which can compete with incandescent and mercury vapor in the low cost, square or round fixture market which the incandescent and mercury sources have dominated for so long. While generally good, lumen maintenance throughout the lamp lifetime is a problem for some fluorescent lamp types.

Metal halide lamps fall into a lamp efficacy range of approximately 50-100 lumens per watt. This makes them more energy efficient than mercury vapor but somewhat less so than high pressure sodium. Metal halide lamps generally have fairly good color rendering qualities. While this lamp displays some very desirable qualities, it also has some distinct drawbacks including relatively short life for an HID lamp, long restrike time to restart after the lamp has been shut off (about 15-20 minutes at 70°F) and a pronounced tendency to shift colors as the lamp ages. In spite of the drawbacks, this source deserves serious consideration and is used very successfully in many applications.

High pressure sodium lamps introduced a new era of extremely high efficacy (60-130 lumens/watt) in a lamp which operates in fixtures having construction very similar to those used for mercury vapor and metal halide. When first introduced, this lamp suffered from ballast problems. These have now been resolved and luminaries employing high quality lamps and ballasts provide very satisfactory service. The 24,000-hour lamp life, good lumen maintenance and high efficacy of these lamps make them ideal sources for industrial and outdoor applications where discrimination of a range of colors is not critical.

The lamp's primary drawback is the rendering of some colors. The lamp produces a high percentage of light in the yellow range of the spectrum. This tends to accentuate colors in the yellow region. Rendering of reds and greens shows a pronounced color shift. This can be compensated for in the selection of the finishes for the surrounding areas, and, if properly done, the results can be very pleasing. In areas where color selection, matching and discrimination are necessary, high pressure sodium should not be used as the only source of light. It is pos-

sible to gain quite satisfactory color rendering by mixing high pressure sodium and metal halide in the proper proportions. Since both sources have relatively high efficacies, there is not a significant loss in energy efficiency by making this compromise.

High pressure sodium has been used quite extensively in outdoor applications for roadway, parking and facade or security lighting. This source will yield a high efficiency system; however, it should be used only with the knowledge that foliage and landscaping colors will be severely distorted where high pressure sodium is the only, or predominant, illuminant. Used as a parking lot source, there may be some difficulty in identification of vehicle colors in the lot. It is necessary for the designer or owner to determine the extent of this problem and what steps might be taken to alleviate it.

Recently lamp manufacturers have introduced high pressure sodium lamps with improved color rendering qualities. However, the improvement in color rendering was not gained without cost—the efficacy of the color-improved lamps is somewhat lower, approximately 90 lumens per watt.

Low pressure sodium lamps provide the highest efficacy of any of the sources for general lighting with values ranging up to 180 lumens per watt. Low pressure sodium produces an almost pure yellow light with very high efficacy, and renders all colors gray except yellow or near yellow. This effect results in no color discrimination under low pressure sodium lighting; it is suitable for use in a very limited number of applications. It is an acceptable source for warehouse lighting where it is only necessary to read labels but not to choose items by color. This source has application for either indoor or outdoor safety or security lighting as long as color rendering is not important.

In addition to these primary sources, there are a number of retrofit lamps which allow use of higher efficacy sources in the sockets of existing fixtures. Therefore, metal halide or high pressure sodium lamps can be retrofitted into mercury vapor fixtures, or self-ballasted mercury lamps can replace incandescent lamps. These lamps all make some compromises in operating characteristics, life and/or efficacy.

Figure 7-3 presents data on the efficacy of each of the major lamp types in relation to the wattage rating of the lamps. Without exception, the efficacy of the lamp increases as the lamp wattage rating increases.

The lamp efficacies discussed here have been based on the lumen output of a new lamp after 100 hours of operation or the “initial

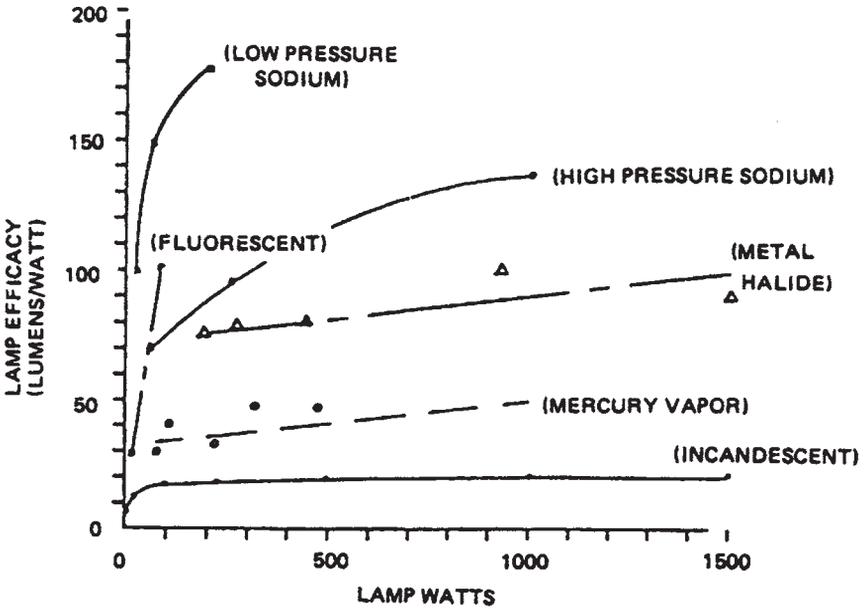


Figure 7-3. Lamp Efficacy
(Does Not Include Ballast Losses)

lumens.” Not all lamps age in the same way. Some lamp types, such as lightly loaded fluorescent and high pressure sodium, hold up well and maintain their lumen output at a relatively high level until they are into, or past, middle age. Others, as represented by heavily loaded fluorescent, mercury vapor and metal halide, decay rapidly during their early years and then coast along at a relatively lower lumen output throughout most of their useful life. These factors must be considered when evaluating the various sources for overall energy efficiency.

LEDs (Light Emitting Diodes)

A light emitting diode (LED) is a semiconductor device which converts electricity into light. LED lighting has been around since the 1960s. At first white LEDs were only possible by “rainbow” groups of three LEDs—red, green, and blue—by controlling the current to each to yield an overall white light. This changed in 1993 when Nichia created a blue indium gallium chip with a phosphor coating that is used to create the wave shift necessary to emit white light from a single diode. This process is much less expensive for the amount of light generated.

The LED has a long life, greater than 50,000 hrs at 70% initial output and produces very little heat. Efficacies (lumens per watt) in the 18-60 range are available with greater than 130 lumens per watt achieved but to date not commercially viable. White light LEDs currently do not produce enough lumen output to make them economically competitive with many general light sources, but this will soon change as higher efficiencies and better designs are achieved.

DOE estimates that LEDs could reduce national lighting energy consumption by 29% by 2025 for a savings of \$125 billion.

LED applications include:

- Exit signs
- Traffic signals
- Car taillights
- Signs
- Flashlights
- Growlights
- Holiday lighting
- Instrumentation
- Some general lighting

Incandescent Replacement

The most efficacious lamps that can be used in incandescent sockets are the compact fluorescent lamps. The most popular systems are the twin tubes and double twin tubes. These are closer to the size and weight of the incandescent lamp than the earlier type of fluorescent (circline) replacements.

Twin tubes with lamp wattages from 5 to 13 watts provide amounts of light ranging from 240 to 850 lumens. Table 7-1 lists the characteristics of various types of incandescent and compact fluorescent lamps that can be used in the same type sockets.

The advantages of the compact fluorescent lamps are larger and increased efficacy, longer life and reduced total cost. The cost per 101 lumen hours of operating the 75-watt incandescent and the 18-watt fluorescent is \$5.47 and \$3.29, respectively. This is based upon an energy cost of \$0.075 per kWh and lamp costs of \$0.70 and \$17 and the 75-watt incandescent and 18-watt fluorescent lamps, respectively. The circline lamps were much larger and heavier than the incandescent and would fit in a limited number of fixtures. The twin tubes are only slightly heavier and larger than the equivalent incandescent lamp. However, there are some fixtures that are too small for them to be employed.

The narrow tube diameter compact fluorescent lamps are now possible because of the recently developed rare earth phosphors. These phosphors have an improved lumen depreciation at high lamp power

Table 7-1. Lamp Characteristics

<i>Lamp Type</i> (Total Input Power)*	<i>Lamp Power</i> W	<i>Light Output</i> (lumens)	<i>Lamp Life</i> (hour)	<i>Efficacy</i> (/M/W)
100 W (Incandescent)	100	1750	750	18
75 W (incandescent)	75	1200	750	16
60 W (Incandescent)	60	890	1000	15
40 W (Incandescent)	40	480	1500	12
25 W (Incandescent)	25	238	2500	10
22 W (Fl. Circline)	18	870	9000	40
44 W (Fl. Circline)	36	1750	9000	40
7 W (Twin)	5	240	10000	34
10 W (Twin)	7	370	10000	38
13 W (Twin)	9	560	10000	43
19 W (Twin)	13	850	10000	45
18 W (Solid-State)†	—	1100	7500	61

*Includes ballast losses.

†Operated at high frequency.

loadings. The second important characteristic of these narrow band phosphors is their high efficiency in converting the ultraviolet light generated in the plasma into visible light. By proper mixing of these phosphors, the color characteristics (color temperature and color rendering) are similar to the incandescent lamp.

There are two types of compact fluorescent lamps. In one type of lamp system, the ballast and lamp are integrated into a single package; in the second type, the lamp and ballast are separate, and when a lamp bums out it can be replaced. In the integrated system, both the lamp and the ballast are discarded when the lamp bums out.

It is important to recognize when purchasing these compact fluorescent lamps that they provide the equivalent light output of the lamps being replaced. The initial lumen output for the various lamps is shown in Table 7-1.

Lighting Efficiency Options

Several lighting efficiency options are illustrated below: (Refer to Formula 7-2.)

Foot-candle Level

The foot-candle level required is that level at the task. Foot-candle levels can be lowered to one third of the levels for surrounding areas such as aisles. (A minimum 20-foot-candle level should be maintained.)

The placement of the lamp is also important. If the luminaire can be lowered or placed at a better location, the lamp wattage may be reduced.

Coefficient of Utilization (Cu)

The color of the walls, ceiling, and floors, the type of luminaire, and the characteristics of the room determine the Cu. This value is determined based on manufacturer's literature. The Cu can be improved by analyzing components such as lighter colored walls and more efficient luminaires for the space.

Lamp Depreciation Factor and Dirt Depreciation Factor

These two factors are involved in the maintenance program. Choosing a luminaire which resists dirt build-up, group relamping and cleaning the luminaire will keep the system in optimum performance. Taking these factors into account can reduce the number of lamps initially required.

The light loss factor (LLF) takes into account that the lamp lumen depreciates with time (L1), that the lumen output depreciates due to dirt build-up (L2), and that lamps bum out (L3). Formula 7-3 illustrates the relationship of these factors.

$$LLF = L_1 \times L_2 \times L_3 \tag{7-3}$$

To reduce the number of lamps required which in turn reduces energy consumption, it is necessary to increase the overall light loss factor. This is accomplished in several ways. One is to choose the luminaire which minimizes dust build-up. The second is to improve the maintenance program to replace lamps prior to burnout. Thus if it is known that a group relamping program will be used at a given percentage of rated life, the appropriate lumen depreciation factor can be found from manufacturer's data. It may be decided to use a shorter relamping period in order to increase (L₁) even further. If a group relamping program is used, (L₃) is assumed to be unity.

Figure 7-4 illustrates the effect of dirt build-up on (L₂) for a dust-proof luminaire. Every luminaire has a tendency for dirt build-up.

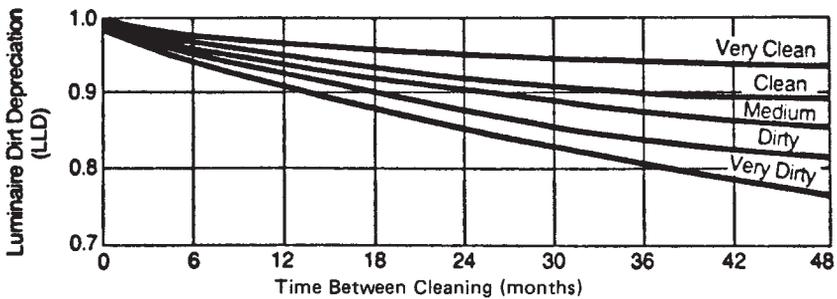


Figure 7-4. Effect of Dirt Build-Up on Dust-proof Luminaires for Various Atmospheric Conditions

Manufacturer's data should be consulted when estimating (L_2) for the luminaire in question.

Electronic Ballasts

After more than 10 years of development and 5 years of manufacturing experience, operating fluorescent lamps at high frequency (20 to 30 kHz) with electronic ballasts has achieved credibility. The fact that all of the major ballast manufacturers offer electronic ballasts and the major lamp companies have designed new lamps to be operated at high frequency is evidence that the electronic ballast is now state-of-the-art.

It has been shown that fluorescent lamps operated at high frequency are 10 to 15 percent more efficacious than 60 Hz operation. In addition, the electronic ballast is more efficient than conventional ballasts in conditioning the input power for the lamps such that the total system efficacy increase is between 20 and 25 percent. That is, for a standard two-lamp, 40-watt F40 T-12 rapid-start system, overall efficacy is increased from 63 lm/W to over 80 lm/W.

In the past few years, continued development of the product has improved reliability and reduced cost. Today electronic ballasts can be purchased for less than \$30, and, in sufficiently large quantities, some bids have been less than \$20. The industry's growth is evidenced by the availability of ballasts for the 8-foot fluorescent lamp, both slimline and high power, as well as the more common F40 (4-ft) size. In order to be more competitive with initial costs, there are three- and four-lamp ballasts for the F40-type lamps. These multi-lamp ballasts reduce the initial cost per lamp, as well as the installation cost, and are even more efficient than the one- and two-lamp ballast system.

The American National Standards Institute (ANSI) ballast committee has been developing standards for electronic ballasts for the past few years. The ballast factor is the light output provided by the ballast-lamp system compared to the light output of the lamp specified by the lamp manufacturer. The ANSI ballast factor standard for 40-watt F40 fluorescent lamps is 95 ± 2.5 percent. Because most electronic ballasts were initially sold on the retrofit market, their ballasts were designed to have a lower ballast factor. Thus, energy was saved not only by the increased efficacy but also by reducing the light output. The thrust was to reduce illumination levels in overlit spaces.

Today, there are electronic ballasts with a ballast factor exceeding 100 percent. These ballasts are most effectively used in new installations. In these layouts, more light from each luminaire will reduce the number of luminaires, ballasts and lamps, hence reducing both initial and operating costs. It is essential that the lighting designer-engineer and consumer know the ballast factor for the lamp-ballast system. The ballast factor for a ballast also depends upon the lamp. For example, a core-coil ballast will have a ballast factor of 95 ± 2 percent when operating a 40-watt F40 argon-filled lamp and less when operating an “energy saving” 34-watt F40 Krypton-filled lamp. The ballast factor instead will be about 87 ± 2.5 percent with the 34-watt energy saving lamp. Because of this problem, the ANSI standard for the ballast factor for the 34-watt lamps has recently been reduced to 85 percent, Table 7-2 provides some data for several types of solid-state ballasts operating 40-watt and 34-watt F40 lamps and lists some parameters of concern for the consumer.

Table 7-2. Performance of F40 Fluorescent Lamp Systems

Characteristic	Core-Coil 2 Lamps,T-12		— Solid-State Ballasts —				
	40W	34W	2 Lamps,T-12 40W	34W	4 Lamps,T-12 40W	34W	2 Lamps,T-8 32W
Power (W)	96	79	72	63	136	111	65
Power Factor (%)	98	92	95	93	94	94	89
Filament Voltage (V)	3.5	3.6	3.1	3.1	2.0	1.6	0
Light Output (lm)	6050	5060	5870	5060	11,110	9250	5820
Ballast Factor	.968	.880	.932	.865	.882	.791	1.003
Flicker (%)	30	21	15	9	1	0	1
System Efficacy (lm/W)	63	64	81	81	82	83	90

The table compares several types of electronic ballasts with a standard core-coil ballast that meets the ANSI standard with the two-lamp, 40-watt F40 lamp. Notice that the system efficacy of any ballast system is about the same operating a 40-watt or a 34-watt F40 lamp. Although the 34-watt "lite white" lamp is about 6 percent more efficient than the 40-watt 44 cool white" lamp, the ballast losses are greater with the 34-watt lamp due to an increased lamp current. The lite white phosphor is more efficient than the cool white phosphor but has poorer color rendering characteristics.

Note that the percent flicker is drastically reduced when the lamps are operated at high frequency with electronic ballasts. A recent scientific field study of office workers in the U.K. has shown that complaints of headaches and eyestrain are 50 percent less under high frequency lighting when compared to lamps operating at 50 cycles, the line frequency of the U.K.

Each of the above ballasts has different factors, which are lower when operating the 34-watt Krypton-filled lamp. Table 7-2 also lists the highest system efficacy of 90 lumens per watt for the electronic ballast and T-8, 32-watt lamp.

All of the above solid-state ballasts can be used in place of core-coil ballasts specified to operate the same lamps. To determine the illumination levels, or the change in illumination levels, the manufacturer must supply the ballast factor for the lamp type employed. The varied light output from the various systems allows the lighting designer-engineer to precisely tailor the lighting level.

CONTROL EQUIPMENT

Table 7-3 lists various types of equipment that can be components of a lighting control system, with a description of the predominant characteristic of each type of equipment. Static equipment can alter light levels semipermanently. Dynamic equipment can alter light levels automatically over short intervals to correspond to the activities in a space. Different sets of components can be used to form various lighting control systems in order to accomplish different combinations of control strategies.

Table 7-3. Lighting Control Equipment

<i>System</i>	<i>Remarks</i>
STATIC:	
Delamping	Method for reducing light level 50%.
Impedance Monitors	Method for reducing light level 30, 50%.
DYNAMIC:	
Light Controllers	
Switches/Relays	Method for on-off switching of large banks of lamps.
Voltage/Phase Control	Method for controlling light level continuously 100 to 50%.
Solid-State Dimming	
Ballasts	Ballasts that operate fluorescent lamps efficiently and can dim them continuously (100 to 10%) with low voltage.
SENSORS:	
Clocks	System to regulate the illumination distribution as a function of time.
Personnel	Sensor that detects whether a space is occupied by sensing the motion of an occupant.
Photocell	Sensor that measures the illumination level of a designated area.
COMMUNICATION:	
Computer/Microprocessor	Method for automatically communicating instructions and/or input from sensors to commands to the light controllers.
Power-Line Carrier	Method for carrying information over existing power lines rather than dedicated hard-wired communication lines.

FLUORESCENT LIGHTING CONTROL SYSTEMS

The control of fluorescent lighting systems is receiving increased attention. Two major categories of lighting control are available -personnel sensors and lighting compensators.

Personnel Sensors

There are three classifications of personnel sensors-ultrasonic, infrared and audio.

Ultrasonic sensors generate sound waves outside the human hearing range and monitor the return signals. Ultrasonic sensor systems are generally made up of a main sensor unit with a network of satellite sensors providing coverage throughout the lighted area. Coverage per sensor is dependent upon the sensor type and ranges between 500 and 2,000 square feet. Sensors may be mounted above the ceiling, suspended below the ceiling or mounted on the wall. Energy savings are dependent upon the room size and occupancy. Advertised savings range from 20 to 40 percent.

Several companies manufacture ultrasonic sensors including Novita and Unenco.

Infrared sensor systems consist of a sensor and control unit. Coverage is limited to approximately 130 square feet per sensor. Sensors are mounted on the ceiling and usually directed towards specific work stations. They can be tied into the HVAC control and limit its operation also. Advertised savings range between 30 and 50 percent. (See Figure 7-5.)

Audio sensors monitor sound within a working area. The coverage of the sensor is dependent upon the room shape and the mounting height. Some models advertise coverage of up to 1,600 square feet. The first cost of the audio sensors is approximately one-half that of the ultrasonic sensors. Advertised energy savings are approximately the same as the ultrasonic sensors. Several restrictions apply to the use of the audio sensors. First, normal background noise must be less than 60 dB. Second, the building should be at least 100 feet from the street and may not have a metal roof.

Lighting Compensators

Lighting compensators are divided into two major groups switched and sensed.

Switched compensators control the light level using a manually operated wall switch. These particular systems are used frequently in

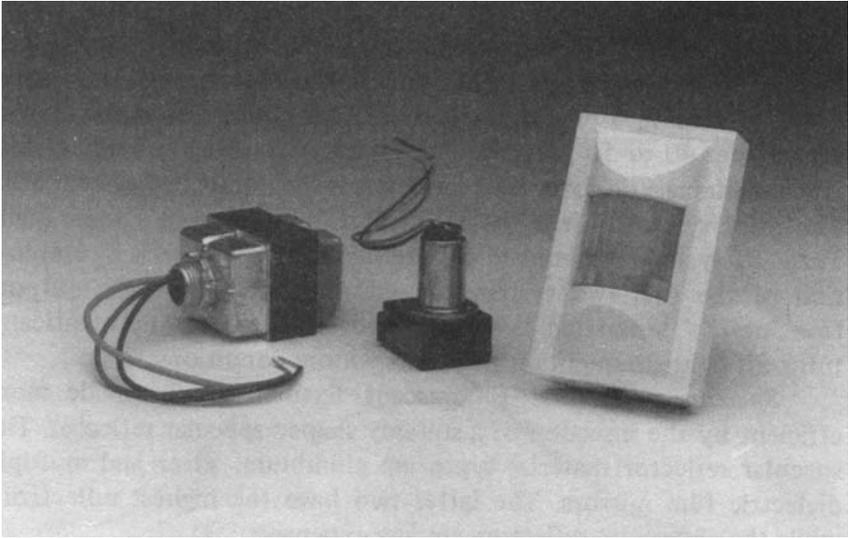


Figure 7-5. Transformer, Relay and Wide View Infrared Sensor to Control Lights (Photograph courtesy of SensorSwitch)

residential settings and are commonly known as “dimmer switches.” Based on discussions with manufacturers, the switched controls are available for the 40-watt standard fluorescent bulbs only. The estimated savings are difficult to determine, as usually switched control systems are used to control room mood. The only restriction to their use is that the luminaire must have a dimming ballast.

Sensored compensators are available in three types. They may be very simple or very complex. They may be integrated with the building’s energy management system or installed as a stand-alone system. The first type of system is the excess light turn-off (ELTO) system. This system senses daylight levels and automatically turns off lights as the sensed light level approaches a programmed upper limit. Advertised paybacks for these types of systems range from 1.8 to 3.8 years.

The second type of system is the daylight compensator (DAC) system. This system senses daylight levels and automatically dims lights to achieve a programmed room light level. Advertised savings range from 40 to 50 percent. The primary advantage of this system is it maintains a uniform light level across the controlled system area. The third system type is the daylight compensator + excess light turn-off system. As implied by the name, this system is a combination of the first two systems. It automatically dims light outputs to achieve a designated light level

and, as necessary, automatically turns off lights to maintain the desired room conditions.

Specular reflectors: Fluorescent fixtures can be made more efficient by the insertion of a suitably shaped specular reflector. The specular reflector material types are aluminum, silver and multiple dielectric film mirrors. The latter two have the highest reflectivity while the aluminum reflectors are less expensive.

Measurements show the fixture efficiency with higher reflectance specular reflectors (silver or dielectric films) is improved by 15 percent compared to a new fixture with standard diffuse reflectors.

Specular reflectors tend to concentrate more light downward with reduced light at high exit angles. This increases the light modulation in the space, which is the reason several light readings at different sites around the fixture are required for determining the average illuminance. The increased downward component of candle power may increase the potential for reflected glare from horizontal surfaces.

When considering reflectors, information should be obtained on the new candle power characteristics. With this information a lighting designer or engineer can estimate the potential changes in modulation and reflected glare.

MOTORS AUDIT

Motors account for a significant portion of energy usage and demand in commercial and industrial applications. It is suggested that information be collected on motors 5 HP and larger. Nameplate information should be gathered as well as the condition, operating hours and operating environment of the motor. Motor loading can be measured or assumed, depending on each situation. In some cases, data loggers can be used to collect data over a specified time period.

Motor Basics

The primary motor used in commercial and industrial applications is the *AC three-phase induction motor*. Three phase induction motors comprise 85 to 90 % of motors in use due to the following characteristics:

- Simple in design
- Efficient
- Rugged

- Low cost
- Reliable
- Adaptable to VFDs

Motor Speed

The speed of a three-phase induction motor depends on the number of poles in the motor, and the frequency of the alternating current. The speed of the rotating magnetic field is called the *synchronous speed* and the equation is as follows:

$$\text{Synchronous speed} = \frac{120 \times \text{frequency}}{\text{Number of poles}}$$

Or, for 60 Hertz frequency,

$$\text{Synchronous speed} = \frac{7200}{\text{Number of poles}}$$

The majority of motors today are two, four or six poles, or 3,600 RPM, 1,800 RPM or 1,200 RPM motors respectively. By using belts, pulleys, gears, VFDs, etc., any load speed can be obtained. Note that the motor shaft rotates a little slower than the rotating magnetic field due to *slip*. The full load RPM on the nameplate reflects the actual shaft speed, and is a little lower than the synchronous speed. For example, the motor nameplate full load speed may say 3,550 RPM, which means it is a 3,600 RPM two pole motor.

<i>Number of Poles</i>	<i>Synchronous Speed (RPM)</i>
2	3,600
4	1,800
6	1,200
8	900

Synchronous speed and number of poles

Electric Motor Efficiency

Efficiency is a measure of the ability of a motor to convert electrical into mechanical energy.

In order to do an economic analysis of a motor replacement, the efficiency of the existing motor must be determined. The efficiency ratings on motors:

- Represents full load efficiency. The efficiency drops off as the motor is more lightly loaded.
- Manufacturers only guarantee that the motor meets nominal efficiency rating which is defined as: “the average efficiency of a large population of motors of the same design.”
- Motors built after 1982 will have the *nominal* efficiency expressed as a numerical value on the nameplate.

Motor Loading Determination

Motors rarely are operated at 100% of their full load rating. This means that motors are loaded or have a *load factor* of less than 100%. Load factor is defined as:

$$\text{Load Factor (\%)} = \frac{\text{Actual Load HP} \times 100}{\text{Nameplate HP}}$$

Motor loading can be estimated in three ways:

1) Estimating motor load by current and voltage

Perhaps the most common method of estimating motor loading is to measure the current and multiply it times the voltage times the square root of three (1.732). Current measurements can be deceiving, however, as a low power factor can distort the results. In order to use this method, estimate the power factor to be 0.8 - 0.9.

$$\text{kW} = \frac{\text{Volts} \times \text{Amps} \times \text{Power Factor} \times 1.732}{1000}$$

2) Estimating motor load by slip

Motor load is closely proportional to slip, so loading can be estimated if you know the slip. The operating speed of the motor is determined by using a tachometer. This number is then used in the following equation to estimate motor loading. An average loading would consist of taking multiple operating speed measurements throughout the day,

month or year.

$$\text{Motor load in percent} = \frac{(\text{synchronous speed} - \text{measured operating speed}) \times 100}{\text{synchronous speed} - \text{nameplate speed}}$$

3) Assume motor loading

If measurements aren't made, it is suggested that you estimate the motor loading to be 60% to 70%. This is a typical motor loading in a fan or pump application. Note that some air compressors may have a higher loading factor.

Motor Economics

Why would a business owner replace a standard efficiency motor that is operating with an energy efficient one? On a first cost basis the energy efficient motors can be as much as 25% more than the cost of a standard motor, but the savings in operating cost can well exceed this additional capital costs.

Demand and Energy Usage Calculations

In order to determine the power requirements of a motor, the following equations can be used:

$$\text{kW} = \frac{(\text{HP}) \times (.746 \text{ kW/HP}) \times (\text{Motor Loading})}{\text{Efficiency}}$$

$$\text{kWh} = \text{kW} \times (\text{Operating Hours})$$

Example:

Determine the simple payback realized by replacing the following motor with an energy efficient one.

Existing motor:

- 50 HP, 1800 RPM standard chilled water pump motor
- 4,500 hours per year operation
- Energy charge = \$.05/kWh
- Demand Charge = \$ 10.00/kW-Month
- Efficiency = 90.2%
- Cost = \$1,080

New motor:

50 HP, 1800 RPM

4,500 hours per year operation

Efficiency = 94.5%

Cost = \$1,340

Solution:

First calculate the operating cost of the existing motor. Assume 70% motor loading and twelve month operation.

$$\text{kW} = \frac{(50) \times (.746 \text{ kW/HP}) \times .7}{.902} = 28.9 \text{ kW}$$

$$\text{kWh} = (28.9 \text{ kW}) \times (4,500 \text{ hours/year}) = 130,050 \text{ kWh/year}$$

$$\text{Energy cost} = (130,050 \text{ kWh/year}) \times (\$0.05/\text{kWh}) = \$6,502/\text{year}$$

$$\begin{aligned} \text{Demand charges} &= (28.9 \text{ kW}) \times (\$10/\text{kW-mo}) \times (12 \text{ mo/year}) \\ &= \$3,468/\text{year} \end{aligned}$$

$$\text{Total operating cost}_{\text{existing motor}} = \$6,502 + \$3,468 = \$9,970/\text{year}$$

Calculate the operating cost of the energy efficient motor. Note that the only thing that changes is the efficiency.

$$\text{kW} = \frac{(50) \times (.746 \text{ kW/HP}) \times .7}{.945} = 27.6 \text{ kW}$$

$$\text{kWh} = (27.6 \text{ kW}) \times (4,500 \text{ hours/year}) = 124,200 \text{ kWh/year}$$

$$\text{Energy Cost} = (124,200 \text{ kWh/year}) \times (\$0.05/\text{kWh}) = \$6,210/\text{year}$$

$$\begin{aligned} \text{Demand Charges} &= (27.6 \text{ kW}) \times (\$10.00/\text{kW-mo}) \times (12 \text{ mo/year}) \\ &= \$3,312/\text{year} \end{aligned}$$

$$\text{Total operating cost}_{\text{energy efficient motor}} = \$6,210 + \$3,312 = \$9,522/\text{year}$$

$$\begin{aligned} \text{Total operating costs savings} &= \text{Existing motor operating cost} \\ &\quad - \text{new motor operating cost} \end{aligned}$$

$$= \$9,970/\text{year} - \$9,522/\text{year} = \$448/\text{year}$$

$$\text{Simple payback} = \frac{\text{Cost of energy efficient motor}}{\text{Annual savings}}$$

$$\text{Simple payback} = \frac{\$1,340}{\$448} = 3.0 \text{ years}$$

This payback assumes that the existing motor is operating. If the existing motor is burned out, then the payback would reflect the difference in cost between the two motors, or

$$\text{Simple payback}_{\text{burn-out}} = \frac{\text{Cost of energy efficient motor} - \text{Cost of standard motor}}{\text{Annual savings}}$$

$$\text{Simple payback}_{\text{burn-out}} = \frac{\$1340 - \$1080}{\$448} = .6 \text{ years}$$

VARIABLE FREQUENCY DRIVES

The synchronous speed of an induction motor is shown by the following equation:

$$\text{Synchronous speed} = \frac{120 \times \text{frequency}}{\# \text{ of poles}}$$

To change the motor speed, we need to change either the:

- Frequency
- Number of poles

Variable frequency drives change the *frequency* using solid state electronics.

Variable frequency drives are used for:

- Controlling speed
- Starting and acceleration control
- Reducing operating costs

Applications

VFDs will only save (energy) costs when used with a *varying* load. Typically weather related equipment will have a varying load, and some industrial applications such as variably loaded conveyors. **If the load does not vary, the drive will not save any energy.** Basic applications include:

- Air handling units
- Chilled water pumps
- Condenser pumps
- Cooling tower fans
- Conveyors
- Rolling mills
- Hoists

ENERGY MANAGEMENT

The availability of computers at moderate costs and the concern for reducing energy consumption have resulted in the application of computer-based controllers to more than just industrial process applications. These controllers, commonly called energy management systems (EMS), can be used to control virtually all non-process energy using pieces of equipment in buildings and industrial plants. Equipment controlled can include fans, pumps, boilers, chillers and lights. This section will investigate the various types of energy management systems which are available and illustrate some of the methods used to reduce energy consumption.

The Timeclock

One of the simplest and most effective methods of conserving energy in a building is to operate equipment only when it is needed. If, due to time, occupancy, temperature or other means, it can be determined that a piece of equipment does not need to operate, energy savings can be achieved without affecting occupant comfort by turning off the equipment.

One of the simplest devices to schedule equipment operation is the mechanical timeclock. The timeclock consists of a rotating disk which is divided into segments corresponding to the hour of the day and the day of the week. This disk makes one complete revolution in, depending on the type, a 24-hour or a 7-day period. (See Figure 7-6.)

On and off "lugs" are attached to the disk at appropriate positions corresponding to the schedule for the piece of equipment. As the

disk rotates, the lugs cause a switch contact to open and close, thereby controlling equipment operation.

A common application of timeclocks is scheduling office building HVAC equipment to operate during business hours Monday through Friday and to be off all other times. As is shown in the following problem, significant savings can be achieved through the correct application of timeclocks.

SIM 7-2

An office building utilizes two 50 hp supply fans and two 15 hp return fans which operate continuously to condition the building. What are the annual savings that result from installing a timeclock to operate these fans from 7:00 a.m. to 5:00 p.m., Monday through Friday? Assume an electrical rate of \$0.08/kWh.

ANSWER

Annual Operation Before Timeclock

$$52 \text{ weeks} \times 7 \text{ days/week} \times 24 \text{ hours/day} = 8736 \text{ hours}$$

Annual Operation After Timeclock =

$$52 \times (5 \text{ days/week} \times 10 \text{ hours/day}) = 2600 \text{ hours}$$

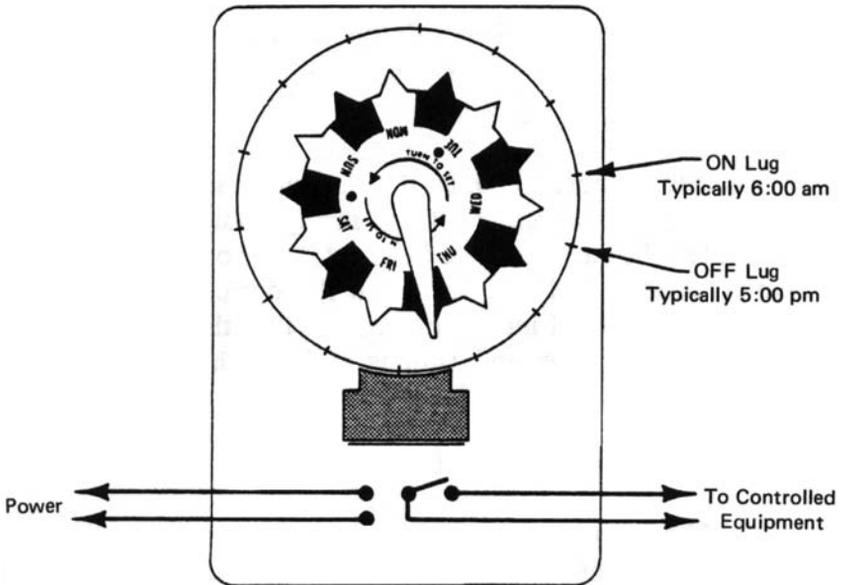


Figure 7-6. Mechanical Timeclock

$$\begin{aligned} \text{Savings} &= 130 \text{ hp} \times 0.746 \text{ kW/hp} \times (8736-2600) \text{ hours} \times \\ &\quad \$0.08/\text{kWh} = \$47,600 \end{aligned}$$

Although most buildings today utilize some version of a timeclock, the magnitude of the savings value in this example illustrates the importance of correct timeclock operation and the potential for additional costs if this device should malfunction or be adjusted inaccurately. Note that the above example also ignores heating and cooling savings which would result from the installation of a timeclock.

Problems with Mechanical Timeclocks

Although the use of mechanical timeclocks in the past has resulted in significant energy savings, they are being replaced by energy management systems because of problems that include the following:

- The on/off lugs sometimes loosen or fall off.
- Holidays, when the building is unoccupied, cannot easily be taken into account.
- Power failures require the timeclock to be reset or it is not synchronized with the building schedule.
- Inaccuracies in the mechanical movement of the timeclock prevent scheduling any closer than ± 15 minutes of the desired times.
- There are a limited number of on and off cycles possible each day.
- It is a time-consuming process to change schedules on multiple timeclocks.

Energy management systems, or sometimes called electronic timeclocks, are designed to overcome these problems plus provide increased control of building operations.

ENERGY MANAGEMENT SYSTEMS

Advances in digital technology, dramatic decreases in the cost of this technology and increased energy awareness have resulted in the increased application of computer-based controllers (i.e., energy management and building automation systems) in commercial buildings and industrial plants. These devices can control anywhere from one to a virtually unlimited number of items of equipment.

By concentrating the control of many items of equipment at a single point, the EMS allows the building operator to tailor building operation to precisely satisfy occupant needs. This ability to maximize energy conservation, while preserving occupant comfort, is the ultimate goal of an energy engineer.

Energy management systems are generally preprogrammed so that operation is relatively straightforward. Programming simply involves entering the appropriate parameters (e.g., the point number and the on and off times) for the desired function. PC-based EMS can have any or all of the following capabilities:

- Scheduling
- Duty Cycling
- Demand Limiting
- Optimal Start
- Monitoring
- Direct Digital Control

Scheduling

Scheduling with an EMS is very much the same as it is with a timeclock. Equipment is started and stopped based on the time of day and the day of week. Unlike a timeclock, however, multiple start/stops can be accomplished very easily and accurately (e.g., in a classroom, lights can be turned off during morning and afternoon break periods and during lunch). It should be noted that this single function, if accurately programmed and depending on the type of facility served, can account for the largest energy savings attributable to an EMS.

Additionally, holiday dates can be entered into the EMS a year in advance. When the holiday occurs, regular programming is overridden and equipment can be kept off.

Duty Cycling

Most HVAC fan systems are designed for peak load conditions, and consequently these fans are usually moving much more air than is needed. Therefore, they can sometimes be shut down for short periods each hour, typically 15 minutes, without affecting occupant comfort. Turning equipment off for predetermined periods of time during occupied hours is referred to as duty cycling, and can be accomplished very easily with an EMS. Duty cycling saves fan and pump energy but does not reduce the energy required for space heating or cooling since the thermal demand must still be met.

The more sophisticated EMSs monitor the temperature of the conditioned area and use this information to automatically modify the

duty cycle length when temperatures begin to drift. If, for example, the desired temperature in an area is 70° and at this temperature equipment is cycled 50 minutes on and 10 minutes off, a possible temperature-compensated EMS may respond as shown in Figure 7-7. As the space temperature increases above (or below if so programmed) the setpoint, the equipment off time is reduced until, at 800 in this example, the equipment operates continuously.

Duty cycling of fans which provide the only air flow to an area should be approached carefully to insure that ventilation requirements are maintained and that varying equipment noise does not annoy the occupants. Additionally, duty cycling of equipment imposes extra stress on motors and associated equipment. Care should be taken, particularly with motors over 20 hp, to prevent starting and stopping of equipment in excess of what is recommended by the manufacturer.

Electric Demand Control

The peak power demand can be reduced by load-shedding, cogeneration, or cool storage systems that produce cold water or ice during off-peak hours. Load-shedding may also reduce the total power consumption, as well as the demand. Cogeneration systems will increase the use of on-site energy, but can also replace electricity consumption with

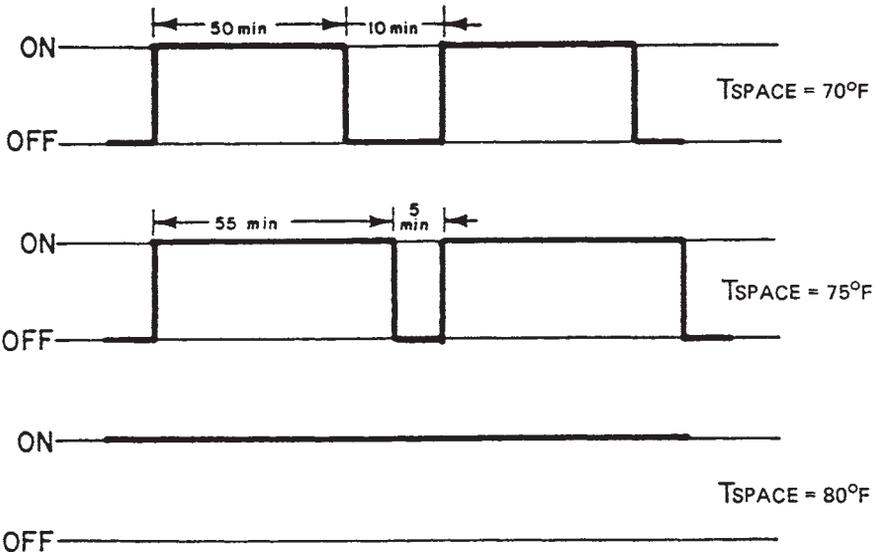


Figure 7-7. Temperature Compensated Duty Cycling

less expensive fossil energy. Also, the waste heat from the cogeneration equipment can meet thermal loads. Cool storage systems shift the chiller demand to off-peak periods, reducing on-peak demand.

Demand Limiting

Energy management systems with demand limiting capabilities utilize either pulses from the utility meter or current transformers to predict the facility demand during any demand interval. If the facility demand is predicted to exceed the user-entered setpoint, equipment is “shed” to control demand. Figure 7-8 illustrates a typical demand chart before and after the actions of a demand limiter.

Electrical load in a facility consists of two major categories: essential loads which include most lighting, elevators, escalators, and most production machinery; and nonessential (“sheddable”) loads such as electric heaters, air conditioners, exhaust fans, pumps, snow melters, compressors and water heaters. Sheddable loads will not, when turned off for short

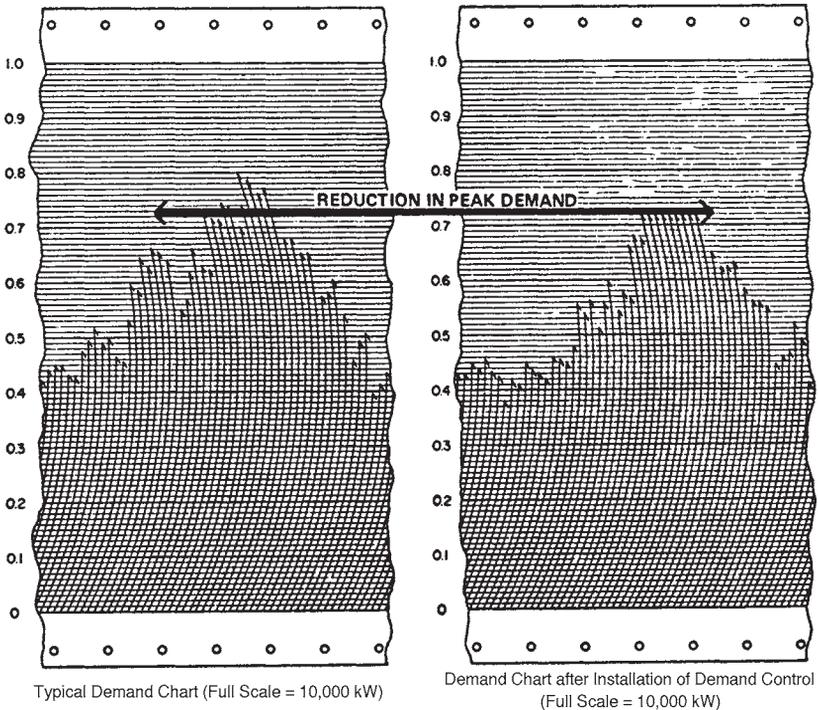


Figure 7-8. Demand Limiting Comparison

periods of time to control demand, affect productivity or comfort.

To prevent excessive cycling of equipment, most energy management systems have a deadband that demand must drop below before equipment operation is restored (see Figure 7-9). Additionally, minimum on and maximum off times and shed priorities can be entered for each load to protect equipment and insure that comfort is maintained.

It should be noted that demand shedding of HVAC equipment in commercial office buildings should be applied with caution. Since times of peak demand often occur during times of peak air conditioning loads, excessive demand limiting can result in occupant discomfort.

Time of Day Billing

Many utilities are beginning to charge their larger commercial users based on the time of day that consumption occurs. Energy and demand during peak usage periods (i.e., summer weekday afternoons and winter weekday evenings) are billed at much higher rates than consumption during other times. This is necessary because utilities must augment the power production of their large power plants during periods of peak demand with small generators which are expensive to operate. Some of the more sophisticated energy management systems can now account for these peak billing periods with different demand setpoints based on the time of day and day of week.

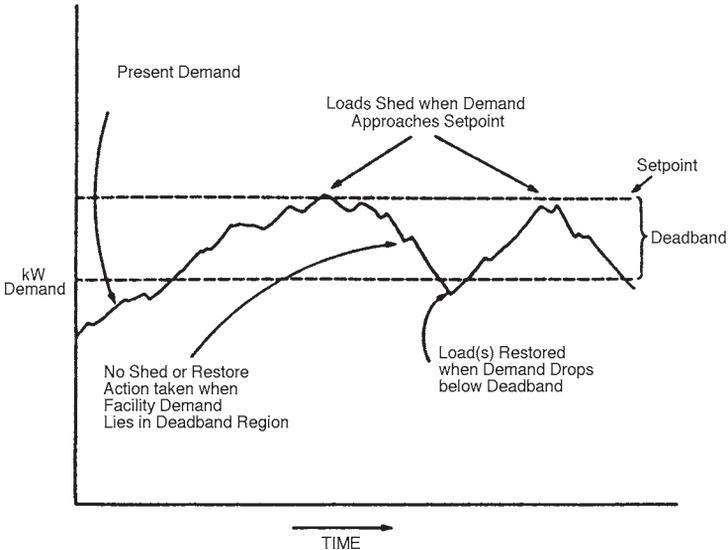


Figure 7-9. Demand Limiting Actions

Optimal Start

External building temperatures have a major influence on the amount of time it takes to bring the building temperature up to occupied levels in the morning. Buildings with mechanical time clocks usually start HVAC equipment operation at an early enough time in the morning (as much as 3 hours before occupancy time) to bring the building up to temperature on the coldest day of the year. During other times of the year when temperatures are not as extreme, building temperatures can be up to occupied levels several hours before it is necessary, and consequently unnecessary energy is used. (See Figure 7-10.)

Energy management systems with optimal start capabilities, however, utilize indoor and outdoor temperature information, along with learned building characteristics, to vary start time of HVAC equipment so that building temperatures reach desired values just as occupancy occurs. Consequently, if a building is scheduled to be occupied at 8:00 a.m., on the coldest day of the year, the HVAC equipment may start at 5:00 a.m. On milder days, however, equipment may not be started until

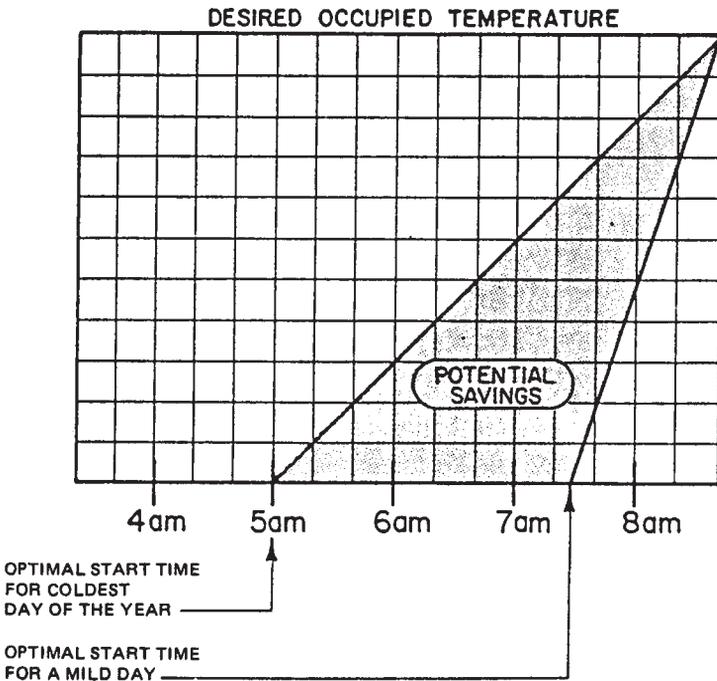


Figure 7-10. Typical Variation in Building Warm-Up Times

7:00 a.m. or even later, thereby saving significant amounts of energy.

Most energy management systems have a “self-tuning” capability to allow them to learn the building characteristics. If the building is heated too quickly or too slowly on one day, the start time is adjusted the next day to compensate.

Monitoring

Microprocessor-based EMS can usually accomplish a limited amount of monitoring of building conditions including the following:

- Outside air temperature
- Several indoor temperature sensors
- Facility electrical energy consumption and demand
- Several status input points

The EMS can store the information to provide a history of the facility. Careful study of these trends can reveal information about facility operation that can lead to energy conservation strategies that might not otherwise be apparent.

Direct Digital Control

The most sophisticated of the microprocessor-based EMSs provide a function referred to as direct digital control (DDC). This capability allows the EMS to provide not only sophisticated energy management but also have temperature control of the building’s HVAC systems.

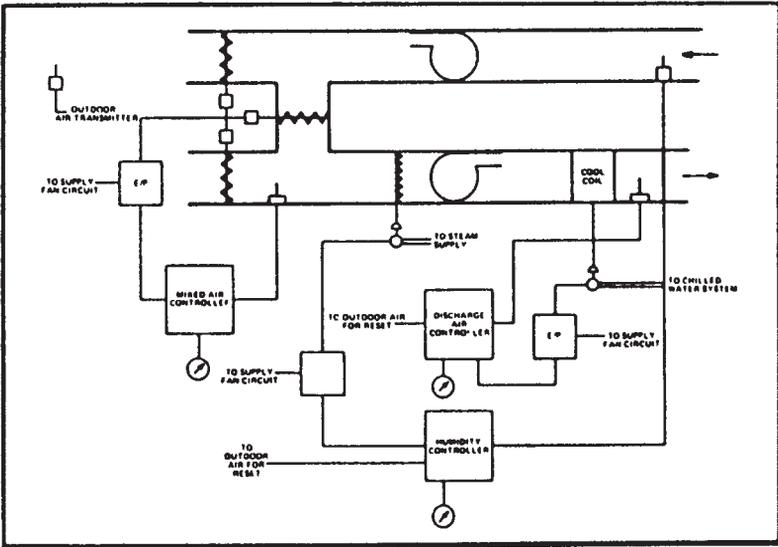
Direct digital control has taken over the majority of all process control applications and is now becoming an important part of the HVAC industry. Traditionally, pneumatic controls were used in most commercial facilities for environmental control.

The control function in a traditional facility is performed by a pneumatic controller which receives its input from pneumatic sensors (i.e., temperature, humidity) and sends control signals to pneumatic actuators (valves, dampers, etc.). Pneumatic controllers typically perform a single, fixed function which cannot be altered unless the controller itself is changed or other hardware is added. (See Figure 7-11 for a typical pneumatic control configuration.)

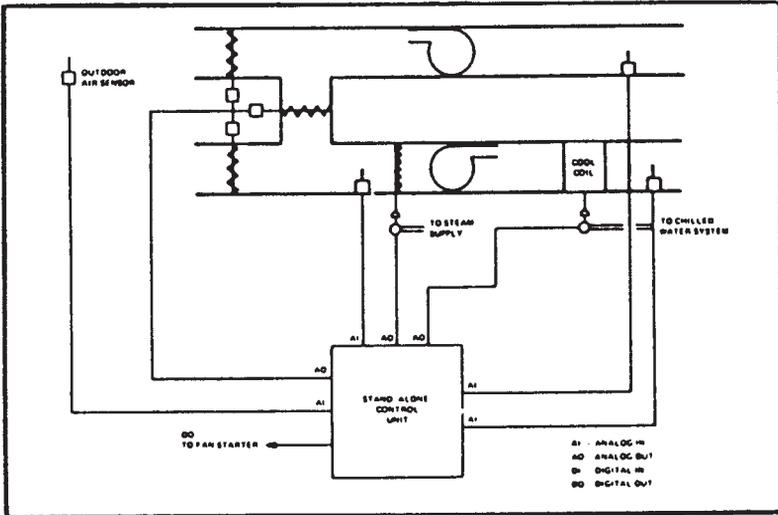
With direct digital control, the microprocessor functions as the primary controller. Electronic sensors are used to measure variables such as temperature, humidity and pressure. This information is used, along with the appropriate application program, by the microprocessor to determine the correct control signal, which is then sent directly to

the controlled device (valve or damper actuator). (See Figure 7-11 for a typical DDC configuration.)

Direct digital control (DDC) has the following advantage over pneumatic controls:



CONVENTIONAL PNEUMATIC CONTROL SYSTEM



DIRECT DIGITAL CONTROL SYSTEM

Figure 7-11. Comparison of Pneumatic and DDC Controls

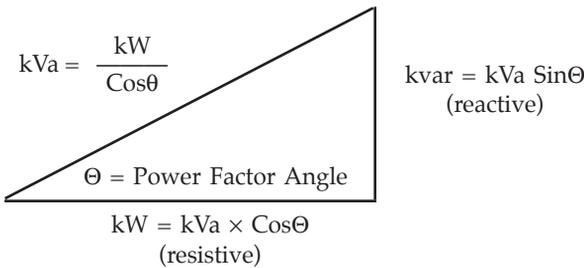
- Reduces overshoot and offset errors, thereby saving energy,
- Flexibility to easily and inexpensively accomplish changes of control strategies.
- Calibration is maintained more accurately, thereby saving energy and providing better performance.

To program the DDC functions, a user programming language is utilized. This programming language uses simple commands in English to establish parameters and control strategies.

ELECTRICAL SYSTEM DISTRIBUTION AUDIT

The inefficient operation of electrical distribution systems stems mainly from a low power factor. Power factor correction is cost-effective when utility penalties are imposed. Low power factors can be improved with power factor correction devices and high-efficiency motors. Additional energy can be saved by installing energy-efficient transformers and replacing existing motors with small and/or higher efficiency motors, or by installing variable-speed motor drives.

The total power requirement of a load is made up of two components, namely, the resistive part and the reactive part. The resistive portion of a load can not be added directly to the reactive component since it is essentially ninety degrees out of phase with the other. The pure resistive power is known as the watt, while the reactive power is referred to as the reactive volt amperes. To compute the total volt ampere load it is necessary to analyze the power triangle indicated below:



- K = 1000
 - W = Watts
 - VA = Volt Amperes
 - VAR = Volt Amperes Reactive
 - Θ = Angle Between kVa and kW
 - CosΘ = Power Factor
- (7-4)

$$\tan \theta = \frac{\text{kvar}}{\text{kW}}$$

For a balanced 3-phase load

$$\text{Power} = \underbrace{\sqrt{3} V_L I_L}_{\substack{\text{Watts} \quad \text{Volt} \quad \text{Power} \\ \text{Amperes} \quad \text{Factor}}} \cos \theta \tag{7-5}$$

For a balanced 1-phase load

$$P = V_L I_L \text{Cos}\Theta \tag{7-6}$$

The standard power rating of a motor is referred to as a horsepower. In order to relate the motor horsepower to a kilowatt (kW) multiply the horsepower by .746 (Conversion Factor) and divide by the motor efficiency.

$$\text{kVa} = \frac{\text{HP} \times .746}{\eta \times \text{P.F.}} \tag{7-7}$$

- HP = Motor Horsepower
- η = Efficiency of Motor
- P.F. = Power Factor of Motor

Motor efficiencies and power factors vary with load. Typical values are shown in Table 7-4. Values are based on totally enclosed fan-cooled motors (TEFC) running at 1800 RPM "T" frame.

Power Factor Efficiency Improvements

The ESEA should collect the following data:

- Plant Power Factor
- Motor nameplate date, type, horsepower, speed, full-load and part-load amperage.
- Nameplate data should be compared to actual running motor amperage.

As indicated in Table 7-4 small, partially-loaded motors contribute to poor power factors and electrical efficiency for buildings and plants.

Table 7-4

<i>HP RANGE</i>	<i>3-30</i>	<i>40-100</i>
$\eta\%$ at		
1/2 Load	83.3	89.2
3/4 Load	85.8	90.7
Full Load	86.2	90.9
P.F. at		
1/2 Load	70.1	79.2
3/4 Load	79.2	85.4
Full Load	83.5	87.4

The ESEA should determine which motors are oversized and may be replaced with a smaller frame size.

A second method to improve the plant or building power factor is to use energy efficient motors. Energy efficient motors are available from manufacturers such as Magnetic. Energy efficient motors are approximately 30 percent more expensive than their standard counterpart. Based on the energy cost it can be determined if the added investment is justified. With the emphasis on energy conservation, new lines of energy efficient motors are being introduced. Figures 7-12 and 7-13 illustrate a typical comparison between energy efficient and standard motors.

A third method to improve the power factor is to add capacitor banks to lower the total reactive kvar. The line current will also be reduced, thus the corresponding I²R loss through cables will also be lowered. Table 7-5 can be used to estimate the connective capacitance required.

SUMMARY

The term energy management system denotes equipment whose functions can range from simple timeclock control to sophisticated building automation.

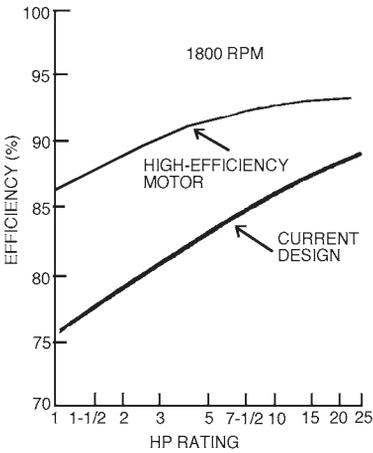


Figure 7-12.
Efficiency vs. Horsepower Rating (Dripproof Motors)

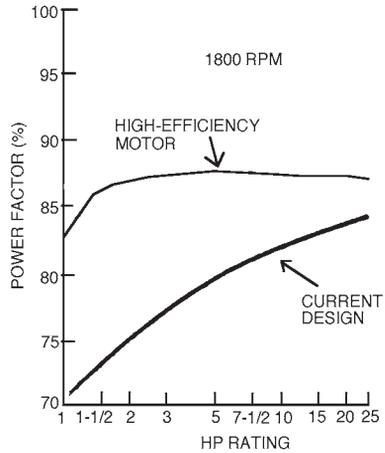


Figure 7-13.
Power Factor vs. Horsepower Rating (Dripproof Motors)

Capabilities of EMS can include scheduling, duty cycling, demand limiting, optimal start, monitoring, direct digital control, fire detection and security. Direct digital control capability enables the EMS to replace the environmental control system so that it directly manages HVAC operations.

Table 7-5. Shortcut Method-Power Factor Correction

kW Multipliers for Determining Capacitor Kilovars

Desired Power-factor in Percentage

	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
50	.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.303	1.337	1.369	1.403	1.441	1.481	1.529	1.590	1.732
51	.936	.962	.988	1.014	1.040	1.066	1.093	1.119	1.146	1.174	1.202	1.230	1.257	1.291	1.323	1.357	1.395	1.435	1.483	1.544	1.688
52	.894	.920	.946	.972	.999	1.024	1.051	1.077	1.104	1.132	1.160	1.188	1.215	1.249	1.281	1.315	1.353	1.393	1.441	1.502	1.644
53	.850	.876	.902	.928	.954	.980	1.007	1.033	1.060	1.088	1.116	1.144	1.171	1.205	1.237	1.271	1.309	1.349	1.397	1.458	1.600
54	.809	.835	.861	.887	.913	.939	.966	.992	1.019	1.047	1.075	1.103	1.130	1.164	1.196	1.230	1.268	1.308	1.356	1.417	1.559
55	.769	.795	.821	.847	.873	.899	.926	.952	.979	1.007	1.035	1.063	1.090	1.124	1.156	1.190	1.228	1.268	1.316	1.377	1.519
56	.730	.756	.782	.808	.834	.860	.887	.913	.940	.968	.996	1.024	1.051	1.085	1.117	1.151	1.189	1.229	1.277	1.338	1.480
57	.692	.718	.744	.770	.796	.822	.849	.875	.902	.930	.958	.986	1.013	1.047	1.079	1.113	1.151	1.191	1.239	1.300	1.442
58	.655	.681	.707	.733	.759	.785	.812	.838	.865	.893	.921	.949	.976	1.010	1.042	1.076	1.114	1.154	1.202	1.263	1.405
59	.618	.644	.670	.696	.722	.748	.775	.801	.828	.856	.884	.912	.939	.973	1.005	1.039	1.077	1.117	1.165	1.226	1.368
60	.584	.610	.636	.662	.688	.714	.741	.767	.794	.822	.849	.878	.905	.939	.971	1.005	1.043	1.083	1.131	1.192	1.334
61	.549	.575	.601	.627	.653	.679	.706	.732	.759	.787	.815	.843	.870	.904	.936	.970	1.008	1.048	1.096	1.157	1.299
62	.515	.541	.567	.593	.619	.645	.672	.698	.725	.753	.781	.809	.836	.870	.902	.936	.974	1.014	1.062	1.123	1.265
63	.483	.509	.535	.561	.587	.613	.640	.666	.693	.721	.749	.777	.804	.838	.870	.904	.942	.982	1.030	1.091	1.233
64	.450	.476	.502	.528	.554	.580	.607	.633	.660	.698	.716	.744	.771	.805	.837	.871	.909	.949	.997	1.058	1.200
65	.419	.445	.471	.497	.523	.549	.576	.602	.629	.657	.685	.713	.740	.774	.806	.840	.878	.918	.966	1.027	1.169
66	.388	.414	.440	.466	.492	.518	.545	.571	.598	.626	.654	.682	.709	.743	.775	.809	.847	.887	.935	.996	1.138
67	.358	.384	.410	.436	.462	.488	.515	.541	.568	.596	.624	.652	.679	.713	.745	.779	.817	.857	.905	.966	1.108

68	.329	.355	.381	.407	.433	.459	.486	.512	.539	.567	.595	.623	.650	.684	.716	.750	.788	.828	.876	.937	1.079
69	.299	.325	.351	.377	.403	.429	.456	.482	.509	.537	.565	.593	.620	.654	.686	.720	.758	.798	.840	.907	1.049
70	.270	.296	.322	.348	.374	.400	.427	.453	.480	.508	.536	.564	.591	.625	.657	.691	.729	.769	.811	.878	1.020
71	.242	.268	.294	.320	.346	.372	.399	.425	.452	.480	.508	.536	.563	.597	.629	.683	.701	.741	.783	.850	.992
72	.213	.239	.265	.291	.317	.343	.370	.396	.423	.451	.479	.507	.534	.568	.600	.634	.672	.712	.754	.821	.963
73	.186	.212	.238	.264	.290	.316	.343	.369	.396	.424	.452	.480	.507	.541	.573	.607	.645	.685	.727	.794	.936
74	.159	.185	.211	.237	.263	.289	.316	.342	.369	.397	.425	.453	.480	.514	.546	.580	.618	.658	.700	.767	.909
75	.132	.158	.184	.210	.236	.262	.289	.315	.342	.370	.398	.426	.453	.487	.519	.553	.591	.631	.673	.740	.882
76	.105	.131	.157	.183	.209	.235	.262	.288	.315	.343	.371	.399	.426	.460	.492	.526	.564	.604	.652	.713	.855
77	.079	.105	.131	.157	.183	.209	.236	.262	.289	.317	.345	.373	.400	.434	.466	.500	.538	.578	.620	.687	.829
78	.053	.079	.105	.131	.157	.183	.210	.236	.263	.291	.319	.347	.374	.408	.440	.474	.512	.552	.594	.661	.803
79	.026	.052	.078	.104	.130	.156	.183	.209	.236	.264	.292	.320	.347	.381	.413	.447	.485	.525	.567	.634	.776
80	.000	.026	.052	.078	.104	.130	.157	.183	.210	.238	.266	.294	.321	.355	.387	.421	.450	.499	.541	.608	.750
81	—	.000	.026	.052	.078	.104	.131	.157	.184	.212	.240	.268	.295	.329	.361	.395	.433	.473	.515	.582	.724
82	—	—	.000	.026	.052	.078	.105	.131	.158	.186	.214	.242	.269	.303	.335	.369	.407	.447	.489	.556	.698
83	—	—	—	.000	.026	.052	.079	.105	.132	.160	.188	.216	.243	.277	.309	.343	.381	.421	.463	.530	.672
84	—	—	—	—	.000	.026	.053	.079	.106	.134	.162	.190	.217	.251	.283	.317	.355	.395	.437	.504	.645
85	—	—	—	—	.000	.027	.053	.080	.108	.136	.164	.191	.225	.257	.291	.329	.369	.417	.478	.548	.690

Example: Total kW input of load from wattmeter reading 100 kW at a power factor of 60%. The leading reactive kvar necessary to raise the power factor to 90% is found by multiplying the 100 kW by the factor found in the table, which is .849. Then 100 kW \leftrightarrow 0.849 = 84.9 kvar. Use 85 kvar.

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Chapter 8

The Heating, Ventilation, and Air-conditioning Audit

Energy audits of heating, ventilation and air-conditioning (HVAC) systems is a very important portion of the overall program. HVAC standards such as ASHRAE 90.1 exist for defining energy-efficient systems in new construction. On the other hand, as of this writing no standards exist to define HVAC-efficient systems for existing buildings.

The purpose of this chapter is to highlight “low cost-no cost” areas that should be investigated in the HVAC Energy Audit. Portions of material used in this section and audit forms appearing in Chapter 15 are based upon two publications: “Guidelines for Saving Energy in Existing Buildings-Building Owners and Operators Manual,” ECM-1; and “Engineers, Architects and Operators Manual,” ECM-2. Both manuals were prepared for the government by Fred S. Dubin, Harold L. Mindell and Selwyn Bloome. The volumes were originally published by the U.S. Department of Commerce National Technical Information Service PB-249928 and PB-249929 and are available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Reference to ECM-1 and ECM-2 in the text refer to the original publication. The original document published is one of the most extensive works on energy conservation in existing buildings. The author expresses appreciation and credit to this work as one of the outstanding contributions in the energy audit field.

To use the short-cut methods described in this chapter and the chapter on building envelope audits (Chapter 6), knowledge of local weather data is required. Chapter 15, Table 15-1 and Figures 15-1 through 15-5 should prove helpful.

In addition Chapter 15 contains various audit forms which can be modified to fit particular needs, such as those shown in Figures 15-6 through 15-24.

A more detailed engineering approach is sometimes required utilizing computer programs, discussed at the end of this chapter, or detailed manual calculations. For manual engineering calculations reference is made to "Cooling and Heating Load Calculations," available from: American Society of Heating, Refrigeration and Air Conditioning Engineers.

Complete engineering weather data can be found in Air Force Manual, "Facility Design and Planning in Engineering Weather Data," available from the Superintendent of Documents, Washington, DC 20402.

INDOOR AIR QUALITY (IAQ) STANDARD

The most effective means to deal with an IAQ problem is to remove or minimize the pollutant source, when feasible. If not, dilution and filtration may be effective.

Dilution (increased ventilation) is to admit more outside air to the building. The current ASHRAE ventilation standard, 62-2007 requires 20 cfm/person, if the prescriptive approach is used.

Increased ventilation will have an impact on building energy consumption. However, this cost need not be severe. If an air-side economizer cycle is employed and the HVAC system is controlled to respond to IAQ loads as well as thermal loads, 20 cfm/person need not be adhered to and the economizer hours will help attain air quality goals with energy savings at the same time.

Energy savings can also be realized by the use of improved filtration in lieu of the prescriptive 20 cfm/person approach. Improved filtration can occur at the air handler, in the supply and return ductwork, or in the spaces via self-contained units. Improved filtration can include enhancements such as ionization devices to neutralize airborne biological matter and to electrically charge fine particles, causing them to agglomerate and be more easily filtered.

Guidelines for IAQ pollutants are illustrated in Figure 8-1.

Specific methods are available for preventing or reducing IAQ concerns. These include:

1. Providing adequate and effective ventilation. This includes complying with the ASHRAE Standard 62-1999. The proper amount of outside air must be brought into the building and the air must be

Pollutant	Concentration	Remarks
Asbestos	0.2 fibers/cm ³	OSHA standard set in July, 1986.
	0.3 fibers/cm ³	OSHA action level requiring monitoring programs; typical background levels in outdoor ambient air in urban areas are 0.00007 fibers/cm ³ .
Carbon Dioxide	1000 ppm	Japanese standard for buildings with floor space exceeding 3000 m ² and HVAC system.
Carbon Monoxide	9 ppm	National Ambient Air Quality standard average of 8 hours.
Formaldehyde	0.1 ppm	ASHRAE recommended limit based on comfort criteria which should protect all but hypersensitive individuals.
	0.4 ppm	HUD standard for pressed wood products used in mobile homes, to prevent formaldehyde in indoor air from exceeding 0.4 ppm.
Nitrogen Dioxide	0.05 ppm	Annual National Ambient Air Quality standard.
Ozone	0.08 ppm	Level of concern in World Health Organization criteria documents.
	0.12 ppm	National Ambient Air Quality standard averaged over 1 hour.
Particulate	50 µg/m ³	National Ambient Air Quality standard annual geometric mean.
	150 µg/m ³	National Ambient Air Quality standard 24 hour average mean.
Radon	4 pCi/L	U.S. Environmental Protection Agency technologically achievable target level.
	8 pCi/L (0.04 WL)	Remedial action level recommended by the National Council on Radiation Protection and Measurements.
Termiticides	1.0 µg/m ³ (Aldrin)	Recommended by the National Academy of Sciences Committee on Toxicology.
	5.0 µg/m ³ (Chlordane)	
	2.0 µg/m ³ ()	
	10 µg/m ³ ()	
	()	
Volatile Organic Compounds	1-5 mg/m ³	Lars Molhave study levels suspected of causing sick building syndrome symptoms in some individuals. U.S. EPA Guideline.

Figure 8-1. Guidelines for Some IAQ Pollutants

effectively distributed to the breathing level zone of the occupants. In addition, air intakes and exhaust systems must be designed so that polluted air is not brought into the building. Those activities which generate high loads of pollutants such as tobacco smoking areas and printing/graphic areas should be exhausted directly to the outside.

2. Insuring that safe, low emitting materials are used in new construction and remodeling activities. These include construction materials and furnishings such as wallboard, floor coverings, wall coverings, paints, adhesives, duct lining, ceiling tiles, furniture, etc. These materials should be pre-tested or certified to be low emitting.
3. Enforcing a well-documented and scheduled HVAC operational plan which includes changing of filters, cleaning of air handling rooms, cleaning of condensate drip pans to discourage the growth of microbial debris, and assuring proper operational performance.
4. Removing or correcting existing sources of indoor pollutants. Special filtration, encapsulation and substitution are common techniques.
5. Educating the staff and building occupants concerning IAQ sources of pollutants and their effects, and control measures.

THE VENTILATION AUDIT

To accomplish an Energy Audit of the ventilation system the following steps can be followed:

1. Measure volume of air at the outdoor air intakes of the ventilation system. Record ventilation and fan motor nameplate data.
2. Determine local code requirements and compare against measurements.
3. Check if measured ventilation rates exceed code requirements.

To decrease cfm, the fan pulley can be changed. Two savings are derived from this change, namely:

- Brake horsepower of fan motor is reduced.
- Reduced heat loss during heating season.

To compute the savings formulas 8-1 and 8-2 are used. Figure 8-2 can also be used to compute fan power savings as a result of air flow reduction.

$$hp \text{ (reduction)} = hp \times \left(\frac{cfm \text{ (new)}}{cfm \text{ (old)}} \right)^3 \tag{8-1}$$

$$Q \text{ (saved)} = \frac{1.08 \text{ Btu}}{Hr \pm cfm \pm ^\circ F} \times cfm \text{ (saved)} \times \Delta T \tag{8-2}$$

$$kW = hp \times .746/\eta \tag{8-3}$$

Where

- hp = Motor horsepower
- cfm = Cubic feet per minute
- ΔT = Average temperature gradient
- kW = Motor kilowatts (k = 1000) η = Motor efficiency

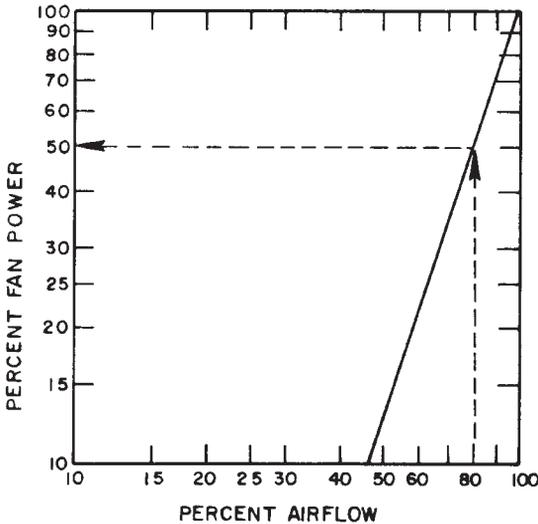


Figure 8-2. Decrease in Horsepower Accomplished By Reducing Fan Speed (Based on Laws of Fan Performance). (Source: NBS Handbook 115 Supplement 1)

In addition to reducing air flow during occupied periods, consideration should be given to shutting the system down during unoccupied hours.

If the space was cooled, additional savings will be achieved. The quantity of energy required to cool and dehumidify the ventilated air to indoor conditions is determined by the enthalpy difference between outdoor and indoor air. To compute the energy savings for the cooling season Figure 8-3 can be used.

SIM 8-1

An energy audit indicates ventilation in a storage area can be reduced from four to two changes per hour during the winter months—240 days, 4200 degree-days.

Comment on the energy savings based on the following audit data:

- Building size: 20H × 150W × 100L
- Inside temperature: 70°F
- Motor Horsepower: 20 hp
- Nameplate Electrical Efficiency: .8
- Utility Costs: \$4/10⁶ Btu, 5¢ per kWh
- Hours of Operation 5760
- Boiler Efficiency = .65

ANALYSIS

$$\text{Volume of Warehouse Area} = 20 \times 150 \times 100 = 300,000 \text{ ft}^3$$

$$\text{Present Rate} = 4 \times 300,000 \times 1/60 = 20,000 \text{ cfm}$$

$$\text{Reduced Rate} = 2 \times 300,000 \times 1/60 = 10,000 \text{ cfm}$$

Savings Due to Reduced Horsepower

$$\text{Reduced Horsepower} = 20 \text{ hp} \times (2/4) = 2.5 \text{ hp}$$

$$\text{Savings Electricity} = (20 - 2.5) \times .746 / .8 \times 5\text{¢ kW} \times 5760 = \$4,699.80$$

Savings Due to Reduced Heat Loss

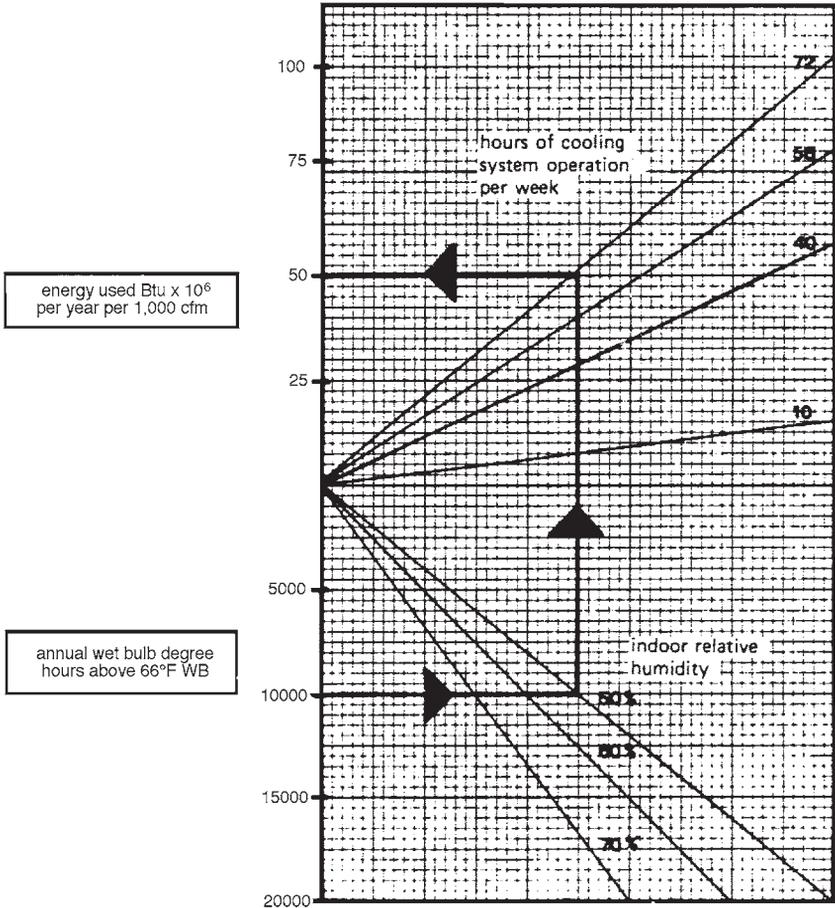
$$\text{Average } \Delta T = 4200 \text{ degree-days} / 240 \text{ days} = 17.5^\circ\text{F}$$

$$\text{Average Outdoor} = 65 - 17.5 = 47.5$$

Temperature during Heating Seasons

$$Q \text{ (saved)} = \frac{1.08 \text{ Btu}}{\text{Hr} \pm \text{cfm} \pm ^\circ\text{F}} \times \text{cfm (saved)} \times \Delta T \tag{8-2}$$

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WE degree hours based on 12 Mos/Yr, 8 Hr/Day

Energy used is a function of the WE degree hours above the base of 66F, the RH maintained the No. of hours of controlled humidity. The base RH is 50% which is approximately 78F DB, 66 WB. The figure expresses the energy used per 1000 cfm of air conditioned or dehumidified.

Figure 8-3. Yearly Energy Used Per 1,000 cfm to Maintain Various Humidity Conditions (Source: Guidelines For Saving Energy in Existing Buildings—Building Owners and Operating Manual, ECM-1)

$$1.08 (20,000 - 10,000) \times 17.5 = 189,000 \text{ Btuh}$$

$$\text{Savings} = 189,000 \times \$4/10^6 \text{ Btu} / .65 \times 5760 = \$6698$$

$$\text{Total Annual Savings} = \$4699 + 6698 = \$11,397$$

SIM 8-2

For the building of SIM 8-1 compute the cooling savings resulting from reducing air changes per hour from 4 to 2.

Audit Data:

Annual Wet Bulb Degree-Hours above 66°F = 8,000

Relative Humidity = 50%

Hours of Cooling System Operation per Week = 40

Electricity Rate = 5¢ per kWh

Refrigeration Consumption = .8 kW/Ton-Hr.

ANALYSIS

From Figure 8-3

Energy Used per year per 1000 cfm is 22.5×10^6 Btu

$$\begin{aligned} \text{Energy Saved} &= (20,000 - 10,000 \text{ cfm}) \times 22.5 \times 10^6 \text{ Btu} \\ &= 225 \times 10^6 \text{ Btu/Yr} \end{aligned}$$

$$\text{Savings} = \frac{225 \times 10^6 \text{ Btu/Yr}}{12,000 \text{ Btu/Ton}\pm\text{Hr}} \times .8 \text{ kW/Ton}\pm\text{Hr} \times 5\text{¢/kWh} = \$750/\text{Yr}$$

THE TEMPERATURE AUDIT

The temperature audit should include the following:

- Determine indoor temperature settings for each space and season.
- Determine spaces which are unoccupied.
- Check if temperatures exceed "Recommended Temperature Standards," Figures 8-4 and 8-5.
- Implement setbacks by resetting thermostats manually, installing clocks or adjusting controls.
- Turn off cooling systems operated in summer during unoccupied hours.
- Experiment to determine optimum setback temperature.
- Lower temperature settings of occupied spaces based on "Recommended Temperature Standards," Figures 8-4 and 8-5.

	A Dry Bulb °F occupied hours maximum	B Dry Bulb °F unoccupied hours (set-back)
1. OFFICE BUILDINGS, RESIDENCIES, SCHOOLS		
Offices, school rooms, residential spaces	68°	55°
Corridors	62°	52°
Dead Storage Closets	50°	50°
Cafeterias	68°	50°
Mechanical Equipment Rooms	55°	50°
Occupied Storage Areas, Gymnasiums	55°	50°
Auditoriums	68°	50°
Computer Rooms	65°	As required
Lobbies	65°	50°
Doctor Offices	68°	58°
Toilet Rooms	65°	55°
Garages	Do not heat	Do not heat
2. RETAIL STORES		
Department Stores	65°	55°
Supermarkets	60°	50°
Drug Stores	65°	55°
Meat Markets	60°	50°
Apparel (except dressing rms)	65°	55°
Jewelry, Hardware, etc.	65°	55°
Warehouses	55°	50°
Docks and platforms	Do not heat	Do not heat
3. RELIGIOUS BUILDINGS		
		Greater than
		24 Hrs or less 24 Hrs
Meeting Rooms	68°	55° 50°
Halls of Worship	65°	550 500
All other spaces	As noted for office buildings	500 400

Source: Guidelines For Saving Energy in Existing Buildings-Building Owners and Operators Manual, ECM-1

Figure 8-4. Suggested Heating Season Indoor Temperatures

I. COMMERCIAL BUILDINGS	Occupied Periods	
	Dry Bulb Temperature	Minimum Relative Humidity
Offices	78°	55%
Corridors	Uncontrolled	Uncontrolled
Cafeterias	75°	55%
Auditoriums	78°	50%
Computer Rooms	75°	As needed
Lobbies	82°	60%
Doctor Offices	78°	55%
Toilet Rooms	800	
Storage, Equipment Rooms	Uncontrolled	
Garages	Do Not Cool or Dehumidify.	

II. RETAIL STORES	Occupied Periods	
	Dry Bulb Temperature	Relative Humidity
Department Stores	800	55%
Supermarkets	78°	55%
Drug Stores	80°	55%
Meat Markets	78°	55%
Apparel	80°	55%
Jewelry	80°	55%
Garages	Do Not Cool.	

*Except where terminal reheat systems are used. With terminal reheat systems the indoor space conditions should be maintained at lower levels to reduce the amount of reheat. If cooling energy is not required to maintain temperatures, 74°F would be recommended instead of 78°F.

Source: *Guidelines For Saving Energy In Existing Buildings*—Building Owners and Operators Manual, ECM-1

Figure 8-5. Suggested Indoor Temperature and Humidity Levels in the Cooling Season

Mandatory state and federal standards should be followed. Check that temperature requirements specified in OSHA are not violated. Changing temperatures in occupied periods could cause labor relations problems.

Other considerations in setting back temperatures during occupied hours include:

1. In spaces used for storage and which are mostly unoccupied, equipment and piping freeze protection is the main consideration.
2. Consider maintaining stairwell temperatures around 55°F in winter.
3. For areas where individuals commonly wear outdoor clothing such as stores, lower temperatures in winter.

SAVINGS AS A RESULT OF SETBACK

Figures 8-6 and 8-7 can be used to estimate savings as a result of setbacks for winter and summer respectively.

To use Figure 8-6:

1. Determine degree-days for location.
2. Calculate Btu/square foot/year used for heating.
3. Draw a line horizontally from specified degree-days to intersection of setback temperature. Extend line vertically and proceed along sloped lines as illustrated in the figure.
4. Draw a line horizontally from Btu/square foot/year until it intersects sloped line. Proceed vertically and read Btu/square foot/year savings on upper horizontal axis.

To use Figure 8-7:

1. Add the Btu/hour/1000 cfm for each temperature starting.
2. Start with one temperature above original setpoint.
3. Add contributions for each setpoint temperature until new setting is reached.

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read both axes in same
order of magnitude in multiple
of 10, 100, or 1,000

saving Btu x 10⁻³ per
sq ft per year

present heating energy
consumption Btu per sq ft
per year times selected
order of magnitude

degree days

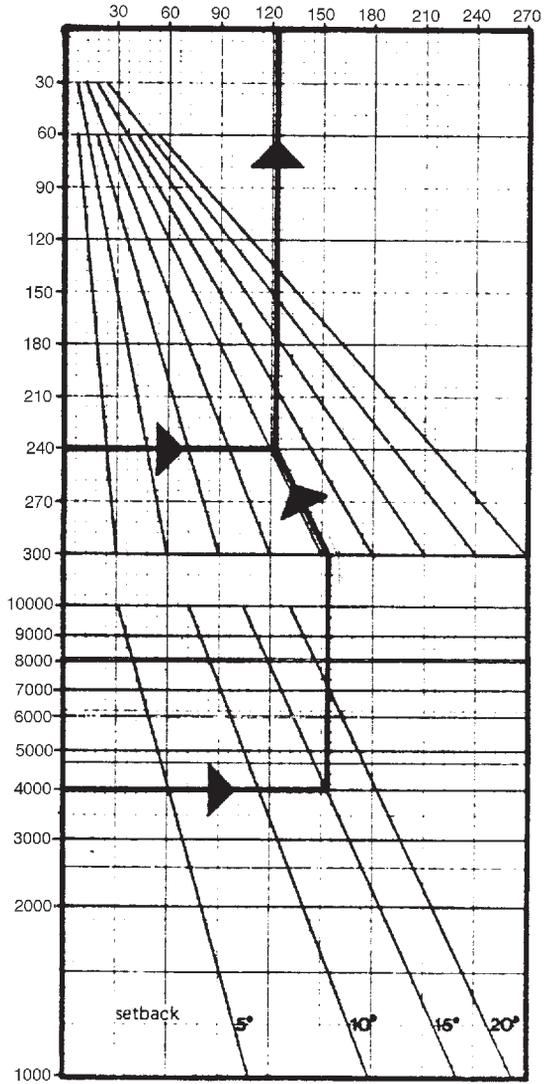


Figure 8-6. Energy Saved (Source: Guidelines For Saving Energy In Existing Buildings—Building Owners and Operators Manual, ECM-1)

Relative Humidity	50%	60%	70%
Dry Bulb Temperature	Btu/Hour/1000 cfm		
72°F	0	0	0
73°F	2,700	2,433	3,000
74°F	2,657	2,400	3,257
75°F	3,000	2,572	3,000
76°F	3,000	2,572	3,000
77°F	3,000	2,572	3,429
78°F	3,000	2,572	3,429

Figure 8-7. Effect of Raising Dry Bulb Temperature (Source: Guidelines For saving Energy In Existing Building—Building owners and Operators Manual, ECM-1)

SIM 8-3

An energy audit indicates that the temperature of the building can be set back 20°F during unoccupied hours.

Comment on the energy savings based on the following audit data:

- Heating Degree-days = 6,000
- Present Heating Consumption
60,000 Btu/square foot/year
- Floor Area = 100,000 square feet
- Utility Cost = \$4/10⁶ Btu
- Boiler Efficiency .65

ANALYSIS

From Figure

- Energy Savings is 36,000 Btu/square foot/year
- Savings = 36,000 × \$4/10⁶ × 100,000/.65 = \$22,153

SIM 8-4

An energy audit indicates an indoor dry bulb temperature in summer of 73°F. It is determined to raise the setpoint to 78°F. Comment on the energy savings based on the following audit data:

- Total outdoor air 15,000 cfm
- Relative Humidity 50%

Hours of Operation	40
Cooling Season	20 weeks/year
Annual WB degree-hours above 66°F, WB	6,000

ANALYSIS

From Figure 8-7, raising the temperature from 73°F to 78°F, a total savings of the following will occur:

74	2,656
75	3,000
76	3,000
77	3,000
78	3,000
Total.....	<u>14,656</u> Btu/Hour/1000 cfm

Savings: 14,656 Btu/Hour/1000 cfm × 15,000 cfm × \$4/10⁶ Btu/.65 × 40 Hours/Week × 20 Weeks/Year = \$1,082 per year.

THE HUMIDITY AUDIT

Desired relative humidity requirements are achieved by vaporizing water into the dry ventilating air. Approximately 1000 Btus are required to vaporize each pound of water. To save energy, humidification systems should not be used during unoccupied hours. Most humidification systems are used to maintain the comfort and health of occupants, to prevent cracking of wood, and to preserve materials. In lieu of specific standards it is suggested that 20% relative humidity be maintained in all spaces occupied more than four hours per day. If static shocks or complaints arise, increase the humidity levels in 5% increments until the appropriate level for each area is determined. Figure 8-8 can be used to estimate the savings in winter as a result of lowering the relative humidity requirements.

SIM

An energy audit of the humidification requirements indicated the following data:

Outdoor air rate plus infiltration	10,000 cfm
Annual Wet Bulb Degree-hours	

Below 54° WB and 68°F	65,000
Cost of Fuel	\$4 per million Btu
Boiler Efficiency	.65
Type	Department Store
	112 hours occupancy/week

Determine the savings as a result of lowering the relative humidity of the building from 50% to 30% during the heating season.

ANALYSIS

From Figure 8-8

Energy used at 50 RH = 65×10^6 Btu/Yr per 1000 cfm

Energy used at 30 RH = 35×10^6 Btu/Yr per 1000 cfm

Energy saved = $(65-35) \times 10^6 \times 10 = 300 \times 10^6$ Btu/Yr

Savings = $300 \times 10^6 \times \$4/10^6 / .65 = \$1,846$

In the case of the cooling season check to determine if levels are consistent with Figure 8-5. Higher levels of humidification than required during the cooling season waste energy. Figure 8-9 should be used to estimate savings as a result of maintaining a higher RH level.

SIM 8-6

Determine the savings based on increasing the relative humidity from 50% to 70% based on the audit data:

Annual Wet Bulb Degree	
Hours above 66°F	8,000
Operation per week	40 hours
Outside cfm	20,000
Refrigeration consumptions	.8 kW/Ton Hour
Electric rate	5¢ per kWh

ANALYSIS

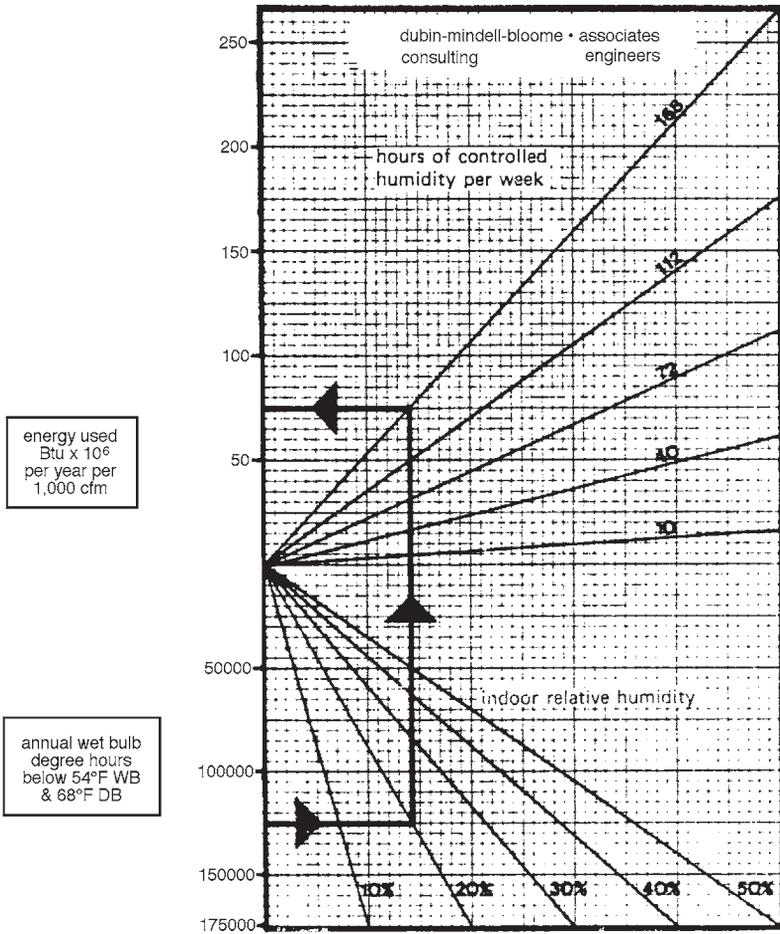
From Figure 8-9:

Energy used at 50% RH 22.5×10^6 Btu/Yr per 1000 cfm

Energy used at 70% RH 16×10^6 Btu/Yr per 1000 cfm

Energy saved = $(22.5 - 16) \times 10^6 \times 20 = 130 \times 10^6$ Btu/Yr

$$\text{Savings} = \frac{130 \times 10^6}{12,000 \text{ Btu/Ton}\pm\text{Hr}} \times .8 \text{ kW/Ton}\pm\text{Hr} \times 5\text{¢/kWh} = \$433/\text{Yr}$$



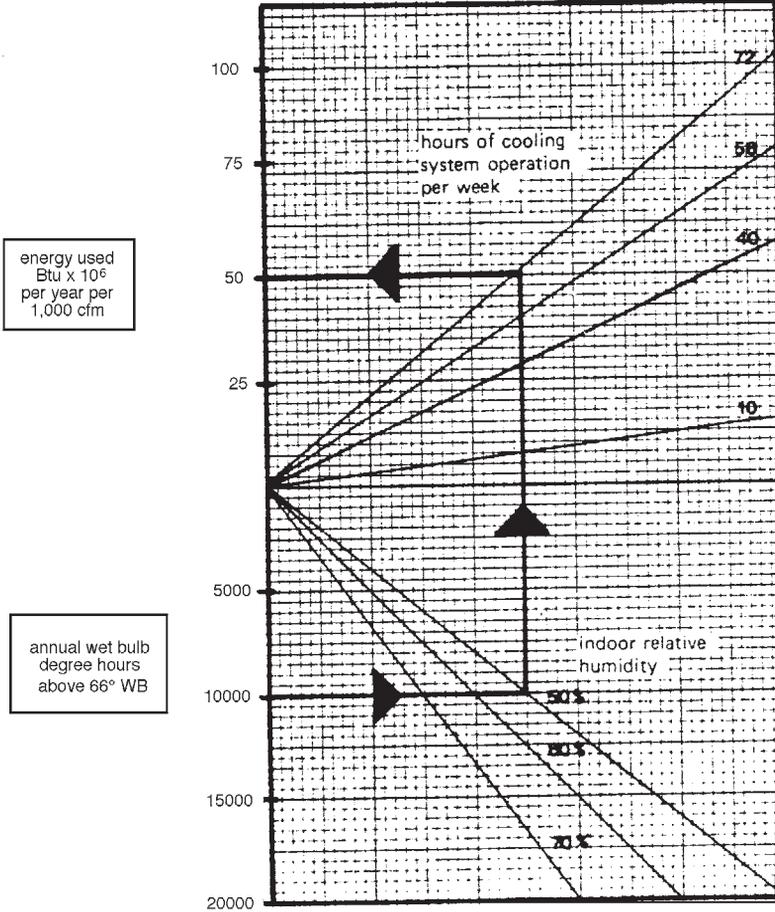
WE degree hours based on 24 hours/day, October—April.
Base Indoor condition for figure is DB=68F, WB=54F, RH=40%.

Energy used is a function of the WB degree hours below the base conditions, the RH maintained and the number of hours of controlled humidity. The figure expresses the energy used per 1000 cfm of air conditioned or humidified.

An analysis of the total heat content of air in the range under consideration indicates an average total heat variation of 0.522 Btu/lb for each degree WB change. Utilizing the specific heat of air, this can be further broken down to 0.24 Btu/lb sensible heat and 0.282 Btu/lb latent heat. 1000 cfm is equal to 4286 lb/hr and since we are concerned with latent heat only, each degree F WB hour is equal to 4286 x 0.282 or 1208 Btu. Further investigation of the relationship between WB temperature, DB temperature, and total heat shows that latent heat varies directly with RH at constant DB temperature. The lower section of the figure shows this proportional relationship around the base of 40% RH. The upper section proportions the hours of system operation with 168 hr/wk being 100%.

Figure 8-8. Yearly Energy Used Per 1,000 cfm to Maintain Various Humidity Conditions (Source: Guidelines For Saving Energy In Existing Buildings—Building Owners and Operators Manual, ECM-1)

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WE degree hours based on 12 Mos/Yr, 8 Hr/Day

Energy used is a function of the WB degree hours above the base of 66F, the RH maintained the No. of hours of controlled humidity. The bass RH is 50% which is approximately 78F DB, 66F WB. The figure expresses the energy used per 1000 cfm of air conditioned or dehumidified.

Figure 8-9. Yearly Energy Used Per 1,000 cfm to Maintain Various Humidity Conditions (Source: Guidelines For Saving Energy In Existing Buildings—Building Owners and Operators Manual, ECM-1)

COMPUTER PROGRAM ANALYSIS

Computer program analysis is a very important design tool in the energy audit process. Manual load calculations are based on steady-state conditions. These calculations are usually based on maximum or minimum conditions and give reasonable indications of equipment size. They do not however indicate how the system will perform. Probably the greatest opportunity for savings exists under part-load conditions.

Computer programs simulate energy consumption based on stored weather data; this enables a comprehensive month-by-month energy report to determine the optimum system performance. The total system can be analyzed including lighting, HVAC, and building envelope. Thus alternatives may be investigated with all parameters considered.

ENERGY RECOVERY SYSTEMS

The HVAC Energy Audit should analyze opportunities for recovering energy. To recover heat from exhausts, several devices can be used including the heat wheel, air-to-air heat exchanger, heat pipe and coil run-around cycle. Examples of these systems and devices are illustrated in Figures 8-10 and 8-11.

Heat Wheels

Heat wheels are motor-driven devices packed with heat-absorbing material such as a ceramic. As the device turns by means of a motor, heat is transferred from one duct to another.

Air-to-air Heat Exchanger

The air-to-air heat exchanger consists of an open-ended steel box which is compartmentalized into multiple narrow channels. Each passage carries exhaust air alternating with make-up air. Energy is transmitted by means of conduction through the walls.

Heat Pipes

A heat pipe is installed through adjacent walls of inlet and outlet ducts; it consists of a short length of copper tubing sealed at both ends. Inside is a porous cylindrical wick and a charge of refrigerant. Its operation is based on a temperature difference between the ends of the pipe, which causes the liquid in the wick to migrate to the warmer end to

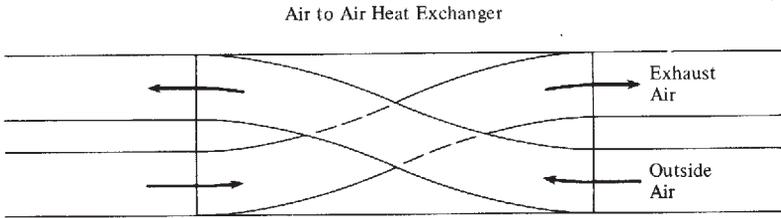
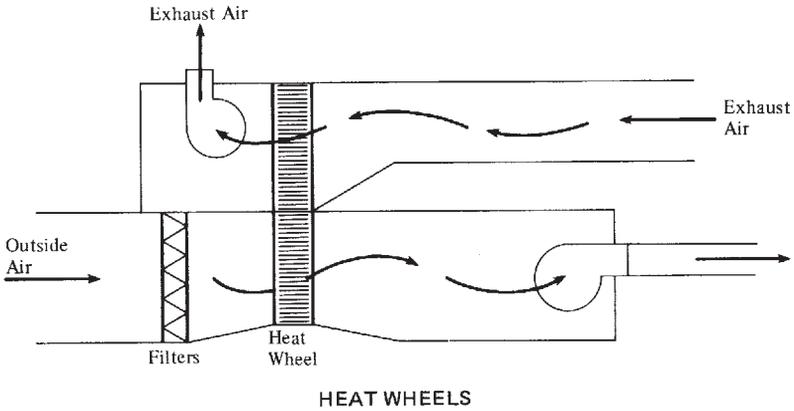


Figure 8-10. HVAC Heat Recovery

evaporate and absorb heat. When the refrigerant vapor returns through the hollow center of the wick to the cooler end, it gives up heat, condenses, and the cycle is repeated.

Coil Run-around Cycle

The coil run-around cycle transfers energy from the exhaust stream to the make-up stream continuously circulating a heat transfer medium, such as ethylene glycol fluid, between the two coils in the ducts.

In winter, the warm exhaust air passes through the exhaust coils and transfers heat to the ethylene glycol fluid. The fluid is pumped to the make-up air coil where it preheats the incoming air. The system is most efficient in winter operation, but some recovery is possible during the summer.

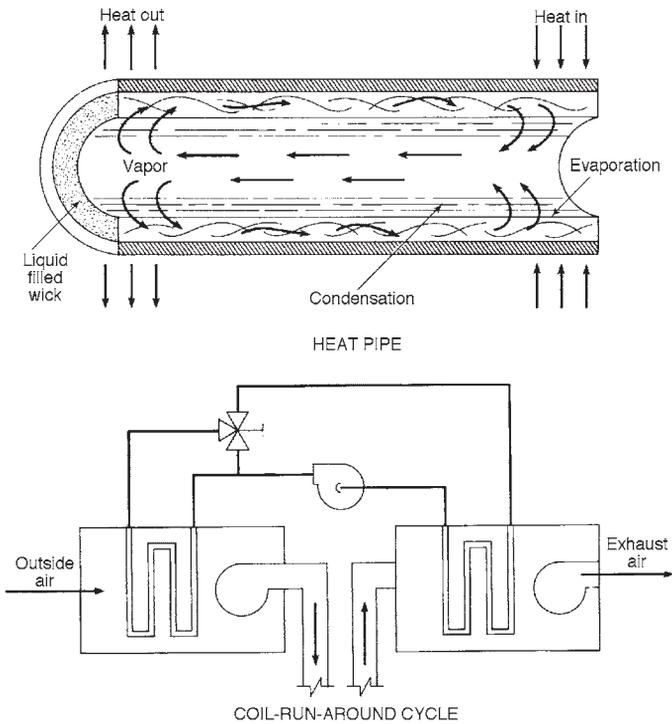


Figure 8-11. HVAC Heat Recovery

Heat from Lighting Systems

Heat dissipated by lighting fixtures which is recovered will reduce air-conditioning loads, will produce up to 13 percent more light output for the same energy input, and can be used as a source of hot air typical recovery schemes are illustrated in Figure 8-12. I the total return system, all of the air is returned through the luminaires. In the bleed-off system, only a portion is drawn through the lighting fixtures. The system is usually used in applications requiring high ventilation rates.

SIM 8-7

Roof-mounted, air-cooled condensers are traditionally used to cool the gas from refrigeration equipment. Comment on how the system diagrammed in Figure 8-13 can be made more efficiently.

ANALYSIS

Figure 8-14 illustrates a retrofit installation where heat is recovered by the addition of a heat exchanger to recapture the energy which was

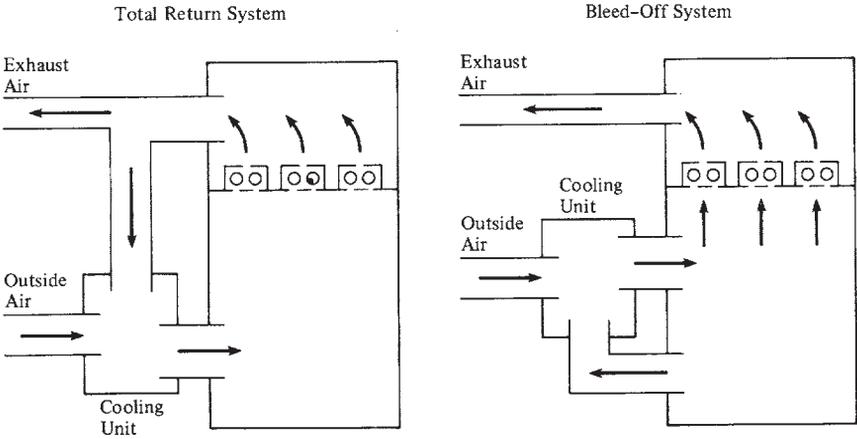


Figure 8-12. Recovery from Lighting Fixtures

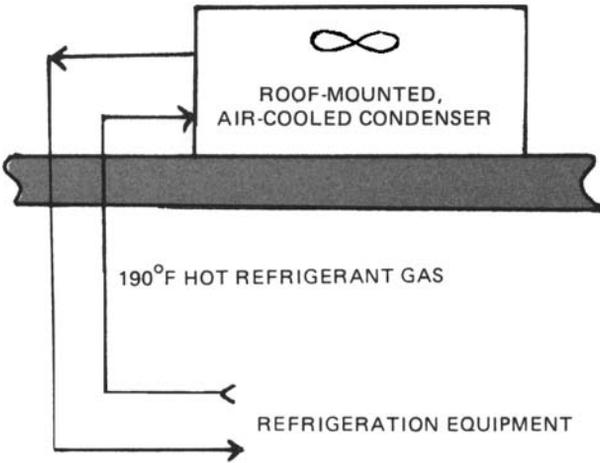


Figure 8-13.

previously dissipated to the atmosphere. This energy can be used to preheat the domestic water supply for various processes.

AIRSIDE ECONOMIZER

In addition to heat recovery opportunities, the audit should uncover system modifications which will save energy such as the economizer cycle. The economizer cycle uses outside air as the cooling source when

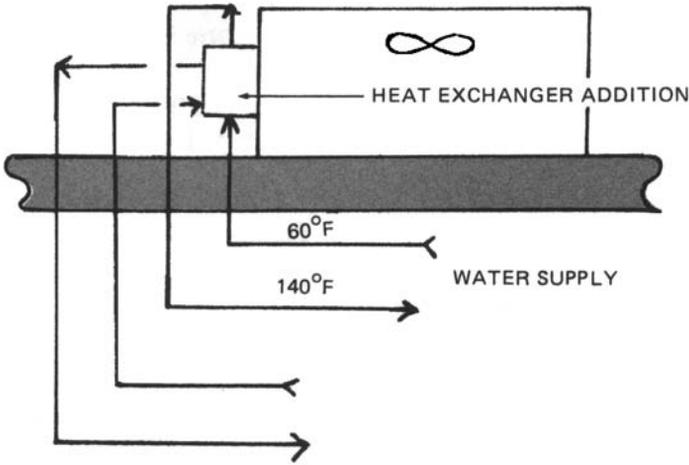


Figure 8-14.

it is cold enough. There are two suitable economizer systems:

1. System monitors and responds to dry-bulb temperature only. It is suitable where wet-bulb degree-hours are less than 8000 per year.
2. System monitors and responds to the WB and DB temperatures (enthalpy), and is most effective and economic in locations which experience more than 8000 WB degree-hours.

System 1—Economizer Cycle Cooling

Provide controls, dampers and interlocks to achieve the following control sequence:

- a) When the outdoor air DB temperature is lower than the supply air DB temperature required to meet the cooling load, turn off the compressor and chilled water pumps, and position outdoor air-return air-exhaust air dampers to attain the required supply air temperature.
- b) When the outdoor air DB temperature is higher than the supply air temperature required to meet the loads, but is lower than the return air temperature, energize the compressors and chilled water pumps and position dampers for 100% outdoor air.

- c) Use minimum outdoor air whenever the outdoor dry-bulb temperature exceeds the return air DB temperature.
- d) Whenever the relative humidity in the space drops below desired levels and more energy is consumed to raise the RH than is saved by the economizer system, consider using refrigeration in place of economizer cooling. This condition may exist in very cold climates and must be analyzed in detail.

System 2—Enthalpy Cycle Cooling

Provide the equipment, controls, dampers and interlocks to achieve the following control sequence:

The four conditions listed for system I above are similar for this system with the exception that enthalpy conditions are measured rather than dry-bulb conditions.

If changes to outside air intake are contemplated, take careful note of all codes bearing on ventilation requirements. Fire and safety codes must also be observed.

Applications of Systems 1 and 2

- Single duct, constant volume systems Variable volume air systems
- Induction systems
- Terminal reheat systems, dual duct systems, and multizone systems.
- Economizer and Enthalpy systems are less effective if used in conjunction with heat-recovery systems. Trade-offs should be analyzed.

WATERSIDE ECONOMIZER

A waterside economizer uses the cooling tower to cool down the chilled water loop, thus reducing the compressor operating hours. A plate and frame heat exchanger is utilized that connects the chilled water loop to a cooling tower water loop. This “free cooling” can be used to save energy whenever the outside wet-bulb temperature drops below the required chilled water set-point. This energy-efficiency measure, under favorable wet-bulb conditions, can save enough compressor electric power to pay for plate-and-frame heat exchanger installation costs in a relatively short time period.

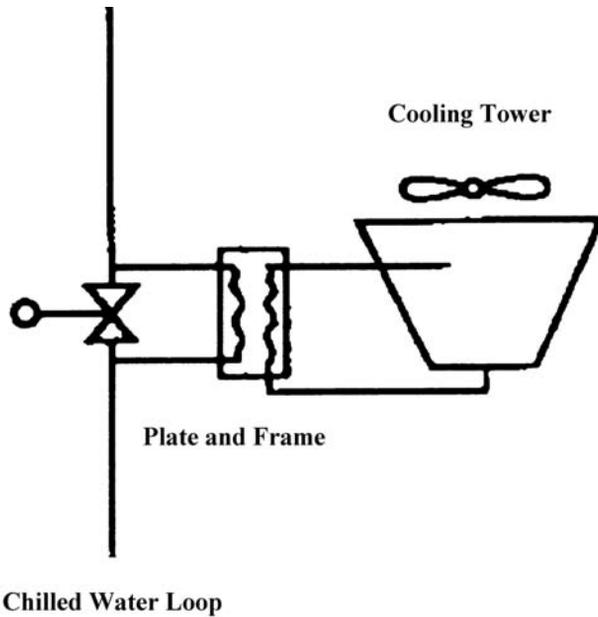


Figure 8-14.

TEST AND BALANCE CONSIDERATIONS

Probably the biggest overlooked low-cost energy audit requirement is a thorough Test, Balance and Adjust Program. In essence the audit should include the following steps:

1. **Test**—Quantitative determination of conditions within the system boundary, including flow rates, temperature and humidity measurements, pressures, etc.
2. **Balance**—Balance the system for required distribution of flows by manipulation of dampers and valves.
3. **Adjust**—Control instrument settings, regulating devices, control sequences should be adjusted for required flow patterns.

In essence the above program checks the designer's intent against actual performance and balances and adjusts the system for peak performance.

Several sources outlining Test and Balance Procedures are:

- Construction Specifications Institute (CSI), which offers a specification series that includes a guide specification entitled "Testing and Balancing of Environmental Systems."
- Associated Air Balance Council (AABC), the certifying body of independent agencies.
- National Environmental Balancing Bureau (NEBB), sponsored jointly by the Mechanical Contractors Association of America and the Sheet Metal and Air Conditioning Contractors National Association as the certifying body of the installing contractors' subsidiaries.

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Chapter 9

Upgrading HVAC Systems For Energy Efficiency—

Verification of System Performance

In an effort to influence customer electricity use, electric utilities offer demand-side management (DSM) programs that provide incentives for retrofit and replacement projects involving energy-efficient systems, including those for heating, ventilating and air-conditioning (HVAC) systems.

Now, utilities are restructuring DSM programs to include a facet of commercial and institutional building operations that too often has been overlooked—the maintenance of these systems that can lead to more efficient energy use.

Maintenance managers have long known that efficient, effective preventive maintenance of HVAC systems can cut a facility's energy use dramatically. Their problem has been finding the time, money and support from facility executives that would let them carry out these procedures properly. Utilities now are recognizing this opportunity and are reshaping DSM programs to include incentives for carrying out these procedures.

Maintenance departments can use the energy conservation opportunities (ECOs) for facilities' engineered systems outlined below to get the largest possible benefits for their facilities from participation in DSM programs.

The opportunities discussed in this chapter typify maintenance procedures for HVAC systems that fall under incentive programs from local utilities. Since each facility, and HVAC system is unique, maintenance managers can identify ECOs for their facilities only by doing an on-site inspection and verification of system performance (VOSP).

VERIFICATION OF SYSTEM PERFORMANCE (VOSP)

Heating, ventilating, and air conditioning systems are among the most complex of all building service systems. To maintain a high level of occupant comfort, worker productivity, indoor air quality (IAQ) and energy efficiency, HVAC systems must be properly designed, installed, maintained and operated. The purpose of verification of system performance testing of HVAC systems is to assure the building owner that the system will perform, or is now performing, according to the owner's design criteria and the engineer's design intent.

Inherent in the design intent is that the system operates with energy efficiently and maintains acceptable IAQ in the building. Both of these design concepts are very important. A large portion of a building's total energy consumption comes from the operation of the HVAC system. Inefficient systems can significantly increase operating costs. On the other hand, a well designed and properly performing HVAC system minimizes operating costs, and helps to prevent IAQ complaints.

Problems can occur in the HVAC system during normal operation, maintenance, or after implementation of design modifications. These problems can prevent the system from performing as designed. Therefore, review the verification of system performance test report periodically, and conduct a new test and evaluation when problems are suspected or changes and retrofits are contemplated.

Verification of system performance testing is a total system approach. An HVAC system is a group of interacting components and conditions. Each component might work fine by itself, but unless the entire system has been performance tested there is no assurance that the HVAC system is functioning in an energy efficient manner.

PERFORMANCE TESTING FANS AND PUMPS

The verification of performance tests for fans and pumps include pressure tests across the fan or pump, pressure tests in the air or water distribution system, and flow readings at the air or water terminal. Fan or pump performance is plotted on its respective performance curve and an analysis of system operation is made. The fan performance curve depicts pressure (inches of water), and all possible combinations of air flow (cfm), that the fan can deliver at any given speed (rpm). The system

curve (the plot of the pressures required to overcome resistance and to move the air through the duct system) depicts the pressure drop (inches of water) through the system for every possible air quantity (cfm). The fan will operate at the intersection of the system curve and the performance curve.

The pump performance curve depicts pressure (feet of water), and all possible combinations of water flow (gpm) that the pump can deliver at any given speed (rpm) or impeller diameter (inches). The system curve (the plot of the pressures required to overcome resistance and to move the water through the pipe system) depicts the pressure drop (feet of water) through the system for every possible water quantity (gpm). The pump will operate at the intersection of the system curve and the performance curve.

PERFORMANCE TESTING HEAT EXCHANGERS— CHILLERS, COOLING TOWERS, BOILERS, COILS

Performance testing a chiller or cooling tower involves a heat balance. The total heat rejected in the air- or water-cooled condenser or the cooling tower should equal the refrigerating capacity (the heat picked up in the evaporator), plus the heat from the compressor (heat of compression). The refrigerating capacity (tons of refrigeration) and the heat rejected through the condenser or cooling tower are calculated from the measured flow (gpm) and water temperature difference

Cooling towers, an evaporative process, are adiabatic. All heat rejected from the condenser/cooling tower water is added to the air passing over the tower. The rejected heat is calculated from the measured air flow and air temperature difference. The measurements and calculations should show that the heat extracted from the water is equal to the heat added to the air.

The basic performance test for boilers is determining combustion efficiency. Thermometers and a chemical test kit or an electronic flue gas analyzer are used for this purpose. The combustion efficiency is a function of net stack temperature and the amount of oxygen or carbon dioxide in the flue gas. The net stack temperature is the difference between the temperature of the boiler room air and the temperature of the flue gas in the boiler stack. A flue gas analyzer kit will provide information on percentage of carbon dioxide and oxygen in the stack gas.

Smoke tests (on oil-fired boilers) and detector tube tests (on any fossil fuel burning equipment) are used to test for incomplete combustion and the presence of carbon monoxide.

Performance testing water coils also involves a heat balance. The heat balance is calculated from the measured water flow (gpm) or air flow (cfm), and the water or air temperature differences.

PERFORMANCE TESTING FOR INDOOR AIR QUALITY (IAQ)

A properly designed and operating HVAC system can help prevent IAQ complaints by meeting performance requirements. When properly designed, installed and operating the HVAC system will keep the temperature and humidity in the conditioned spaces comfortable. It will also provide an adequate amount of outside air to meet ventilation requirements, for make-up air and zone pressurization, and to remove airborne pollutants.

Performance testing HVAC systems for IAQ includes testing the system for air flow patterns and room pressurization. This consists of measuring air flow quantity, temperature and humidity. Depending on how the conditioned space is used and the type of HVAC equipment, tests may also be conducted for the following: carbon dioxide, carbon monoxide, refrigerant vapors, nitrogen dioxide, sulfur dioxide, ethylene oxide, ozone, radon, formaldehyde, respirable particles, volatile organic compounds and biological contaminants.

PERFORMANCE TESTING FOR SYSTEM COMMISSIONING

System commissioning is the process of assessing system performance to assure proper functioning and adherence to design criteria, including the actual start-up and testing of the HVAC system. The commissioning process includes varying the operating load at different times during the performance testing and documenting how the system responds. Commissioning provides an opportunity to observe and document a baseline performance. The documentation demonstrates to the owner how the system is operating. It also provides a reference

for monitoring the system to determine when servicing or repair is required, and whether that service or repair restored the system to its original operating condition. An important part of the commissioning process is performance testing the operation of life safety components and their controls. The commissioning service, which is a verification of system performance test, uncovers problems in operation, installation, and design of HVAC systems. HVAC equipment, even in small installations, rarely runs properly without some adjustment. Of course, the larger and the more complex the system the greater the need for performance testing. The only way to assure the building's owner, manager, and occupants that the installed HVAC system meets design, comfort, safety and health criteria is with verification of system performance testing. In addition to increasing comfort and safety for occupants VOSP testing will lead to a savings in energy and operating costs, and extends equipment life.

WHAT THE CLIENT SHOULD EXPECT FROM THE VERIFICATION OF SYSTEM PERFORMANCE CONTRACTOR

Today's complex HVAC systems with their sophisticated equipment, intricate controls, closer tolerances, variable volume systems, and special applications such as fume hood and clean room systems, demand greater skills and knowledge in performance testing. Therefore, it is important for the client to be diligent in selecting a VOSP agency. The VOSP agency should first inspect the HVAC system to determine if it is complete and clean. The mechanical, electrical, and controls VOSP should include items such as dampers and valves installed and operating, ductwork and piping complete, air diffusers and water coils installed, terminal boxes installed and operating, filters and strainers changed, motors installed and energized, etc. The VOSP report should also note that the building envelop is complete, e.g., no gaps between walls, windows, doors, etc. The VOSP agency should then test the system and provide a report with the following information: power requirements, system pressures, and operation of fans, pumps, motors, terminal boxes, controls, etc. Fluid flow testing should be done and a quantitative VOSP report submitted. Through review of the VOSP reports and by taking a synergistic approach to

consult with each other to clarify and solve problems, the design engineer, facility manager, and the VOSP agency can work together to improve system design and operation.

HVAC SYSTEM ENERGY CONSERVATION OPPORTUNITIES (ECO)

It is generally assumed that the HVAC systems and lighting systems account for most of a building's energy use. HVAC energy consumption is affected, in part, by the too common practice of specifying oversized heating and cooling equipment to compensate for any energy inefficiency in a building's design and/or construction. Therefore, energy savings will come from energy management conservation opportunities, maintenance and retrofitting the systems. It is understood that demand-side management success depends on on-going maintenance. To manage and reduce energy consumption consider the following energy conservation opportunities:

Here are the 5 Ts of ECOs

1. Turn it off
 2. Turn it down
 3. Tune it up
 4. Turn it around
 5. Tear it out
- Use nameplate data to prepare an up-to date list of motors, and list routine maintenance to be performed on each.
 - Routinely check time clocks and other control equipment for proper operation. Correct time and day and proper programming of on-off set points to protect them from any unauthorized adjustment.
 - Reduce or turn off heating and cooling systems during the last hour of occupancy. This allows a building to 11 coast."
 - Close interior blinds and shades to reduce night heat loss in the winter and solar heat gain in the summer.
 - Repair or replace damaged or missing shading devices.

- Inspect room supply air outlets and return and exhaust air inlets—diffusers, grilles and registers.
- Clean ducts.
- Open access doors to check for possible obstructions, such as loose insulation in lined ducts, loose turning vanes and closed volume or fire dampers. Adjust, repair or replace these items as necessary.
- Reduce outdoor air intake quantity to the minimum allowed under codes by adjusting outdoor air dampers. Maintain a rate of 1525 cubic feet of air per person.
- Set up and schedule maintenance for outside air economizers.
- List automatic and gravity dampers, and routinely check that they open and close properly.
- Adjust linkage or replace dampers if the blades do not close tightly.
- Replace unsatisfactory, automatic dampers with higher quality opposed blade dampers with seals at edges and ends to cut air leaks.
- Readjust position indicators to accurately show the position of all dampers.
- Clean or replace dirty or ineffective filters regularly.
- Clean coils and other heat exchangers.
- Ensure that all fans rotate in the proper direction.
- Check fan-motor voltage and current and the static pressure across fans. Compare these readings with the VOSP report or the fan curve to determine if the correct amount of air is flowing.
- Adjust fan speed or inlet vanes for proper air flow.
- Maintain correct belt tension.

- Check for drive misalignment.
- Discontinue use of unneeded exhaust fans.
- Rewire toilet exhaust fans to operate only when lights are on,
- Check pump suction and discharge pressures, and plot differential pressure on the pump curve.
- Close the discharge valve if the pump circulation is more than 10% greater than the required water flow.
- Reduce the impeller size for greater energy savings.
- Properly adjust and balance air and water systems and controls.
- Install a time clock or automated energy management system that will reduce heating and/or cooling.
- Close some air conditioning supply and return ducts for HVAC systems operating in lobbies, corridors, vestibules, public areas, unoccupied areas or little-used areas.
- Disconnect electrical or natural gas heating units to these areas.

HVAC Subsystems—Boilers

- Ensure the proper amount of air for combustion is available.
- Check that primary, and secondary air can enter the boiler's combustion chamber only in regulated quantities and at the correct place.
- Inspect boiler gaskets, refractory, brickwork and castings for hot spots and air leaks. Defective gaskets, cracked brickwork and broken casings allow uncontrolled and varying amounts of air to enter the boiler and prevent accurate fuel-air ratio adjustment.
- Perform a flue gas analysis regularly to ensure proper air-to-fuel ratio.
- Take stack temperatures and oxygen readings routinely, and inspect the boiler for leaks.

- Repair all defects before resetting the fuel-air ratio.
- Consider installing an oxygen analyzer with automatic trim for larger boilers. The device continuously analyzes the fuel-air ratio and automatically adjusts it to meet the changing stack draft and load conditions.
- Check that controls are turning off boilers and pumps as outlined in the sequence of operations.
- Observe the fire when the boiler shuts down. If it does not cut off immediately, then check for a faulty solenoid valve, and repair or replace it as needed.
- Adjust controls on multiple systems so a second boiler will not fire until the first boiler can no longer satisfy the demand.
- Make sure that reset controls work properly to schedule heating water temperature according to the outside air temperature.
- Install automatic blowdown controls.
- Pipe blowdown water through an exchanger to reuse heat.
- Experiment with hot-water temperature reduction until reaching an acceptable comfort level.
- Inspect boiler nozzles for wear, dirt or incorrect spray angles.
- Clean fouled oil nozzles and dirty gas parts.
- Replace all oversized or undersized nozzles.
- Adjust nozzles as needed.
- Verify that fuel oil flows freely and oil pressure is correct.
- Watch for burner short cycling.
- Inspect boiler and pipes for broken or missing insulation, and repair or replace it as needed.

- Clean the fire side, and maintain it free from soot or other deposits.
- Clean the water side, and maintain it free from scale deposits.
- Remove scale deposits and accumulation of sediment by scraping or treating chemically, or both.
- Maintain the correct water treatment.

HVAC Subsystems—Cooling

- Adjust controls on multiple staging systems so a second compressor won't energize until the first compressor can no longer satisfy the demand.
- Clean all condenser coils on air-cooled systems.
- Clean off scale build-up in water-cooled condensers.
- Defrost evaporator coils if iced. Determine the cause of icing, and correct it.
- Record normal operating temperatures and pressures, and check gauges frequently to ensure conditions are met.
- Check for proper refrigerant charge, superheating, and operation of the metering device.
- Repair leaking compressor valves.
- Repair leaking liquid line solenoid valves, and clean liquid line strainers.
- Experiment with chilled water supply temperature while maintaining an acceptable comfort level.
- Increase temperatures to reduce energy used by the compressor.
- Decrease temperature to reduce water pump horsepower.

HVAC Subsystems—Controls

- Set the locking screws on the stat cover after setting and calibrating thermostats; they are vulnerable to occupant readjustment.

- Replace missing locking screws.
- Consider replacing existing covers with tamper-proof covers, moving thermostats to a less accessible area, such as the return air duct, or installing solid-state thermostats if tampering persists.
- Change the location of thermostats from areas subject to extreme temperature fluctuations, such as next to a heating or cooling unit, window, outside wall or wall with a lot of vibration.
- Remove moisture, oil and dirt from pneumatic control lines.
- Clean contacts on electrical controls.
- Calibrate controllers.
- Ensure that control valves and dampers are operating properly.
- Check that 3-way valves are installed properly.

CONCLUSION

Before making a final go-ahead decision to upgrade, change or retrofit any HVAC system conduct verification of system performance testing. It is importation to know exactly what the system is doing now and what it is capable of doing in the future to avoid disappointment and embarrassment after costly changes are completed.

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Chapter 10

The Physical Plant Audit

Optimizing utility system performance for steam, air, and water is a very important part of the overall program. This chapter presents utility and combustion energy audit procedures.

THE COMBUSTION AUDIT

A boiler tune-up should be a high priority on the energy audit program. The reason being that with a minimal cost, high operating savings are achieved.

Techniques used to analyze air/fuel ratios, waste heat recovery, and combustion conservation opportunities are presented in this chapter.

COMBUSTION PRINCIPLES

The boiler plant should be designed and operated to produce the maximum amount of usable heat from a given amount of fuel.

Combustion is a chemical reaction of fuel and oxygen which produces heat. Oxygen is obtained from the input air which also contains nitrogen. Nitrogen is useless to the combustion process. The carbon in the fuel can combine with air to form either CO or CO₂. Incomplete combustion can be recognized by a low CO₂ and high CO content in the stack. Excess air causes more fuel to be burned than required. Stack losses are increased and more fuel is needed to raise ambient air to stack temperatures. On the other hand, if insufficient air is supplied, incomplete combustion occurs and the flame temperature is lowered.

BOILER EFFICIENCY

Boiler efficiency (E) is defined as:

$$\%E = \frac{\text{Heat out of Boiler}}{\text{Heat Supplied to Boiler}} \times 100 \quad (10-1)$$

For steam-generating boiler:

$$\%E = \frac{\text{Evaporation Ratio} \times \text{Heat Content of Steam}}{\text{Calorific Value of Fuel}} \times 100 \quad (10-2)$$

For hot water boilers:

$$\%E = \frac{\text{Rate of Flow from Boiler} \times \text{Heat Content of Water}}{\text{Calorific Value of Fuel}} \times 100 \quad (10-3)$$

The relationship between steam produced and fuel used is called the evaporation ratio.

The overall thermal efficiency of the boiler and the various losses of efficiency of the system are summarized in Figure 10-1.

To calculate dry flue gas loss, formula 10-4 is used.

$$\text{Flue gas loss} = \frac{K (T \pm t)}{\text{CO}_2} \quad (10-4)$$

where

K	= constant for type of fuel =	0.39 Coke
		0.37 Anthracite
		0.34 Bituminous Coal
		0.33 Coal Tar Fuel
		0.31 Fuel Oil

T = temperature of flue gases in °F

t = temperature of air supply to furnace in °F

CO₂ = percentage CO₂ content of flue gas measured volumetrically.

It should be noted that formula 10-4 does not apply to the combustion of any gaseous fuels, such as natural gas, propane, butane, etc. Basic combustion formulas or nomograms should be used in the gaseous fuel case.

To estimate losses due to moisture, Figure 10-2 is used.

The savings in fuel as related to the change in efficiency is given by formula 10-5.

$$\text{Savings in Fuel} = \frac{\text{New Efficiency} \pm \text{Old Efficiency}}{\text{New Efficiency}} \times \text{Fuel Consumption} \quad (10-5)$$

1. Overall thermal efficiency.....	_____
2. Losses due to flue gases	
(a) Dry Flue Gas	_____
<p>The loss due to heat carried up the stack in dry flue gases can be determined, if the carbon dioxide (CO₂) content of the flue gases and the temperatures of the flue gas and air to the furnace are known.</p>	
(b) Moisture % Hydrogen.....	_____
(c) Incomplete combustion	_____
3. Balance of account, including radiation and other unmeasured losses.....	_____
TOTAL.....	100%

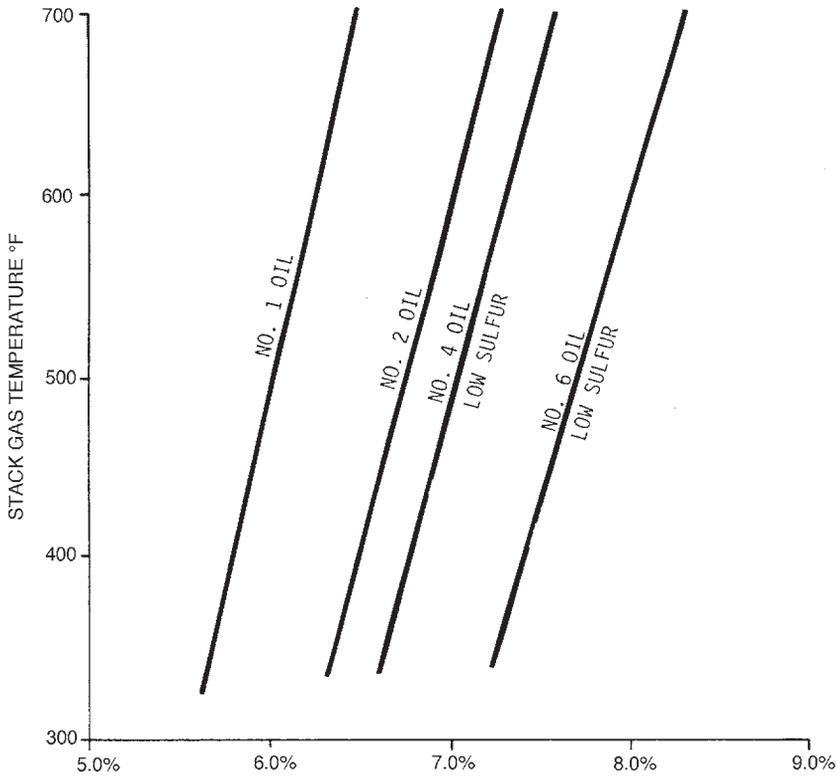
Figure 10-1. Thermal Efficiency of Boiler

Figure 10-3 can be used to estimate the effect of flue gas composition, excess air, and stack temperature on boiler efficiency.

Instructions for use of nomograph (Figure 10-3):

1. Enter the nomograph at the lower horizontal line at the percentage of CO₂ in the flue gas for the fuel being used.
2. Enter the lower left-hand vertical part of the nomograph at the percentage O₂ in the flue gas and proceed horizontally right to the intersection of the plotted curved line.
3. Proceed vertically upward at this intersection to the stack temperature line.
4. Proceed horizontally left at this intersection and read the boiler efficiency corresponding to the fuel used.

Primary and secondary air should be allowed to enter the combustion chamber only in regulated quantities and at the correct



NOTE:

- 1. The figure gives a simple reference to heat loss in stack gases due to the formation of water in burning the hydrogen in various fuel oils.
- 2. The graph assumes a boiler room temperature of 80°F.

Figure 10-2. Heat Loss Due to Burning Hydrogen in Fuel (Source: Instructions For Energy Auditors, Volume I)

place. Defective gaskets, cracked brickwork, broken casings, etc. will allow uncontrolled and varying quantities of air to enter the boiler and will prevent accurate fuel/air ratio adjustment. If spurious stack temperature and/or oxygen content readings are obtained, inspect the boiler for air leaks and repair all defects before a final adjustment of the fuel/air ratio.

When substantial reductions in heating load have been achieved, the firing rate of the boiler may be excessive and should be reduced.

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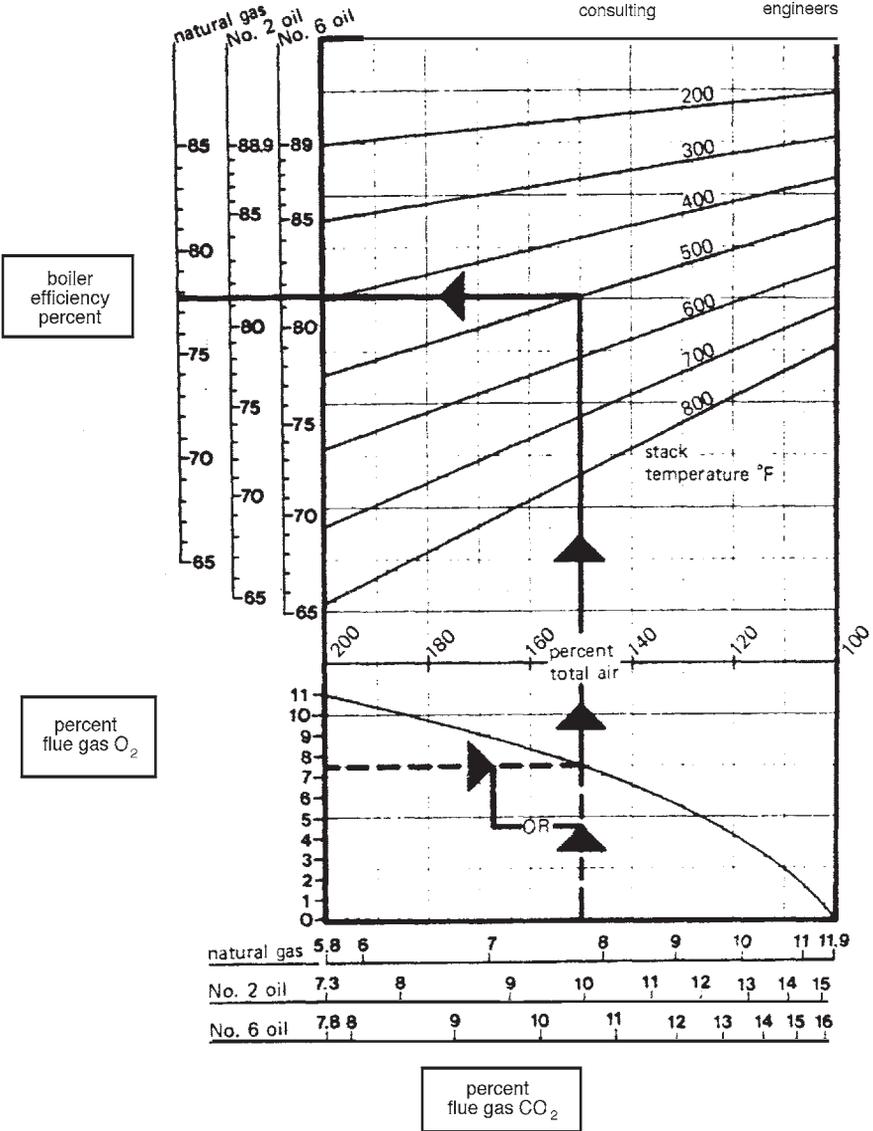


Figure 10-3. Effect of Flue Gas Composition and Temperature on Boiler Efficiency (Source: Guidelines For Saving Energy in Existing Buildings—Engineers, Architects and Operators Manual, ECM-21)

Consult the firing equipment manufacturer for specific recommendations. (A reduced firing rate in gas and oil burners may require additional bricking to reduce the size and shape of the combustion chamber.)

Use Figure 10-3 determine the optimum fuel/air ratio for any given combination of circumstances. Indicators of maximum combustion efficiency are stack temperature, percentage CO₂ and percentage O₂.

Devices are available which continuously measure CO₂ and stack temperature to produce a direct reading of boiler efficiency. These indicators provide boiler operators with the requisite information for manual adjustment of boiler fuel/air ratio. They are suitable for smaller installations or buildings where money for investment in capital improvements is limited. A more accurate measure of combustion efficiency, however, is obtained by an analysis of oxygen content rather than of other gases such as carbon dioxide and carbon monoxide. As shown in Figure 10-3, the cross checking of O₂ concentrations is useful in judging burner performance more precisely. Due to the increasing utilization of multifuel boilers, however, O₂ analysis is the single most useful criterion for all fuels since the O₂ total air ratio varies only within narrow limits.

For larger boiler plants, consider the installation of an automatic continuous oxygen analyzer with "trim" output that will adjust the fuel/air ratio to meet changing stack draft and load conditions. Most boilers can be modified to accept an automatic fuel/air mixture control by a flue gas analyzer, but a gas analyzer manufacturer should be consulted for each particular installation to be sure that all other boiler controls are compatible with the analyzers.

It is important to note that some environmental protection laws might place a higher priority on visible stack emissions than on efficiency and optimization of fuel combustion, especially where fuel oil is burned. The effect of percent total air on smoke density might prove to be an overriding consideration and limit the approach to minimum excess air. All applicable codes and environmental statutes should be checked for compliance.

PREHEAT COMBUSTION AIR AND HEAVY FUEL OIL TO INCREASE BOILER EFFICIENCY

Preheating the primary and secondary air will reduce its cooling effect when it enters the boiler combustion chamber, thus increasing

the efficiency of the boiler as indicated in Figure 10-4 will also promote a more intimate mixing of fuel and air which will further improve efficiency. Waste heat from flue gases, blowdown, condensate, hot wells, etc. may be used to preheat combustion air and/or oil, either in the storage tanks (low sulfur oil requires continuous heating to prevent wax deposits) or at the burner nozzle.

A waste heat exchange directly from flue gases to combustion air using static tubular, plate, or rotary exchangers can be implemented. Heat exchange may also be made indirectly through run-around coils in the stack and combustion air duct. In most boiler rooms, air is heated incidentally by hot boiler and pipe surfaces and rises to collect below the ceiling. Use this air directly as preheated combustion air by ducting it down to the firing level and directing it into the primary and secondary air inlets.

Preheating combustion air has the following advantages:

- Flame temperature is raised, thus permitting air increase in boiler output.
- Higher flame temperature reduces excess air requirements.
- Dual firing is made simpler.

As indicated by Figure boiler efficiency will increase by approximately 2 percent for each 100°F added to combustion air temperature.

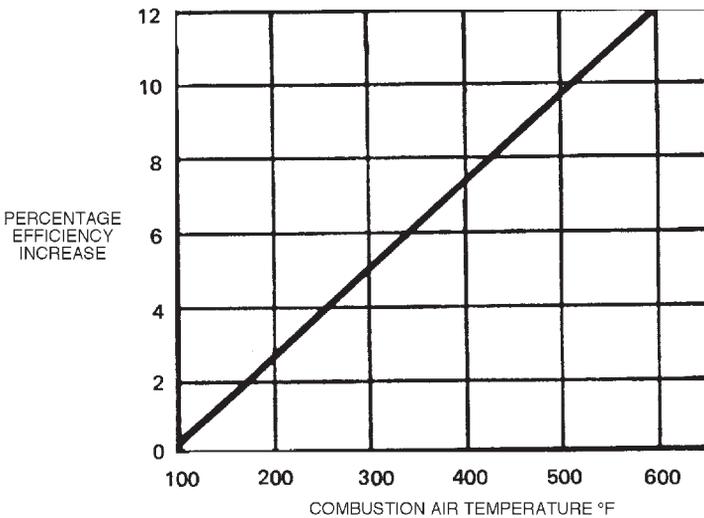


Figure 10-4. Efficiency Increase with Pre-Heated Air

Oil must be preheated to at least the following temperatures to obtain complete atomization:

No. 4 oil - 135°F

No. 5 oil - 185°F

No. 6 oil - 210°F

Heating beyond these temperatures will increase efficiency, but care must be taken not to overheat, as vapor-locking could cause flame-outs. The increased efficiency obtained by preheating oil could be as high as 3 percent but depends on the particular constituents of the oil.

In doing the analysis, obtain the manufacturer's recommendations on preheated fuel and air for the particular equipment being considered. Obtain the fuel oil dealer's recommendations on the preheating levels most appropriate for the fuel to be used. (Combustion air can be preheated up to 600°F for pulverized fuels and up to 350°F for stoker-fired coal, oil, and gas. The upper temperature limit is determined by the design and materials of the firing equipment.)

REPLACE EXISTING BOILERS WITH MODULAR BOILERS

Heating boilers are usually designed to operate at maximum efficiency only when producing their rated output of Btu. As shown in Figure 10-5, however, most boilers operate at 60 percent or less of capacity for 90 percent of the heating season, resulting in significant boiler inefficiencies and wasted fuel.

This waste can be diminished but not eliminated by high-low firing systems in large capacity boilers, as shown in Figure 10-6.

A generally superior means of meeting a fluctuating boiler load demand is a system of modular boilers which can be fired independently. Each small-capacity unit has a relatively low thermal inertia (giving rapid response and low heat-up and cool-down losses) and will either be firing at a maximum efficiency can be improved from 68 to 75 percent in a typical installation where single-unit, large-capacity boilers are replaced by any modular boilers. This represents a saving of approximately 9 percent of the present yearly fuel consumption of most commercial buildings.

To increase seasonal efficiency, it is advisable to replace a single boiler with an array of smaller modular boilers. Each module would

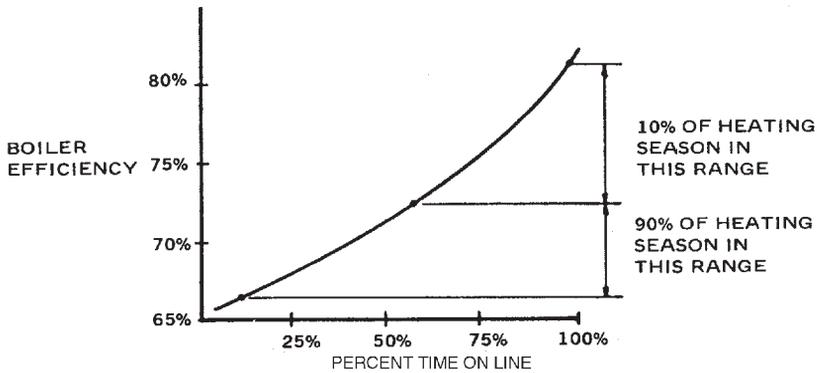


Figure 10-5. Effects of Boiler Cycling

be fired on demand at 100 percent capacity, with load fluctuations being met by firing more or fewer boilers. Especially where the present boiler plant has deteriorated to the point where it is at or near the end of its useful life, it is often worthwhile to consider replacement with modular boilers sized to meet the reduced heating load resulting from other ECOs.

Note: Modular boilers are particularly effective in buildings with intermittent short-time occupancy, such as churches. They provide rapid warm-up for occupied periods and low standby losses during extended unoccupied periods.

To calculate the potential energy savings due to this change, refer to

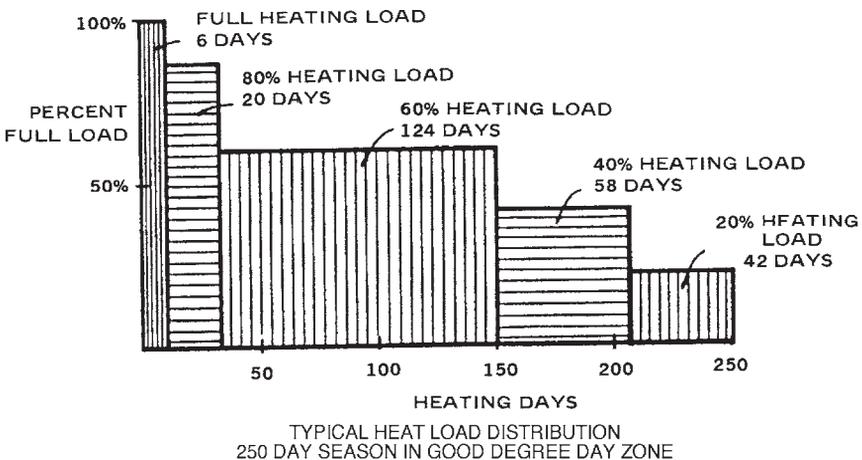


Figure 10-6. Seasonal Heat Load Distribution

Figure 10-6 to determine the seasonal efficiency of the proposed modular boiler installation.

MAINTAIN FUEL BURNING EQUIPMENT AND HEAT TRANSFER SURFACES

Fuel burning equipment allowed to become dirty and out of adjustment becomes increasingly inefficient with continued usage. Likewise, both fire-side and water-side heat transfer surfaces become less and less effective if allowed to become fouled by products of combustion, scaling, and other impurities. All heat not properly transferred is discharged through the stack.

After reducing the building and distribution heating load, clean and/or replace dirty oil nozzles, oversized or undersized nozzles, fouled gas parts, and improperly sized combustion chambers. Reduce nozzle sizes and modify combustion chambers for proper combustion.

The condition of the heat transfer surface directly affects heat transfer from the combustion chamber and/or hot gases. Keep the fire-side of the heat transfer surface clean and free from soot or other deposits and the air- and water-sides clean and free of scale deposits. Remove deposits by scraping where they are accessible, by chemical treatment, or by a combination. In the case of steam boilers, once the water-side of the boiler is clean, institute correct water treatment and blowdown to maintain optimum heat transfer conditions.

REDUCE BLOWDOWN LOSSES

The purpose of blowing down a boiler is to maintain a low concentration of dissolved and suspended solids in the boiler water and to remove sludge in the boiler to avoid priming and carryover. There are two principal types of blowdown intermittent-manual blowdown and continuous blowdown. Manual blowdown (or sludge blowdown) is necessary for the operation of the boiler regardless of whether continuous blowdown is being used. The frequency of manual blowdown will depend on the volume of solids in the boiler makeup water and the type of water treatment used. While continuous blowdown requires a steady supply of additional energy (because the makeup water must be heated), these losses can be minimized with automatic blowdown control and

heat recovery systems.

Install automatic blowdown controls to monitor the conductivity and pH of the boiler water allowing the boiler to blow down only when required to maintain acceptable water quality. Further savings can be realized by piping the blowdown water through a heat exchanger or through a flash tank with a heat exchanger.

To calculate the potential savings:

1. Determine the blow-down rate and calculate the total heat available from blowdown.
2. Compute the heat to be recovered by using a heat exchanger and/or by adding a flash tank.

BURNERS

The choice of a burner is critical to the whole boiler efficiency operation. The basic requirement of an oil burner is that it change the oil into tiny particles thus exposing the greatest surface area of combustible materials in the shortest possible time. Some burners atomize the oil better than others.

Another important aspect is that the burner have the same operating range or turndown ratio as the boiler. Losses of up to 20 percent in fuel consumption may be occurring when a poor turndown ratio burner is matched against a fluctuating steam load. Burners and associated control systems should be able to modulate through the whole range of output called for by the facility.

Air-atomizing burners are considerably more efficient than steam-atomizing burners, due primarily to the relatively higher O₂ content of the fuel at the instant of combustion.

FLAKY PRODUCTS AND SERVICES

As with any new technology, care should be given to “fly-by-night con artists.” The market place will clean itself, but in the meantime many people will be hurt. The example of the “unturned automobile” should not be overlooked. If the automobile was “unturned” and fitted with an energy saving carburetor, the end result may be a savings in gasoline.

The question asked is whether the savings is the result of the carburetor or a tune-up which had to be done after the unit was installed.

COMPRESSED AIR AUDIT

Air leaks are a major energy loss as indicated in Table 12-3, Chapter 12. Doubling the size of air leak increases the loss four times, as illustrated in Figure 10-7.

The energy audit should determine pressure requirements of each user. If the pressure of the distribution system can be lowered savings will be realized, as illustrated by Figure 10-8. If only one or two users require a higher pressure, it may be desirable to purchase a smaller compressor for these users.

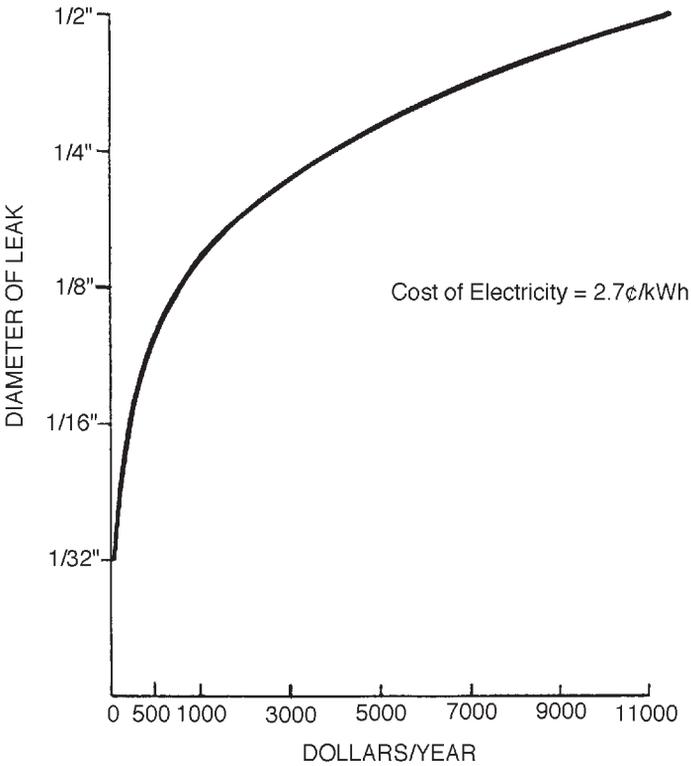


Figure 10-7. Cost of Air Leaks at 100 PSI (Source: *Instructions For Energy Auditors, Volume II*)

A third area to check is the temperature of the incoming air. The lower the inlet air temperature, the greater the volume of air that can be delivered at room temperature. Thus the installation of a manual inlet damper may be justified. This would permit use of outside air during winter and inside air during summer.

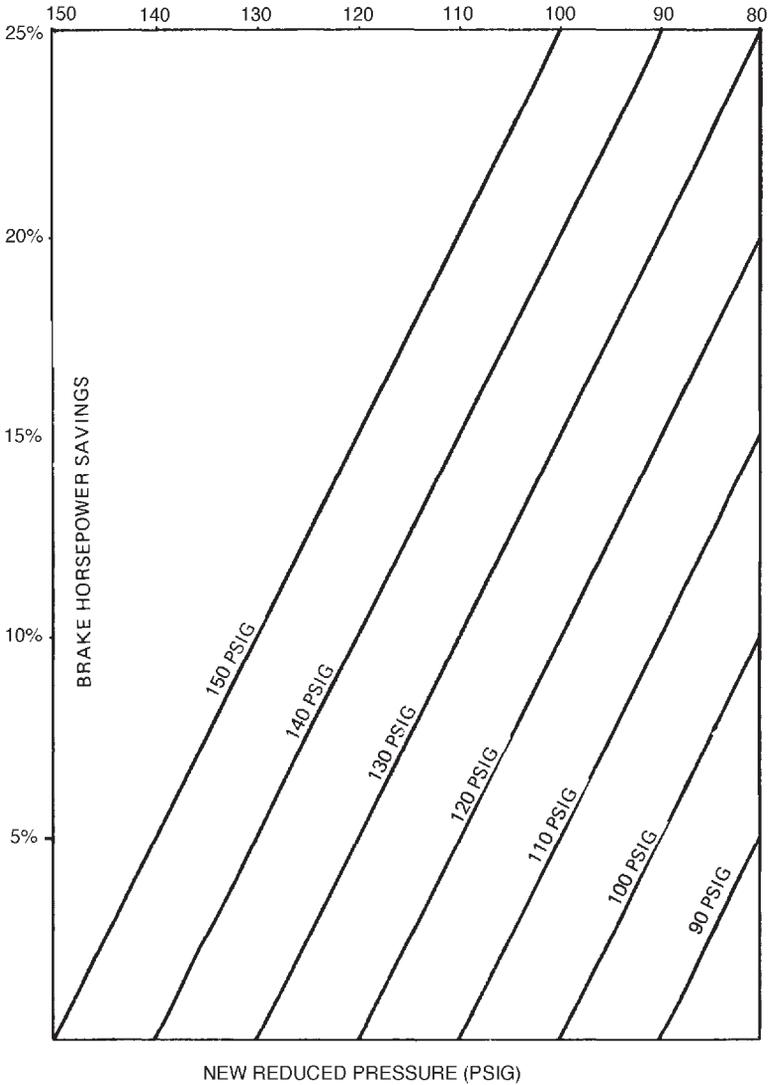


Figure 10-8. Savings with Reduction in Pressure (Source: *Instructions for Energy Auditors, Volume I*)

INSULATION

Savings as a result of using the optional economic insulation thickness has been estimated as 1,400 trillion Btus.

Figure 10-9 illustrates minimum recommended pipe size insulation for each pipe diameter.

Several manufacturers offer access to computer program simulation by use of a touch dial telephone and an assigned user number. These programs can calculate economic thickness for tanks as well as equipment and piping. To use these programs the user dials the computer telephone number and then talks to a computer by touching numbers on the telephone. In a simulated voice the computer transmits the economic thickness. The detailed analysis is given to the user by a local sales representative.

The primary function of insulation is to reduce the loss of energy

<i>Piping System</i>	<i>Temperature Range °F</i>	<i>Insulation Thickness Inches</i>
<i>Heating</i>		
High pressure steam	306 to 400	1.5-2.0
Medium pressure steam	251 to 305	1.0- 1.5
Low pressure steam	up to 250	1.0
Condensate	190 to 220	1.0
Hot water	up to 200	1.0
Hot water	over 200	1.0
<i>Cooling</i>		
Chilled water	40 to 60	.75-1.0
Refrigerant and Brine	below 32	1.0-1.5
A WORD OF WARNING: Make absolutely sure that the pipe or vessel to be insulated is properly primed with zinc or silicone costing before installing the insulation.		

Figure 10-9. Minimum Piping Insulation (Source: *Instructions for Energy Auditors, Volume II*)

from a surface operating at a temperature other than ambient. The economic use of insulation reduces plant operating expenditures for fuel, power, etc.; improves process efficiency; increases system output capacity; or may reduce the required capital cost.

There are two costs associated with the insulation type chosen: a cost for the insulation itself, and a cost for the energy lost through this thickness. The total cost for a given period is the sum of both costs.

The optimum economic thickness is that which provides the most cost-effective solution for insulating and is determined when total costs are a minimum. Since the solution calls for the sum of the lost energy and insulation investment costs, both costs must be compared in similar terms. Either the cost of insulation must be estimated for each year and compared to the average annual cost of lost energy over the expected life of the insulation, or the cost of the expected energy loss each year must be expressed in present dollars and compared with the total cost of the insulation investment. The former method, making an annual estimate of the insulation cost and comparing it to the average expected annual cost of lost energy, is the method used in this analysis. Use Figure 10-10 to calculate heat loss through pipes at various sizes, insulation levels, and temperatures.

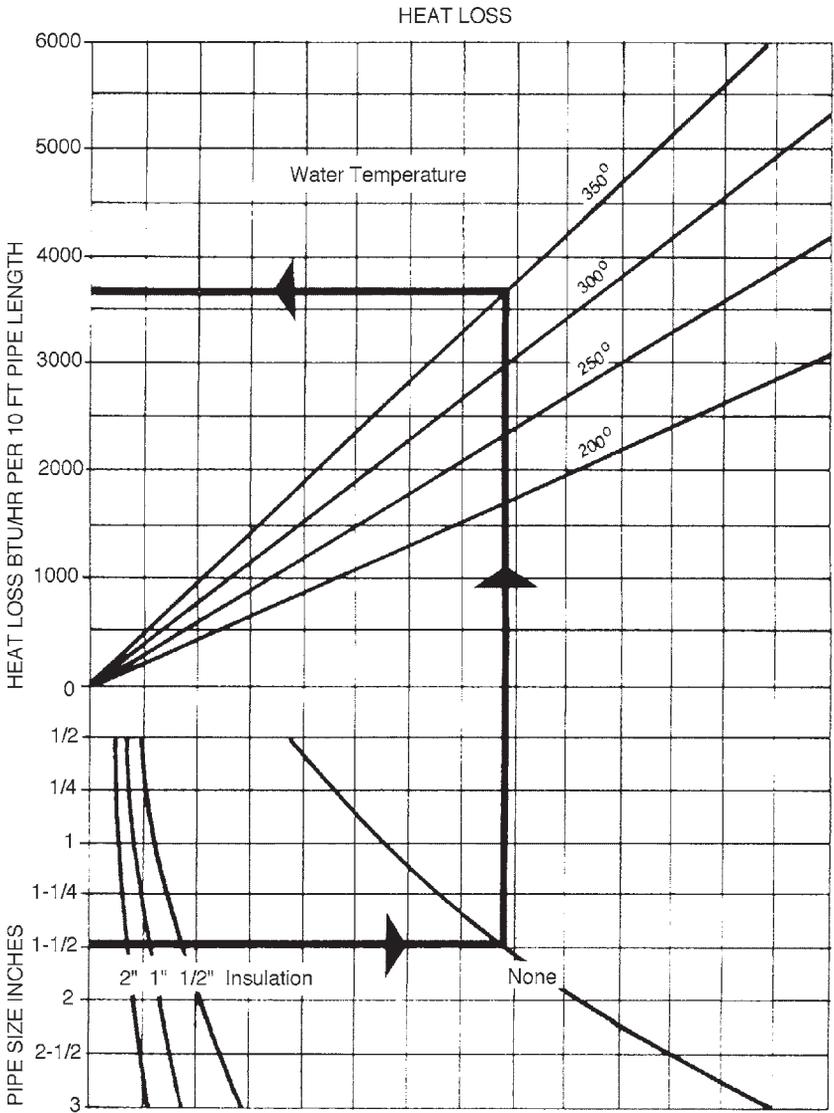


Figure 10-10. Pipe Heat Losses

Chapter 11

Central Plant Retrofit Considerations*

Refrigerant changes, along with normal aging, are driving the need to retrofit or replace chillers within a central plant at a much greater pace than ever before. This is an opportunity to improve the efficiency of the chiller as well as the overall performance of the plant. The key to taking advantage of this opportunity is to “re-engineer, not replace.” In addition to issues relating to type and size of chillers, chilled water piping, control systems, cooling tower selection and condenser water piping should be addressed to ensure maximum benefit from the cost of the retrofit.

INTRODUCTION

The central cooling plant is a critical component of any building or facility. As with all mechanical equipment, there is a finite useful life for the equipment. While an aggressive and extensive maintenance program can extend this useful life, there comes a time when replacement of the equipment is necessary. In addition, retrofit projects can be undertaken as part of a refrigerant management strategy, a desire to improve efficiency or as a result of changes in the use or needs of the facility. The major component is the chiller, however the cooling tower also deserves specific consideration. Because this system is generally deemed to be critical to the operation and because it is a major energy consumer within the facility, special consideration should be given to the retrofit process. Since a significant cost is anticipated and budgeted, changes that will im-

*This chapter by Jon R. Haviland, P.E., CEM, was originally presented at the 22nd World Energy Engineering Congress, sponsored by the Association of Engineers, October 1999.

prove efficiency and reliability may be easier to justify based on the incremental cost and savings. In addition, life cycle cost analysis is more likely to be used since these projects are generally undertaken directly by the owner.

RE-ENGINEERING

The first consideration in undertaking a central plant retrofit project is that the scope of the project should not be limited to simple replacement of the components. Because this project is usually taking place at least 20 years after the facility was originally constructed, the system should be re-engineered based on the current and presently anticipated loads and usage of the facility. This will help to promote the goals of increasing efficiency and reliability and position the facility for the long term. While it may not be possible to create an ideal new central plant, the re-engineering process should strive to create as efficient and effective a plant as possible.

There are a number of reasons for this re-engineering. The first involves the original equipment selection. In general, engineers are conservative in their load calculations and equipment selection. While this is generally good, as the intent is to ensure adequate cooling even if the system is slightly overloaded or not operating at full capability, too much of a good thing can lead to inefficient operation. A second reason for re-engineering is due to changes in the peak load and/or load profile for the facility. This can be either an increase, such as added equipment, or a decrease, such as the results of lighting retrofits or other efficiency improvements in the facility. Another example is changes due to a change in occupancy or use of the space. This can lead to a change in the design load of the facility as well as to changes in the operating profile which affects equipment selection. Changes in the operating profile are very common because of the proliferation of 24/7 operations and the increased need for continuous cooling for specific areas within a facility.

Technology changes are another big reason for re-engineering the central plant. One major advance is in the area of control systems. Today's control systems have much greater capacity than the systems that were available when the plant was first constructed, and the limitations in control strategies sometimes played a significant role in the design of the central plant. An offshoot of this is the inclusion

of digital control panels on the equipment. This greatly improves the operation of the equipment as well as providing availability of better information on the operation of the equipment. Strategies like variable flow in chillers were difficult to achieve with analog control panels. Another big change is the availability of variable speed drives and the efficiency improvements that can be gained from their proper application. Potential uses are for secondary pumping systems, chilled water and condenser water pumps for variable flow chillers, chillers and cooling tower fans.

ALTERNATIVES TO CONSIDER

As is always the case with engineering, there are multiple solutions to any problem and different ways to design a system that will produce the desired result, cooling for people and/or equipment. Each option will have good features and bad features that must be weighed to determine what system should be chosen for a particular application. There is no one best solution for every application. This section will present some of the alternatives that should be considered and some of the good and bad features of each, as well as some of the criteria that should be considered. The final evaluation is generally site-specific and requires a detailed engineering analysis to properly evaluate the various factors to choose the best system for the particular operation. Among the factors that must be considered are electric costs and rate structure, natural gas rates, maintenance requirements and costs, electric deregulation impact and potential changes in operation.

Hybrid Plants

The first alternative comes under the general heading of hybrid cooling plants. There are a number of different technologies that will provide cooling and a hybrid plant incorporates more than one of these technologies. These technologies include electric chillers, absorption chillers, engine-drive and/or dual-drive chillers, thermal storage systems and use of a water-side economizer cycle. Most of these choices seek to provide some or all of the cooling without using electricity during the high cost, peak period. Thus the electric rate structure is one of the primary determinants of the choice of cooling medium. Hybrid plants are generally a better option because the cost

of cooling with electricity during some periods is less than the cost of cooling with natural gas.

Absorption chillers, especially double-effect, offer a good option for utility rate structures with high peak period demand or usage charges or rate schedules with ratchet clauses for the demand charges. There is a significant first cost premium for this equipment. Maintenance costs are generally comparable with electric chillers, although the absorption chiller requires better day-to-day maintenance.

Engine-driven chillers provide an alternative to absorption chillers when a natural gas cooling is desired. Engine-driven chillers utilize the same type of equipment as electric chillers for cooling, but replace the electric motor with a natural gas fueled engine. One problem with this equipment is that the maintenance and operation people are unfamiliar with the requirements of the engine.

Especially for truck- derivative engines, maintenance costs are significant and must be accounted for in the operating cost analysis. Noise and vibration are significant concerns that must be addressed. A major benefit of engine-driven chillers is the opportunity to capture waste heat from the engine as a mechanical cogeneration system. An offshoot of these units is the limited availability of dual-drive chillers with both an electric motor and a natural gas engine available to drive the chiller.

Thermal storage systems are useful to shift cooling load from the high cost times to low cost times. While there were equipment and application problems when these systems were first being installed, most of these have been corrected. There are several good design and equipment guides for these systems. The major design concern is allowing for sufficient storage and re-charging capacity to allow for some load and temperature increase for overnight periods. There is significant danger of poor operation and inability to fully transfer load if some reasonable spare capacity is not provided in the design of these systems.

Water-side economizers are of use in areas with low wet bulb temperatures, especially when the use of an air-side economizer cycle is not feasible. One problem that must be considered in the design is the change-over from economizer operation to chiller operation since the low condenser water temperature may affect the operation of the chiller. The use of a water-side economizer also affects the cooling tower selection as there is additional benefit to providing a larger than necessary cooling tower.

Primary-secondary Chilled Water Distribution

Primary-secondary chilled water distribution systems were developed to allow constant flow through chillers, required by the chiller manufacturers, with variable flow for the load side of the system to improve efficiency. The primary applications were for multi-building systems or systems with larger variations in load. The advent of variable speed drives and DDC control systems made the operation of these systems much more effective. Newer chillers with digital control panels are able to operate effectively and safely with variable flow, and they can be used in a simplified system to achieve the savings of variable flow in the load-side loop. Another significant advantage of the primary-secondary system is the system flexibility that it offers. This type of system makes it easier to incorporate hybrid systems, as well as thermal storage systems and water-side economizers. Depending on the piping and valving arrangement, the system can load chillers evenly, load chillers sequentially or allow for preferential loading of particular chillers as is required for a hybrid system to gain the maximum benefit. The complexity of these systems also requires a well developed sequence of operations to ensure that the control system will provide the proper operation.

Chiller Sizing

Over the years, engineers have gotten into the habit of specifying equal size chillers for multiple chiller installations. The primary argument for this is to reduce the complexity of the system and make it easier to maintain the equipment. In addition, control systems did not have the intelligence to deal with different size chiller effectively. With the advent of DDC control systems and the trend away from stocking of spare parts, these reasons no longer apply. For most applications, such as office buildings and retail, there appears to be a definite benefit to providing two different sized chillers. For many applications, sizing at 60% and 40% of design load seems to provide better operation, although this should be confirmed in the analysis phase. The benefits are twofold. First, one chiller can supply all the requirements for the building for more hours, thus reducing the total hours of chiller operation. Second, fewer of the hours of operation of the chillers are at less than 50% of capacity where the machines are less efficient.

Condenser Water System

Typically, condenser water systems for electric chillers are designed with a 10°F temperature differential. Absorption chiller sys-

tems have been designed with higher temperature differentials due to the greater amount of heat rejected from these units. There may be benefits for electric chiller systems in using a larger temperature differential for the condenser water system. The primary benefit is the reduction in the quantity of water to be pumped for the condenser water system to reject the same amount of heat. This allows the use of smaller piping and pumps. This is especially useful if the system capacity is being increased and the condenser water pipe size is a limiting factor. The higher temperature will improve the efficiency of the cooling tower, but will reduce the efficiency of the chiller. There is a reduction in first costs due to the smaller pumps and piping, with no change in the cooling tower or the chiller. Note that there may be a minor change in the cooling tower, but having an oversize cooling tower is generally beneficial so no change is recommended. Oversizing the cooling tower provides additional capacity and allowance for equipment problems for the least additional cost. For operating costs, there is a reduction in pumping energy, possibly a reduction in cooling tower energy, offset by an increase in chiller energy. The net impact depends on the size of the system, amount of pumping, climate and hours of operation, but generally results in a net reduction in energy consumption.

RETROFIT PROCESS

While the basic process of a retrofit project is similar to a new construction project, there are some special considerations in a retrofit project. Most of these stem from the difference between working with the existing system and design versus the ability to start with a clean sheet of paper for a new system. It is very beneficial to the process if the engineer and contractor have some experience working with retrofit projects.

Engineer Selection

As noted above, having an engineer experienced with retrofit projects is an important criteria in the selection of an engineer. Typically the best option is an engineer with some background in facilities management or engineering. As one who has a facilities management background, not a design background, I can attest to the potential problems caused by engineers who do not have the experience of

living with a system over a period of time. Generally, these are sins of omission, not commission, in that they have not had this type of experience to guide their thinking about systems and equipment. Locating these engineers may not be easy, and the best source is people who have recently completed a similar project. Another consideration in the selection of an engineer is having someone who is willing to work with and listen to a peer reviewer and to the operating personnel. Because of the complex nature of most retrofit projects, the inclusion of a peer review activity, primarily as part of the commissioning process, is important. This person provides another set of opinions and brings a different range of experiences to the project. Both parties have to keep in mind that there is always more than one option that will provide the desired results and they must help the owner evaluate these options. Both parties should have the best interests of the owner in mind, but also must remember that the ultimate responsibility belongs to the engineer of record.

Information Sources

The first step in the information gathering process is a site visit. This is an opportunity to review the original design documents of the plant as it currently exists and to determine the history of changes that have occurred. This also provides the engineer an opportunity to review the current method of operation of the plant. The site visit is also an opportunity to interview the operators about the plant.

The operator interview should elicit information about the general operation of the plant, operational history of the existing equipment, plant history and a discussion of any idiosyncrasies that may exist with the plant or facility. While it is important that the engineer be willing to talk with and listen to the operators, this does not mean that everything they say is to be taken as gospel and that all problems they refer to need to be addressed. Given the opportunity, they will be sure to gild the lily to make their job easier without necessarily providing real benefit to the owner.

The site visit is also an opportunity to review the operating logs for the equipment. The engineer needs to review these to evaluate the reliability of the information they contain. Assuming they contain reliable information, this can provide information to support, or to refute, the information provided by the operators. Unfortunately, sometimes the information is not collected properly and inaccuracies are not questioned. In these cases, the logs have limited value to the process.

The final information source that may or may not be used is monitoring of the plant operation. The use of monitoring data is most prevalent when retrofit projects are part of a larger energy services agreement. In these cases, the financial backers of the project are interested in a better baseline than can be provided by other methods. Monitoring can utilize an existing building management system, although additional inputs and memory capability may be required, or may be done with temporary data logging equipment. If the project is part of an energy services project, then utilizing the existing BMS is a good option since the same information will be required for post implementation monitoring to confirm the savings.

Evaluation of the Alternatives

Because there will be several options that will provide the desired results, the evaluation of these alternatives is important. In addition, this is somewhat more involved than it is for new construction because in most cases the facility will continue to operate during the retrofit project. This means that the constructability of the proposed design is an important factor. Ideally, having a contractor involved as part of the team throughout the process may help address this issue. This is a case where the contractor should be reimbursed for his time if he has no guarantee of getting the job. If the owner has one contractor he is comfortable working with, then this contractor should be brought into the process early and can work on a negotiated contract basis. The second important consideration is the opinion of probable costs. It is necessary to have a good idea of the first costs of each option to provide a good base for the analysis. Again, the involvement of a contractor will help improve this part of the process.

The major factor in the evaluation will be the estimates of operating costs. Note that since there will be a significant investment in the retrofit project, it may be easier to justify efficiency improvements based on incremental costs and savings instead of having to justify the entire cost of a project solely by the anticipated efficiency gains. There are several levels of estimates of operating costs that can be utilized, and the extent of the analysis will depend on the extent of the project. In addition, the simpler methods may be used as a screening tool to reduce the amount of simulation work that may be required. The simplest methods are generally spreadsheet approaches that frequently rely on bin weather data. A second step that may or may not have application is to use simple programs that evaluate specific

equipment or proposed changes. The ultimate analysis tool is a full energy simulation, using DOE 2 or one of the proprietary programs that are available. As a reality check, the results of the analysis should be compared to current utility bills.

Design Phase

After one of the alternatives has been selected, the next step is the design phase. Again, the commissioning agent should be involved throughout and provide the peer review function as well. The plant operators should have the opportunity to review and comment on the design as it progresses. Again, this is additional input that should be considered, but the final responsibility lies with the engineer of record. Contractor input continues to be valuable, especially in developing the sequence of construction. This also needs to be reviewed with management in terms of the number and length of any shut-downs that may be required. A very important part of the design includes the development of the sequence of operations. This is necessary to guide the controls contractor in developing his programming to ensure the operation follows that developed through the analysis phase.

Construction Phase

These considerations carry over to the construction phase. Proper coordination between the contractor and the operating personnel is critical to the success of the project. Contractor selection should, to the extent possible, be limited to those who have had experience with similar projects. Especially critical is the attitude of the on-site superintendent and project manager, who should be interviewed as part of the selection process.

Commissioning

The final step to ensure the success of the retrofit project is commissioning of the system. Development of the commissioning plan must proceed with the design and construction phases, especially since it is likely that completion of the project will occur in stages over time. The commissioning information provides a baseline to check proper operation of the plant over time, especially if there are operations people who get involved in changing the operation in perhaps misguided efforts to improve the operation. After the project is completed, there should be some on-going monitoring of the

operation. This is to ensure that the systems continue to operate as intended, as well as to provide the information for possible refinement of the sequence of operations.

SUMMARY

In summary, a retrofit project needs to be approached in some ways as if it were a new installation and the opportunity should be taken to examine all feasible options that will improve the efficiency of the system. The process should focus on the system efficiency, not just on the individual components. The process is complicated by the limitations imposed by the existing plant, available space and need to keep the system operating during the construction phase. For these reasons, the choice of engineers and contractors is critical to the success of the project.

Chapter 12

Maintenance and Energy Audits

An audit for a good preventive maintenance program as well as good housekeeping methods is essential. Probably no single one area offers the best rate of return and is the most overlooked and underemphasized area. This chapter will illustrate both the administrative and technical areas that make up a good preventive maintenance program.

WORK ASSIGNMENTS

Each major item of equipment must show a history of maintenance and repair. A procedural system of indexing scheduled work and quality control should be established by the supervisor in conjunction with the company's standards of performance.

Personnel assigned to the maintenance control system must be made familiar with all work items. Thus assignments are to be regularly rotated so as to familiarize each man with the equipment.

TRAINING

Periodically, personnel will be requested to attend manufacturers' seminars on maintenance methods for physical plant, building, kitchen equipment, etc.

To assure skilled maintenance personnel and maintenance supervisors, an apprentice mechanics training program should be initiated. The maintenance supervisor will be responsible for the work progression and technical training of the apprentice.

<i>Typical Manufacturer</i>	<i>Equipment Type</i>
A—Sellers Manufacturing Company —	Boilers
B—Hobart Manufacturing Company —	Kitchen Equipment, Dishwashers, etc.
C—Gaylord Manufacturing Company —	Kitchen Exhaust Hoods
D—Vogt Manufacturing Company —	Ice Machines
E—Traulsen —	Reach-In, Pass-Through Refrigeration
F—Groen —	Steam Kettles, Tilting Fry Pans
G—Etc. —	

PREVENTIVE MAINTENANCE PROCEDURES

The preventive maintenance (PM) program is a method of budgeting and controlling maintenance expense. It pinpoints problem areas, it helps avoid repetitive maintenance, excessive parts replacement, and purchasing errors. Thus, money spent on a well-planned system of preventive maintenance reduces profit loss due to breakdown, emergency work, and related parts failures.

In order to introduce controls, the PM program must be effective but very simple to avoid assigning administrative chores to maintenance for recordkeeping, etc. When maintenance fills out a simplified work ticket, illustrated in Figure 12-1, the data acquired helps pinpoint costs to accomplish the following:

- Show areas of high cost.
- Change criteria of new construction to reduce high-cost areas.
- Set incentive goals for satisfaction of work.
- Eliminate high-priced skilled labor performing mediocre, unskilled chores.
- Point out high-cost areas to obtain help from qualified technicians, controllers, etc.

NAME: _____

BILLET #: _____

SHIFT: _____

OPERATION #	HOURS	CODE
1		
2		
3		
4		
5		
6		
7		
8		
OVER-TIME		

REMARKS: _____

CODES: A APPRENTICE
 Mi MECHANIC (JUNIOR)
 M MECHANIC
 S SUPERVISOR
 CL CLERK

Code Description

- AM Administration
- AC Air Conditioning
- B Boilers
- C Carts
- D Malicious Damage
- EP Electrical Power
- EL Lighting
- EV Elevators
- G Building Maintenance General
- H Heating
- K Kitchen Equipment
- LS Landscaping & Site Work
- M Miscellaneous
- P Plumbing
- PM Preventative Maintenance
- R Refrigeration
- T Supervisor's Technical Time
- V Ventilation

- 1 Boiler Room
- 2 Dry Storage
- 3 Cafeteria
- 4 Restrooms & Locker Rooms
- 5 Assembly Area
- 6 Dishroom
- 7 Gift Shop
- 8 Loading Dock
- 9 General Storage Area
- 10 General Offices
- 11 Miscellaneous

Figure 12-1. Simplified Work Ticket

The coding on the ticket will enable study of the shift for more effective coverage of the operation after evaluation of the time cards. Information on time tickets, such as the nature of breakdown and what action was taken to correct it, is only valuable to supervisory personnel for evaluation of satisfactory performance of maintenance duties.

The information needed to reduce costs in PM is compiled from data collected from high-cost areas. This appears in the labor required to effectively maintain the operation and the labor needed for an effective PM program.

A typical coding system is as follows:

- AM- Administration** is directed to the maintenance supervisor so as to pinpoint his administrative duties vs. his technical supervision.
- AC - Air-conditioning** is to point out costs in this area to take corrective steps in future program criteria.
- B - Boiler** would pertain to breakdown, lack of PM, etc. It can be directly attributed to that area of time required to maintain service.
- C - Carts (Rolling Stock)** would be maintenance of casters, modules, baker's racks, dunnage racks, portable mop sinks, etc. It would enable us to pinpoint areas such as specifying heavier duty casters, welding in key point areas, etc.
- D - Malicious Damage** would include mistreating equipment (carts, kitchen equipment, etc.)
- EP - Electrical Power** would entail the following: from the service entrance, main disconnect, electricity to source of lighting, power to all equipment, etc.
- EL - Lighting** will encompass the area of lamp replacement and maintenance of the lighting system throughout the operation.
- EV - Elevators** where applicable, will deal strictly in the area that is directly pertaining to the satisfactory function of the elevator.
- G - Building Maintenance (General)** will cover the areas of painting, tile replacement, roof repair, windows, etc.
- H - Heating** will deal in the areas of what means the building is being heated, such as steam, HVAC units, space heaters, etc.
- K - Kitchen Equipment** would entail all equipment which includes ranges, conveyors, dishwashers, etc.
- LS - Landscaping & Site Work** would encompass the exterior of the building such as lawn, trees, sprinkler system, paving and striping of roads and lots.

- M - Miscellaneous** will be used in areas that have not been covered by defined codes.
- P - Plumbing** will deal with the areas of water, sewer, industrial wastes, grease traps, septic tanks, etc.
- PM -Preventive Maintenance** will cover time and location spent on preventive maintenance program so as to pinpoint high PM areas.
- R - Refrigeration** will cover the areas of maintaining compressors, condensers, evaporative coils on all walk-ins, reach-throughs, and pass-throughs.
- T - Supervisor's Technical Time** will cover the amount of time actually spent in supervising maintenance in the field.
- V - Ventilation** will cover the areas of the supply air system and exhaust.

To further pinpoint costs numbers should be assigned to descriptive areas. For example:

1. Boiler Room
2. Dry Storage
3. Cafeteria
4. Restroom and Locker room
5. Assembly Areas
6. Dishroom
7. Gift Shop
8. Loading Dock
9. General Storage Areas
10. General Offices
11. Miscellaneous

The purpose for setting up these codes is to shorten the time for filling out the time tickets, which could be a time-consuming and meaningless task when the ultimate goal is to reduce costs and pinpoint high-cost areas. Naturally, as the system is introduced, other codes will be initiated to cover areas that have not been covered in the start-up of the preventive maintenance program.

To keep personality out of the PM program and to reduce administrative chores of the mechanics, helpers, etc., each maintenance supervisor or mechanic assigned (whichever the case may be) will assign a billet number to each maintenance mechanic, helper, etc. The explanation of these codes is as follows:

A	Apprentice	A	A-1	_____	Series
MJ	Mechanic (Junior)	MJ	MJ-2	_____	Series
M	Mechanic	M	M-3	_____	Series
S	Supervisor	S	S-4	_____	Series
CL	Clerk	CL	CL-5	_____	Series

Example: John Smith: M-3 —(will be mechanic’s billet #). In case John Smith leaves the company, the new employee will be assigned the same billet number for payroll purposes, etc.

The time ticket attached covers an eight-hour shift, but an area has been designated for overtime which will require an explanation from _____.

The steps required for a fully encompassing preventive maintenance program are described in this section. Each step must be performed initially and then added to and revised as new equipment is purchased or existing equipment requires more frequent maintenance.

The initial organization and subsequent administration of the program is the responsibility of the supervisor of maintenance.

PREVENTIVE MAINTENANCE SURVEY

This survey is made to establish a list of all equipment on the property that requires periodic maintenance and the maintenance that is required. The survey should list all items of equipment according to physical location. The survey sheet should list the following columns:

1. Item
2. Location of Item
3. Frequency of Maintenance
4. Estimated Time Required for Maintenance
5. Time of Day Maintenance Should Be Done
6. Brief Description of Maintenance To Be Done

PREVENTIVE MAINTENANCE SCHEDULE

The preventive maintenance schedule is prepared from the information gathered during the survey. Items are to be arranged on schedule sheets according to physical location. The schedule sheet should list the following columns:

1. Item
2. Location of Item
3. Time of Day Maintenance Should Be Done
4. Weekly Schedule with Double Columns for Each Day of the Week (one column for "scheduled" and one for "completed")
5. Brief Description of Maintenance To Be Done
6. Maintenance Mechanic Assigned To Do the Work

USE OF PREVENTIVE MAINTENANCE SCHEDULE

At some time before the beginning of the week, the supervisor of maintenance will take a copy of the schedule. The copy that the supervisor prepares should be available in a three-ring notebook. He will go over the assignments in person with each mechanic.

After the mechanic has completed the work ' he will note this on the schedule by placing a check under the "completed" column for that day and the index card system for cross-checking the PM program.

The supervisor of maintenance or the mechanic will check the schedule daily to determine that all work is being completed according to the plan. At the end of the week, the schedule will be removed from the book and checked to be sure that all work was completed. It will then be filed.

USE OF THE SCHEDULE TO RECORD REPAIRS

Any repairs or replacement of parts on a particular piece of equipment should be noted on the preventive maintenance schedule. The work done should be written in the weekly schedule section or reference should be made to an attached sheet if more space is necessary. This will provide a history of repairs or replacements on each piece of equipment.

The supervisor of maintenance or mechanic should analyze these schedules twice a year to determine if certain pieces of equipment are requiring more than acceptable maintenance and if replacement of the piece of equipment is necessary.

Figure 12-2 illustrates a form used by the supervisor of maintenance, lead mechanic, etc., for accumulating cost and labor information on a weekly, monthly, and yearly basis. The accumulated information pinpoints high-cost areas, preventive maintenance labor, etc., plus the necessary information for yearly budgeting and other purposes.

The index card system illustrated in Figure 12-3 will become a source of data collecting plus a cross check on preventive maintenance schedules and the analyzing time needed to perform PM work for future maintenance schedules. When the initial program goes into effect, it will require estimating the time required to perform PM on equipment. The data collected will also compile a record of which type motor belts, filters, etc., will be needed to reduce inventory, etc.

The card will be placed in a waterproof enclosure and attached to or located near the equipment which will require preventive maintenance. This will eliminate PM being performed in the office, since the mechanic will fill out the required information listed on the index card and will be responsible if the PM work was not performed. It would further help the supervisor of maintenance or lead mechanic to evaluate the mechanic's performance. See Figure 12-4.

PREVENTIVE MAINTENANCE TRAINING

The supervisor of maintenance or mechanic is responsible for assisting department heads in the training of employees in handling, daily care, and the use of equipment. When equipment is mishandled, he must take an active part in correcting this through training.

SPARE PARTS

All too often equipment is replaced with the exact model as presently installed. Excellent energy conservation opportunities exist in upgrading a plant by installing more efficient replacement parts. Consideration should be given to the following:

Actual Maintenance Cost Expenditures Weekly	Removed/Exist. Inventory	
	Air Conditioning	
	Boilers	
	Carts	
	Electrical	
	Lighting	
	Bldg. Maintenance (Gen.)	
	Heating	
	Kitchen Equipment	
	Land & Site Work	
	Miscellaneous	
	Plumbing	
	Preventative Maintenance	
	Refrigeration	
	Ventilation	
	Labor	
	Overtime	
		Total Cost of Estimated Maintenance Expenditure.

Figure 12-2. Maintenance Cost Expenditure Form

- Efficient line motor to replace standard motors
- Efficient model burners to replace obsolete burners
- Upgrading lighting systems.

How many times are steam traps replaced with a size corresponding to the pipe thread size? Instead of this energy inefficient procedure, before a steam trap is replaced the correct orifice size should be determined. In this way the steam trap will be checked periodically for correct sizing. When a discharge pipe needs to be replaced because it has corroded, a check should be made to determine if a larger size diameter pipe should be used as its replacement. The larger diameter pipe reduces pipe friction losses, thus saving energy.

EQUIPMENT MAINTENANCE

When equipment is properly maintained energy will be saved. This section contains representative equipment and types of maintenance checks to be performed. In addition to equipment checks, leaks in steam, water, air and other utilities should be made and uninsulated or damaged insulation, furnace refractory damages, etc. should be recorded and corrected.

Figures 12-5 and 12-6 illustrate maintenance survey and log book forms respectively.

EQUIPMENT PM AND OPERATIONS

Boilers

Operating and maintenance procedures depend on the type of boiler, the fuel used, and the manufacturer's instructions. Permanent records should be kept covering all inspections, testing, and servicing.

A general maintenance checklist is illustrated in Figure 12-7. A specific form similar to this figure should be incorporated into the overall PM program based on the details of the unit in operation.

Ovens (Monthly)

1. Inspect compartment for proper primary and secondary air conditions.

<i>System</i>	<i>Daily Requirements</i>	<i>Weekly</i>	<i>Monthly</i>	<i>Annual</i>
Blowdown and Water Treatment	<ul style="list-style-type: none"> • Check that blowdown valve does not leak. • Make sure blowdown is not excessive. 		<ul style="list-style-type: none"> • Make sure that solids are not built-up. 	
Exhaust Gases	<ul style="list-style-type: none"> • Check temperature at two different firings 	<ul style="list-style-type: none"> • Measure exhaust gas temperature and composition at selected firings and adjust to recommended values. 	<ul style="list-style-type: none"> • Same as weekly. • Compare with readings of previous months 	<ul style="list-style-type: none"> • Same as weekly. • Record reference data
Burner	<ul style="list-style-type: none"> • Check controls are operating properly. • Burner may need cleaning several times daily if #6 fuel is used. 	<ul style="list-style-type: none"> • Clean burner pilot pilot assemblies. • Check condition of spark gap, electrode, burner. 	<ul style="list-style-type: none"> • Same as weekly. 	<ul style="list-style-type: none"> • Same as weekly. • Clean and recondition
Feedwater Systems	<ul style="list-style-type: none"> • Check & correct unstable water level. • Causes of unstable conditions: contaminants, overload, malfunction. 	<ul style="list-style-type: none"> • Check control by stopping feedwater pump and allow control to stop fuel flow. 		<ul style="list-style-type: none"> • Clean condensate receivers, de-aeration system. • Check pumps.
Steam Pressure	<ul style="list-style-type: none"> • Check for excessive loading on boiler which will cause excessive variations in pressure. 			

Air Temperature in Boiler Rooms	<ul style="list-style-type: none"> • Check that temperature in boiler room is within acceptable range
Relief Valve	<ul style="list-style-type: none"> • Check if relief valve leaks. • Remove and recondition.
Boiler Operating Characteristics	<ul style="list-style-type: none"> • Observe flame failure system & characteristics of flame.
Combustion Air Supply	<ul style="list-style-type: none"> • Check that adequate openings exist for combustion air inlet. • Clean inlet if fouled.
Fuel System	<ul style="list-style-type: none"> • Check pumps, filters, pressure gauges and transfer lines. • Clean filters as required. • Clean and recondition system.
Belts and Packing Glands	<ul style="list-style-type: none"> • Check belts for proper tension and damage. • Check packing glands for leakage and proper compressions.
Air Leaks	<ul style="list-style-type: none"> • Check for leaks around access openings and flame scanner.

Figure 12-7. Boiler Operations and Maintenance Requirements.

<i>System</i>	<i>Daily Requirements</i>	<i>Weekly</i>	<i>Monthly</i>	<i>Annual</i>
Air Leak Waterside & Fireside Surfaces				<ul style="list-style-type: none"> • Clean surfaces according to manufacturer's recommendations.
Refractor on Fireside				<ul style="list-style-type: none"> • Repair refractor.
Electrical Systems				<ul style="list-style-type: none"> • Clean electrical terminals and replace defective parts.
Hydraulic & Pneumatic Valves				<ul style="list-style-type: none"> • Check all operations and repair all leakages.
Start-Up and Operation				<ul style="list-style-type: none"> • Check during start-up and operation.
Records	<ul style="list-style-type: none"> • Record type and amount of fuel used, exhaust gas temperature, and firing position and boiler room temperature. 			

Figure 12-7. Boiler Operations and Maintenance Requirements (concluded)

2. Regulate automatic pilot and safety valve for proper operation.
3. Check motor, belts, fans, on convection ovens.
4. Adjust thermostat for accurate calibration.
5. Check oven doors for (heat loss) tight fit.
6. Clean and adjust orifice and burner to rated Btu input.
7. Lubricate gas valves.
8. Adjust burner flame for proper gas/air mix.

Pumps

Based on the pump manufacturer's recommendations, a PM Form of checks to be made should be incorporated. Checks should include:

1. Clean inside pump casing periodically and check impeller for wear or damage.
2. Check gland stuffing boxes and repack where necessary.
3. Check and adjust drives (as for fans).
4. Check non-return valves, pressure by-pass valves, etc., for correct and effective operation.

Compressors and Evaporators

1. Weekly Checklist
 - a. Box temperature
 - b. Thermostat setting
 - c. Oil level of compressor (where appropriate)
 - d. Flood back to compressor—no frost on compressor
 - e. Operation of condenser and evaporator fans. Clean.
 - f. Clean evaporator coils, pan and fans
 - g. Leaks and oil spots
 - h. Synchronization of timers (where applicable)
 - i. Receiver temperature should be warm
 - j. Short cycling
 - k. Over heater strips, hardware
2. Semi-Annual Checklist
 - a. Bank water level and immersion heater
 - b. Leak test entire system
 - c. Grease bearings on belt-driven fans
 - d. Tighten all electrical terminals
 - e. Check discharge pressure, receiver pressure, evaporator pressure, interstage pressure, and suction pressure as per

- manufacturer's recommendations
- f. Check expansion valve
- g. Check volts and amps of compressor and evaporator
- h. Noncondensibles in system
- i. Low-side pressure control setting. Cut in and cut out according to installation or condensed instruction.

Note: Do not make pressure adjustments without gauges installed, or without first checking recommended pressure setting in the manufacturer's instructions.

The ratio of brake horsepower consumed per ton of refrigerant output can vary considerably with the cleanliness of the condenser and evaporation. Table 12-1 indicates the measured variations of a nominal 15-ton capacity machine having a reciprocating compressor.

Table 12-1. The Effects of Poor Maintenance on the Efficiency of a Reciprocating Compressor, Nominal 15-Ton Capacity

<i>Conditions</i>	(1) °F	(2) °F	(3) <i>Tons</i>	(4) %	(5) <i>HP</i>	(6) <i>HP/T</i>	(7) %
Normal	45	105	17	—	15.9	0.93	—
Dirty Condenser	45	115	15.6	8.2	17.5	1.12	20
Dirty Evaporator	35	105	13.8	18.9	15.3	1.10	18
Dirty Condenser and Evaporator	35	115	12.7	25.4	16.4	1.29	39

- (1) Suction Temp, °F
- (2) Condensing Temp, °F
- (3) Tons of refrigerant
- (4) Reduction in capacity %
- (5) Brake horsepower
- (6) Brake horsepower per Ton
- (7) Percent increase in compressor bh per/ton

It can be seen that in the worst case, a reduction in capacity of some 25% occurred with an increase of 39% in power requirement per ton of refrigerant.

Refrigeration Maintenance

1. Manufacturer's specifications should be followed for selection of *all* lubricants and refrigerants.
2. Inspect and repair any damage to insulation on duct work and piping to avoid temperature loss and damage from condensation.
3. Check for plugged spray nozzles on condenser.
4. Check for dirt on fan blades or rotors causing an unbalanced condition and vibration. Do not paint fan blades.
5. Do not over-lubricate blower bearings. This will avoid oil or grease being thrown on blades and acting as catch agents for dust and dirt.
6. Check for wasted condenser and cooling water in terms of gallons per minute per ton of refrigeration.
7. Check controls on outdoor air sources, so that outside air supply is increased when sufficiently cool to replace refrigerated air.
8. Check for air leakage around doors and transoms through worn weather stripping.
9. Check for worn gaskets on refrigerator doors.
10. Check pump impellers and packings on circulating pumps.
11. Check for clean condensers to avoid poor heat transfer.
12. Check for excessive head pressure and proper suction pressure for longer life of compressor.
13. Check for possibilities of reclaiming condensing water where applicable.
14. Check defrosting cycles to avoid power loss from frost buildup.
15. Check for condition of compressor valves and pistons.
16. Check air cool condenser for fin damage and clean.
17. Seasonal Maintenance. Towards the end of the cooling season, a complete check should be made of air-conditioning equipment while it is still performing. The following should be included:
 - a. Possible replacement of controls, belts, air filters, refrigerant filter dryers, and insulation.
 - b. Check to see whether units are increasing in power consumption or cooling water requirements. Taking one unit at a time out of service, service it for idleness, drain water, back-off packing glands, drain oil, flush bearings, add new oil, and clean catch pans and tanks.
 - c. Check for worn parts and compression clearance. The above work should be done regardless of how well the machinery has operated during the previous season.

Table 12-2 shows the measured effect of dirty evaporators and condensers on a nominal 520-ton absorption chiller.

Table 12-2. The Effects of Poor Maintenance on the Efficiency of an Absorption Chiller, 520-Ton Capacity

Condition	Chilled Water °F	Tower Water °F	Tons	Reduction in Capacity %	Steam lb/ton/H	Per Cent
Normal	44	85	520	—	18.7	—
Dirty Condenser	44	90	457	12	19.3	3
Dirty Evaporator	40	85	468	10	19.2	2.5
Dirty Condenser and Evaporator	40	90	396	23.8	20.1	7.5

A reduction in output of 23.8% occurs at the worst case with an increase in steam consumption of 7.5% per ton of refrigerant.

Fans

1. Wheel shaft bearings on belt-driven units of all types with pre-lubricated pillow blocks and grease fittings should be relubricated every three (3) years. For normal operating conditions, use a grease conforming to NLGI No. 2 consistency.

Motor bearings are prelubricated and should be relubricated every three (3) to five (5) years. Consult instructions on motor. Motors not having pipe plugs or grease fittings in bearing housing can be relubricated by removing end shields from motor.

2. Check belt tension every six (6) months. Belt should depress its width when pressed firmly inward at mid-way point between the pulleys. Too much tension will damage bearings; belt should be tight enough to prevent slippage. When replacing belt, replace motor sheave if “shoulder” is worn in groove. Do not replace with a larger diameter pulley as this will overload the motor.
3. Clean fan (or blower) blades and check for blade damage, which may cause out-of-balance running.
4. Check fan casing and duct connections for air leakage.

Filters, Coils, Strainers, Ducts, and Registers

1. *Filters*—Manufacturer's recommendations regarding the method and interval of cleaning/replacement should be followed. The manually-serviced type air filter requires periodic cleaning or replacement. The usual indication that cleaning/replacement is required is either (a) a decrease in air flow through the filter (up to 10%), or (b) an increase in resistance across the filter (more than 100%).

Large installations having a number of filters, can arrange a maintenance program of cleaning/replacement on a rotated basis at a regular interval. In certain large duct installations and central air-handling units, it is possible to install simple manometers to indicate the pressure differential across the filter.

Self-cleaning filters and precipitators should also be examined periodically to observe expiration of the disposable media or accumulation of sludge into the collecting pan. Many manufacturers provide indicators for their equipment to show when servicing is required.

2. *Coils*—The efficient operation of both cooling and heating coils depends largely upon the cleanliness of the heat-transfer surface. Finned tube surfaces require particular attention and can be cleaned with detergents and high-pressure water using portable units.

Spray coil units may require chemical treatment for the build-up of algae and slime deposited by cooling water. Chemical cleaning can be most effective, but caution must be exercised with the choice of chemicals on certain metal surfaces.

3. *Strainers*—Regular cleaning of strainer screens keeps pressure losses in liquid systems to a minimum, thus saving pumping energy. It may be possible to replace fine-mesh strainer baskets with large mesh, without endangering the operation of the system. This again will reduce the pressure loss in the system and save pumping energy.
4. *Ducts*—Periodic opening and cleaning of the inside of ducts, plenum chambers, air-handling units, etc., to remove residually deposited dust and particulate matter. This will assist in keeping down the duty of the air filter, and maximizing the period between air filter servicing.
5. *Registers*—Periodically check for accumulation of material or other foreign matter behind registers. Check also the register seal to the

duct, to ensure that all the conditioned air louvers are in the direction required.

Adjustable registers should be checked for setting, as these are sometimes moved by accident or by unauthorized personnel.

Electric Motors

Inspection of electric motors will cover the following:

1. Check electric starter contactors, and loose wire connections.
2. Using a meter, check the starting load and running load against rated loads.
3. Adjust the belt tension to a slight slackness on the top side.
4. Align the belt to avoid damage to belts, bearings, and excessive electrical consumption.
5. Check bearings for wear, dust and dirt.
6. Check internal insulation to see that it is free of oil.
7. Check commutator slots and motor housing for dust and good air circulation.
8. Examine fusing and current limiting devices for protection while starting and then while running.
9. Check brushes for wear.

Leaks—Steam, Water, and Air

The importance of leakage cannot be understated. If a plant has many leaks, this may be indicative of a low standard of operation involving the loss not only of steam, but also water, condensate, compressed air, etc.

If, for example, a valve spindle is worn, or badly packed, giving a clearance of 0.010 inch between the spindle, for a spindle of 3/4-inch diameter, the area of leakage will be equal to a 3/32-inch diameter hole. Table 12-3 illustrates fluid loss through small holes:

Table 12-3. Fluid Loss Through Small Holes

<i>Diameter of Hole</i>	<i>Steam—lb/hour</i>		<i>Water —gals/hour</i>		<i>Air SCFM</i>
	<i>100 psig</i>	<i>300 psig</i>	<i>20 psig</i>	<i>100 psig</i>	<i>80 Psig</i>
1/16"	14	33	20	45	4
1/8"	56	132	80	180	16
3/16"	126	297	180	405	36
1/4"	224	528	320	720	64

Although the plant may not be in full production for every hour of the entire year (i.e., 8760 hours), the boiler plant water systems and compressed air could be operable. Losses through leakage are usually, therefore, of a continuous nature.

Thermal Insulation

Whatever the pipework system, there is one fundamental—it should be adequately insulated. Table 12-4 gives a guide to the degree of insulation required. Obviously there are a number of types of insulating materials with different properties and at different costs, each one of which will give a variancy return on capital. Table 12-4 is based on a good asbestos or magnesia insulation, but most manufacturers have cataloged data indicating various benefits and savings that can be achieved with their particular product.

Table 12-4. Pipe Heat Losses

<i>Pipe Dia</i> <i>Inches</i>	<i>Surface</i> <i>Temp °F</i>	<i>Insulation</i> <i>Thickness</i> <i>Inches</i>	<i>Heat Loss (Btu/Ft/Hr)</i>		<i>Insulation</i> <i>Efficiency</i>
			<i>Uninsulated</i>	<i>Insulated</i>	
4	200	1-1/2	300	70	76.7
	300	2	800	120	85.0
	400	2-1/2	1500	150	90.0
6	200	1-1/2	425	95	78.7
	300	2	1300	180	85.8
	400	2-1/2	2000	195	90.25
8	200	1-1/2	550	115	79.1
	300	2	1500	200	86.7
	400	2-1/2	2750	250	91.0

Steam Traps

The method of removing condensate is through steam trapping equipment. Most plants will have effective trapping systems. Others may have problems with both the type of traps and the effectiveness of the system.

The problems can vary from the wrong type of trap being installed, to air locking, or steam locking. A well-maintained trap system can be a great steam saver. A bad system can be a notorious steam waster, particularly where traps have to be bypassed or are leaking.

Therefore, the key to efficient trapping of most systems is good installation and maintenance. To facilitate the condensate removal, the pipes should slope in the direction of steam flow. This has two obvious advantages in relationship to the removal of condensate; one is the action of gravity, and the other the pushing action of the steam flow. Under these circumstances the strategic siting of the traps and drainage points is greatly simplified.

One common fault that often occurs at the outset is installing the wrong size traps. Traps are very often ordered by the size of the pipe connection. Unfortunately the pipe connection size has nothing whatsoever to do with the capacity of the trap. The discharge capacity of the trap depends upon the area of the valve, the pressure drop across it, and the temperature of the condensate.

It is therefore worth recapping exactly what a steam trap is. It is a device that distinguishes between steam and water and automatically opens a valve to allow the water to pass through but not the steam. There are numerous types of traps with various characteristics. Even within the same category of traps, e.g., ball floats or thermoexpansion traps, there are numerous designs, and the following guide is given for selection purposes:

1. Where a small amount of condensate is to be removed an expansion or thermostatic trap is preferred.
2. Where intermittent discharge is acceptable and air is not a large problem, inverted bucket traps will adequately suffice.
3. Where condensate must be continuously removed at steam temperatures, float traps must be used.
4. When large amounts of condensate have to be removed, relay traps must be used. However, this type of steam trap is unlikely to be required for use in the food industry.

To insure that a steam trap is not stuck open, a weekly inspection should be made and corrective action taken. Steam trap testing can utilize several methods to insure proper operation:

- Install heat sensing tape on trap discharge. The color indicates proper operation.
- Place a screw driver or more sophisticated acoustical instrument to the ear lobe with the other end on the trap. If the trap is a bucket-type, listen for the click of the trap operating.

Control Devices

The functional operation of control equipment is of no use unless the equipment operates correctly at the required set point. Periodic checking and recalibration of all control equipment is an essential aspect of energy conservation.

1. *Thermostats*—In many cases, thermostats can be checked with a mercury-in-glass thermometer, and calibration adjustments can be made. Temperature differential for a signal is not usually adjustable. If it is found that the differential is too great, then usually it is necessary to replace the unit. Checks should be made at both maximum and minimum set positions.
2. *Humidistats*—These can be checked with a wet and dry bulb thermometer. Most units can be easily recalibrated, but operating differentials across a set point cannot usually be adjusted.
3. *Control Valves*—These should be checked and adjusted for operation by monitoring the actuating signal with a known standard,* or by using an auxiliary signal for an alternative corrected source.

Adjustments

1. *Actuators*—These should be checked for operation (and repetition of operation) from a signal. Length of stroke, or angle of arc should be checked to ensure full operational movement.
2. *Linkages*—Check for ease of motion; lubricate fulcrum and check for heat. Check locking devices on adjustable linkages and make sure that they are in the original position determined during the testing and balancing of the system.
3. *Motor Drives*—These are used for the control of some types of valves, dampers, etc. Check for length of stroke/angle of arc, security of fixing, and adjust where required,

*Direct acting valves-mercury/glass thermometer
Pneumatic valves-pressure gauge
Electrically operated valves-ammeter/voltmeter.

4. *Manual Dampers*—Check that these are set at positions determined during the testing and balancing of the system. Check for leakages around the spindle, and check that the quadrant permits full open/close operation of the blade. Check that the blades give a tight shut-off.
5. *Registers*—Check that these are set to discharge the air in the direction required. Make sure that short-circuiting of delivered conditioned air into the return air system does not occur.

Chapter 13

Self-evaluation Checklists

INTRODUCTION

*T*he self-evaluating checklists are to be used to:

1. Determine the major factors of energy consumption in the facility and determine factors contributing to the overall energy usage in the specific area.
2. Discover transferable techniques for saving energy.
3. Provide guidance to federal facility managers to pinpoint modifications in building systems and operational practices that would result in reducing energy consumption.
4. Identify areas where additional information would be helpful and constructive suggestions welcome.

The initiative and the responsibility of corrective actions remain with the individual manager. To aid in this analysis, these self-evaluating checklists have been developed. They provide the manager with an indication of the factors of thermal performance which require correction.

The checklists consist of separate sections or areas of evaluation. A relative numerical value has been assigned to those specific conditions that effect the energy loss in these areas. Additional instructions are also provided in the self-evaluating checklists to assist in completion of the form and provide consistency of results between federal facilities. When completing the forms using these instructions and computing a resultant overall score for each section, both strong and weak areas become apparent. This scoring method is valid for each of the sections as well as for each item within a section.

The purpose of these checklists is to assist in dealing with the

“How” of starting an energy management program. In this handbook space does not permit listing the recommendations of possible remedies for the twenty evaluation sections. Each manager must determine the best use of budgeted expenditures for reducing energy consumption.

INSTRUCTIONS FOR SELF-EVALUATION CHECKLISTS

To demonstrate the use of self-evaluating checklists, an example is presented as follows:

Seven windows are used to demonstrate the typical checklist shown in the following example. Note that each window condition is assigned a value if the condition applies. The overall rating for the windows listed is 51 percent. This rating scale of 51 percent indicates that corrective action is required in this area since its rating is only half of the maximum score of 100 allowable.

Although the example covers only seven windows, a typical building evaluation will include hundreds of windows. Each form provides for the listing of 25 windows. A sufficient number of forms should be used to list each window as an individual item.

For record-keeping purposes, it is suggested that each window be assigned an “address” which will serve to positively identify that opening for all references regarding that window. Architectural building exterior elevation drawings will be useful as a means of tabulating and recording work on windows.

There are twenty categories or evaluation sections, as follows:

- | | |
|---------------------------|-----------------------------------|
| 1. Window | 11. Heat Distribution |
| 2. Door | 12. Cooling Generation |
| 3. Ceiling | 13. Cooling Distribution |
| 4. Wall | 14. Electrical Power Distribution |
| 5. Roof | 15. Hot Water Service |
| 6. Storage Area | 16. Laundry |
| 7. Shipping and Receiving | 17. Compressed Air |
| 8. Illumination | 18. Water |
| 9. Food Area | 19. Process Heating |
| 10. Heat Generation | 20. Transportation |

Completion of these 20 forms by the manager and/or his staff will provide the current status of energy consumption in those areas

EVALUATOR A. AUD
 DATE 5/10/74
 UNIT Anywhere
 NAME
 SHEET NO. 1

			WINDOW CONDITIONS																		
No.	Location	Rating Value Max. = 10	Storms	Solar Protection	Tight Fit	Minor Infiltration	Major Infiltration	Cannot Be Opened	Can Be Opened	Weather Stripped										TOTAL POINTS	
			2	2	2	1	0	3	0	1											
1	Bldg. 4, Room 401		2			1			0	1											4
2	Bldg. 4, Room 402			2	2				3	1											8
3	Bldg. 4, Room 609					1			0	1											2
4	Bldg. 4, Room 102		2	2	2			3	1												10
5	Bldg. 4, Room 104, W1		2			1			0	1											4
6	Bldg. 4, Room 104, W2		2				0	0	1												3
7	Bldd. 4, Room 104, W3		2		2				0	1											5
25	GRAND TOTAL																				36

$$\text{RATING SCORE} = 100 \times \frac{36}{(7) (10)} = 51\%$$

identified as needing the most attention. Recommendations to improve any faulty conditions should be evaluated using an energy savings cost analysis for these 20 parameters to ensure that the greatest energy savings per dollar are attained.

Each of the 20 sections will be evaluated on a separate rating schedule. There are three parts to each section:

1. Recommendations for improvements (not included in this text)
2. Instructions for evaluating ratings
3. Checklist

Specific conditions in each category are determined by completing the corresponding checklist. Each item being evaluated is identified and located in the appropriate space on the form. An example would be Building 4, Room 406, Window 1.

Each of the specific conditions listed on the checklist is evaluated for each item. The instruction sheet provides guidance in properly identifying correct conditions. The assigned value for each existing condition should be listed in the proper column to credit the item being evaluated.

Total points for each item are determined and this total listed in the item total points column.

Each form will accommodate 25 items of similar nature, such as 25 windows or 25 doors. As many forms as are necessary to list all similar items on an individual line should be used. The total points for each section are determined by adding all item total points for that section.

Using the following scoring formula, the rating score of each of the 20 sections should be individually calculated.

$$\text{Rating Score} = \frac{(100) \times (\text{Point Total for Section})}{(\text{No. of Items}) \times (\text{Maximum Rating Value in Section})}$$

This rating score is then applied to the following table which indicates the urgency of corrective action.

<i>Range of Rating Score</i>	<i>Action Required</i>
0- 20	Immediate Corrective Action Required
20- 40	Urgent Corrective Action Required
40- 60	Corrective Action Required
60- 80	Evaluation for Potential Improvement Required
80- 100	No Corrective Action Required

Recommendation sheets are included in the government \guide that list several methods to improve the score in each section. These recommendations are general in nature. The recommendation that is prevalent in all sections is: Education and training of personnel to reduce energy consumption. It is critical that managers realize the importance of the individual's role in a personal commitment to energy conservation. Employee awareness of energy consumption and its reduction should be given high priority when establishing energy conservation policies and practices.

In the following pages are checklists and instruction for their \use for each of the 20 sections.

WINDOW RATING INSTRUCTIONS

2 points if the window has storm windows adequate for cold weather protection. The storm windows must fit tightly and block the wind from entering around the window.

- 2 points if the window has protection from the direct sun during warm weather. Solar protection can be part of the building design such as overhang, awnings or physical shields. Protection can also be tinted or reflective film applied to the windows, double-glazed windows, solar screening or trees blocking out direct sunlight.
- 2 points for a tight fitting window. A window is tight fitting if the infiltration will not be detected around the window during a windy day. The window must fit well and all caulking must be in place. Weather-stripping will contribute to a tight fit.
- 1 point if the wind has some infiltration around the window. The window should fit fairly well and not be loose and rattle.
- 0 points if infiltration can be felt to a large degree. The window is loose in the frame and caulking is missing or in poor condition.
- 3 points if the window is designed so physically it cannot be opened.
- 0 points if it can be opened. If it can be opened, it will be opened to “regulate” room temperature.
- 1 point if window is weather-stripped all around and the weather-stripping is in good condition.

SELF-EVALUATING CHECKLIST FOR WINDOWS

EVALUATOR _____			WINDOW CONDITIONS																			
DATE _____			Storms	Solar Protection	Tight Fit	Minor Infiltration	Major Infiltration	Cannot Be Opened	Can Be Opened	Weather Stripped												TOTAL POINTS
UNIT NAME _____																						
SHEET NO. _____																						
No.	Location	Rating Value Max. = 10	2	2	2	1	0	3	0	1												
1																						

DOOR RATING INSTRUCTIONS

This section applies to all doors that open to the outside and all doors that open to an unconditioned space such as warehouses and storerooms.

- 2 points if door is part of an air-lock system.
- 1 point if door has a closer which may be either spring, air or hydraulic.
- 1 point if door closer does not have a hold-open feature.
- 0 points if door closer has a hold-open feature.

- 2 points if door fits snugly into the door frame with no loose condition and where no infiltration exists around the edges.
- 1 point if door is an average fit and can be slightly rattled in the frame and has a slight infiltration around the edges.
- 0 points if door is loose in the frame and infiltration exists.
- 2 points if weather-stripping exists on all four edges and is in good condition. (Thresholds with elastic or fiber to close the space, and astragals on double doors are considered weather-stripping.)
- 1 point if weather-stripping exists on jambs and head only.
- 0 points if no weather-stripping exists or if it exists and is in poor condition.
- 1 point if door is protected from outside wind. This can be building design, wind screen or shrubbery.

SELF-EVALUATING CHECKLIST FOR EXTERIOR DOORS

EVALUATOR _____

DATE _____

UNIT NAME _____

SHEET NO. _____

			DOOR CONDITIONS																				
No.	Location	Rating Value Max. = 10	Air Lock	Door Has Closer	Closer Has No Hold-Open	Closer Has a Hold-Open	Snug Fit	Average Fit	Loose F it	Weather-strip 4 Edges	Weather-strip jamb Head	No Weather-strip	Wind Screens or Other									TOTAL POINTS	
1			2	1	1	0	2	1	0	2	1	0	1										

CEILING RATING INSTRUCTIONS

- 1 point if a drop ceiling exists.
- 1 point if insulation exists above ceiling on top floor below roof or mechanical space.
- 1 point if space above drop ceiling is mechanically vented. Natural draft is not considered mechanical venting.
- 2 points if all panels are in place and in good condition, no broken or missing panels are present.
- 1 point if panels are broken or in poor condition.
- 0 points if panels are missing or removed and out of place.

ROOF RATING INSTRUCTIONS

- 2 points if roof insulation is in dry condition.
- 0 points if roof insulation is in poor condition, wet, aged, brittle, cracked, etc., or if no insulation exists.
- 1 point if roof has a reflective surface; this may be the type of material used or the color and condition of surface (gravel, etc.).
- 1 point if mechanical ventilation exists between roof and ceiling below. This should be properly sized so adequate air flow exists.
- 2 points if no leaks exist in the roof.
- 1 point if minor leaks exist.
- 0 points if there are many leaks.

SELF-EVALUATING CHECKLIST FOR ROOFS

EVALUATOR _____	ROOF CONDITIONS																				
DATE _____	Dry Insulation	Wet Insulation	Reflective Surface	Ventilation Under Roof	No Leaks	Small Leaks	Many Leaks														TOTAL POINTS
UNIT NAME _____																					
SHEET NO. _____																					
No.	Location	Rating Value Max. = 6	2	0	1	1	2	1	0												
1																					

STORAGE AREA RATING INSTRUCTIONS

- 1 point if area is not temperature controlled.
- 1 point if the doors are kept closed.
- 2 points if there are no windows in the area.
- 1 point if one window is in the area.
- 0 points if two or more windows are in the area.
- 2 points if area is used as it was designed.
- 0 points if area is used for storage but designed for other usage.

ILLUMINATION RATING INSTRUCTIONS

- 1 point if extensive decorative lighting has been eliminated where used for reasons of appearances (not security, walkway lighting and other necessities).
- 1 point if lighting has been arranged to illuminate only the work area.
- 0 points if lighting has been designed to illuminate the entire room to a working level.
- 2 points if light fixture diffuser is clean and clear.
- 1 point if diffuser is slightly yellowed or dirty.
- 0 points if diffuser is noticeably yellowed or dust is visible. This restriction can amount to 10% or more of the light flux being transmitted.
- 2 points if fixture internal reflective surface is in good condition (the paint is reflective and clean).
- 1 point if the fixture internal reflective surface gives dirt indication on clean white cloth.
- 0 points if the reflective surface is yellowed and dull.
- 1 point if fluorescent lights are used for all illumination.
- 0 points if incandescent lights are used.
- 1 point if lights are properly vented so the heat can escape to ceiling space, providing that ceiling space is ventilated to prevent heat build-up.
- 1 point if lights are turned off when area is not occupied.
- 1 point if illumination level is adequate for designed usage.
- 0 points if area is "over illuminated" for designed usage.*
- 0 points if two or more lamps have blackened ends or are glowing without lighting.

SELF-EVALUATING CHECKLIST FOR ILLUMINATION

EVALUATOR _____			ILLUMINATION CONDITIONS																
DATE _____			No Decorative Ltg.	Light Work Area	Light Entire Room	Diffusers Good	Diffusers Average	Diffusers Poor	Reflection Good	Reflection Average	Reflection Poor	Flourescent Lights	Incandescent Lights	Lights Vented	Lights Turned Off	Illumination Adeq.	Excessive Illumination	TOTAL POINTS	
UNIT NAME _____																			
SHEET NO. _____																			
No.	Location	Rating Value Max. = 10																	
1			1	1	0	2	1	0	2	1	0	1	0	1	1	1	0		

*Note: Momentarily disconnect lamps until level is reached which is adequate for the intended function. The following light meter readings will assist in determination of average adequate light levels. These are below Illumination Engineering Society recommendations in some instances. Absence of reflected glare is mandatory for reading tasks requiring careful fixture placement.

Corridors, lobbies	-10-15 foot-candles average
Typing areas	-50 foot-candles in area of work, 20 elsewhere
Storerooms	-5 foot-candles
Prolonged reading task areas	-50 foot-candles
Kitchens	-50 foot-candles in areas of work, 20 elsewhere
Laboratories	-50 foot-candles in areas of work
Toilet rooms	-20 foot-candles at mirrors

Federal Energy Administration
Recommended Maximum Lighting Levels

<i>Task or area</i>	<i>Foot-candle levels</i>	<i>How measured</i>
Hallways or corridors	10±5	Measured average, minimum 1 foot-candle.
Work and circulation areas surrounding work stations	30±5	Measured average.
Normal office work, such as reading and writing (on task only), store shelves, and general display areas	50±10	Measured at work station.

<i>Task or area</i>	<i>Foot-candle levels</i>	<i>How measured</i>
Prolonged office work which is somewhat difficult visually (on task only)	75 ±15	Measured at work station.
Prolonged office work which is visually difficult and critical in nature (on task only)	100±20	Measured at work station.

FOOD AREA RATING INSTRUCTIONS

- 2 points if the food preparation equipment is only energized when actually needed. This includes, but is not limited to, ovens, warmers, steam tables, delivery equipment and coffee urns.
- 0 points if equipment is turned on and left on all day.
- 1 point if refrigerator and freezer doors are kept tightly closed.
- 0 points if refrigerator and freezer doors can be left ajar.
- 1 point if faucets and valves are in good condition and not leaking.

- 0 points if faucets and valves are leaking. Leaks may be external or internal in the system.
- 3 points if doors between kitchen area and other areas are kept closed.
- 2 points if adequate vent hoods are used over heat-producing equipment.
- 1 point if some vent hoods are used over heat-producing equipment.
- 0 points if no or inadequate vent hoods are used.
- 1 point if ventilation air supply is adequate to remove most of the heat produced by the kitchen equipment.
- 2 points if refrigerator equipment is in good repair, seals are good, condenser is clean, air passage over condenser is clear.
- 1 point if refrigeration equipment is in average condition, dust and dirt exist on condensers but the air flow is not restricted, door gaskets seal all around although they may have lost some resiliency.
- 0 points if refrigeration equipment is in poor condition, a large collection of dust and dirt on the condenser or the fins may be bent to restrict air flow, door gaskets do not seal all around, are brittle, broken or missing.
- 3 points if heat-recovery systems are utilized. These can be applied to the exhaust air, the hot waste water or on the refrigeration equipment.

SELF-EVALUATING CHECKLIST FOR FOOD AREA

EVALUATOR _____			FOOD AREA CONDITIONS																		
DATE _____			Equipment Turned Off	Equipment Left On	Refrig. Doors Closed	Refrig. Doors Ajar	Faucets Not Leaking	Faucets Leaking	Access Doors Closed	Good Vent Hoods	Average Vent Hood	Poor Vent Hood	Adequate Ventilation	Refrig. Equip. Good	Refrig. Equip. Avar	Refrig. Equip. Poor	Heat Recovery System				TOTAL POINTS
No.	Location	Rating Value Max. = 15	2	0	1	0	1	0	3	2	1	0	1	2	1	0	3				
1																					

HEATING SYSTEM (GENERATION) RATING INSTRUCTIONS

- 2 points if the insulation is in good condition with no broken or missing sections. The insulation must not be wet, crumbly or cracked.
- 1 point if insulation is in average condition with small sections broken or missing. The insulation must not be wet or crumbly.
- 0 points if insulation is in poor condition with sections missing, broken, wet, crumbly or cracked.

- 2 points if flanges, valves and regulators are insulated with removable lagging.
- 2 points if the steam system has no leaks.
- 1 point if the steam system has minor leaks around valve packing, shaft seals, etc.
- 0 point if the steam system has many leaks, valves, regulators and traps have dripping leaks, steam plumes, etc.
- 1 point if boiler combustion controls are automatic.
- 1 point if definite standard operating procedures are used. These should be written and posted near the boiler control panel.
- 1 point if each boiler has an individual steam flow meter.
- 1 point if each boiler has an individual make-up water meter.
- 1 point if each boiler has an individual fuel flow meter.
- 1 point if a definite preventive maintenance schedule is followed.
- 0 points if equipment is maintained or repaired only when it breaks down.
- 3 points if an energy recovery system is used. This may be a heat exchanger of water to water, an air wheel or any of several types in common use.
- 2 points if heat generation is controlled by a system using an economizer system by comparing inside and outside temperature.

SELF-EVALUATING CHECKLIST FOR HEAT GENERATION

EVALUATOR _____			HEAT GENERATION CONDITIONS																	
DATE _____			Insulation Good	Insulation Average	Insulation Poor	Flanges Insulated	No Leaks	Some Leaks	Many Leaks	Auto Controls	Standard Op. Procedure	Steam Meter	Fuel Meter	Make-Up Water Meter	Preventive Maintenance	Fix as Required Schedule	Energy Recovery	Economizer Controls	TOTAL POINTS	
UNIT NAME _____																				
SHEET NO. _____																				
No.	Location	Rating Value Max. = 17	2	1	0	2	2	1	0	1	1	1	1	1	0	3	2			
1																				

HEATING SYSTEM (DISTRIBUTION) RATING INSTRUCTIONS

- 2 points if insulation is in good condition with no broken or missing sections. The insulation must not be wet, crumbly or cracked.
- 1 point if insulation is in average condition with small sections broken or missing. The insulation must not be wet, crumbly or cracked.
- 0 points if insulation is in poor condition with sections missing, broken, wet, crumbly or cracked.

- 2 points if flanges, valves and regulators are insulated with removable lagging.
- 2 points if the steam system has no leaks.
- 1 point if the steam system has minor leaks around valve packing, shaft seals, etc.
- 0 points if the steam system has many leaks, valves, regulators and traps have dripping leaks, steam plumes, etc.
- 2 points if the control system to each area is adequate. The control system shall maintain the temperature in each room close to the thermostat setting.
- 1 point if the control system to each area is only a general control without the ability to control each room.
- 0 points if the control system has little or no control over the area temperature. Also included here is a control system that allows the heating and cooling systems to oppose each other in the same general area.
- 1 point if definite standard operating procedures are used. These should be written and posted.
- 1 point if a definite preventive maintenance schedule is followed.
- 0 points if equipment is maintained or repaired only when it breaks down.
- 1 point if the area is conditioned only when occupied. This will apply especially to auditoriums, work rooms, hobby shops, TV rooms, etc.
- 0 points if the area is conditioned all the time regardless of occupancy.
- 2 points if the zone control is good and certain areas can be secured when not in use or require less temperature conditioning.
- 1 point if the zone control only allows general areas to be secured when conditions dictate.
- 0 points if zone control cannot be secured without securing a large general area.

SELF-EVALUATING CHECKLIST FOR HEAT DISTRIBUTION

EVALUATOR _____
 DATE _____
 UNIT NAME _____
 SHEET NO. _____

HEAT GENERATION CONDITIONS																		
Insulation Good	Insulation Average	Insulation Poor	Flanges Insulated	No Leaks	Some Leaks	Many Leaks	Control Good	Control Average	Control Poor	Standard Op. Procedure	Preventive Maintenance	Fix as Required	Condition as Required	Constant Conditioning	Zone Control Good	Zone Control Average	Zone Control Poor	TOTAL POINTS
2	1	0	2	2	1	0	2	1	0	1	1	0	1	0	2	1	0	
1																		

No.	Location	Rating Value Max. = 13
1		

COOLING SYSTEM (GENERATION) RATING INSTRUCTIONS

- 2 points if the insulation is in good condition with no broken or missing sections. The insulation must not be wet, crumbly or cracked. Closed cell insulation will be considered average condition because of deterioration that occurs in this type of material.
- 1 point if insulation is in average condition with small sections broken or missing. The insulation must not be wet or crumbly. The outside shell of open cell insulation must be intact with only minor breaks.
- 0 points if insulation is in poor condition with sections missing, broken, wet, crumbly or cracked.
- 1 point if flanges and valves are insulated.
- 1 point if definite standard operating procedures are used. These should be written and posted near the control panel.
- 1 point if unit has an individual watt-hour meter so the real-time power consumption can be determined.
- 1 point if a definite preventive maintenance schedule is followed.
- 0 points if equipment is maintained or repaired only when it breaks down.
- 3 points if an energy recovery system is used. This may be a heat exchanger of water to water, an air wheel or any of several types in common use.
- 2 points if outside air is utilized to help condition areas that require cooling even on cold days.
- 1 point if the fresh air ratio is regulated by comparing inside requirements with outside temperatures.

**SELF-EVALUATING CHECKLIST FOR
COOLING SYSTEM GENERATION**

EVALUATOR _____
 DATE _____
 UNIT NAME _____
 SHEET NO. _____

COOLING GENERATION CONDITIONS												
Insulation Good	Insulation Average	Insulation Poor	Flanges Insulated	Standard Op. Procedure	Ind. Power Meter	Preventive Maintenance	Fix as Required	Energy Recovery	Outside Air Used	Req. Fresh Air		TOTAL POINTS
2	1	0	1	1	1	1	0	3	2	1		
1												

No.	Location	Rating Value Max. = 12
1		

COOLING SYSTEM (DISTRIBUTION) RATING INSTRUCTIONS

- 2 points if the insulation is in good condition with no broken or missing sections. The insulation must not be wet, crumbly or cracked. "Closed cell" insulation will be considered average condition because of deterioration that occurs in this type of material.
- 1 point if insulation is in average condition with small sections broken or missing. The insulation must not be wet, crumbly. The outside shell of "open cell" insulation must be intact with only minor breaks.
- 0 points if insulation is in poor condition with sections missing, broken, wet, crumbly or cracked.
- 1 point if flanges and valves are insulated.
- 1 point if definite standard operating procedures are used. These should be written and posted near the control panel.
- 2 points if the control system to each area is adequate. The control system shall maintain the temperature in each room close to the thermostat setting.
- 1 point if the control system to each area is only a general control without the ability to control each room.
- 0 points if the control system has little or no control over the area temperature. Also included here is a control system that allows the heating and cooling systems to oppose each other in the same general areas.
- 1 point if a definite preventive maintenance schedule is followed.
- 0 points if equipment is maintained or repaired only when it breaks down.
- 1 point if the area is conditioned only when occupied. This will apply especially to auditoriums, work rooms, hobby shops, TV rooms, etc.
- 0 points if the area is conditioned all the time regardless of occupancy.
- 2 points if the zone control is good and certain areas can be secured when not in use or require less temperature conditioning.
- 1 point if the zone control only allows general areas to be secured when conditions dictate.
- 0 points if zone control cannot be secured without securing a large general area.

SELF-EVALUATING CHECKLIST FOR COOLING DISTRIBUTION

EVALUATOR _____
 DATE _____
 UNIT NAME _____
 SHEET NO. _____

COOLING DISTRIBUTION CONDITIONS															
Insulation Good	Insulation Average	Insulation Poor	Flange Insulated	Standard Op. Procedure	Controls Good	Controls Average	Controls Poor	Preventive Maintenance	Fix as Required	Condition as Required	Constant Conditioning	Zone Control Good	Zone Control Average	Zone Control Poor	TOTAL POINTS
2	1	0	2	1	2	1	0	1	0	1	0	2	1	0	
1															

No.	Location	Rating Value Max. = 11
1		

ELECTRICAL POWER DISTRIBUTION RATING INSTRUCTIONS

- 2 points for operation of a recording ammeter.
- 1 point for hourly electrical usage pattern of building being determined.
- 1 point for study of electrical requirements with the Power Company staff.
- 1 point for installation of a power peak warning system.
- 1 point for analysis to eliminate power peak demands.
- 1 point if a definite standard operating procedure is used. This shall be written and posted near the control panel.
- 1 point if definite preventive maintenance schedule is followed.
- 0 points if equipment is maintained or repaired only when it breaks down.
- 2 points for overall system Power Factor of 90% or above at main service.

SELF-EVALUATING CHECKLIST FOR ELECTRICAL POWER DISTRIBUTION

EVALUATOR _____	POWER DISTRIBUTION CONDITIONS																		
DATE _____	Recording Meter	Usage Pattern	Power Co. Coord.	Power Peak Warning	Power Demand Limited	Standard Op. Procedure	Preventive Maintenance	Fix as Required	90% Power Factor										TOTAL POINTS
UNIT NAME _____	2	1	1	1	1	1	1	0	2										
SHEET NO. _____	1																		

HOT WATER SERVICE RATING INSTRUCTIONS

- 2 points if the insulation is in good condition with no broken or missing sections. The insulation must not be wet, crumbly or cracked.
- 1 point if insulation is in average condition with small sections broken or missing. The insulation must not be wet or crumbly.
- 0 points if insulation is in poor condition with sections missing, broken, wet, crumbly or cracked.
- 1 point if faucets and valves are in good repair.
- 0 points if faucets and valves leak externally or internally.
- 1 point if definite standard operating procedures are used. These should be written and posted.
- 1 point if a definite preventive maintenance schedule is followed.
- 0 points if equipment is maintained or repaired only when it breaks down.

WATER SERVICE RATING INSTRUCTIONS

- 1 point if faucets and valves are in good repair.
- 0 points if faucets and valves leak externally or internally.
- 1 point if definite standard operating procedures are used. These should be written and posted.
- 1 point if a definite preventive maintenance schedule is followed.
- 0 points if equipment is maintained or repaired only when it breaks down.
- 1 point if there is no equipment that uses once-through cooling water and discharges to sewer.
- 1 point if water-consuming equipment is turned off when not in use.

SELF-EVALUATING CHECKLIST FOR WATER

EVALUATOR _____	WATER CONDITIONS																				
DATE _____	No Faucet Leaks	Faucet Leaks	Standard Op. Procedure	Preventive Maintenance	Fix as Required	No Equip. Use Water Once	Equipment Off														TOTAL POINTS
UNIT NAME _____																					
SHEET NO. _____																					
	Rating Value Max. = 5	1	0	1	1	0	1	1													
1																					

PROCESS HEATING RATING INSTRUCTIONS

- 1 point if the flue gas waste heat from processing equipment is extracted to heat relatively low temperature makeup, process and space heating water.
- 2 points if all high-temperature piping, ovens, dryers, tanks and processing equipment are covered with suitable insulating material. The insulation must not be wet, crumbly or cracked.
- 0 points if insulation is in poor condition with sections missing, broken, wet, Crumbly or cracked.
- 1 point if definite standard operating procedures are used. These should be written and posted near the control panel.
- 1 point if gas-heated equipment is checked for combustion efficiency on a regular basis.
- 1 point if a definite preventive maintenance schedule is followed.
- 0 points if equipment is maintained or repaired only when it breaks down.

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Chapter 14

In Transition from Energy Audits to Industrial Assessments

INTRODUCTION

The present Energy Analysis and Diagnostic Centers' program, sponsored by the U.S. Department of Energy is in transition from providing industrial energy audits to providing industrial assessments. This chapter presents the perspective of one of the centers which is currently undergoing this transition. This process of transition includes a change from the point of view of training future energy engineers. Currently, the focus is on energy management engineering for the U.S. manufacturing sector. The new focus will include multi-facet assessments for energy savings, waste minimization, and process improvements.

The expanded role of the newly converted centers combines an interdisciplinary approach of engineering analysis which includes the traditional engineering disciplines of electrical, mechanical, chemical, and industrial engineering. These newly converted centers have the responsibility to perform industrial assessments, hence the new name for these centers is Industrial Assessment Centers indicating the transition from recommending energy conservation opportunities to broader-based assessments.

This chapter will give examples of the expanded scope in assessments for various technologies showing the role of each of the three facets, i.e. energy savings, waste minimization and process improvements. The technologies include alternative refrigerants, reclamation &

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recycling, pollution prevention technologies, natural gas opportunities and new high-efficiency products. Illustrations from future case studies might show some compounding effects for opportunities which were not previously diagnosed as economically feasible, which are now becoming more attractive. The compounding effects are not limited to the interdependence of energy savings and waste minimization but also the improved process gains.

BACKGROUND

The U.S. Department of Energy (DOE), Energy Analysis and Diagnostic Center Program (EADC) has offered no-cost energy conservation audits to industrial plants since 1976. In 1988 the Waste Minimization Assessment Center (WMAC)¹ program funded by the U.S. Environmental Protection Agency was initiated in order to assist small and medium-size manufacturers. An initiative for phasing experienced EADCs into Industrial Assessment Centers (IAC) began in 1993. The establishment of the IACs provides the small and medium-size manufacturers with a combined energy, waste and process assessment. The energy assessment includes identification of energy conservation opportunities, annual cost savings, annual energy savings, implementation costs and paybacks. The waste assessment includes identification of waste minimization opportunities, annual cost savings, annual mass savings, implementation costs and paybacks. Finally, the process assessment includes identification of process efficiency improvements, annual cost savings, implementation costs and paybacks.

As one of the successful programs offered by the U.S. Department of Energy, Office of Industrial Technologies², the EADC program is designed to show how to conserve energy and reduce costs for small and medium-sized manufacturers. Engineering faculty and students, who perform these no-cost energy audits, identify all energy using systems in the plant. After the visit, the EADC issues a detailed, confidential report outlining the manufacturing plant's present energy usage and presenting specific energy conservation opportunities (ECOs). Each ECO includes appropriate technology and economic justification. A total of thirty energy audits per year are performed by each EADC.

ENERGY CONSERVATION OPPORTUNITIES

One approach to categorizing the various ECOs originates from the energy source, i.e. electricity, fossil fuels, and alternate energy sources. The fossil fuels can be subdivided into natural gas, propane, fuel oils, and coal. Examples of alternative energy sources include wood and waste materials.

Electricity-sourced ECOs

Within the various electricity-sourced ECOs, one can categorize these ECOs by the end-use equipment or function, such as electric motors, lighting systems, air compressors, cooling towers, chillers, electric water heaters, electric ovens, electric furnaces, refrigeration units, electric space heaters, transformers, fans, blowers, and other electric devices. For each type of end-use equipment or function, a series of energy conservation opportunities exist. Table 14-1 gives a set of potential ECOs that might be considered for lighting systems at a manufacturing plant.

Table 14-1. Lighting System ECOs

Install High-frequency Electronic Ballasts
Install High Efficacy Lamps
Install Occupancy Sensors
Install Photosensors & Utilize Daylighting
Reduce Lighting Usage

These lighting ECOs illustrate the potential for new technologies to be adopted into practice based on cost savings due to improved energy efficiency. Other electric sourced ECOs represent the energy conservation practice in good engineering, such as in air compressors. Table 14-2 illustrates a series of ECOs for air compressors.

Other electricity-sourced ECOs reflect potential trade-offs between initial costs, operating cost associated with energy, and cycle life of the equipment. Electric motors and their associated mechanical drives have several ECOs. Table 14-3 lists a set of potential ECOs for electric motors.

Table 14-2. Air Compressor ECOs

Use Synthetic Lubricants in Air Compressors
Reduce Compressed Air Pressure
Recover Compressor Waste Heat
Reduce Compressed Air Leaks
Install Larger Header Line in Compressed Air System
Use Outside Air for Compressor Intake

Table 14-3. Electric Motor ECOs

Install High-Efficiency Motors
Install Variable Speed Controls
Replace Standard V-Belts with High-Efficiency Belts
Install Synchronous Belts & Drives

In general each type of electricity-sourced end-use equipment would have a corresponding set of potential energy saving opportunities.

Natural Gas ECOs

Natural gas energy conservation opportunities can be sorted by end-use equipment such as boilers, burners, ovens, furnaces, coolers, and heaters. Also, several cost saving opportunities exist without a corresponding energy savings. An example of these cost savings could be the purchase of contract natural gas to achieve lower unit cost of the fuel. Table 14-4 gives a set of potential ECOs for a natural gas fired boiler.

As a point of reference, the first ECO listed in Table 14-4 entitled *Improve Boiler Combustion Efficiency* might involve several recommended actions. For example, a typical recommendation for a natural gas fired boiler would be to clean and adjust the air-to-fuel ratio to achieve an improved combustion efficiency. However, some boilers might be candidates for the installation of an oxygen sensor combined with a continuous trimming of the combustion air to achieve an optimum air-to-fuel ratio under all operating conditions and variations of natural gas composition.

Table 14-4. Boiler ECOs

Improve Boiler Combustion Efficiency
Install Condensate Return Systems
Install High-Pressure Condensate Return Systems
Install Tubulators in Boiler Tubes
Install Small Boilers
Recover Steam Blowdown
Repair Steam Traps
Install Feedwater-Preheater Systems
Shut Off Boiler during Idle Periods
Duct Warm Combustion Air to Boilers
Repair Condensate Leaks
Repair Steam Leaks

General ECOs

There exists many end-use devices that are general in that their function is not dependent of the energy source. Examples of such equipment include heat exchangers, thermal insulation, stack dampers, infiltration inhibitors, heat recovery, and various controllers. Table 14-5 lists a set of general ECOs that might be examined for potential applicability at each manufacturing plant for cost savings.

WASTE MINIMIZATION OPPORTUNITIES

With the increasing cost of management and disposal waste material, including process-related and residues from waste treatment, for manufacturers, a logical approach to minimizing the effect and stress on the environment is to reduce or eliminate the waste as its source. In the past, the WMAC identified and analyzed waste minimization opportunities (WMO). Specific WMO were recommended and the essential supporting technological and economical information was developed and presented to the manufacturing clients in the form of waste minimization assess-

Table 14-5. General ECOs

Install Stack Heat Exchangers
Install Covers for Heated Tanks
Install Dock Seals or/and Dock Shelters
Install Strip Doors (Interior/Exterior)
Install Stack Dampers
Install Destratification Fans
Install Radiant Heaters
Install Automatic Clock Thermostats
Install Energy Management Systems
Install Exhaust Hood for Ovens
Insulate Pipes/Ovens/Boilers/Dock Doors/Ducts/etc.
Balance Make-Up Air Systems

ment reports at a no out-of-pocket cost.

The classification of WMOs can be divided into source reduction, material substitution, recycling, waste treatment, and alternative waste management techniques. One can draw analogies between each of the basic classes of WMOs and a corresponding classes of ECOs. For example, a source reduction WMO might have a parallel energy conservation opportunity due to reduced material handling. Likewise a material substitution WMO might have a corresponding ECO related to a change in energy source, i.e. higher unit energy cost of electricity to a lower unit energy cost of natural gas. For some recycling WMOs, for example, one might be able to recover a solvent as a fuel additive ECO.

Source Reduction WMOs

The source reduction WMOs would be the natural first choice for a manufacturer. The direct cost savings would be clearly identified and accountable. Table 14-6 gives several candidate source reduction WMOs.

Material Substitution WMOs

The material substitution WMOs might be especially recommended

Table 14-6. Source Reduction WMOs

Reduction of Liquid <i>Drag-Out</i>
Reduction of Solid <i>Drag-Out</i>
Reduction of Water Use
High Transfer Efficiency Spray Paint Guns

when one could substitute a non-hazardous substance for a hazardous substance. Table 14-7 presents several types of material substitution WMOs.

Recycling WMOs

Recycling WMOs receive significant attention because of various local, state and federal regulations. In addition, the economics of recycling can be significant for manufacturers. In pursuing recycling goals, manufacturers might well develop an awareness program. For example, they might develop a program of rational metal-working oils and coolants management. The positive benefit of having such an awareness program among the labor forces can be well recognized by the local, state, federal and even world community. While the environmental issues facing the manufacturing industry today have expanded considerably beyond the traditional concerns of recycling, these WMOs are still viable. Table 14-8 gives several candidate recycling waste minimization opportunities specifically suitable to the manufacturing industry.

Treatment WMOs

The assessment process to identify WMOs requires consideration of the manufacturer’s process operation, basic chemistry, and various environmental concerns and needs. The manufacturers have become increasingly concerned with wastewater treatment, air emissions, potential

Table 14-7. Material Substitution WMOs

Alternative Cleaners or Solvents
Alternative Cleaning Methods
Other Material Substitutions

soil and groundwater contamination, solid waste disposal and employee health and safety. For example in the microelectronics industry, potential WMOs include the evaporation of sodium hydroxide waste and the use of ion exchange systems.

Alternative Waste Management WMOs

Various waste segregation or exchange opportunities might be considered as alternative waste management WMOs. For example, a more thorough segregation of scrap materials such as plastics, metals, and wood products might be a candidate WMO. Another example of an alternative waste management WMO is the segregation of waste solvents and sludge. Yet another example of an alternative waste management WMO is the de-emulsification and segregation of waste oils.

PROCESS IMPROVEMENT OPPORTUNITIES

The recommendations from the new IACs will include not only energy conservation opportunities and waste minimization opportunities, but also process improvement opportunities (PIO). With continuous improvement being a key to competing in the 90's, manufacturers need an assessment of how efficient their plant facilities are and how to improve their processes. They would like to know how to improve their profits while maintaining customer satisfaction. Implementation of PIOs depend on the manufacturer's goals, constraints, budgets, and time frame. Of course, each manufacturer would like to know how their plant ranks with their competitors on manufacturing performance. Recommended PIOs by an IAC can provide a manufacturer with access to alternative technologies to improve their efficiency. In addition, these PIOs can help correct problems causing low quality products, low productivity or low morale. In the past, the recommendations made by either the EADCs or the WMACs provided their clients with a list of recommendations that established a plan for improved energy efficiency or waste minimization management. Now the IACs have the benefit of both of those along with a plan for continuous improvement in manufacturing processes.

SUMMARY

The capabilities of the Industrial Assessment Centers in combining energy conservation, waste minimization and process improvement

recommendations is not unique for small and medium-sized manufacturers. For example, the Mid-America Manufacturing Technology Center (MAMTC)³ is a non-profit organization designed to improve the competitiveness and productivity of small and medium sized manufacturers. However, one difference between the IAC program and the MAMTC program is that the IAC operates on a *no out-of-pocket cost* basis.

In conclusion, the goals of any such program to improve the competitiveness and productivity of our small and medium sized manufacturers includes the delivery of a timely evaluation report that covers: technology, operation, quality, and safety issues. An integral part of such a report would be the inclusion of a combined energy, waste and process efficiency assessment.

References

- [1] "Waste Minimization Assessment Center—An EPA Program for Small and Medium-Size Manufacturers," Industrial Technology and Energy Management Division, University City Science Center, Philadelphia, PA.
- [2] "The Office of Energy Efficiency and Renewable Energy," DOE/CH10093-160, June 1993.
- [3] CITE (Continuous Improvement Targets for Excellence) Assessment Program, NIST/Mid-America Manufacturing Technology Center, Overland Park, KS, 1994.

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Chapter 15

A Compendium Of Handy Working Aids

This chapter contains tables, figures, and forms to supplement information in the foregoing chapters. Examples of energy audit forms are presented. Feel free to modify these forms to meet your requirements.

ENERGY AUDIT FORMS

- Figure 15-6 Energy Management Form
- Figure 15-7 Energy Use Audit Form
- Figure 15-8 HVAC System Data
- Figure 15-9 Reheat Coil Data
- Figure 15-10 Building Occupancy Schedule
- Figure 15- 11 CFM Audit
- Figure 15-12 Hot Water Converter
- Figure 15-13 Absorption Refrigeration Machine Data
- Figure 15-14 Building Information
- Figure 15-15 Lighting Audit
- Figure 15-16 Energy Survey Lights
- Figure 15-17 Energy Survey Electrical Equipment
- Figure 15-18 Electrical Worksheet
- Figure 15-19 Energy Survey Gas Equipment
- Figure 15-20 Gas Worksheet
- Figure 15-21 Fuel Oil Worksheet
- Figure 15-22 Steam Worksheet
- Figure 15-23 Water Worksheet
- Figure 15-24 Combustion System Data

CONVERSION FACTORS

- Table 15-2 List of Conversion Factors

Table 15-1. Degree Day Data

(Source: Cooling and Heating Load Calculation Manual ASHRAE GRP 158)

Average Winter Temperature and Yearly Degree Days for Cities in the United States and Canada ^{a,b,c} (Base 65°F)

State	Station	Avg. Winter Temp, ^a F	Degree-Days Yearly Total	State	Station	Avg. Winter Temp. F	Degree-Days Yearly Total
Ala.	Birmingham.....A	54.2	2551	Calif.	Bakersfield.....A	55.4	2122
	Huntsville.....A	51.3	3070		Bishop.....A	46.0	4275
	Mobile.....A	59.9	1560		Blue Canyon.....A	42.2	5596
	Montgomery.....A	55.4	2291		Burbank.....A	58.6	1646
Alaska	Anchorage.....A	23.0	10864		Eureka.....C	49.9	4643
	Fairbanks.....A	6.7	14279		Fresno.....A	53.3	2611
	Juneau.....A	32.1	9075		Long Beach.....A	57.8	1803
	Nome.....A	13.1	14171		Los Angeles.....A	57.4	2061
Ariz.	Flagstaff.....A	35.6	7152	Los Angeles.....C	60.3	1349	
	Phoenix.....A	58.5	1765	Mt. Shasta.....C	41.2	5722	
	Tucson.....A	58.1	1800	Oakland.....A	53.5	2870	
	Winslow.....A	43.0	4782	Red Bluff.....A	53.8	2515	
	Yuma.....A	64.2	974	Sacramento.....A	53.9	2502	
						
Ark.	Fort Smith.....A	50.3	3292	Sacramento.....C	54.4	2419	
	Little Rock.....A	50.5	3219	Sandberg.....C	46.8	4209	
	Texarkana.....A	54.2	2533				

^aData for United States cities from a publication of the United States Weather Bureau *Monthly Normals of Temperature, Precipitation and Heating Degree Days*, 1962, are for the period 1931 to 1960 inclusive. These data also include information from the 1963 revisions to this publication, where available.

^bData for airport station, A, and city stations, C, are both given where available.

^cData for Canadian cities were computed by the Climatology Division, Department of Transport from normal monthly mean temperatures and the monthly values of heating days data were obtained using the National Research Council computer and a method devised H.C.S. Thom of the United States Weather Bureau. The heating days are based on the period from 1931 to 1960.

^dFor period October to April, inclusive.

<i>State</i>	<i>Station</i>	<i>Avg. Winter Temp.,^a F</i>	<i>Degree-Days Yearly Total</i>	<i>State</i>	<i>Station</i>	<i>Avg. Winter Temp. F</i>	<i>Degree-Days Yearly Total</i>
Calif. (Cont'd)	San Diego.....A	59.5	1458	Iowa	Burlington.....A	37.6	6114
	San Francisco.....A	53.4	3015		Des Moines.....A	35.5	6588
	San Francisco.....C	55.1	3001		Dubuque.....A	32.7	7376
	Santa Maria.....A	54.3	2967		Sioux City.....A	34.0	6951
			Waterloo.....A		32.6	7320	
Colo.	Alamosa.....A	29.7	8529	Kans.	Concordia.....A	40.4	5479
	Colorado Springs.....A	37.3	6423		Dodge City.....A	42.5	4986
	Denver.....A	37.6	6283		Goodland.....A	37.8	6141
	Denver.....C	40.8	5524		Topeka.....A	41.7	5182
	Grand Junction.....A	39.2	5641		Wichita.....A	44.2	4620
Pueblo.....A	40.4	5462					
Conn.	Bridgeport.....A	39.9	5617	Ky.	Covington.....A	41.4	5265
	Hartford.....A	37.3	6235		Lexington.....A	43.8	4683
	New Haven.....A	39.0	5897		Louisville.....A	44.0	4660
Del.	Wilmington.....A	42.5	4930	La.	Alexandria.....A	57.5	1921
D.C.	Washington.....A	45.7	4224		Baton Rouge.....A	59.8	1560
					Lake Charles.....A	60.5	1459
Fla.	Apalachicola.....C	61.2	1308		New Orleans.....A	61.0	1385
	Daytona Beach.....A	64.5	879		New Orleans.....C	61.8	1254
	Fort Myers.....A	68.6	442	Shreveport.....A	56.2	2184	
	Jacksonville.....A	61.9	1239	Me.	Caribou.....A	24.4	9767
	Key West.....A	73.1	108		Portland.....A	33.0	7511
	Lakeland.....C	66.7	661	Md.	Baltimore.....A	43.7	4654
	Miami.....A	71.1	214		Baltimore.....C	46.2	4111
	Miami Beach.....C	72.5	141		Frederich.....A	42.0	5087
	Orlando.....A	65.7	766				
Pensacola.....A	60.4	1463					

Table 15-1. Degree Day Data (Cont'd)

State	Station	Avg. Winter Temp, ^d F	Degree-Days Yearly Total	State	Station	Avg. Winter Temp. F	Degree-Days Yearly Total
	Tallahassee.....A	60.1	1485	Mass.	Boston.....A	40.0	5634
	Tampa.....A	66.4	683		Nantucket.....A	40.2	5891
	West Palm Beach.....A	68.4	253		Pittsfield.....A	32.6	7578
					Worcester.....A	34.7	6969
Ga.	Athens.....A	51.8	2929	Mich.	Alpena.....A	29.7	8506
	Atlanta.....A	51.7	2961		Detroit(City).....A	37.2	6232
	Augusta.....A	54.5	2397		Detroit(Wayne).....A	37.1	6293
	Columbus.....A	54.8	2383		Detroit(Willow Run).....A	37.2	6258
	Macon.....A	56.2	2136		Escanaba.....C	29.6	8481
	Rome.....A	49.9	3326		Flint.....A	33.1	7377
	Savannah.....A	57.8	1819		Grand Rapids.....A	34.9	6894
	Thomasville.....C	60.0	1529		Lansing.....A	34.8	6909
					Marquette.....C	30.2	8393
Hawaii	Libue.....A	72.7	0		Muskegon.....A	36.0	6696
	Honolulu.....A	74.2	0		Sault Ste. Marie.....A	27.7	9048
	Hilo.....A	71.9	0				
Idaho	Boise.....A	39.7	5809	Minn.	Duluth.....A	23.4	10000
	Lewiston.....A	41.0	5542		Minneapolis.....A	28.3	8382
	Pocatello.....A	34.8	7033		Rochester.....A	28.8	8295
Ill.	Cairo.....C	47.9	3821	Miss.	Jackson.....A	55.7	2239
	Chicago(O'Hare).....A	35.8	6639		Meridian.....A	55.4	2289
	Chicago(Midway).....A	37.5	6155		Vicksburg.....C	56.9	2041
	Chicago.....C	38.9	5882	Mo.	Columbia.....A	42.3	5046
	Moline.....A	36.4	6408		Kansas City.....A	43.9	4711
	Peoria.....A	38.1	6025		St. Joseph.....A	40.3	5484
	Rockford.....A	34.8	6830		St. Louis.....A	43.1	4900
	Springfield.....A	40.6	5429		St. Louis.....C	44.8	4484
					Great Falls.....A	32.8	7750

Ind.	Evansville.....A	45.0	4435	Mont.	Springfield.....A	44.5	4900
	Fort Wayne.....A	37.3	6205		Billings.....A	34.5	7049
	Indianapolis.....A	39.6	5699		Glasgow.....A	26.4	8996
	South Bend.....A	36.6	6439		Columbus.....A	39.7	5660
Mont. (Cont'd)	Havre.....A	28.1	8700	Columbus.....C	41.5	5211	
	Havre.....C	29.8	8182	Dayton.....A	39.8	5622	
Neb.	Helena.....A	31.1	8129	Mansfield.....A	36.9	6403	
	Kalispell.....A	31.4	8191	Sandusky.....C	39.1	5796	
	Miles City.....	31.2	7723	Toledo.....A	36.4	6494	
	Missoula.....A	31.5	8125	Youngstown.....A	36.8	6417	
	Grand Island.....A	36.0	6530	Okla.	Oklahoma City.....A	48.3	3725
	Lincoln.....C	38.8	5864		Tulsa.....A	47.7	3860
	Norfolk.....A	34.0	6979	Ore.	Astoria.....A	45.6	5186
	North Platte.....A	35.5	6684		Burns.....C	35.9	6957
Omaha.....A	35.6	6612	Eugene.....A		45.6	4726	
Scottsbluff.....A	35.9	6673	Meacham.....A		34.2	7874	
Valentine.....A	32.6	7425	Medford.....A		43.2	5008	
			Pendleton.....A		42.6	5127	
Nev.	Elko.....A	34.0	7433	Portland.....A	45.6	4635	
	Ely.....A	33.1	7733	Portland.....C	47.4	4109	
	Las Vegas.....A	53.3	2709	Roseburg.....A	46.3	4491	
	Reno.....A	39.3	6332	Salem.....A	45.4	4754	
	Winnemucca.....A	36.7	6761				
N.H.	Concord.....A	33.0	7383	Pa.	Allentown.....A	38.9	5810
	Mt. Washington Obsv.....	15.2	13817		Erie.....A	36.8	6451
N.J.	Atlantic City.....A	43.2	4812		Harrisburg.....A	41.2	5251
	Newark.....A	42.8	4589		Philadelphia.....A	41.8	5144
	Trenton.....A	42.4	4980		Philadelphia.....C	44.5	4486
					Pittsburgh.....A	38.4	5987

Table 15-1. Degree Day Data (Cont'd)

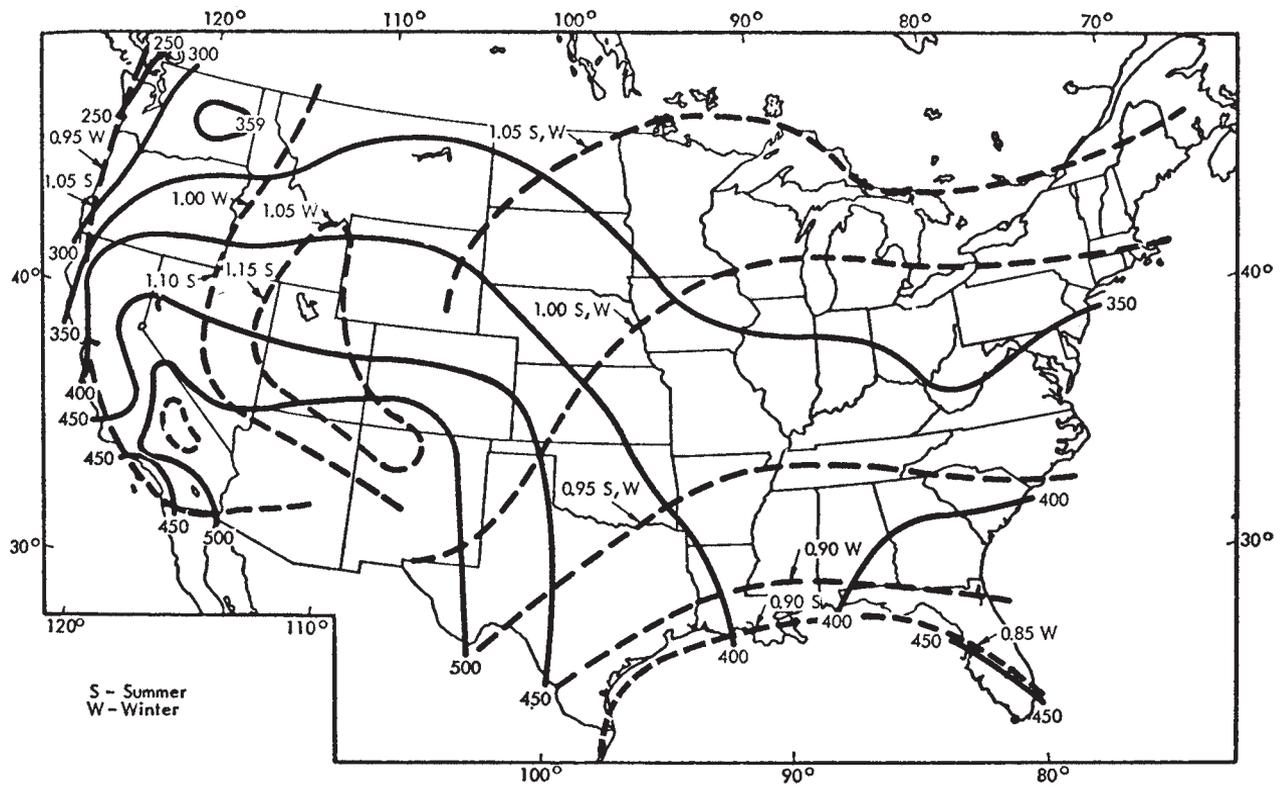
<i>State</i>	<i>Station</i>	<i>Avg. Winter Temp,^d F</i>	<i>Degree-Days Yearly Total</i>	<i>State</i>	<i>Station</i>	<i>Avg. Winter Temp. F</i>	<i>Degree-Days Yearly Total</i>
N.M.	Albuquerque.....A	45.0	4348		Pittsburgh.....C	42.2	5053
	Clayton.....A	42.0	5158		Reading.....C	42.4	4945
	Raton.....A	38.1	6228		Scranton.....A	37.2	6254
	Roswell.....A	47.5	3793		Williamsport.....A	38.5	5934
	Silver City.....A	48.0	705				
N.Y.	Albany.....A	34.6	6875	R.I.	Block Island.....A	40.1	5804
	Albany.....C	37.2	6201		Providence.....A	38.8	5954
	Binghamton.....A	33.9	7286	S.C.	Charleston.....A	56.4	2033
	Binghamton.....C	36.6	6451		Charleston.....C	57.9	1794
	Buffalo.....A	34.5	7062		Columbia.....A	54.0	2484
	New York (Cent. Park)...C	42.8	4871		Florence.....A	54.5	2387
	New York (LaGuardia)...A	43.1	4811		Greenville-Spartenburg...A	51.6	2980
	New York (Kennedy).....A	41.4	5219				
	Rochester.....A	35.4	6748	S.D.	Huron.....A	28.8	8223
	Schenectady.....C	35.4	6650		Rapid City.....A	33.4	7345
	Syracuse.....A	35.2	6756		Sioux Falls.....A	30.6	7839
N. C.	Asheville.....C	46.7	4042	Tenn.	Bristol.....A	46.2	4143
	Cape Hatteras.....	53.3	2612		Chattanooga.....A	50.3	3254
	Charlotte.....A	50.4	3191		Knoxville.....A	49.2	3494
	Greensboro.....A	47.5	3805		Memphis.....A	50.5	3232
	Raleigh.....A	49.4	3393		Memphis.....C	51.6	3015
	Wilmington.....A	54.6	2347		Nashville.....A	48.9	3578
	Winston-Salem.....A	48.4	3595		Oak Ridge.....C	47.7	3817
N.D.	Bismarck.....A	26.6	8851	Tex.	Abilene.....A	53.9	2624
	Devils Lake.....C	22.4	9901		Amarillo.....A	47.0	3985
	Fargo.....A	24.8	9226		Austin.....A	59.1	1711
	Williston.....A	25.2	9243		Brownsville.....A	67.7	600
					Corpus Christi.....A	64.6	91

Ohio	Akron-Canton.....A	38.1	6037		DallasA	55.3	2363	
	CincinnatiC	45.1	4410		El PasoA	52.9	2700	
	Cleveland.....A	37.2	6351		Fort Worth.....A	55.1	2405	
Texas (Cont'd)	Galveston.....A	62.2	1274	Alta.	BanffC	—	10551	
	Galveston.....C	62.0	1235			Calgary.....A	—	9703
	HoustonA	61.0	1396			Edmonton.....A	—	10268
	HoustonC	62.0	1278		LethbridgeA	—	8644	
	LaredoA	66.0	797	B.C.	KamloopsA	—	6799	
	LubbockA	48.8	3578			Prince George*.....A	—	9755
	MidlandA	53.8	2591			Prince Rupert.....C	—	7029
	Port ArthurA	60.5	1447			Vancouver*A	—	5515
	San Angelo.....A	56.0	2255			Victoria*A	—	5699
	San AntonioA	60.1	1546		Victoria.....C	—	5579	
	Victoria.....A	62.7	1173	Man.	Brandon*A	—	11036	
Waco.....A	57.2	2030			Churchill.....A	—	16728	
Wichita FallsA	53.0	2832			The PasC	—	12281	
Utah	MilfordA	36.5	6497		WinnipegA	—	10679	
	Salt Lake City.....A	38.4	6052	N.B.	Fredericton*A	—	8071	
	WendoverA	39.1	5778			Moncton.....C	—	8727
					St. JohnC	—	8219	
Vt.	BurlingtonA	29.4	8269	Nfld.	ArgentiaA	—	8440	
Va.	Cape Henry.....C	50.0	3279			Corner BrookC	—	8978
	LynchburgA	46.0	4166			GanderA	—	9254
	Norfolk.....A	49.2	3421			Goose*A	—	11887
	RichmondA	47.3	3865			St. John's*A	—	8991
	RoanokeA	46.1	4150	N.W.T.	Aklavik,C	—	18017	
Wash.	OlympiaA	44.2	5236					
	Seattle-Tacoma.....A	44.2	5145					

Table 15-1. Degree Day Data (Concluded)

<i>Days</i>		<i>Avg.</i>	<i>Degree-Days</i>			<i>Avg.</i>	<i>Degree-</i>	
<i>State</i>	<i>Station</i>	<i>Winter Temp,^a F</i>	<i>Yearly Total</i>	<i>State</i>	<i>Station</i>	<i>Winter Temp. F</i>	<i>Yearly Total</i>	
Seattle	C.....	46.9	4424	Fort Norman.....	C	—	16109	
	Spokane	A	36.5		6655	Resolution Island	C	—
Wash. (Cont'd)	Walla Walla	C	43.8	4805	Fort William.....	A	—	10405
	Yakima	A	39.1	5941	Kapuskasing	C	—	11572
W. Va.	Charleston	A	44.8	4476	Kitchner	C	—	7566
	Elkins.....	A	40.1	5675	London.....	A	—	7349
	Huntington.....	A	45.0	4446	North Bay.....	C	—	9219
	Parkersburg.....	C	43.5	4754	Ottawa	C	—	8735
Wisc.	Green Bay.....	A	30.3	8029	Toronto.....	C	—	6827
	La Crosse.....	A	31.5	7589	P.E.I. Charlottetown.....	C	—	8164
	Madison.....	A	30.9	7863	Summerside	C	—	8488
	Milwaukee.....	A	32.6	7635	Que. Arvida.....	C	—	10528
Wyo.	Casper.....	A	33.4	7410	Montreal*.....	A	—	82033
	Cheyenne.....	A	34.2	7381	Montreal	C	—	7899
	Lander.....	A	31.4	7870	Quebec*.....	A	—	9372
	Sheridan.....	A	32.5	7680	Quebec	C	—	8937
N. S.	Halifax	C	—	7361	Sasks Prince Albert.....	A	—	11630
	Sydney	A	—	8049	Regina	A	—	10806
	Yarmouth.....	A	—	7340	Saskatoon.....	C	—	10870
Ont.	Cochrane.....	C	—	11412	Y.T. Dawson.....	C	—	15067
					Mayo Landing.....	C	—	14454

*The data for these normals were from the full 10-year period 1951-1960, adjusted to the standard normal period 1931-1960.



ANNUAL MEAN DAILY INSOLATION (solid lines), in Langleys, and summer and winter clearness numbers (broken lines) are plotted on United States map. Note: To convert Langleys per day to Btu/ft² day multiply number in figure by 3.69.

Figure 15-1. Annual Mean Daily Insolation
 (Courtesy of Heating/Piping/Air Conditioning, Sept. 1966)

Building _____

_____ Year

Month*	Heating Degree Days	Cooling Degree Days	electricity				Oil					Natural Gas			Coal <input type="checkbox"/>	Purchased Steam <input type="checkbox"/>		Total Energy Cost	
			Quantity kWh	Cost (dollars)			Quantity Gallons	Cost (dollars)			Quantity mcf	Cost (Dollars)			Quantity Unit	Cost (dollars)			
				Total \$	\$/kWh	\$/MMBtu		\$/Gal.	Total \$	\$/MMBtu		Total \$	\$/mcf	\$/MMBtu		Total \$	\$/Unit		\$/MMBtu
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
January																			
February																			
March																			
April																			
May																			
June																			
July																			
August																			
September																			
October																			
November																			
December																			
Annual Totals																			
Annual Averages																			

*Or comparable time period

Electricity = 3412 Btu/kWh
Gas = 1030 Btu/cf

Oil: #2 = .139 MMBtu/gal
#4 = .150 MMBtu/gal
#5 = .152 MMBtu/gal
#6 = .153 MMBtu/gal

mcf = 1000 cubic feet of gas
MMBtu = one million Btu

Figure 15-6. Energy Management Form

1. Gross Annual Fuel and Energy Consumption

Line No.	A	B Conversion Factor	C Thousands of Btus/yr
		× 138 (1) =	_____
		× 146 (2) =	_____
1. Oil-gallons	_____	× 1.0 (3) =	_____
2. Gas-Cubic Feet	_____	× 0.8 (4) =	_____
3. Coal-Short tons	_____	× 26,000 =	_____
4. Steam-Pounds × 10 ³	_____	× 900 =	_____
5. Propane Gas-lbs	_____	× 21.5 =	_____
6. Electricity-kW/Hrs	_____	× 3.413 =	_____
7. Total Btus × 10 ³ /yr		_____
8. Btus × 10 ³ /Yr/Per Square Foot of Floor Area (Line 7 + Figure 4, Line 7)			_____

Use for (1) No. 2 Oil; (2) No. 6 Oil; (3) Natural Gas; (4) Mfg. Gas

2. Annual Fuel and Energy Consumption for Heating

Line No.	A	B Conversion Factor	C Thousands of Btus/yr
		× 138 (1) =	_____
		× 146 (2) =	_____
		× 1.0 (3) =	_____
10. Gas-Cubic Feet	_____	× 0.8 (4) =	_____
11. Coal-Short tons	_____	× 26,000 =	_____
12. Steam-Pounds × 10 ³	_____	× 900 =	_____
13. Propane Gas-lbs	_____	× 21.5 =	_____
14. Electricity-kW/Hrs	_____	× 3.413 =	_____
15. Total Btus ×		_____
16. Btus × 10 ³ /Yr Per Square Foot of Floor Area (Line 15 Line 7)			_____

3. Annual Fuel and Energy Consumption for Domestic Hot Water

Line No.	A	B Conversion Factor	C Thousands of Btus/yr
17. Oil-Gallons	_____	× 138 (1) =	_____
		× 146 (2) =	_____

Figure 15-7. Energy Use Audit Form

(Source: Guidelines for Saving Energy in Existing Buildings-Building Owners and Operators Manual, ECM-1)

	A	B	C
		<i>Conversion Factor</i>	<i>Thousands of Btus/yr</i>
18. Gas- Cubic Feet		× 1.0 (3) =	_____
		× 0.8 (4) =	_____
19. Coal- Short Tons		× 26,000 =	_____
20. Steam-Pounds × 10 ³		× 900 =	_____
21. Propane Gas lbs		× 21.5 =	_____
22. Electricity kW/Hrs		× 3.413 =	_____
23. Totals Btus/Yr × 10 ³			_____
23. Totals Btus/Yr × 10 ³			_____
24. Btu × 10 ³ Yr/Per Square Foot of Floor Area (Line 23 + Figure 4, Line 7)			_____
 4. Annual Fuel and/or Energy Consumption for Cooling (Compressors & Chillers)			
Line No.	A	B	C
		<i>Conversion Factor</i>	<i>Thousands of Btus/yr</i>
a) if absorption cooling		× 138 (1) =	_____
		× 146 (2) =	_____
25. Oil Gallons		× 146 (2) =	_____
		× 1.0 (3) =	_____
26. Gas- Cubic Feet		× 0.8 (4) =	_____
27. Coal Short Tons		× 26,000 =	_____
28. Steam-Pounds × 10 ³		× 900 =	_____
29. Propane Gas-lbs		× 21.5 =	_____
30. Totals Btus/Yr × 10 ³			_____
31. Btus × 10 ³ /Yr Per Square Foot of Floor Area (Line 30 + Figure 4, Line 7)			_____
b) if electric cooling			
32. Electricity-kWh		× 3.413 =	_____
33. Btus × 10 ³ /Yr Per Square Foot of Floor Area (Line 32 + Figure 4, Line 7)			_____
 5. Estimated Annual Energy Consumption for Interior Lighting			
Line No.	A	B	C
		<i>Conversion Factor</i>	<i>Thousands of Btus/yr</i>
a) if absorption cooling		× 3.413 =	_____
34. kWh		× 3.413 =	_____
			(Fig. 10, Line 3 × Fig. 10, Line 33 (1))
35. Btus × 10 ³ /Yr/Per Square Foot of Floor Area (Fig. 10, Line 35, Col. C + Fig. 4, Line 7)			_____
 6. Estimated Annual Electrical Energy Consumption for all Motors and Machines if Building and Hot Water are Not Electrically Heated. (1)			
36. Total kW Hrs _____ Less kW Hrs Lighting _____ = _____ kW Hrs (Line 22, Col. A)			
37. kW Hrs/Yr/Sq Ft floor area = _____ (1) (Line 37 Col. C + Fig. 4, Line 7)			
38. Btus × 10 ³ /Yr/Sq Ft floor area = (Line 37) × 3.431 _____ (2)			

(1) and (2). If building heat and hot water are electrically heated, deduct the kW Hrs/Yr per sq ft and Btus/Yr per sq ft for heating and hot water. (Lines 37 & 38)

Figure 15-7. Energy Use Audit Form (Concluded)

PROJECT NO. _____

Job Name _____ Date _____

System No. _____ Type _____ O.A.T. _____ Time of Day _____

Location _____ Tested By _____

1. DRIVE INFORMATION

Motor Manufacturer..... _____ Frame Size _____

Motor HP _____

Phases _____

Amperage..... Rated _____ Actual _____

Voltage Rated _____ Actual _____

Fan RPM..... Regular _____ Actual _____

Fan Manufacturer _____

Fan Type..... _____

Motor Sheave Position, Type, and Size _____

Shaft Diameter _____

Key Size..... _____

NOTE: ALL TEMPERATURES MUST BE TAKEN AT THE SAME TIME: AND TIME OF DAY, WHEN THE READINGS ARE TAKEN MUST BE INDICATED.

2. FAN DATA

Does system have return fan? Yes _____ No _____

If Yes, Fan No _____

CFM (Design)..... Supply _____ Return _____ O.A. _____

CFM (Actual)..... Supply _____ Return _____ O.A. _____ at _____ ΔP (inches H₂O)

SP Filters..... Inlet _____ Discharge _____

SP PH Coil..... Inlet _____ Discharge _____

Figure 15-8. HVAC System Data
(Source: Certified Test & Balance Company, Inc., Chicago, Illinois)

(Continued)

SP H Coil Inlet _____ Discharge _____
 SP C Coil..... Inlet _____ Discharge _____
 SP Sup. Fan..... Inlet _____ Discharge _____
 SP Ret. Fan..... Inlet _____ Discharge _____
 Temp. Readings..... RAT _____ RFDT _____ MAT _____ PHDT _____
 HCDT _____ CCDT _____ SFDT _____

3. COIL DATA

Preheat Coil EWT _____ LWT _____ GPM _____ PDPH _____
 Heating Coil EWT _____ LWT _____ GPM _____ PDPH _____
 Cooling Coil..... EWT _____ LWT _____ GPM _____ PDPH _____
 Reheat Coil..... EWT _____ LWT _____ GPM _____ PDPH _____
 For dual duct..... HDT _____ CDT _____
 Discharge for multizone (zone temps °F) Z₁ _____ Z₂ _____
 Z₃ _____ Z₄ _____ Z₅ _____ Z₆ _____
 Z₇ _____ Z₈ _____ Z₉ _____ Z₁₀ _____

4. COMPONENT CONDITION (VISUAL INSPECTION)

Casing or Plenum..... Heavy Leaks _____ Medium Leaks _____ Nominal _____
 Outside Air Louver..... Clean _____ Dirty _____ Clogged _____
 Filters Clean _____ Dirty Clogged _____
 Filter Face Area _____ Ft² Air Velocity Across Filter Face _____ GPM
 Cooling Coil..... Clean _____ Dirty _____ Clogged _____
 Heating Coil Clean _____ Dirty _____ Clogged _____

Figure 15-8 (Continued). HVAC System Data
 (Source: Certified Test & Balance Company, Inc., Chicago, Illinois)

PROJECT NO. _____

JOB NAME _____ DATE _____

UNIT NO. _____ TYPE _____ (Steam-to-water/Water-to-water)

LOCATION _____ TESTED BY _____

Steam Pressure (PSIG).....	Actual _____	Design _____
Flow Rate (GPM).....	Actual _____	Design _____
Pressure Drop.....	Actual _____	Design _____
EWT.....	Actual _____	Design _____
LWT.....	Actual _____	Design _____
Reset Control.....	Automatic _____	Manual _____

REMARKS:

Figure 15-12. Hot Water Converter Data

(Source: Certified Test & Balance Company, Inc., Chicago, Illinois)

PROJECT NO. _____

JOB NAME _____ DATE _____

SYSTEM NO. _____ MACHINE NO. _____ REFRIGERANT TYPE _____

LOCATION _____ TESTED BY _____

COOLER:

GPM Capacity.....	Actual _____	Design _____
Pressure Drop.....	Actual _____	Design _____
EWT.....	Actual _____	Design _____
LWT.....	Actual _____	Design _____

CONDENSER:

GPM Capacity.....	Actual _____	Design _____
Pressure Drop.....	Actual _____	Design _____
EWT.....	Actual _____	Design _____
LWT.....	Actual _____	Design _____

REMARKS:

Figure 15-13. Absorption Refrigeration Machine Data

(Source: Certified Test & Balance Company, Inc., Chicago, Illinois)

1. GENERAL INFORMATION

Surveyed by: _____

IDENTITY:

Survey Date: _____

OPERATION _____

Address _____

Type(s) of occupancy _____

Name of person in charge of energy _____

PHYSICAL DATA:

Building orientation _____

No. of floors _____

Floor area, gross, square feet _____

Net air conditioned square feet _____

Construction type:

Walls (masonry, curtain, frame, etc.)

N _____ S _____ E _____ W _____

Figure 15-14. Building Information

Roof:

Type: Flat _____ Color: Light _____
 Pitched _____ Dark _____

Glazing:

Exposure	*Type	%Glass/Exterior wall area
N	_____	_____
S	_____	_____
E	_____	_____
W	_____	_____

*Type: Single, double, insulating, reflective, etc.

Glass shading employed outside (check one)

Fins _____ Overhead _____ None _____ Other _____

Glass shading employed inside (check one):

Shades ____ Blinds ____ Drapes, open mesh ____ Drapes opaque ____ None ____ Other ____

SKETCH OF BUILDING SHOWING PRINCIPLE DIMENSIONS.

BUILDING TYPE:

All electric _____
 Gas total energy _____
 Oil total energy _____
 Other _____

BUILDING OCCUPANCY AND USE:

Weekdays: Occupied by:* _____ people from _____ to _____ (hours)

Saturdays:

Sundays, holidays

Hours air conditioned: Weekdays from ____ to ____; Saturdays ____ to ____ Sundays, holidays from ____ to ____

*(Account for 24 hours a day. If unoccupied, put in zero)

2. ENVIRONMENTAL CONDITIONS

OUTDOOR CONDITIONS

Winter: Day _____ °F. dB _____ mph wind Night _____ °F. dB _____ mph wind

Summer: Day _____ °F. dB _____ mph wind Night _____ °F. dB _____ mph wind

MAINTAINED INDOOR CONDITIONS:

Winter: Day-°F. dB-%rh Night _____ °F. dB _____ %rh

Summer: Day-°F. dB-%rh Night _____ °F. dB _____ %rh

Figure 15-14. Building Information (Cont'd)

3. SYSTEMS AND EQUIPMENT DATA

HVAC SYSTEMS:

Air handling systems (check as appropriate):

Perimeter system designation:

Single zone _____	Multizone _____
Fan coil _____	Induction _____
Variable air volume _____	Dual duct _____
Terminal reheat _____	Self-contained _____
Heat pump _____	

Interior system designation:

Fan coil _____	Variable air volume _____
Single zone _____	Other (describe) _____

Principle of operation:

Heating-cooling-off _____

Air volume variation _____

Air mixing control _____

Temperature variation _____

Interior:

Heating-cooling-off _____

Air volume variation _____

Temperature variation _____

4. AIR HANDLING UNIT - SUPPLY, RETURN, EXHAUST

System Description _____

Horsepower _____ OSA Dampers - Yes No M.A. Setting _____ °F

Location _____ Area Served _____

Terminal Units: Quantity _____ Type _____

Operations (Start-Stop)	Start Time	Stop Time
Monday thru Friday	_____	_____
Saturday	_____	_____
Sunday	_____	_____
Holiday	_____	_____
Method of Start-Stop	Time Clock <input type="checkbox"/>	Manual <input type="checkbox"/> Other <input type="checkbox"/>

Figure 15-14. Building Information (Cont'd)

5. AIR HANDLING UNIT - SUPPLY, RETURN, EXHAUST

System Description _____

Horsepower _____ OSA Dampers - Yes No M.A. Setting _____ °F

Location _____ Area Served _____

Terminal Units: Quantity _____ Type _____

Operations (Start-Stop)	Start Time	Stop Time
Monday thru Friday	_____	_____
Saturday	_____	_____
Sunday	_____	_____
Holiday	_____	_____

Method of Start-Stop Time Clock Manual Other

6. COOLING PLANT

Chillers: Number _____ Total Tonnage/kW _____

Chilled Water Pumps _____ Total HP _____

Condensed Water Pumps _____ Total HP _____

Cooling Tower Fan(s) _____ Total HP _____

Chilled Water Supply Temp., Setpoint _____ °F

Operations (Start-Stop)	Start Time	Stop Time
Monday thru Friday	_____	_____
Saturday	_____	_____
Sunday	_____	_____
Holiday	_____	_____

Method of Start-Stop Time Clock Manual Other

Figure 15-14. Building Information (Cont'd)

Months Operation per Year _____

Remarks _____

7. BOILER PLANT

Boiler No. _____ Size _____ Type _____

Fuel Used _____

Hot Water Supply Setpoint _____°F Steam Pressure Setpoint _____ psi

Number of Pumps _____ Total HP _____

Remarks _____

8. ROOFTOP/UNITARY SYSTEMS

Manufacture and Model _____

Quantity _____ Location _____

Cooling Capacity _____ Tons Total _____

Heating Capacity _____ Btu Output _____ Btu Input (Gas/Oil) _____

Electric Gas Steam/HW

Single Zone Units _____ Multizone Units _____ Number of Zones _____

O.A. Damper Control _____

Fans:	CFM	HP
Supply	_____	_____
Return	_____	_____
Exhaust	_____	_____

Operations (Start-Stop)	Start Time	Stop Time
Monday thru Friday	_____	_____
Saturday	_____	_____
Sunday	_____	_____
Holiday	_____	_____

Figure 15-14. Building Information (Cont'd)

Method of Start-Stop Time Clock Manual Other

9. EXHAUST, AIR, MAKEUP AIR SYSTEMS

Designation	Location	Area Served	CFM	HP
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
Operating Schedule		TOTAL	_____	_____

All fans (supply, return and exhaust):

Location	Horsepower	Type	Method of Operation
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Source of heating energy:

Hot water _____ Steam _____ Electric resistance _____ Other _____

Heating plant:

Boiler No. _____ Rating _____ MBH

Boiler type:

Firetube _____ Watertube _____ Elec. resist. _____ Electrode _____ Other _____

Fuel _____ Standby _____

Hot water supply _____ °F, Return _____ °F

Steam Pressure _____ psi

Pumps No. _____ Total HP _____

Room heating units:

Type: Baseboard _____ Convectors _____ Fin tube _____

Ceiling or wall panels _____ Unit heaters _____ Other _____

Cooling plant:

Chillers: _____ No. _____ Total capacity (tons) _____

Type: Centrifugal _____ Reciprocating _____ Absorption _____

Figure 15-14. Building Information (Cont'd)

Capacity controlled by: _____

Chiller operation: Starting controls _____

Stopping controls _____

Chilled water temp. supply _____ °F, return _____ °F

Condenser water temp. _____ in °F _____ out °F

Heat dissipation device:

Evaporative condense _____

Air cooled condense _____

Cooling tower _____

Condenser/cooling tower fan HP _____

Heat recovery device: Double bundle condenser _____ Other _____

Chilled water pumps _____ Total HIP _____

Condenser water pumps _____ Total HP _____

Self-contained units:

Type: Thru-the-wall-air conditioner _____ Other _____

No. of units _____ Basic module served _____

Capacity (tons) _____

10. ENERGY CONSERVATION DEVICES:

Type:

Condenser water used for heating _____
 Demand limiters _____
 Energy storage _____
 Heat recovery wheels _____
 Enthalpy control of supply-return-exhaust damper _____
 Recuperators _____
 Others _____

LIGHTING:

Interior lighting type: _____
 watts/ft²: Hallway/corridor _____
 Work stations _____
 Circulation areas within work space _____
 On-off from broaker panel _____ Wall switches _____
 Control switching _____
 Exterior Lighting: Type _____ Total kW _____

DOMESTIC HOT WATER HEATING:

Size _____ Rated input _____ Water Temp. _____°F
 Energy Source: Gas _____, Oil _____, Electric _____, Other _____

Figure 15-14. Building Information (Cont'd)

OTHER EQUIPMENT (Kitchen, etc.):

Equip. Description	Quantity	Size/Capacity in Btu, kW, HP, etc.
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

11. OPERATING SCHEDULE:

OPERATION (Start-stop)

Equipment description	Weekdays	Saturday	Sunday	Holiday
Refrigeration cycle mach.	_____	_____	_____	_____
Fans - supply	_____	_____	_____	_____
Fans - return/exhaust	_____	_____	_____	_____
Fans - exhaust only	_____	_____	_____	_____
HVAC auxilliary equip.	_____	_____	_____	_____
Lighting - interior	_____	_____	_____	_____
- exterior	_____	_____	_____	_____
Fan kitchen exhaust	_____	_____	_____	_____
Elevators	_____	_____	_____	_____
Escalators	_____	_____	_____	_____

Domestic hot water ht. _____

Other (describe: _____) _____

12. LIGHTING

1. Interior Lighting Type _____
 Watts/Ft² Offices _____ Other _____
 Total Install kW _____ Foot Candles _____
 On-Off from Breaker Panel? _____
 Wall Switch? _____ Control Switching? _____
 Operating Schedule _____
2. Exterior Lighting Type _____
 Total kW _____
 Operating Schedule _____
3. Remarks _____

Figure 15-14. Building Information (Cont'd)

13. UTILITIES

Electric Utility _____

Rate Schedule _____ Effective _____

Name of Rep _____ Phone _____

Gas Utility _____

Rate Schedule _____ Effective _____

Name of Rep _____ Phone _____

Water Utility _____

Rate Schedule _____ Effective _____

Name of Rep _____ Phone _____

14. EMERGENCY GENERATORS

Number _____ Size _____ kW _____

SUMMARY SHEET

GENERAL INFORMATION

Building/Plant/Business Center: _____
 Address: _____
 City, State: _____
 Building Supervisor: _____
 Building Use: _____

TOTALS BY BUILDING LOCATION:

Building Location	Total Area Building Location	Allowance Sq Ft	Total Watt Allowance	Total Connected Load
1		3.0		
2		1.0		
3		0.5		
Interior Total				
		Allowance		
		Ft		
4		5.0		
5		0.5		
Exterior Total				

BUILDING LOCATION DESIGNATIONS:

- 1 = Office Space/Personnel
- 2 = Rest, Lunch, Shipping/Warehouse
- 3 = Malls, Lobby
- 4 = Building Perimeter, Facade, Canopy
- 5 = Parking

DETAIL SHEET

GENERAL INFORMATION

Building/Plant/Business Center: _____
 Address: _____
 BUILDING LOCATION USE: _____

Room Name	Area Sq Ft	Lamp or Fixture Type	Quantity	Watts Unit	Total Connected Load (Watts)
TOTAL					

Figure 15-15. Lighting Audit

(Continued)

TYPICAL LIGHTING FIXTURE WATTAGE

I. FLUORESCENT

Lamp Description	Lamps per/Lamp Fixture/Type	Fixture Wattage*
4 Ft 40 Watt Rapid Start	1-F40T12	50
	2-F40T12	92
	3-F40T12	142
	4-F40T12	184
8 Ft Slimline Instant Start	1-F96T1 2	100
	2-F96T1 2	170
	3-F96T12	270
	4-F96T1 2	340
8 Ft High Output	1-F96T12/HO	140
	2-F96T12/HO	252
	3-F96T12/HO	392
	4-F96T12/HO	504
8 Ft 1500 ma Power Grove, SHO or VHO	1-F96PG17	230
	1-F96T12/SHO or VHO	
	2-F96PG17	450
	2-F96T12/SHO or VHO	
	3-F96PG17	680
	3-F96T12/SHO or VHO	
	4-F96PG17	900
	4-596T12/SHO or VHO	

II. HIGH INTENSITY DISCHARGE

Lamp Type	Lamp Designation	Fixture Watts	Wattage*
Mercury	MV 100	100	118
	MV 175	175	200
	MV 250	250	285
	MV 400	400	450
	MV 1000	1000	1075
Metal Halide	MH 175	175	210
	MH 250	250	292
	MH 400	400	455
	MH 1000	1000	1070
High Pressure Sodium	HPS 70	70	88
	HPS 100	100	130
	HPS 150	150	188
	HPS 250	250	300
	HPS 400	400	465
	HPS 1000	1000	

*Includes Lamp and Ballast Wattage.

Figure 15-15. Lighting Audit (Cont'd)

To plan more adequate lighting, refer to the table below which illustrates the energy used by various types of lighting.

LUMEN/WATT TYPICAL LIGHT SOURCES

<i>Source</i>	<i>Initial Lumens Watt</i>
Low pressure sodium (35 to 180 watts)	133 to 183
High pressure sodium (70 watts to 1,000 watts)	83 to 140
Metal halide (175 watts to 1,000 watts)	80 to 125
Fluorescent (30 watts to 215 watts)	74 to 84
Mercury (100 watts to 1,000 watts)	42 to 62
Incandescent (100 watts to 1,500 watts)	17 to 23

RECOMMENDED REFLECTANCE VALUES

<i>Surfaces</i>	<i>Reflectance (Percent)</i>
Ceiling	80-90%
Walls	40-60%
Desks and Bench Tops, Machines and Equipment	25-45%
Floors	Not less than 20%

Figure 15-15. Lighting Audit (Concluded)

OPERATION _____ LOCATION _____ DATE _____

MFG'R.	EQUIPMENT ITEM	LOCATION	ELECTRICAL EQUIPMENT RATED INPUT						COMMENTS
			1 AMPS	2 VOLTS	3 kW* 1 × 2 1000	4 HRS OPERATED PER DAY	5 DAYS OPERATED PER WEEK	6 kWh PER WEEK 3 × 4 × 5	

1. Fuel or power requirement is usually listed on equipment name plate.
2. To find Btu's per hour for
 Electricity — multiply amps × volts × 3.413 or watts × 3.413
 Natural Gas—multiply cubic feet per hour × 1,000
 #2 Fuel Oil—multiply gallons per hour × 140,000
 Steam—multiply pounds per hour × 1,000
3. To find cost per hour, multiply the cost per Btu for that unit's fuel (from Worksheet × the Btus per hour by that unit.

*To find Btu equivalents (expressed in millions) for electricity, multiply kilowatt hours × .003414.
 For natural gas, multiply cubic feet × 001.
 For #2 fuel oil, multiply gallons × .14.
 For purchased steam, multiply pounds × 001.
 To find the cost per million Btu's in each category, divide the total cost in that category by the total Btu's, expressed in millions, for that category.

Figure 15-17. Energy Survey—Electrical Equipment

METER NO. _____
 LOCATION _____

MONTHLY ENERGY USE _____ OPERATION _____ STATE _____

	Consumption	Demand		Fuel Adj.		65°	65°	kWh	Cost	Cost Increase
Month	kWh	kW	Rate	Rate/kWh	Cost	Heating Days	Cooling Days	Increase Over Past Year	Increase Over Past Year	Fuel Adj. Rate Over/Under Past Year
JAN.										
FEB.										
MAR.										
APR.										
MAY										
JUNE										
JULY										
AUG.										
SEPT.										
OCT.										
NOV.										
DEC.										
TOTALS										

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	COMMENTS
% INCREASE COST													
% INCREASE kWh													
% INCREASE FUEL ADJ. RATE													
BASIC RATE INCREASE													

Figure 15-18. Electrical Worksheet

OPERATION _____ LOCATION _____ DATE _____

MFG'R.	EQUIPMENT ITEM	LOCATION	ELECTRICAL EQUIPMENT RATED INPUT					COMMENTS
			7 BTU PER HOUR	8 CU. FT. PER HR. 7/1000	9 HOURS OPERATED PER DAY	10 DAYS OPERATED PER WEEK	11 CU. FT. PER WEEK 8 × 9 × 10	

1. Fuel or power requirement is usually listed on equipment name plate.
 2. To find Btu's per hour for
 Electricity — multiply amps × volts × 3.413 or watts × 3.413
 Natural Gas—multiply cubic feet per hour × 1,000
 #2 Fuel Oil—multiply gallons per hour × 140,000
 Steam—multiply pounds per hour × 1,000
 3. To find cost per hour, multiply the cost per Btu for that unit's fuel (from Worksheet × the Btus per hour by that unit.
- *To find Btu equivalents (expressed in millions) for electricity, multiply kilowatt hours × .003414.
 For natural gas, multiply cubic feet × 001.
 For #2 fuel oil, multiply gallons × .14.
 For purchased steam, multiply pounds × 001.
 To find the cost per million Btu's in each category, divide the total cost in that category by the total Btu's, expressed in millions, for that category.

Figure 15-19. Energy Survey - Gas Equipment

METER NO. _____

LOCATION _____

MONTHLY ENERGY USE _____ OPERATION _____ STATE _____

Month	Consumption CCF	Rate	Fuel Adj. Rate/CCF	Cost	65° Heating Days	65° Cooling Days	CCF Increase Over Past Year	Cost Increase Over Past Year	Cost Increase Fuel Adj. Rate Over/Under Past Year
JAN.									
FEB.									
MAR.									
APR.									
MAY									
JUNE									
JULY									
AUG.									
SEPT.									
OCT.									
NOV.									
DEC.									
TOTALS									

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	COMMENTS
% INCREASE COST													
% INCREASE CCF													
%INCREASE FUEL ADJ. RATE													
BASIC RATE INCREASE													

Figure 15-20. Gas Worksheet

METER NO. _____

LOCATION _____

MONTHLY ENERGY USE _____ OPERATION _____ STATE _____

Month	Consumption Gallons	Rate	Fuel Adj. Rate/Gal.	Cost	65° Heating Days	65° Cooling Days	Gal. Increase Over Past Year	Cost Increase Over Past Year	Cost Increase Fuel Adj. Rate Over/Under Past Year
JAN.									
FEB.									
MAR.									
APR.									
MAY									
JUNE									
JULY									
AUG.									
SEPT.									
OCT.									
NOV.									
DEC.									
TOTALS									

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	COMMENTS
% INCREASE COST													
% INCREASE Gallons													
% INCREASE FUEL ADJ. RATE BASIC													
RATE INCREASE													

Figure 15-21. Fuel Oil Worksheet

METER NO. _____

LOCATION _____

MONTHLY ENERGY USE _____ OPERATION _____ STATE _____

Month	Consumption Gallons	Rate	Fuel Adj. Rate/Lbs.	Cost	65° Heating Days	65° Cooling Days	Lbs. Increase Over Past Year	Cost Increase Over Past Year	Cost Increase Fuel Adj. Rate Over/Under Past Year
JAN.									
FEB.									
MAR.									
APR.									
MAY									
JUNE									
JULY									
AUG.									
SEPT.									
OCT.									
NOV.									
DEC.									
TOTALS									

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	COMMENTS
% INCREASE COST													
% INCREASE Lbs.													
% INCREASE FUEL ADJ. RATE BASIC													
RATE INCREASE													

Figure 15-22. Steam Worksheet

METER NO. _____

LOCATION _____

MONTHLY ENERGY USE _____ OPERATION _____ STATE _____

Month	Consumption Gallons	Rate	Fuel Adj. Rate/Gal.	Cost	65° Heating Days	65° Cooling Days	Gal. Increase Over Past Year	Cost Increase Over Past Year	Cost Increase Fuel Adj. Rate Over/Under Past Year
JAN.									
FEB.									
MAR.									
APR.									
MAY									
JUNE									
JULY									
AUG.									
SEPT.									
OCT.									
NOV.									
DEC.									
TOTALS									

	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	COMMENTS
% INCREASE COST													
% INCREASE Gallons													
%INCREASE FUEL ADJ. RATE BASIC													
RATE INCREASE													

Figure 15-23. Water Worksheet

Building or location _____

Type (check below)

Steam boiler _____ Hot water generator _____

Hot air furnace _____ Other _____

Fuel source: Natural gas _____ #1 Oil _____

Butane _____ #2 Oil _____

Propane _____ #6 Oil _____

Other _____

Rated pressure of boiler or generator _____

Measured water or steam system, pressure drop _____ psig

Pump motor: Voltage _____ Amperage _____

Manufacturer _____ Phases _____

Minimum pressure drop, assuming no corrosion or fouling _____ psig

Nameplate or rated output _____ Btu/hr; Hp

Design heat loss of system _____ Btu/hr

Measured draft pressure \pm _____ in. H₂O

Location of measurement:

_____ Over-the-fire _____ Breaching

Type of draft: _____ Forced _____ Induced

Acceptable draft pressure \pm _____ in. H₂O

(Refer to table at end of form)

Measured smoke density reading

(For oil burners only)

Measured CO₂ concentration _____ %

Acceptable CO₂ range _____ %

(Refer to table at end of form)

Measured stack temperature _____ °F

Measured make-up air (or boiler room air) temperature _____ °F

Net stack temperature = _____ °F

Acceptable net stack temperature _____ °F

Measured boiler efficiency _____ %

**RECOMMENDED DRAFT PRESSURES (IN. H₂O)
FOR COMBINATION SYSTEMS**

Gas or Oil Burners	Location	
	Over the Fire	Boiler Breaching
Natural or induced draft	-0.02 to -0.05	-0.07 to -0.10
Forced draft	0.70 to 0.10	0.02 to 0.05

Figure 15-24. Combustion System Data

(Source: Manual of Procedures for Authorized Class A Energy Auditors in Iowa)

**APPROXIMATE STOICHIOMETRIC AND RECOMMENDED CO₂
CONCENTRATIONS FOR VARIOUS FUELS**

Gases	Stoichiometric	% CO ₂ Recommended Value
Natural	12	7-10
Propane or Butane	14	8.5-11.5
<i>Fuel Oils</i>		
No. 1 or No. 2	15	9-12
No. 6	16.5	10-14

Figure 15-24. Combustion System Data (Concluded)

Table 15-2. List of Conversion Factors

1 U.S. barrel	=	42 U.S. gallons
1 atmosphere	=	14.7 pounds per square inch absolute (psia)
1 atmosphere	=	760 mm. (29.92 in) mercury with density of 13.6 grams per cubic centimeter
1 pound per square inch	=	2.04 inches head of mercury
	=	2.31 feet head of water
1 inch head of water	=	5.20 pounds per square foot
1 foot head of water	=	0.433 pound per square inch
1 British thermal unit (Btu)	=	heat required to raise the temperature of 1 pound of water by 1°F
1 therm	=	100,000 Btu
1 kilowatt (kW)	=	1.341 horsepower (hp)
1 kilowatt-hour (kWh)	=	1.34 horsepower-hour
1 horsepower (hp)	=	0.746 kilowatt (kW)
1 horsepower-hour	=	0.746 kilowatt hour (kWh)
1 horsepower-hour	=	2545 Btu
1 kilowatt-hour (kWh)	=	3412 Btu
To generate 1 kilowatt-hour (kWh)	requires 10,000 Btu of fuel burned by average utility	
1 ton of refrigeration	=	12,000 Btu per hr
1 ton of refrigeration	requires about 1 kW (or 1.341 hp) in commercial air conditioning	
1 standard cubic foot	is at standard conditions of 60°F and 14.7 psia.	
1 degree day	=	65°F minus mean temperature of the day, °F
1 year	=	8760 hours
1 year	=	365 days
1 MBtu	=	1 million Btu
1 kW	=	1000 watts
1 trillion barrels	=	1 × 10 ¹² barrels
1 KSCF	=	1000 standard cubic feet

Note: In these conversions, inches and feet of water are measured at 62°F (16.7°C), and inches and millimeters of mercury at 32°F (0°C).

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Chapter 16

Computer Software for Energy Audits

INTRODUCTION

This chapter intends to visit the subject of computer software as it applies to or contributes to the performance of energy audits in commercial buildings. In doing so, the chapter will attempt to overview the various uses to which software could be put to use in an energy audit and then focus in on the use which we believe is perhaps the most important (building simulation), offering in the process both some general philosophies regarding building simulation and some very specific guidance and suggestions on how to perform building simulation in a practical and highly accurate fashion.

SOFTWARE... THE POSSIBILITIES

It seems that personal computers and their software have invaded our lives. Everywhere we turn there's a new program or capability that we just can't live without (or at least the competition has convinced our mutual customers that this is so!). Well, the energy auditing business is no different than the rest of the world. In fact, given the technical nature of the business of energy auditing, it's perhaps not surprising that computers have such a significant impact on the process, in the following possible ways.

Energy Accounting

While discussed elsewhere in this book, energy accounting is a particular activity that lends itself to computerization. A range of "off the shelf" software is available here, as is advertised in the energy trade publications. In addition, both ASHRAE and *Energy Engineering* regularly publish catalogs of energy-related software, which list

energy accounting programs.

Whether a home-built spreadsheet or a stand-alone program, energy accounting software can provide a number of functions, including:

- tabulating large quantities of energy use data
- pro-rating the data so as to provide calendar-month consumption figures (as opposed to varying-length billing periods)
- calculating energy use (Btu/sf/yr) and energy cost (\$/sf/yr) indexes, which are useful for comparing buildings against each other and other established “norms”
- showing recent trends in energy use (is energy use going up or down?) accounting for savings achieved by an energy retrofit program, including documenting and adjusting for the effects of weather and other independent variables
- calculation of average unit costs and showing trends in same

Our belief is that no energy conservation project should begin or end without passing through the energy accounting process.

Survey Data Reduction

While this use of software is somewhat minor and perhaps obscure, it is nonetheless very important. A technically rigorous energy audit should include a significant amount of measurements of the actual operating parameters of the installed equipment. Since nearly all energy-using systems in buildings use electricity, instantaneous electrical measurements of the power draw of lighting panels, receptacle panels, motors, chillers, computer rooms and other process loads can amount to a prodigious quantity of data. Our experience has shown that calculation of the actual kw of these measurements (from measured volts, amps and power factor—we recommend against kw meters) utilizing the computer instead of manual calculations has numerous beneficial effects, including:

- minimizes calculational errors

- provides reliable and neatly organized data for use in analysis and post-retrofit troubleshooting
- shows the client that the analysis has been accomplished in a well-organized and professional fashion, especially if the print-outs are included in the final report

Either home-grown or professionally-developed/automated spreadsheets can be effective in this activity.

Cost Estimating

Only three issues must really be addressed when considering energy retrofit; technical feasibility, cost of installation and probable energy savings. While many practitioners perform their cost estimating by hand, the well-known estimating guides (Means for example) offer complete software programs to perform a wide range of estimating tasks. Those involved in large quantities of energy retrofit estimating would be well to consider utilizing an automated method of estimating.

Computer Assisted Design and Drafting (CADD)

Many people would be slow to recognize that CADD has a significant contribution to offer to the energy auditing process. A large recent project brought home the potential for utilizing CADD in the energy auditing process in the following ways:

- it is always helpful to have reduced-size floor plans to assist in finding the way around a facility (especially a large and complex facility) having the building floor plans on CADD allows printing out whole or partial floor plans to whatever size is convenient for use during the field survey
- lighting surveys, especially when reflected ceiling plans are not available, can be greatly assisted by printing out small-size partial floor plans for recording fixture types and counts during the field survey
- during development of retrofit measures, some equipment (chiller, cogeneration units, etc.) require significant “real estate” for their installation—printing out a portion of the building floor

plan can greatly assist in planning the equipment installation and documenting it in the project report/files

- building simulation usually requires “zoning” the building for eventual building dimension take-off and data entry into the simulation program using CADD-produced, to-scale floor plans can greatly facilitate this process

Again, though it is not an “obvious” energy audit tool, there are many contributions that may be made by CADD software.

Estimating Energy Savings

While some practitioners still perform savings calculations the old-fashioned way, by hand, the majority of savings calculations are automated to at least a minimal extent at this time. Such calculations, when not part of a building simulation program (discussed below), are based on a large number of simplifying assumptions and utilize fairly simplistic formulae. In some cases these “stand-alone” calculations are highly automated and are based on extensive weather files and other elaborate data sources. Such calculations depend upon pre-established spreadsheet (Lotus, Excel, etc.) or math program (e.g., Mathcad) files, or are implemented through stand-alone programs. The advantages of such automated calculations are standardization, speed, ease of use and generally good documentation. However, they suffer from a lack of context. That is, because they stand alone, these calculations may easily overstate potential savings because they exist “outside” of a building energy balance—which would otherwise constrain the calculation to the actual energy consumed by a given end-use.

Building Energy Simulation

Originating around the mid-1970’s, computers simulation of building energy use was developed as a tool for analyzing buildings during their initial design to develop load estimates and optimal combinations of building features. The technique has possibly found even better use in analyzing existing buildings for energy conservation retrofit. By simulating retrofit options on the computer, reliable estimates of potential energy savings may be achieved, assuming that the initial modeling and subsequent modeling of retrofit measures has been correctly performed. In fact, the author has used a wide range of computer simulation tools over the past decade to

prepare savings estimates for a large number of comprehensive energy retrofits in both large (1.8 million square feet) and small (25,000 square feet) buildings with great success.

In at least one case, a major energy services company declined to accept the conservative savings figures generated by computer modeling of the building, implemented a project based on their own optimistic estimates of savings, and ended up reimbursing their client for more than \$100,000 annually for the project's "shortfall" in savings (from their optimistic estimates). Their optimistic estimates increased total estimated savings by more than \$200,000 per year—fortunately (for them), the energy services company did not guarantee 100% of their estimated savings.

The importance of accurate modeling of existing buildings is clearly critical to the business of energy services, demand-side management, or any form of energy retrofit. This is even more important given the growing employment of demand-side management as a supply strategy by utility companies nationwide.

BUILDING ENERGY SIMULATION— WHAT AND WHY

In the building simulation phase of an energy audit, all the data gathered during the field survey is converted into a form acceptable to the computer. The building's architectural and functional use characteristics are described, including orientation and thermal properties of the structure ("U values and shading coefficients, for example). Thermal zones or spaces in the facility having similar external and internal characteristics are designated, and aggregate schedules and thermal loads for people, lights and equipment developed. The space heating and cooling system characteristics are described, including the mode of operation and control (e.g., multi-zone versus terminal reheat, supply air temperatures, economizers, etc.) air flow rates, operating schedules and assignment of building thermal zones to individual systems. Central equipment (boilers, chillers, etc.) that serve space-conditioning systems are described, including the equipment type (e.g., water tube versus fire tube boilers), efficiencies, method of control, operating schedules, and flow rates.

Once the simulation model is assembled it is run on the computer (in some cases taking as much as 6 hours for a single com-

plex building, even when using a fast P.C.!) and is then verified by comparing it to the actual energy use of the building, as recorded by the utility company. In addition, the model is examined in detail to confirm that individual components are faithful to known physical realities of the building. For example, if chiller electrical use was measured during the survey, this actual measured energy use of the chiller would be contrasted to the model to confirm that cooling loads were being faithfully simulated in the model. Only when the model agrees with reality in terms of total annual energy use (less than 10% variation), seasonal patterns of energy use and individual component energy use, should the model be considered complete.

The model then, serves two purposes. First of all, it serves as an energy balance in that it accounts for all sources and uses of energy in the building. As such, the model cannot be faithful unless the investigators' knowledge of the building and how it operates agrees with reality, and creating the model "tests" the investigators' knowledge and forces that knowledge to be added to or corrected until it agrees with and encompasses the truth (as revealed in the utility company invoices) about the building being modeled. Secondly, the model, once verified, serves as a "test bed" for examining the effectiveness of energy retrofit modifications being considered for a building. Literally, these modifications can be tested, before being built, by simulating them on the model.

BUILDING ENERGY SIMULATION— WHAT THEY DON'T TELL YOU

The business of building energy simulation has been around for over two decades now, and has developed an image and reputation all its own. However, the image is often quite distant from the reality, particularly with respect to energy simulation of existing buildings.

The History of Building Simulation

In the beginning, building simulation was oriented towards new building design (remember two decades ago when new construction was virtually "the industry"?). All the programs had to do was perform a good load calculation and simulate a fairly narrow range of HVAC system types that were expected to operate the way

they were designed to operate. Pretty simple, right?

This was appropriate at the time because the time to get such things as the building envelope correct is when it hasn't been constructed yet. As new construction was the "frontier" in this business at that time, efforts spent on developing building energy codes and certification of computer programs for use in demonstrating code-compliance were focused on new construction. Furthermore, since building codes and new frontiers are a specialty of government agencies and the R&D side of the industry, the people doing the lion's share of computer program development and program certification had little or no experience in the business of designing and building real buildings (for example, one firm acknowledged as experts in the field, cannot show any actual construction project experience at all among it's entire resume of professionals!). The result, was computer programs, "certified" or not, that were poorly suited for analysis of existing buildings—buildings where control systems function not as intended, where building occupancy is far from "neat and tidy," where HVAC systems frequently have little resemblance to the "models" offered in the simulation programs (how about a *single* air handling system combining variable volume, multi-zone and high-pressure induction?), and where building equipment operating practices are anything but consistent. Such factors are far more important in determining the energy use of an existing building than the precision with which we are able to model the insulation value of an exterior wall.

Evidence of this highly theoretical nature of the programs and the "profession" include the sprinkling of articles in the literature regarding "shoot-offs" and other "blind" comparisons of one building simulation program against another. These are all *meaningless* relative to existing buildings, as we are not "blind" when working with existing buildings—we *can* observe and develop a body of reasonably accurate knowledge regarding the real connected loads, real occupancy patterns, real system and equipment operating characteristics, etc., and use this body of knowledge to build and calibrate accurate and (most importantly) *useful* models of existing buildings.

The only correct conclusion that can be drawn from all this is that there is not and can not be such a thing as a "perfect" building energy simulation computer program. There can only be a well trained, knowledgeable and experienced professional who employs the tools in his/her possession in a professional manner.

The State of the Art

Newcomers to the field (and “innocent” bystanders—frequently a practitioner’s clients) are frequently awed by the sophistication and complexity of the building simulation process and the computer programs employed in the process. However, the naked truth is that a very large number of practitioners of building simulation are woefully ignorant of its correct use and are very often guilty of perpetuating the “garbage-in-garbage-out” syndrome. One reason for this is that, unless modeling critique and calibration procedures as discussed later in the chapter are followed, a perfectly “plausible” simulation can be prepared that is largely fallacious—often with the ignorance of the building energy simulation practitioner themselves. To make matters worse, few receivers of such services, i.e., clients, are in a position to question, let alone critique, such a work product. A principal underlying cause of this situation is that virtually all of the training that is available on the subject of building energy simulation is focused on the software programs themselves, not the *process* of building energy simulation. As we will have implied above and will see later below, the software itself is perhaps the *least* important part of the building energy simulation process (an assertion that, however true it may be, is sure to create consternation among the leading professionals in the building energy simulation “profession”).

BUILDING ENERGY SIMULATION— HOW TO DO IT RIGHT

For a computer simulation of a building to be of value in evaluating energy retrofit opportunities, it must be accurate. To be “accurate,” the model should account for essentially all of the sources and uses of energy in a building. Such a model would calculate a total energy consumption that is close to the building’s actual annual energy use, say within 5%. Such a model would also reasonably accurately mirror the building’s actual response to the changing seasons of the year and closely mimic the actual seasonal variations in energy used by the building. Finally, such a model would allocate energy use by function in a faithful fashion. This last virtue is particularly important if the model is to be used to evaluate the effectiveness of specific energy retrofit measures, for example, lighting controls, outside air

economizers, etc.

Accuracy in computer simulation of buildings, in our experience, is founded in three basic areas:

1. an intimate understanding of the simulation tool being used, including its various idiosyncrasies and nuances;
2. an intimate understanding of the building being simulated, vis-a-vis its physical and operational characteristics—in essence, in existing buildings, the quality of the survey or “audit” determines the quality of the simulation;
3. careful analysis and critique of output data (just because it is carefully prepared and computer generated doesn’t mean it is correct)—our comments elsewhere herein generally apply to “mainframe” programs, though they also apply to other simulation tools.

By utilizing the above techniques, we have found it possible to regularly model buildings within 5% of their actual annual energy use with a high degree of confidence in the simulation of each energy-using system and functional use of energy in the building. It should be noted that, in buildings where weather is a strong energy-use factor, modeling to less than 10% variance from the actual energy use may be of limited value as our ability to predict weather for a given future year may not even be that accurate.

Knowledge of the Tool

The first foundation of accurate building simulation is knowledge of the tool to be employed.

While the above statement may seem obvious, the computer simulation tools available to consulting engineers are very complex and have a “reality” of their own that cannot be ignored or violated if accurate models of buildings and energy retrofit measures are to be accomplished.

Very specific experience comes to mind in this regard having to do with assignment of lighting loads and quantities of outside air. It is fairly common to utilize return air troffer lighting fixtures to reduce the in-space load on supply air, thus allowing a lower supply air quantity and a raising of return air temperature that allows selection

of a smaller cooling coil for the same cooling capacity. In one project during the design development stage, the engineer was modeling an office building that had a large amount of core space that served mostly as trafficways, secretarial space, and file/storage space. As a result, the principal cooling load was created by the lighting systems. Unfortunately, the design engineer assigned virtually all of the lighting load to the return air (which is not physically possible) and specified a minimum outside air quantity as a cfm/ft² figure. The result was that supply air was calculated by the program at something like 0.2 cfm/ft², the outside air was 0.1 cfm/sf² and the computer calculated a return air temperature of around 500 degrees. When half this return air was discarded, roughly half the cooling load went with it, for an amazing "savings" in energy use. Upon detailed examination of the computer output, we were able to point out the fallacy of the simulation and got the project back on track. The experience did make the point, however, that a lack of detailed understanding and familiarity with the calculational methodology of the simulation program can easily lead the modeler astray!

Another example is the capability or lack of capability to handle desired simulations by the program. Before variable-flow chilled-water pumping was commonly employed, few programs had the ability to simulate such a system. In order to do so, a series of "dummy" chillers were described to the program in such a manner that the program selected each in turn as loads increased. Associated with each of these "dummy" chillers was a constant speed and power pump. The effect of each chiller/pump combination was to sequentially simulate the overall pump power curve that would be produced by a single variable speed pump. For accurate estimation of savings, only the energy consumed by the pumping systems was compared from one run to the next, thereby eliminating unwanted secondary impacts such as changes in chiller efficiency.

To be knowledgeable about a simulation program, the user must understand how the input data is understood and utilized by the program, the calculations/algorithms employed by the program, the flow of input and calculated values through the program, and the precise effect various program "controls" exert on the calculations performed by the program. The bottom line here is that an inferior simulation tool in the hands of an engineer well versed in its features and capabilities is superior to the best simulation tool in the hands of an engineer unfamiliar with it.

Knowledge of the Building

Perhaps the single most important factor in developing accurate computer models of existing buildings is developing an intimate knowledge of the physical and operational characteristics of the building to be modeled.

Envelope and Weather Versus Operators and Controls

While many practitioners of computer simulation of buildings work toward more detailed time-related simulation of weather its effect on building structures, those who are well acquainted with the practical aspects of building operation know that the effect of operating engineers and temperature control systems are manyfold more dominant in affecting a building's energy use. Perhaps one or two anecdotes would be illustrative of this point.

In one study of a major high-rise office building in San Francisco, it was observed late one evening that the watch engineer was "fiddling" with the central temperature control panel. Immediately thereafter, the indicating instruments on the panel all began to change their values rapidly. Gently interrogating the watch engineer, it was learned that the "fiddling" was to put the outside air economizer control for the entire building back on "automatic." Further investigation revealed that it was this engineer's nightly practice to override these controls to place all operating HVAC systems (a few terminal reheat systems serving the entire core of the building) on 100% outside air! The reason for this was that the supply air for the engineer's office in the basement was return air from the core of the building and, by overwhelming the reheat coils with 100% outside air, the building core temperature dropped a few degrees and, in turn, cooled the engineer's office a few degrees. Modeling the building with automatic control of outside air would not have produced an accurate simulation; in fact the building was modeled using an average outside air percentage of 70%. The very first output for the mainframe program simulation of this building showed a calculated energy use that was within 5% of the building's actual energy consumption.

In another downtown San Francisco high-rise, the chief engineer utilized a variety of electro-mechanical time clocks and "patch cords" to start and stop the building's various HVAC systems (he literally "plugged in" to whichever time clock he wanted a particular system to use). As he explained, he was then using the 7 a.m. to 6 p.m.

time clock. Late night observation, however, backed up by review of building electrical demand recordings, revealed that he had inadvertently "patched" himself into the time clock set for 6 a.m. to 7 p.m., resulting in a 10% to 12% increase in the building's HVAC energy use. Modeling this building based on scheduling information obtained from "the horse's mouth" could never have provided an accurate simulation.

In larger buildings, not only are operational practices manyfold more dramatic in their effect than the effects of changes to the building envelope (which influence weather-related loads), but, we believe that the whole issue of weather data is greatly misunderstood in the industry. Some building simulation programs have been criticized in the past for not providing 8,760 hours of actual weather data for simulations. The well-known mainframe program developed by the Department of Energy (D.O.E.) and its various offspring provide 8,760 hours of simulation by means of (among others) a weather data source known as the TRY or "test reference year." Other programs, such as the TRACE program developed by the Trane Company, provide a weather data file consisting of an average 24-hour profile for each month of the year, for a total of 288 hours of simulation. In truth, there is little if any meaningful difference between these methods for two reasons. The first reason is that the "test reference year" is not an actual year's weather data. It is, in fact, an amalgam of 12 actual month-long "chunks" of data. These months of real data are selected for incorporation into the reference year by a process that effectively chooses the mean month out of the months of data available. Unless each weather data file is examined in detail, the user cannot be certain that "real" (whatever that means) weather extremes actually reside in the file or not. Furthermore, given the continuous nature of our solar system and the statistical difference between an "average" and the "mean," the true difference between 8,760 hours of simulation and 288 is difficult to discern, except in the run times of the various programs (which vary according to the number of hourly calculations that must be made). The second reason, which applies to new or existing buildings, relates to the purpose of performing a building simulation in the first place. The general thrust of any simulation is to project the future so as to make technical and economic decisions regarding building design or retrofit features. All of this presupposes that the weather that will actually occur in the future period under consideration (3 to 10 years generally) will be essentially equal to

the weather data being used for the simulation. Since this cannot be known for a certainty, and the fact that weather-related factors are not dominant in determining energy use in the first place, any decision that would be influenced by the small effects in the calculations caused by the difference between 8,760 and 288 hours of simulation, would be a decision of doubtful wisdom at best.

Observational Surveys

As a result of experiences similar to the above, it has become our practice to perform two specific types of surveys in the buildings we study.

The first of these surveys is observational in nature and includes careful observation of the *functioning* of the building's temperature control systems—as opposed to simply reviewing the temperature control as-built drawings. We have found that frequently the controls were not installed as drawn, have been overridden (known as “auto-manual” control), or have simply failed in one fashion or another. This observational survey generally includes sample measurement of system operating parameters (supply air temperature, mixed air temperature, space discharge air temperature, etc.) as a means of observing the actual performance of the control system. The results of the inspection are frequently quite amazing!

The observational survey also regularly includes a “late night” tour of the facility and its HVAC systems to identify actual operating schedules (frequently at odds with what is reported by the operating engineers) and control system performance during this period. In one building surveyed, the control air compressor was off at night but the fans and pumps were still running—resulting in extreme overheating of the facility at night, which also made the chillers work hard in the morning to bring the building back down to temperature when the controls came back on! This late night survey is also invaluable in confirming the operating schedules for lighting systems, which are frequently under the control of the custodial crew.

Electrical Load Surveys

The second type of survey we find essential is an electrical load survey. Where great accuracy is desired, such as in the modeling of large high-rise office buildings, every electrical panel and piece of equipment should have its instantaneous power draw measured. This can be done with a hand-held power factor meter, with the data

recorded and entered into a spreadsheet developed just for this purpose (see Table 16-1, which is a sample output page from just such a spreadsheet). It should be noted that simply reading voltage and amperage is insufficiently accurate, as induction motors especially have very wide ranges of power factors (depending upon their loading) that can cause volt/amp readings to be in error by 50% or more when compared to true power draw. In addition to the instantaneous measurement of electrical loads, it is also important to look at specific large loads (chillers, elevators, computer rooms, etc.) over time, using a power-recording instrument. This instrument can also be used to observe the total power demand profile for the entire building if the building is small and time-of-day metering is not employed by the utility company. Frequently, particularly for large buildings, the utility company records the building's power demand over time (utilizing magnetic tape or bubble memory meters) and the information from these meters is almost always available from the utility company (see Figure 16-1, which shows a 24-hour plot of utility company demand interval records).

As large buildings, even in cold climates, spend most of their time in a cooling mode of HVAC system operation, electrical energy use makes up the vast majority of the building's energy use. This being the case, it is important to compare the sum of the various instantaneous load measurements with the recorded peak demand for the building, as shown in Table 16-2. If the individual measurements don't equal the total demand, then any attempt at modeling will fail. Furthermore, a building's energy use is determined by connected loads multiplied by hours of use. By utilizing the data from the operational survey and checking it against the record of electrical demand over time, a high level of confidence can be achieved as to the actual operating schedules of the various energy-using systems in the building.

Output Critique

One of the hardest things to do in performing a building simulation is to honestly critique the computer output. After spending hours or even days preparing the input data, it is easy to fall into the trap of believing that the output must be correct. However, as our mistakes prove to us, it is critically important to critique the computer output with a skeptical attitude. Three specific techniques are valuable in regard to critiquing simulation program output.

Annual Energy-Use Profile Comparison

The first technique is a gross, year-long evaluation of the modeled energy use in comparison to actual energy use. While the totals may agree, seasonal variations may not agree well with each other, indicating that weather influenced systems are not modeled well. Graphic comparison of modeled and actual energy use is most valuable in this evaluation, as can be seen in Figures 16-2 and 16-3. In addition, since computer simulations generally utilize weather data that are a composite of multiple years' data (including NOAA's "TRY" tapes as previously discussed), it is valuable to contrast the actual weather data for the year being modeled to the weather data employed in the simulation, as shown in Figure 16-4. When modeling a building using a year's worth of actual energy use for validation, it is more important that the modeled energy use vary according to the changes in the model weather for the same period rather than absolutely agree with the actual utility data being used for comparison. For example, if the model shows higher than actual electrical use for cooling in a given month and both the actual electrical use and actual temperatures are lower than the model, then this lends credence to the model and means the model is meaningful for evaluation of multiple future years' potential for energy savings.

Peak Load Comparison

The second of these techniques is to evaluate peak modeled loads against known values. From the utility company's data, the building's peak electrical demand is known for all seasons of the year. Generally, computer models will provide a monthly peak electrical demand for the various components of the model. By comparing the principal seasons (summer, fall/spring, and winter), it can be observed whether all of the loads measured during the survey found their way into the model and whether the seasonal modeling of cooling loads is correct. Furthermore, the building's peak cooling load is probably known from operating engineers' observations and/or operating logs, and this too, can be used as a scale of measure for evaluating the accuracy of the computer model.

Again, the issue of the weather data employed for the simulation must be taken into consideration. Generally, all weather data used for simulations are missing the hottest and coldest days of the year.

Table 16-1. Example of electrical load survey data tabulation.

POWER MEASUREMENT FORM											
DATE:8/30/94											
RECORDED BY: CDS &JPW											
LOAD	TIME	AVE VOLTS	L-1	P.F.	L-2	P.F.	L-3	P.F.	KW	REMARKS	
HV-1A	2:40P	278	3.7	0.23	3.8	0.33	3.4	0.29	0.9	East Campus Basement MCC	
EF-1A	2:40P	278	1	0.43	1	0.54	0.9	0.48	0.4	East Campus Basement MCC	
EF-3A	2:40P	278	1.1	0.49	1.2	0.59	1	0.58	0.5	East Campus Basement MCC	
HV-2A	2:40P	278	2.1	0.33	2.1	0.44	1.9	0.41	0.7	East Campus Basement MCC	
AC UNIT (OLD ICU)	2:40P	Not in Operation	0.00	0	0.00	0	0.00	0.0	Roof of Incinerator		
P-1	2:40P	278 11.1	0.75	11.6	0.78	11.1	0.79	7.3	Heating Water Pump		
P-4	2:40P	278 0.5	0.30	0.5	0.54	0.3	0.61	0.2	Heating Water Pump		
P-5	2:40P	278 1.7	0.62	1.7	0.72	1.5	0.71	0.9	Heating Water Pump		
CWB PUMP	2:40P	Not in Operation	0.00	0	0.00	0	0.00	0.0	Cold Water Booster Pump		
CWB PUMP	2:40P	278	3.7	0.49	3.8	0.57	3.4	0.55	1.6	Cold Water Booster Pump	
AC-1	2:12P	277	9.8	0.74	9.6	0.78	10.3	0.76	6.3	1st Floor MCC Panel	
CHW PUMP	2:12P	277	1.5	0.46	1.6	0.37	1.4	0.44	0.5	1st Floor MCC Panel	

EXHAUST FAN	1:50P	276	0.7	0.50	0.7	0.50	0.8	0.41	0.3 3rd Floor Roof MCC
SUPPLY FAN	1:50P	276	16.5	0.83	15.4	0.87	15	0.81	10.8 On Roof
RETURN FAN	1:50P	276	5.8	0.83	5.5	0.83	5.6	0.80	3.8 On Roof
HEATING PUMP	1:50P	276	3.1	0.55	3.2	0.54	3.2	0.56	1.4 In Penthouse
EF-1 SURGERY	1:06P	277	2.7	0.54	2.7	0.63	2.4	0.58	1.3 Roof MCC
EF-2 SURGERY	1:06P	277	9.1	0.67	9	0.67	8.9	0.66	5.0 Roof MCC
EF-9	1:06P	277	11.4	0.37	1.5	0.49	1.2	0.50	1.5 Roof MCC
HV-2 STORAGE Area	1:06P	277	4.2	0.52	4.3	0.59	4	0.57	1.9 Roof MCC
HV-3 KITCHEN	1:06P	277	5.6	0.61	6	0.67	5.4	0.70	3.1 Roof MCC
HV-4	1:06P	277	8.4	0.82	9.1	0.85	8.4	0.87	6.1 Roof MCC
EF-4 RANGE HOOD	1:06P	Not in Operation	0.00	0	0.00	0	0.00	0.0	Roof MCC
EF-3 STORAGE	1:06P	277	3.3	0.49	3.4	0.56	3.1	0.53	1.4 Roof MCC
EF-7 ADMITTING	1:06P	277	3.1	0.68	3.2	0.73	2.9	0.74	1.8 Roof MCC
EF-6 TOILET EXT	1:06P	277	2.1	0.79	2.1	0.84	1.9	0.85	1.4 Roof MCC
EF-8 DINING RM	1:06P	277	1.6	0.60	1.7	0.67	1.4	0.73	0.9 Roof MCC
HV-1 ADMITTING	1:06P	277	3.1	0.70	3.3	0.72	3.1	0.75	1.9 Roof MCC

PAGE 1

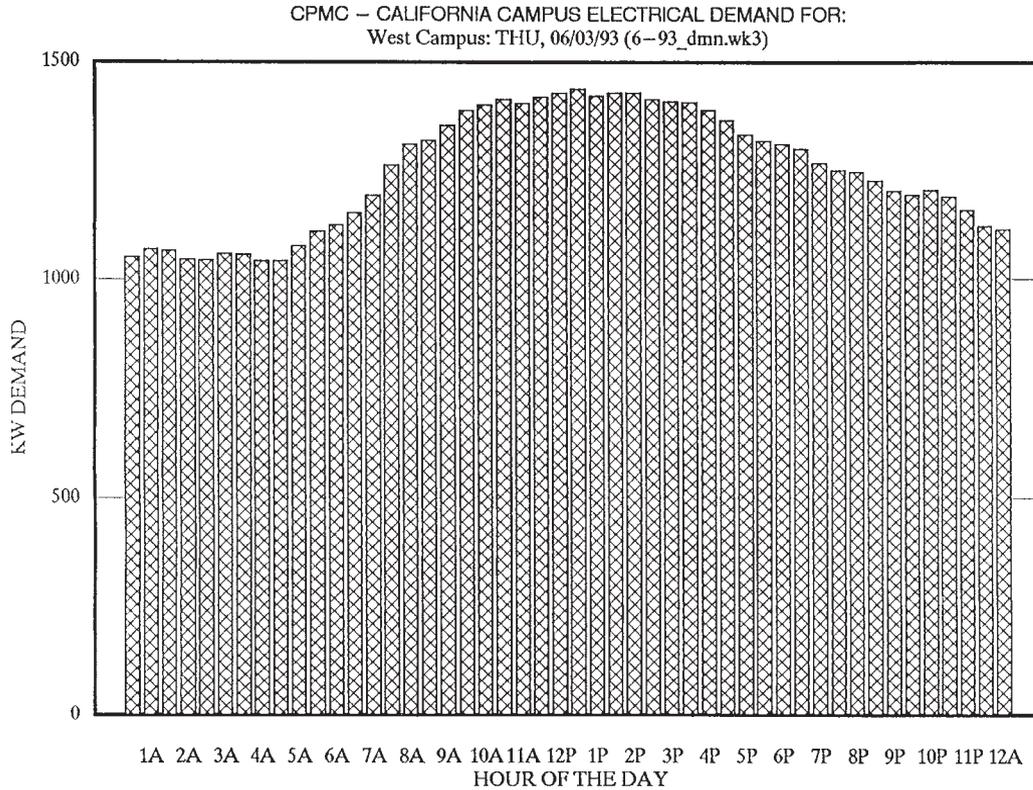


Figure 16-1. Example of analysis of utility company demand interval records.

Table 16-2.
Example of comparison of field-measured electrical loads to peak demand recorded by the utility company.

CALCULATION SHEET				DATE: 10/29/94	
(PRE-MODL)				INIT: JPW	
PRELIMINARY MODEL OF CPMC, CA-WEST CAMPUS:					
LOAD	PEAK KW	MIN KW	HR/YR	KWH	
LIGHTING	492	246	5111	2514396	
MISC PROCESS/OFFICE	212	85	4344	922661	
AIR HANDLING UNITS					
SUPPLY FANS	243	243	8760	2128680	
RETURN FANS	78	78	8760	683280	
CHILLERS	340	170	2500	850000	
CHW PUMP	30	30	3000	90000	
CHW PUMP	20	20	429	8580	
CW PUMP	25	25	3000	75000	
CW PUMP	25	25	429	10725	
CLG TOWER	15	15	3000	45000	
CLG TOWER	15	15	429	6435	
PROCESS USE					
DATA PROCESSING **	67	67	8760	586920	
KITCHEN	107	107	7884	843588	
CHERRY ST GARAGE	32	32	8760	280320	
MISC FANS/PUMPS	32	32	8760	276904	
MED AIR/VACUUM	30	30	8760	262800	
	TOTALS	1763	1220	9585288	
	ACTUAL	1662	1306	10140698	
	VARIATION	6.1%	-6.6%	-5.5%	

**INCLUDES HVAC

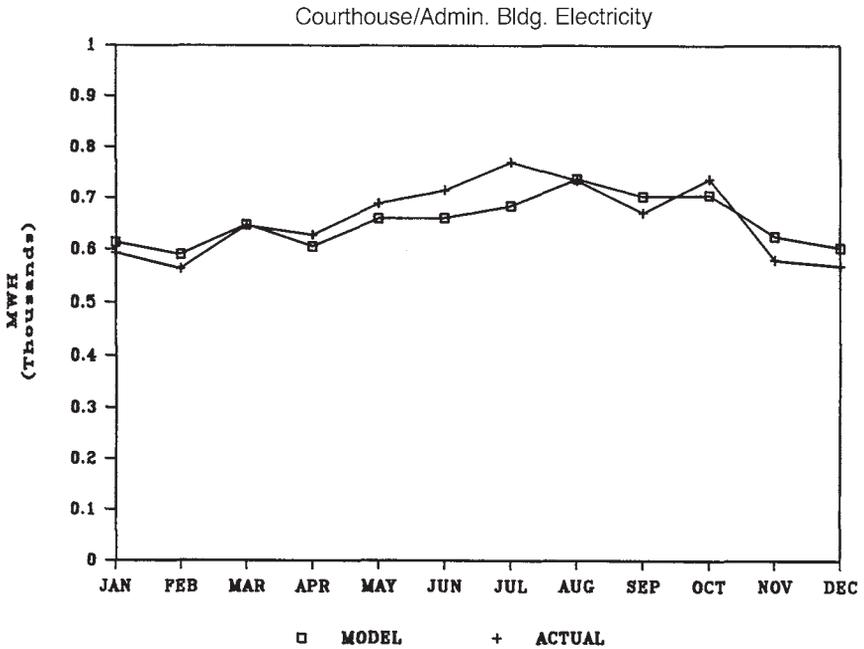


Fig. 16-2. Comparison of model and actual annual electrical use profile.

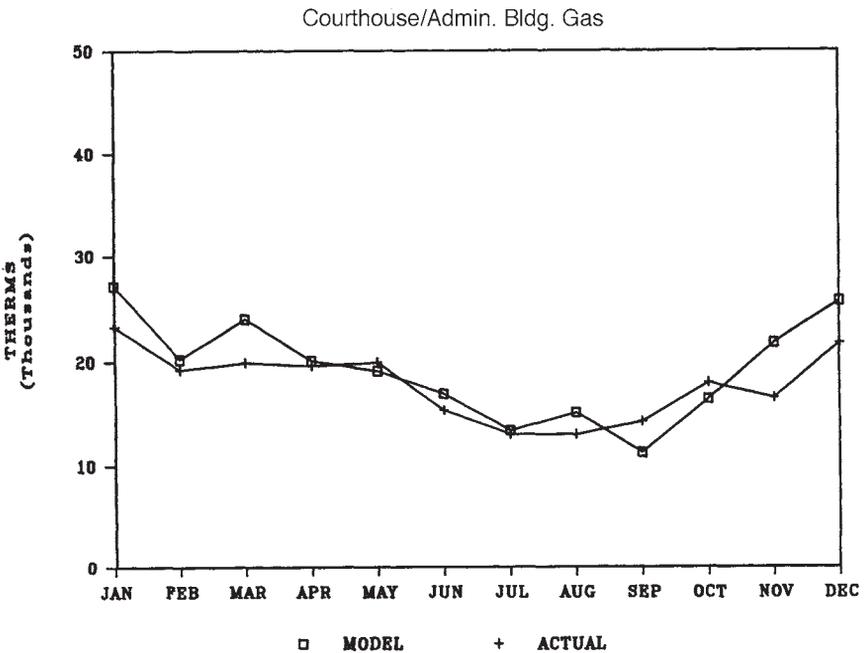


Figure 16-3. Comparison of model and actual annual gas use profile.

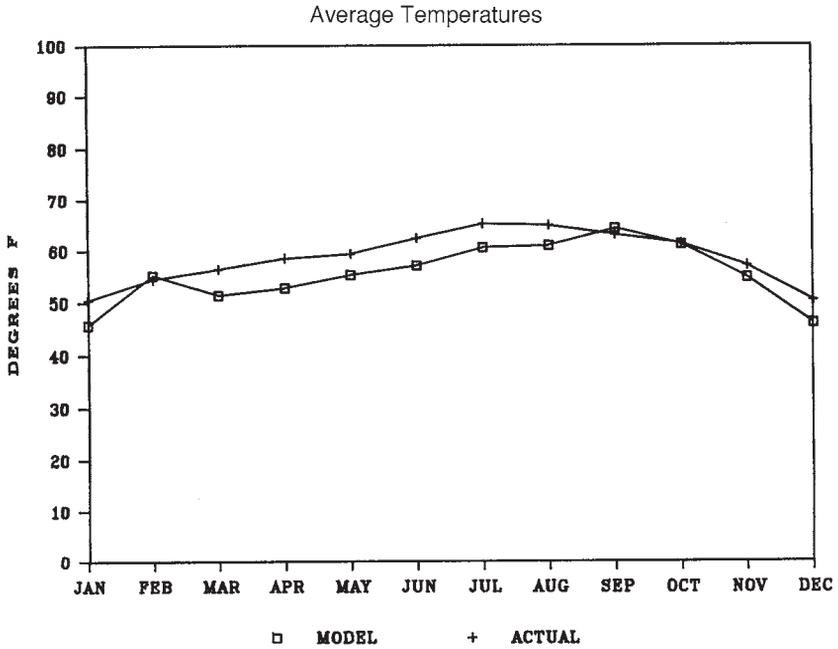


Figure 16-4. Comparison of model and actual weather data.

Accordingly, the actual demand data used for comparison would best be selected as a day experiencing the same, or nearly the same, temperature extremes as present in the weather data used for simulation. Interestingly enough, one building we modeled had one of its chillers fail and was short of capacity to support anything close to a “design” day. As a part of assessing the comfort “risk” caused by the failed chiller, the mainframe simulation output was reviewed and we identified the ambient temperature at which the simulation would predict “losing” the building on a hot day. In fact, within a few weeks of completing the modeling process, an unseasonably hot day was encountered with a peak temperature exceeding our predicted “lose the building” temperature by a few degrees. Indeed, the chief engineer reported that he had “lost” the building on that one day.

Detailed Output Analysis

The third technique is primarily oriented towards evaluation of energy retrofit models. In order to develop savings estimates for energy retrofit measures under consideration, the retrofit is mod-

eled and then contrasted with the original model, thus showing the savings that might be achieved. Since it is very easy to make small errors in editing the input data for a computer model and cause an unintended result, a useful quality control technique has been to analyze the computer model in detail (by functional use, i.e., lighting, cooling, fans, pumps, etc.) and develop a specific figure for the savings estimated for each retrofit in each functional use area. As can be seen in Table 16-3, a very detailed analysis of the output from a mainframe proprietary computer model is possible. The analysis allows a "plausibility" check of the savings from a particular retrofit. For example, if a variable-air-volume retrofit is under consideration, it is possible to develop a specific estimate for the savings to be achieved by the fan alone. This savings can then be compared to the original energy used by the fan and the plausibility thereof evaluated. If a simple inlet vane conversion is anticipated and the system operates a single shift per day during weekdays, a savings figure in the neighborhood of 30% to 40% might be anticipated on a "rule of thumb" basis. If the detailed analysis indicates a savings of 70% or 80%, then review of the model input is warranted to determine the error in the input or determine the reason that a savings figure much higher than the engineer's "rule of thumb" is reasonable. For example, perhaps the system does, after all, operate on a 24-hour per day basis or was grossly oversized and will experience very low loads compared to its installed capacity for most of its operating hours. In any event, when the savings vary greatly from that which is "plausible," it indicates either an error in the modeling or an error in the plausibility logic—either of which should be determined before using the savings numbers generated by the model.

It is theoretically possible to create a "perfect" model in which every small unique thermal zone in a building responds to weather inputs virtually the same as the actual building. However, the practicality of such modeling is doubtful, as the engineering costs to prepare such a model may actually exceed the value to be created by the modeling process, particularly in smaller buildings. As a result, even the best modeling tools and reasonably constructed models will be limited in their ability to predict the effect of retrofit measures. Therefore, in some cases, it is an appropriate engineering step to de-rate or discount the savings figures for *engineering* conservatism (see Table 16-4 for example). A good example of this is the fact that

many computer models that utilize hourly heating and cooling load calculations as part of their modeling (not all do, as we shall see below) are unable, without laborious and extensive micro-zoning of the model, to avoid the sharing of *internal* heat gain with *external* zones needing heating and thus underestimate the actual heating requirements of the building. Similarly, tall buildings in central city locations often have large vertical exterior zones, part of which need cooling and part of which need heating at any given time, primarily due to solar exposure and shading from adjacent buildings. These perimeter systems can be difficult to model and sometimes will show optimistic results from even the most conservative attempts at modeling—thus necessitating an engineering discounting of savings. The bottom line here is that even the best models still have limits to their capabilities—even when using the most complex simulation programs available!

Plausibility Check

Finally, by summing all the savings for all retrofits, a gross plausibility check can be performed, based on engineering judgement regarding whole building energy-use levels that are reasonable for the type of building being evaluated. This is a gross measure, but it is an excellent *final* check on the entire process, as shown in Table 16-5. Even such a simple check can be effective in catching unreasonable optimism in energy savings estimates that may have slipped through all the other quality control measures in this very complex process of building simulation. Had such a macro check been part of the project documentation associated with the project mentioned in the introduction, that energy services company would not have the problem they currently face.

SIMULATION TOOLS

It is likely that a wide range of opinion exists in the energy engineering field as to what constitutes “building energy simulation.” Our view is a rather broad one and encompasses a wide range of calculational strategies as being appropriate to specific project goals and project environments.

Table 16-3. Example of detailed analysis of output from “mainframe” simulation.

CALCULATION SHEET						DATE: 3/24/89
(TRC_ANL1)						INIT: JPW
ANALYSIS OF TRACE RUN / ALTERNATES TO DETERMINE ENERGY SAVINGS:						
ECM #	1 & 2					
TITLE	ADMN BLDG PENTHOUSE AND BASEMENT DOUBLE DUCT TO VAV					
EQUIPMENT	ENERGY	BASE	COMP TO	ECM USE	DELTA	% REDUCTION
CHILLER 1	KWH	442052	442052	430574	11478	2.6
CHLR 1 AUX	KWH	157787	157787	155471	2316	1.5
CHILLER 2	KWH	390069	390069	337348	52721	13.5
CHLR 2 AUX	KWH	70208	70208	64355	5853	8.3
CHILLER 3	KWH	44762	44762	25963	18799	42.0
CHLR 3 AUX	KWH	38332	38332	24441	13891	36.2
BOILER	THERMS	191586	191586	137840	53746	28.1
BOILER AUX	KWH	65831	65831	60051	5780	8.8
SYS 1 SF	KWH	397881	397881	129122	268759	67.5
SYS 1 RF	KWH	183582	183582	59574	154008	67.5
SYS 1 EF	KWH	13690	13690	5397	8293	60.6

SYS 2 SF	KWH	46228	46228	46228	0	0.0
SYS 3 SF	KWH	38082	38082	38082	0	0.0
SYS 4 SF	KWH	147921	147921	147921	0	0.0
SYS 5 SF	KWH	48861	48861	48861	0	0.0
SYS 5 RF	KWH	1972	1972	1972	0	0.0
SYS 6 SF	KWH	16701	16701	16701	0	0.0
SYS 6 RF	KWH	3336	3336	3336	0	0.0
SYS 7 SF	KWH	83202	83202	83202	0	0.0
SYS 8 SF	KWH	67196	67196	67196	0	0.0
LIGHTS	KWH	1827783	1827783	1827783	0	0.0
BASE ELEC	KWH	3652192	3652192	3652192	0	0.0
BASE GAS	THERMS	39909	39909	39909	0	0.0
TOTAL ELECTRIC SAVINGS:			511898	KWH		
TOTAL GAS SAVINGS:			53746	THERMS		

————— ENERGY RESOURCE ASSOCIATES —————

Table 16-4. Example of conservative derating of energy savings from a simulation model.

		CALCULATION SHEET			DATE: 10/29/94	
		(WCT-ECM2)			INIT: JPW	
ANALYSIS OF TRACE RUN / ALTERNATES TO DETERMINE ENERGY SAVINGS:						
ECM #	2					
TITLE	WEST CAMPUS, BUILDING AUTOMATION SYSTEM					
EQUIPMENT	ENERGY UNITS	BASE MODEL USE	COMPARE ECM TO: – BASE	ECM MODEL = USE	CHANGE IN USE	% REDUCTION FROM BASE USE
PRIMARY HTG	KWH	728982	728982 –	706808 =	22174	3.0
	THERMS	458035	458035 –	409214 =	48821	10.7
PRIMARY CLG						
COMPRESSOR	KWH	673322	673322 –	382807 =	290514	43.1
TOWER FANS	KWH	47730	47730 –	28865 =	18864	39.5
COND PUMP	KWH	137788	137788 –	81035 =	56753	41.2
OTHER ACCES	KWH	8122	8122 –	4829 =	3292	40.5

AUXILIARY							
SUPPLY FANS	KWH	3042355	3042355 –	2971744 =	70611	2.3	
CIRC PUMPS	KWH	310135	310135 –	218513 =	91622	29.5	
BASE UTIL.	KWH	1850988	1850988 –	1850988 =	0	0.0	
LIGHTING	KWH	2883474	2883474 –	2883474 =	0	0,0	
RECEPTACLE	KWH	986380	986380 –	986380 =	0	0.0	
DHW & PROCESS	THERMS	347034	347034 –	347034 =	0	0,0	
COGENERATION	KWH	0	0 –	0 =	0	100.0	
	THERMS	0	0 –	0 =	0	100.0	
TOTAL SAVINGS:			553831	KWH	48821	THERMS	
TECHNICAL PLAUSIBILITY FACTOR:			0.95		0.85		
NET SAVINGS:			526139	KWH	41498	THERMS	

————— ENERGY RESOURCE ASSOCIATES —————

Table 16-5. Example of “gross” or “overview” check of savings calculations.

4/5/89	—————CALCULATION SHEET—————	DATE:
	(CABC_SUM)	INIT: JPW
ENERGY SAVINGS SUMMARY		
ENERGY CONSERVATION MEASURE; KWH	THERMS	\$\$\$
1. ADMIN PENTHOUSE DOUBLE DUCT TO VAV		
&		
2. ADMIN BASEMENT DOUBLE DUCT TO VAV	511898	53746
3. ADMIN COURTROOM MULTIZONES TO VAV	37124	3589
4. CONVERT JAIL MULTIZONES TO VAV	53579	0
&		
7. LARGE COURTHOUSE MULTIZONES TO VAV	127761	36682
SUB TOTAL	181340	36682
5. SUPERVISOR’S AHU CONTROL MOD	12372	332
6. LIGHTING RETROFIT	448987	-1946
8. COURTHOUSE SMALL MZ’S TO VAV		\$38,888
&		
9. COURTHOUSE SMALL MZ TO VAV	148703	43771
		\$27,093

10.	SUMMER STEAM SHUT-DOWN	0	10287	\$3,292
11.	ENERGY MANAGEMENT COMPUTER	74974	6190	
	63146	0		
	SUB TOTAL	138120	6190	\$14,135
12.	VARIABLE FLOW CHILLED WATER	15647	0	\$1,377
	BTU/SF/YR			
	TOTAL (EXCL ECM#12)	43680	1478544	152561
	PLAUSIBILITY FACTOR		0.95	0.95
	NET SAVINGS	<u>41496</u>	<u>1404617</u>	<u>145018</u>
	EXISTING CONSUMPTION	104035	7896022	214272
	PERCENT REDUCTIONS	39.9	17.8	67.7
	RETROFIT BTU/SF/YR	60355		22.3

1. ELECTRICITY AVERAGE UNIT COST FOR 12 MO. ENDING OCT '88 WAS \$0.0796/KWH, PLUS APPROX 10% PG&E RATE INCREASE IN JAN '89 EQUALS \$0.088/KWH USED ABOVE.
2. NATURAL GAS UNIT COST USED IS \$0.32/THERM.

————— ENERGY RESOURCE ASSOCIATES —————

Building Simulation Programs

The high end of the practice are programs that have traditionally run on mainframe computers. Both proprietary and public-domain programs are in common use, and include such programs as DOE-2, TRACE, and others. The availability of such programs to run on high-end personal computers has become fairly commonplace. In general these programs have similar, if not common, ancestry and are founded in hourly heating and cooling load calculations that are then applied to the HVAC systems and equipment described to the program. These types of programs are powerful simulation tools, allowing for detailed input of both the envelope and the lighting and HVAC systems in the building, and produce excellent results (see Figures 16-2 and 16-3). Also, these programs provide extensive output data for use in output critique. While very powerful, these programs may require significant engineering labor to prepare the data necessary for input (often 40 to 80 engineering labor hours, even for fairly straightforward models) and are sometimes too costly for use on smaller buildings or in the qualification of sales prospects in the energy retrofit business. Some programs use "drag & drop" functionality to add equipment from extensive libraries and allow creation of building templates to reduce input time. A listing of several programs is included at the end of this chapter.

Complex Spreadsheet Simulation Tool

Another possible simulation tool is a complex, automated spreadsheet that allows time-related loads to be scheduled by hour, by three day types (Weekday, Saturday and Sunday/Holiday), by type of energy used, or by type of functional energy use (cooling, fans, lighting, etc.). Too, the calendar of day types for the model year can be customized to cover most any situation. With respect to weather-related loads, this model takes a totally different approach than mainframe programs. In this case, the program accepts peak loads as inputs and distributes the loading over the period of a year according to the differential between the modeled ambient temperature and user-input "no-load" temperatures for heating and cooling. Other variables include heating and cooling lockout temperatures, minimum loads, and daily and seasonal operating schedules. The model calculates hourly ambient temperatures for application of the loads by using a near-sinusoidal model and varying the temperature up or down from the average temperature by half the average daily range. The model utilizes as input degree-days and average daily range by month, or

average maximum and minimum temperatures by month. The model provides hourly heating and cooling loads, and hourly time-related loads, for typical day types each month.

As can be concluded from observation of Figures 16-5 and 16-6, this modeling tool can produce simulations of high accuracy and requires only a few hours for input generation and model runs. In addition, because there is great control over the model, many different retrofit measures can be modeled and custom simulations can be produced by modifying the code or extracting output from the base building model and performing subsequent calculations thereon. This tool is most effective on smaller or simpler buildings, where a high level of confidence in energy-savings figures is desired but engineering costs must be kept to a minimum, and is finding favor among contractors, energy service companies and utility companies.

Simple Spreadsheet Simulation Tool

Another possible simulation tool is a one-page simulation spreadsheet. Its purpose was to provide an extremely quick and inexpensive simulation tool for use where limited accuracy is acceptable and simu-

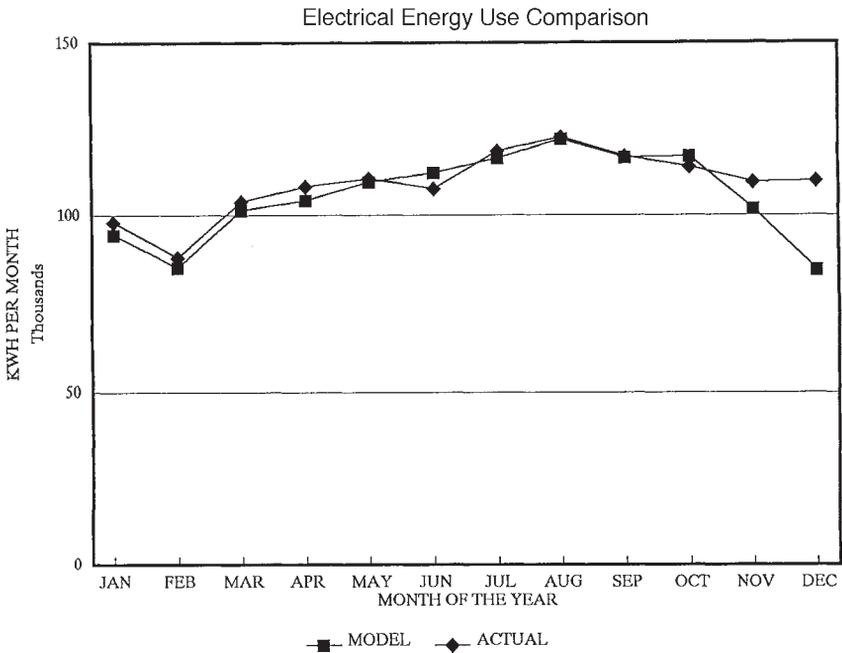


Figure 16-5. Example of complex spreadsheet simulation results.

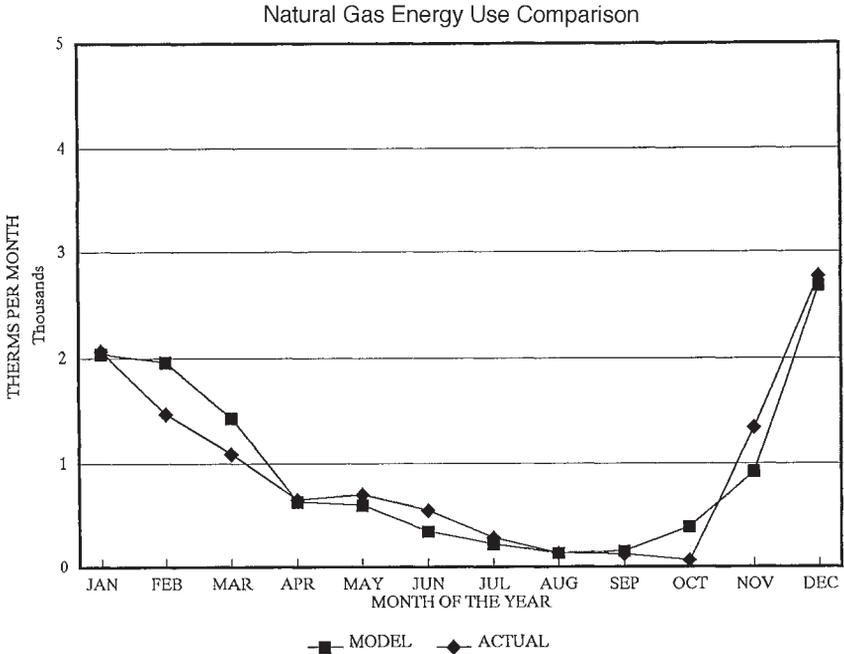


Figure 16-6. Example of complex spreadsheet simulation results.

lation costs are of greater importance than accuracy. Two versions of this model exist, one for HVAC systems that mix heating and cooling (e.g., terminal reheat) and one for non-mixing systems. As shown in Table 16-6, this simulation tool has very simplistic input and basically views a building as having lighting, heating, cooling, HVAC accessories, domestic hot water, and two types of miscellaneous energy use (electrical and heating fuel). Inputs are generally in units per square feet (e.g., lighting input is in watts per square foot) and percentage of operating hours. In addition, provision is made for reduced summer operation (primarily for schools) and “off hours” loads in all functional areas. Time-related loads are calculated based on “hours on” times input loads, similar to the spreadsheet described above, without the ability to customize day types or the annual calendar. Weather-related loads assume a linear, directly proportional relationship with degree-days, which are input to the spreadsheet.

This model was developed to simulate a college campus of more than 100 buildings (all of which had fairly simple HVAC systems) using one model per building. This tool was also used to model a small community hospital that had a very large number of very different

Table 16-6. Example of input and output from simple spreadsheet simulation.

SWEENEY COMMUNITY HOSPITAL ENERGY USE TEMPLATE FOR NON-MIXING SYSTEMS				ENERGY UNITS>>> UNIT #				TYPE	
INPUT BY [M. MUNIZ]	DATE [9/7/89]			1 ELEC, KWH					
				2 GAS, MBTU					
				3 STEAM, MBTU					
				4 CHW, MBTU					
AREA NAME [EMERGENCY]	SYS NO. [8-2]	OCCUPIED SQ. FT. [3200]	YEAR BUILT [1974]						

LIGHTING	COOLING	HEATING	CLG/HTG ACCESSORIES	DOM. HW OFFICE	DOM. HW RESID.	MISCELLANEOUS A	MISCELLANEOUS B		
NRG UNIT > 1	NRG UNIT > 1	NRG UNIT > 1	NRG UNIT > 2	NRG UNIT > 1	NRG UNIT > 3	NRG UNIT > 3	NRG UNIT > 1	NRG UNIT > 2	
WATTS/SF > 2.1	SF/TON > 350	BTU/SF > 20	KW/TON > 0.2	SF/PERSON > 150	SF/PERSON > 200	WATT/SF > 0.5	MBH CAPAC > 0		
HRS OCC. > 80	EQU. FCTR > 1	EQU. FCTR > 0.3	EQU. FCTR > 1	GAL/PER/DA > 0	GAL/PER/DA > 0	% OCCUP. > 60	% OCCUP. > 33		
SUM LOAD % > 100	EQU. FCTR > 0.1	EQU. FCTR > 1.2	% OCCUP. > 100	TEMP FCTR > 1	TEMP FCTR > 1	UNOCC LD % > 20	UNOCC LD % > 5		
UNOCC. LD% > 80	% HRS OCC. > 60	% HRS OCC. > 60	UNOCC LD % > 0	SUMMER LD% > 100	SUMMER LD% > 20	% SUMMER > 100	% SUMMER > 50		
	UNOCC LD% > 60	UNOCC LD % > 100	HTG USE % > 0	assumed	assumed				
	% SUMMER > 100	MIN LOAD % > 0	SUMMER LD% > 100	HWS TEMP > 140	HWS TEMP > 140				
	MIN LOAD % > 0	% SUMMER > 100		CWS TEMP > 60	CWS TEMP > 60				

KW TOTAL > 7	TONS > 9	MBTU'S > 64	KW > 1.8	OCCUPANCY > 21	OCCUPANCY > 16	KW > 2			

USAGE	UNITS	NRG	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	TOTALS
LIGHTING	ELEC, KWH	:	4,645	4,800	4,645	4,800	4,800	4,335	4,800	4,645	4,800	4,645	4,800	4,800	56513
COOLING	ELEC, KWH	:	4,627	2,694	1,451	94	42	672	545	2,232	3,575	5,256	6,857	5,798	33843
HEATING	GAS, MBTU	:	0	0	2,905	17,142	12,876	7,456	3,910	0	0	0	0	0	44289
CLG/HTG ACCESSORIES	ELEC, KWH	:	1,317	1,360	1,317	1,360	1,360	1,229	1,360	1,317	1,360	1,317	1,360	1,360	16018
DOM. HW OFFICE	STEAM, MBTU	:	0	0	0	0	0	0	0	0	0	0	0	0	0
DOM. HW RESID.	STEAM, MBTU	:	0	0	0	0	0	0	0	0	0	0	0	0	0
MISCELLANEOUS A	ELEC, KWH	:	783	809	783	809	809	731	809	783	809	783	809	809	9531
MISCELLANEOUS B	GAS, MBTU	:	0	0	0	0	0	0	0	0	0	0	0	0	0

EMERGENCY	ELEC, KWH	:	11,371	9,664	8,196	7,064	7,012	6,967	7,515	8,977	10,545	12,000	13,826	12,767	115905
SYS. NO. 8-2	GAS, MBTU	:	0	0	2,905	17,142	12,876	7,456	3,910	0	0	0	0	0	44289
OCC. SQ FT 3200	STM, MBTU	:	0	0	0	0	0	0	0	0	0	0	0	0	0
	CHW, MBTU	:	0	0	0	0	0	0	0	0	0	0	0	0	0

TOTAL COMBINED BTU/SF 137,424

Computer Software for Energy Audits

HVAC systems. This model was used to simulate each of the hospital's HVAC systems individually with the modeling accuracy results as shown in Figure 16-7. Considering the relatively small amount of engineering effort required for modeling, the results were excellent. Another appropriate and attractive use of this spreadsheet simulation tool would be as a first-order conservation assessment tool in the energy conservation sales process.

BUILDING SIMULATION AND ENERGY SERVICES

In the last ten years or so, a mini-industry has formed that has traditionally been referred to as the "energy services" industry. The term "demand-side management" has also been applied to this business. What is essential to this industry is the business proposition of retrofitting an owner's building at essentially no initial cost to the owner (financing is provided by the energy services company or a third party) and guaranteeing in some fashion that the utility cost avoided by the project will equal or exceed the cost of the project

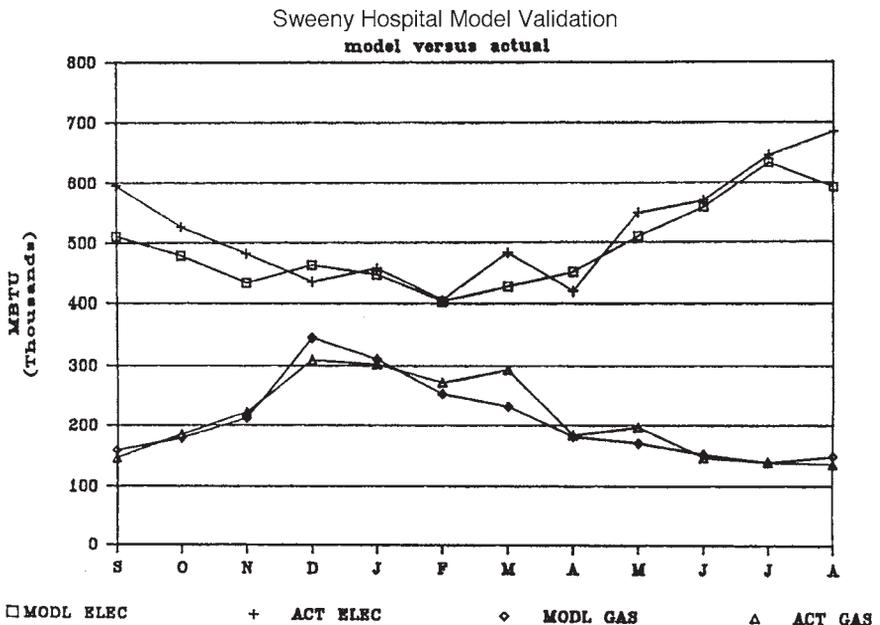


Figure 16-7. Example of simple spreadsheet simulation results.

(debt service plus any other ongoing costs such as project management or maintenance). Unfortunately for some projects done in this industry, the sales people involved viewed the business proposition as simply a way to make their job easier and they exhorted their technical staffs to generate savings calculations that would support a high dollar value for their projects. This is unfortunate, and even frightening, because savings figures so generated are difficult if not impossible to achieve in reality and, if the guarantee offered is reputable, it must then come into play to cover the savings shortfall that must necessarily occur. In a most dramatic example, one energy services company with which the author has worked had the unpleasant experience of having a sales engineer substitute his own savings calculations for those generated by the computer model. The result of this was a *guarantee of natural gas savings* on one project that actually *exceeded the natural gas consumption* of the building. Needless to say, management failed to properly consider the plausibility of such a proposition and approved the project for funding—and wound up funding the annual savings “shortfall” to the tune of more than \$100,000 per year (not to mention destroying their relationship with the building owner). The use of cost-effective and accurate tools and methods of building simulation is an essential part of identifying and implementing successful energy services or demand-side management projects.

While it is a fascinating and complex engineering tool, the fundamental value of computer simulation of buildings is that it forces a quality-enhancing step in the analytical process. This step is essentially a systematic confirmation of the engineer’s knowledge of where and how energy is being used in a building. If the modeling step is done and done well, it is difficult to make “off target” recommendations for specific types of retrofits or “off target” estimates of savings. With such a high level of confidence established on the technical side of a project, the assessment and mitigation of project performance risk can rightly be performed on the financial side of the project evaluation, resulting in a very high probability of success for energy retrofit and demand-side management projects.

CONCLUSION

As has been discussed herein, tremendous opportunities exist to refine, improve and automate calculational and other procedures which are part of the energy auditing process. Caution is advised,

however, regarding the too-rapid introduction of new computer-based methodologies into the practice of energy auditing, as it is all-too-easy to get lost in the morass of technology and lose direction and momentum in the process of an audit. We caution adding new procedures and tools slowly, in an evolutionary fashion, so that valid use thereof can be established and confirmed one at a time.

References

- "Energy Conservation With Comfort," 2nd Edition, Honeywell, 1979
- "Energy Conservation Control" (EFACT Manual), Johnson Controls, 1982
- "Practical Experience in Achieving High Levels of Accuracy in Energy Simulations of Existing Buildings," ASHRAE Transactions: Symposia, AN-92-1-2
- "Computerized Building Simulation... A DSM Strategy?" Globalcon '94 Proceedings, 1994
- "TRACE 600 User's Manual," The Trane Company, 1992

Energy Auditing Software Directory

Developed by the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE), the energy tools listed in this directory include databases, spreadsheets, component and systems analyses, and whole-building energy performance simulation programs. For each tool in the directory, a short description is provided along with other information including expertise required, users, audience, input, output, strengths, weaknesses, internet address, and availability. This list is intended to provide a representative sample of simulation programs that are currently available and is not intended to represent all programs on the market. All of the programs in the DOE directory can be viewed at http://appl.eere.energy.gov/buildings/tools_directory.

DOE developed this directory because many Office of Building Technology, State and Community Program (BTS) programs develop software tools to help researchers, designers, architects, engineers, builders, code officials, and others involved in the building life-cycle to evaluate and rank potential energy-efficiency technologies and renewable energy strategies in new or existing buildings. Many of the tools were sponsored by DOE at some point in their life cycle.

AUDIT

AUDIT calculates monthly and annual heating and cooling costs for residential and light commercial buildings. Virtually any type of cooling and heating system can be simulated by AUDIT including standard DX, evaporative, air source heat pumps, water source heat pumps, and all types of fossil fueled furnaces and boilers (both modulating and on/off controlled). An optional version of AUDIT with appliance capabilities can calculate appliance and hot water energy use as well. AUDIT uses monthly bin weather data and full load cooling hours in its calculations. Weather data for hundreds of cities throughout the world are built-in to AUDIT and additional weather data can be easily added. Along with calculating energy costs, AUDIT also performs an economic analysis that allows you to compare system types and costs over any given study period. There is even a loan and lease analysis report designed to demonstrate affordability of better systems by showing that the effective net monthly cost is often very low when monthly energy savings are considered. To make system comparisons easy, AUDIT allows you to manually enter equipment data or automatically look it up for you from ARI and GAMA equipment data files. AUDIT provides a wide selection of nicely formatted color charts, graphs, and reports. AUDIT shares data with Elite's RHVAC, CHVAC, and Quick Quote programs.

Expertise Required

Knowledge of various types of hvac equipment is helpful.

Users

5000 worldwide.

Audience

HVAC Contractors and Engineers.

Input

Two types of data are requested: general project data and specific HVAC system data. The general project data include the summer and winter design conditions, total cooling hours, the project name and location, client information, fuel cost data, optional appliance data, and the design heating and cooling loads. The HVAC system data include specific information on the system type, model number, efficiency, cost, capacity, and fuel used. Economic data concerning initial system cost,

interest and inflation rates, and loan amounts can also be entered. AUDIT can also import data from project data files created by the Elite's RHVAC and CHVAC load calculation programs.

Output

The AUDIT program provides numerous color presentation quality reports including a title page, project summary, system comparisons, appliance analysis, hot water heating, investment, loan, and lease analysis, line graphs, pie charts, and bar graphs. The reports can be previewed on screen or printed on any printer supported by Windows.

Strengths

Minimal input data required for obtaining hvac operating costs. Great sales tool for showing the benefits of using high efficiency equipment.

Weaknesses

The simple and easy to use monthly bin method of calculation does not allow the simulation sophistication provided by hourly energy analysis methods.

Website:

<http://www.elitesoft.com>

Availability

Contact Elite Software, or visit website for more information. Cost starts at \$495. Free evaluation version available for download from website.

DOE-2

Hourly, whole-building energy analysis program calculating energy performance and life-cycle cost of operation. Can be used to analyze energy efficiency of given designs or efficiency of new technologies. Other uses include utility demand-side management and rebate programs, development and implementation of energy efficiency standards and compliance certification, and training new corps of energy-efficiency conscious building professionals in architecture and engineering schools.

Expertise Required

Recommend 3 days of formal training in basic and advanced DOE-2 use.

Users

800 user organizations in U.S., 200 user organizations internationally; user organizations consist of 1 to 20 or more individuals.

Audience

Architects, engineers in private A-E firms, energy consultants, building technology researchers, utility companies, state and federal agencies, university schools of architecture and engineering.

Input

Hourly weather file plus Building Description Language input describing geographic location and building orientation, building materials and envelope components (walls, windows, shading surfaces, etc.), operating schedules, HVAC equipment and controls, utility rate schedule, building component costs. Available with a range of user interfaces, from text-based to interactive/graphical windows-based environments.

Output

20 user-selectable input verification reports; 50 user-selectable monthly/annual summary reports; user-configurable hourly reports of 700 different building energy variables.

Strengths

Detailed, hourly, whole-building energy analysis of multiple zones in buildings of complex design; widely recognized as the industry standard.

Weaknesses

High level of user knowledge.

Website:

<http://simulationresearch.lbl.gov>

Availability

Cost \$300 to \$2000, depending upon hardware platform and software vendor.

To keep up-to-date on DOE-2 and other simulation programs, request most recent copy and free subscription to *Building Energy Simulation User News* from Kathy Ellington, fax (510) 486-4089.

ENERGYPLUS

A new generation building energy simulation program that builds on the most popular features and capabilities of BLAST and DOE-2. EnergyPlus includes innovative simulation capabilities including time steps of less than an hour, modular systems simulation modules that are integrated with a heat balance-based zone simulation, and input and output data structures tailored to facilitate third party interface development. Recent additions include multizone airflow, electric power simulation including fuel cells and other distributed energy systems, and water manager that controls and report water use throughout the building systems, rainfall, groundwater, and zone water use.

Expertise Required

High level of computer literacy not required; engineering background helpful for analysis portions.

Users

Over 46,000 copies of EnergyPlus downloaded since it was first released in April 2001.

Audience

Mechanical, energy, and architectural engineers working for architect/engineer firms, consulting firms, utilities, federal agencies, research universities, and research laboratories.

Input

EnergyPlus uses a simple ASCII input file. Private interface developers are already developing more targeted/domain specific user-friendly interfaces. See the EnergyPlus website for up-to-date information on interfaces and other tools for EnergyPlus.

Output

EnergyPlus has a number of ASCII output files—readily adapted into spreadsheet form for further analysis.

Strengths

Accurate, detailed simulation capabilities through complex modeling capabilities. Input is geared to the 'object' model way of thinking. Successful interfacing using IFC standard architectural model available for obtaining geometry from CAD programs. Extensive testing (comparing to available test suites) is completed for each version and results are available on the website. Weather data for more than 1250 locations worldwide available on the website.

Weaknesses

Text input may make it more difficult to use than graphical interfaces.

Website:

<http://www.energyplus.gov>

Availability

EnergyPlus Version 2.2.0 was released in April 2008. EnergyPlus and weather data for more than 1250 locations worldwide can be downloaded at no cost from the EnergyPlus website.

EZDOE

An easy to use IBM PC version of DOE-2. EZDOE calculates the hourly energy use of a building and its life-cycle cost of operation given information on the building's location, construction, operation, and heating and air conditioning system. Using hourly weather data and algorithms developed by Lawrence Berkeley National Laboratory, EZDOE takes into account complex thermal storage effects of various building materials. In addition, it can also accurately simulate the operation of all types of heating and cooling plants including ice water thermal storage and cogeneration systems. Up to 22 different air handling systems each with multiple control options are supported. The types of heating and cooling plants allowed are nearly infinite, as thousands of combinations of chillers, boilers, furnaces, pumps, and cooling towers are allowed. There is even provision for user defined plants and performance curves. The economic analysis capabilities of EZDOE allow for complex utility rate structures, fuel costs, initial equipment costs, replacement costs,

and annual costs for non-plant items and baseline data for comparative runs. A large library of over 230 hourly weather data files is available for EZDOE. One weather data file of your choice is supplied with EZDOE while others are available at additional cost.

Expertise Required

Basic familiarity with building geometry and HVAC systems is desirable but not absolutely necessary.

Audience

Architects and engineers involved in new and retrofit building projects, researchers, equipment and utility marketers.

Input

Features full screen editing with simple input screens.

Output

Offers all of the standard reports as the workstation version of DOE-2. These reports can be viewed on the screen, stored in a disk file, or printed.

Strengths

Implements DOE-2 in an easy-to-use full screen editing environment with dynamic error checking. All input data is checked at the time of entry so that no improper data can be entered. If you have a question about what the program is requesting, you can press the "?" or F10 key to obtain additional help explanations. All data is saved to disk as it is entered. Four major types of data are requested: Loads, Systems, Plants, and Economics. Load data contains the building and space dimensions, wall and glass orientations, construction materials, people, lighting, equipment, and much more. The Systems data involves all information concerning air handling and heat delivery systems. VAV, constant volume, PTAC, dual duct, two/four pipe fan coils, and radiators are just a small sampling of the many system types supported by EZDOE. The Plant data concerns the cooling and heating equipment such as chillers, boilers, cooling towers and pumps. The Economic section considers initial, annual, cyclical, replacement, and operating costs.

Weaknesses

Limited to capabilities within the DOE-2 program.

Website:

<http://www.elitesoft.com>

Availability

Demonstration copy available for download from the website, or order a copy, with complete documentation. Demonstration copies retain all the functionality of the full programs, they are just limited on the size of the project data that can be entered.

ENERGY PROFILE TOOL

A customizable, commercially available energy analysis tool. Users enter information about their facilities to receive detailed profiles of the energy use, as well as benchmark comparison results. The tool helps identify opportunities to reduce energy and costs, and take the next steps to long-term savings.

Expertise Required

No expertise needed, but the more knowledgeable the users are about their building characteristics and concepts, the better the results.

Users

Various websites have been accessed thousands of times by users in the U.S. and Canada.

Audience

Building facility managers and owners, utilities, engineers, designers, policy analysts.

Input

User supplies information about building type, weather region, floor area and general HVAC system. Existing buildings should also provide billing data for benchmarking to be most relevant. However, specifying general shell, HVAC, lighting and equipment, and DHW information provide for a more accurate analysis. All entries provide for defaults which are estimated to be the most typical or average for the building characteristic. Data entry is accommodated on two levels: 1) Basic—provides automated controls (e.g., pulldown lists, radio buttons) and limits data entry to the most relevant and important building

characteristics, 2) Advanced—supplements the Basic level by allowing for additional entries and discrete entry for all inputs.

Output

Typically, users receive energy benchmark and end-use breakdown information about their facility in the form of graphs and tables. They receive low-cost/no-cost energy saving tips, and a list of energy efficiency measures show good potential of save energy in their facility. The tool also generates a PDF report that shows results and action plan in printable format. The system may be customized to provide further information, such as comparisons between facilities and more detailed energy analysis results.

Strengths

Provides a quick, initial estimate on building energy performance and benchmarking, including relative greenhouse gas emission levels. The tool helps identify opportunities to reduce energy and costs, which is intended to act as early decision-making tool to empower the user to take the next steps to securing energy savings.

Weaknesses

Intended for entry-level analysis and is not detailed enough to assess very specific energy management scenarios. Therefore, it cannot replace having a professional personally assess specific opportunities for a given facility.

Website:

<http://www.energyprofiletool.com>

Availability

Available for limited, free trial use at www.energyprofiletool.com. To purchase a customized application, contact EnerSys for a customized cost proposal.

eQUEST®

eQUEST® is a sophisticated, yet easy to use, freeware building energy use analysis tool that provides professional-level results with an affordable level of effort. Use eQUEST for the most up-to-date user

interface and DOE-2 simulation capabilities. It is a powerful and flexible building energy use and cost estimation tool which includes a graphical user interface that provides 2-D and 3-D displays of your building layout including architectural and HVAC features as well as graphical modeling results. eQUEST was designed to allow you to perform detailed comparative analysis of building designs and technologies by applying sophisticated building energy use simulation techniques but without requiring extensive experience in the “art” of building performance modeling. This is accomplished by combining schematic and design development building creation wizards, an energy efficiency measure (EEM) wizard and a graphical results display module with a complete up-to-date DOE-2 (version 2.2) building energy use simulation program.

New Note: eQUEST 3.6 and D2comply 3.6 were approved by the California Energy Commission as 2005 Title 24 non-residential ACMs by the CEC at their 11 April 2007 business meeting. eQUEST 3.6 and 3.60b are approved for use with Savings By Design.

eQUEST is supported as a part of the Energy Design Resources program which is funded by California utility customers and administered by Pacific Gas and Electric, San Diego Gas & Electric, Southern California Edison, Southern California Gas under the auspices of the California Public Utilities Commission as well as the Sacramento Municipal Utilities District.

Website:

<http://doe2.com/equest/index.html>

Availability

Version 3.6 and 3.60b available free from website.

EZ SIM

Quick spreadsheet tool equivalent to sophisticated engineering analysis. EZ Sim lets you use utility bills to calibrate a simulation of a commercial facility in an interactive graphic window. Once it matches your bills, the simulation model can provide reliable estimates of potential conservation savings. The calibration process reveals how energy is used within the facility, helping diagnose why there is excessive consumption or poorly functioning building components. Potential users

can review case study examples on the website. Model also provides precision and confidence limits of savings estimates consistent with IPMVP performance verification protocol.

Use utility bills to reveal the patterns of use in your facility:

- Diagnose energy patterns and consumption.
- Calibrate savings estimates to agree with your actual usage.
- Estimate energy end-uses within the facility.
- Verify vendor claims for energy products and services. Generate performance targets and compare against your utility bills.

Expertise Required

Basic knowledge, users should know about lighting density, U value, and types of HVAC.

Users

To date about 90 users in Pacific NW, supported by Northwest Energy Efficiency Alliance.

Audience

Facility managers, resource conservation managers, utility reps, and ESCOs.

Input

Minimal building description (floor area, type of business, type of heating/cooling). Monthly utility bills. Can be cut-and-pasted from other applications. Weather files using mean daily temperature as proxy for all other weather variables. Can be easily updated to actual local weather. Website provides current local weather files for 250 US locations. Default building parameter values based on type of facility, but can be easily changed or updated by entry into spreadsheet windows.

Output

Primarily spreadsheet tables and graphs, several preformatted reports but all can be cut-and-paste into other applications.

Strengths

Simulation is easily tuned to match actual bills, provides performance targets to compare against post-retrofit bills--a low-cost commissioning tool. Provides precision of savings estimate (error bands) for IPMVP protocols. Works with PC or Mac.

Weaknesses

Simplified model, assumes one heating or cooling plant. Difficult to use when there are multiple plants.

Website:

<http://www.ezsim.com>

Availability

\$199 for standard version, \$299 for multiple-fuels version. weather files \$24 each or by annual subscription.

FEDS

Provides a comprehensive method for quickly and objectively identifying energy improvements that offer maximum savings. FEDS (Facility Energy Decision System) makes assessments and analyzes energy efficiency of single buildings, multiple buildings, or all buildings of an entire facility. It provides an easy-to-use tool for identifying energy efficiency measures, selecting minimum life-cycle costs, determining payback, and enabling users to prioritize retrofit options and compare alternative financing options (site funding, leases, loans, ESPCs).

Expertise Required

Minimal using readily available information. Requires two or more hours depending on number of buildings.

Users

Over 1,500.

Audience

Energy and facility managers, architects-engineers, utility planners, building technology researchers, educators, federal agencies, and energy consultants.

Input

Location, building types, operating hours, age, square footage, fuels used by facility and energy price data are required. Numerous detailed engineering parameters are optional.

Output

Fuel-neutral analysis with full life-cycle costing of retrofit options (ECMs) for the on-site buildings. Output data includes energy and cost savings, emissions reductions, and a wide range of economic measures.

Strengths

Allows but does not require input of engineering parameters. Energy/economic analysis. Models peak demand. Optimizes retrofit opportunities. Performs analysis that meets unique Federal needs. Accepts unlimited number of buildings. Engineering and economic parameters provided are user adjustable.

Weaknesses

Not a buildings design tool.

Website:

<http://www.pnl.gov/feds>

Availability

Version 4.1 available free to Federal agencies through the Energy Efficiency and Renewable Energy Clearinghouse, 1-800-DOE-EREC (363-3732).

MARKETMANAGER

Models any type of commercial, institutional, industrial, and residential facility and determines the energy and cost impact of virtually any type of energy conservation measure or utility rate schedule. MarketManager calculates the operating costs of any piece of equipment in the facility and determines the cost-effectiveness of improving the building envelope, HVAC controls, motors, lighting systems, heating and cooling equipment.

Expertise Required

MarketManager is best used by energy professionals who have a good understanding of HVAC systems. Others have been known to use it.

Users

Approximately 1000 users worldwide, mostly in the United States.

Audience

ESCOs, performance contractors, energy consultants, utilities and energy managers.

Input

Users input building envelope characteristics (windows, walls, etc.), occupancy and thermostat schedules, lighting and internal equipment data and schedules, HVAC system information (including chillers, fans, system type, etc.), HVAC controls, and rate information. Users can speed up the process by using pre-defined template projects, libraries filled with hundreds of equipment and building envelope items. Users can also use default values in the data forms for the more esoteric inputs (such as thermal mass and infiltration information).

Output

MarketManager includes over twenty standard reports formats as well as graphing capabilities. Users can also configure results output. The program also allows users to create and print lists of inputted data (such as information on all fans).

Strengths

For users who don't want to spend days creating models. Through the use of templates, libraries, defaults and drag and drop, Market-Manager users can create detailed models in a very short time. The program's calculations are based upon methods outlined in ASHRAE Fundamentals and used in DOE-2.

Weaknesses

Users must understand HVAC to correctly create models. The program doesn't run well with huge detailed models, such as 300 zone hospitals.

Website:

<http://www.abraxasenergy.com/marketmanager.php>

Availability

MarketManager costs \$2495 per license. You can download a 30 day trial version at the website.

TRACE 700

Trane's TRACE 700 software—the latest version of Trane Air Conditioning Economics—brings the algorithms recommended by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) to the familiar Windows operating environment. Use it to assess the energy and economic impacts of building-related selections such as architectural features, comfort-system design, HVAC equipment selections, operating schedules, and financial options.

Flexible data entry, coupled with multiple views and “drag-and-drop” load assignments, simplify the modeling process and help you identify optimal zoning and plant configurations. Compare up to four alternatives for a single project by modeling various air distribution and mechanical system/control options; then assess the life-cycle cost and payback of each combination based on 8,760 hours of operation... without investing lots of extra time.

Templates provide a fast, easy way to analyze the effects of changes in building loads such as airflows, thermostat settings, occupancy, and construction. An extensive library of construction materials, equipment, and weather profiles (nearly 500 locations) enhances the speed and accuracy of your analyses. Choose from seven different ASHRAE cooling and heating methodologies, including the Exact Transfer Function.

Expertise Required

General knowledge of HVAC engineering principles, building geometry, and the Microsoft Windows operating system.

Users

Approximately 1,200 worldwide, including single and site/LAN licenses.

Audience

Engineers, architects, and contractors who design and analyze commercial HVAC systems/equipment for new and existing buildings; also energy consultants and utility companies; building technology researchers; state and federal agencies; colleges and universities.

Input

Building design parameters; operating schedules; HVAC system configurations, equipment types, and control strategies; utility rates.

Output

Display, print, graph, or export any of 55 monthly/yearly summary reports and hourly analyses, including system “checksums,” system component selection, psychrometric state points, peak cooling/heating loads, building envelope loads, building temperature profiles, equipment energy consumption, and ASHRAE 90 analysis.

Strengths

Models 33 different airside systems, plus many HVAC plant configurations and control strategies, including thermal storage, cogeneration, and fan-pressure optimization, and daylighting controls. Customizable libraries and templates simplify data entry and allow greater modeling accuracy. Documentation includes detailed online Help and a printed modeling guide. Experienced HVAC engineers and support specialists provide free technical support.

Weaknesses

Formal training is recommended for new users (Visit the website for training options.)

Website:

<http://www.trane.com/commercial/software>

Availability

\$1,995 USD for a standard single license; \$3,990 USD for a site license. \$3,990 USD for a Network (LAN) license plus \$75 per seat; the amount of seats purchased represents the amount of simultaneous users allowed. Special pricing available for educational institutions and during promotions. Annual renewal fee (23 percent of purchase price) entitles licensee to unlimited technical support, plus automatic updates and documentation. All Trane C.D.S. software carries an unconditional, 30-day, money-back guarantee.

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Chapter 17

World-class Energy Assessments

*Christopher H. Russell, Director, Industry Sector
Alliance to Save Energy*

ABSTRACT

This chapter summarizes recommendations for improving the impact of industrial energy assessments. This initiative responds to the observation that less than half of recommended energy improvements are implemented as a result of traditional assessment methods. The need to rethink energy assessment strategies coincides with industry's greater interest in controlling its energy costs. The Alliance to Save Energy conducted three roundtables at different U.S. locations during the first half of 2006. These events solicited feedback from 80 people, including energy assessment practitioners, representatives from energy-consuming facilities, and government and utility program personnel. All participants in this discussion are interested in promoting industrial energy efficiency and recognize the pivotal role of energy assessments in achieving their goals. The recommendations address the considerations prior to, during, and after an energy assessment. Among this chapter's leading conclusions is that the assessment experience need not be confined to a report—it can become a relationship between the assessor and the client facility. A side-by-side comparison of traditional vs. the world-class energy assessment format is shown in Table 17-1.

INTRODUCTION

Energy-efficient technologies, procedures, and operating behaviors allow facilities to control their energy costs. Energy-efficient principles and activities also contribute to the mechanical integrity and reliability of energy-using equipment such as boilers, furnaces, air compressors,

fans, pumps, and motor-drive systems. As a facility boosts the reliability of these assets, it offsets the risk of operational failure or “down-time.” Reliable plant assets work longer and make more products, therefore helping the facility to achieve higher production targets and bring in more revenue.

An **energy assessment** (often referred to as an *audit*) is the key to identifying energy-saving opportunities. The traditional assessment is strictly a technical exercise, led by a mechanical or industrial engineer. It culminates in a summary document that lists recommended energy improvements, giving a brief description of each opportunity, along with its projected cost, savings, and financial payback. The assessment concludes with a presentation of the assessor’s findings. The client then decides when, and if, the organization will act on any of the recommendations.

Industrial facilities face a variety of barriers to becoming energy efficient, including a general lack of awareness of energy waste and ways to reduce that waste. The challenge for an energy assessor is to make those benefits more obvious to the clients’ facility managers and their key staff. An even larger challenge is to ensure that facilities follow through on implementation.

Industry’s top decision makers may be concerned by the overall cost of energy, but not so much by the technical aspects of energy use. Therefore, the client may need an explanation of energy use

THE TRACK RECORD OF ENERGY ASSESSMENT PROGRAMS

To what extent does industry actually implement energy improvement recommendations? Anecdotal evidence suggests that the very best publicly sponsored energy assessment programs lead to implementation rates of just over 40 percent:

- Bradley University of Peoria, Illinois, which hosts one of 26 Industrial Assessment Centers sponsored by the U.S. Department of Energy,² surveyed 125 facilities that it served between 1999 and 2003 (Najafi, et al., 2005). The results indicate a 42 percent implementation rate (by volume of energy), or 49 percent (by dollar value of energy savings).
- Enbridge Gas Distribution, an Ontario, Canada, based utility company, has conducted at least 92 energy assessments for large steam users through its “Steam Saver” program since 1997 (Griffin, et al. 2006). The follow-up to these assessments indicates a 42 percent implementation rate by energy volume, or 32 percent by number of projects (in other words, 157 out of 491 potential projects had been implemented through March 2006).

**Table 17-1. Side-by-side Comparison
Traditional Energy Assessments vs. World-Class Energy Assessments**

Feature	Traditional Assessments	World-Class Energy Assessments
<i>Goal:</i>	Identify equipment repair, upgrade, and replacement projects that will reduce the client's expenses through avoided energy consumption.	Identify, prioritize, and suggest alternative strategies for improving the client's business performance through more effective energy choices.
<i>Elements for study:</i>	Energy bills, energy-using equipment, technologies, as well as maintenance procedures and operational behavior.	Energy-using equipment and technology PLUS: <ul style="list-style-type: none"> • organizational design and relationships • skills and training needs • operations and maintenance procedures • management commitment and communications needed to effectively capture and sustain potential energy savings.
<i>Client participation:</i>	A power house superintendent and a couple of subordinates supply key documentation and provide access to key energy-using assets.	Preparation for an assessment requires input from the general manager plus leadership for engineering, finance, maintenance, procurement, and operations. The client should designate an "energy champion" as the lead contact. Conduct of the assessment itself requires the participation of plant engineers, maintenance leaders, and equipment operators. Presentation of assessment findings requires an audience of all the above.
<i>Deliverable:</i>	A written report that lists potential energy improvement projects , indicating their probable cost and payback.	An active, ongoing relationship keeps the client apprised of changes to the costs and benefits of potential energy improvements as market variables change. Communication may include: <ul style="list-style-type: none"> • a written report of the initial assessment findings • a presentation of findings to client staff • implementation scenarios that present different options for organizing recommended improvements • periodic updates of cost-benefit findings as market conditions change • a spreadsheet template for modeling cost-benefit • a listing of contacts for financial and technical assistance services • announcements that recognize implementation milestones, reminding key decision-makers of the progress made and what remains to be done
<i>Outcome:</i>	30-40% of projects may be implemented on an isolated basis as time, money, and interest permit.	The client pursues continuous energy improvement through a business plan that identifies what needs to be done, assigns goals and responsibilities, and provides a framework for tracking, evaluating, and communicating progress.

and its impact on business performance. For example, many facility managers believe that big, capital project investments are the only solution to high energy costs. They may be unaware of the savings potential inherent in certain behavioral and procedural changes applied to current equipment. The client should understand the options for controlling energy costs and how each option may impact its business activities. With that understanding, the client can better express to the assessor its needs and expectations for effective energy cost control. The energy assessment becomes a foundation for understanding how business performance improves with better energy decision-making.

An energy assessment is worthless if it does not lead to the implementation of improvements. An energy assessor's report—and the process for developing, presenting, and reacting to it—must be conducted in a way that compels the client to take action. Facility managers deal with competing priorities and their associated risks. When considering an energy improvement, a facility manager may ask: How reliable is the proposed solution? Will it disrupt my process? Will it cost more than it saves? Will the savings not accrue before my next performance report?

Fortunately, there is current evidence that should dispel industry's reluctance to act on energy improvement recommendations. In 2006, the U.S. Department of Energy's *Save Energy Now* initiative is documenting the attractiveness (great savings relative to their cost) of industrial energy improvements.¹

The Alliance to Save Energy notes both documented and anecdotal evidence revealing that less than half of traditional energy assessment recommendations are actually implemented, regardless of who provides the assessment (see sidebar discussion below).

These results beg a number of questions about the practice of energy assessments:

- What are the shortcomings of the typical energy assessment format?
- What characterizes the gap between a traditional energy assessment and what industrial decision-makers need?
- How might assessors improve the energy assessment experience from the industrial client's vantage point? This would require exam-

1. For the current status of the *Save Energy Now* findings, please see <http://www.eere.energy.gov/industry/saveenergynow/>

2. <http://www1.eere.energy.gov/industry/bestpractices/iacs.html>

ining the entire assessment process including the assessment's preparation, conduct, presentation of results, and follow-up activities.

To answer these questions, the Alliance conducted a series of roundtable discussions that engaged a total of 80 individuals, including assessment practitioners, industrial engineers, and energy policy and program professionals. They attended the following roundtables:

- Westborough, Massachusetts. February 16, 2006
- Columbus, Ohio. March 1, 2006
- New Orleans, Louisiana. May 12, 2006

The body of this chapter synthesizes the recommendations that were generated by these round tables.³ It should be noted that the roundtables discussed energy assessment practices *as if time and money were not an issue*—in other words, participants described the services and activities that would be provided in the best of conditions. In reality, organizations are hesitant to pay for traditional energy assessments, much less the additional activities that are suggested here. Future assessments may draw elements from these recommendations, as needed, to overcome hurdles specific to a facility, its management, and its staff.

ENERGY ASSESSMENTS: THE TRADITIONAL APPROACH

Energy assessments are traditionally a technical exercise, conducted by mechanical engineers for the benefit of the client's chief engineer or maintenance leader. By virtue of their training, engineers have a great affinity for equipment and hardware. This engineer-to-engineer dialogue usually leads to the recommendation of energy improvement "projects" that focus on equipment, components, and systems. In working with an energy assessor, the client's facility engineer will often express needs and expectations that only reinforce the "project" approach to energy cost control. This focus excludes improvements that are derived from procedural or behavioral changes.

The organizational aspects of energy cost control become apparent

3. A few recommendations were contradictory. For example, while some participants suggested that facility assessments could be expanded in scope to include non-energy improvement opportunities. Another suggested that the scope should be limited to energy alone. This chapter resolves those suggestions at the author's discretion.

in the campus-like physical layout that characterizes most industrial facilities. Structural features underscore delineations in the client's organization as well as transitions of authority. Unfortunately, "silos" or departmental turf issues are a fact of life in many organizations. This means that departments within the same company compete against each other for budgetary authority and procedural control. When cooperation across departmental boundaries is limited, many energy-saving opportunities—especially those involving procedural and behavioral change—are much harder to accomplish. The client's ability to act on energy improvement recommendations is directly related to the client's organizational structure and its business culture.

A manufacturing organization will almost always assign energy cost control responsibility to a single department or even a single person. This leads to implementation that is limited to reflect the confines of that department's authority and budget. In other words, the department that tackles energy issues tends to under-

THE OUTLOOK FOR FREE ASSESSMENT SERVICES

Energy assessment activities are provided by a variety of sources, including universities, electric and gas utility companies, product vendors, and independent engineering consultants. Large, multi-plant corporations often organize their own in-house engineering staff to provide energy assessments. Many university-based technical assistance centers are publicly subsidized to provide energy assessments, often at no cost, to small- and medium-sized manufacturers as a regional economic development activity. Industrial energy assessment providers are found in every state, but their services vary in scope, quality, and cost.

The funding outlook for publicly-sponsored assessment offerings does not look good for 2007 and beyond. Utilities (especially those operating in deregulated markets) are cutting back on technical assistance in an effort to minimize their overall costs of service. Direct assistance to industry is often perceived as "corporate welfare," so government-sponsored outreach is being reduced accordingly. For the foreseeable future, manufacturers seeking to control their energy costs can expect to pay for solutions—either by hiring consultants or by developing their own in-house expertise.

Even in the best of times, scarce funding is a fact of life for many publicly-sponsored assessment programs. These organizations could not expect to deliver all the energy assessment services that this chapter recommends. However, these assessors could partner with other agencies to deliver energy assistance to clients. By "bundling" their services, a regional coalition of assistance organizations can respond more effectively to energy consumers' needs.

stand, seek, and prioritize solutions that its staff can perform while minimizing their interference (and collaboration) with other departments.

For example, a facility may seek energy cost-savings for its steam system. Consequently, the assessor is asked to work primarily with the superintendent of the facility power house, which contains boilers, air compressors, and other large energy-consuming assets. The assessor's focus only begins with the power house. A thorough steam system assessment will cross over into the maintenance department's jurisdiction by examining the distribution system that connects the power house with the many buildings that the power house serves. The assess-

COMBINING ASSESSMENT AGENDAS

A facility assessment can often be conducted for a combination of purposes. Recall that energy use encompasses combustion, heat transfer, and the conversion of heat and power to mechanical force and movement. The assessment of combustion and heat transfer activities has obvious implications for documenting safety compliance in the facility. Combustion analysis will also allow the management of air emissions output and compliance with air pollution regulations. The mechanical integrity of facility equipment varies directly with their energy-efficient operation. In this way, efficiency has a direct impact on equipment reliability and the facility's ability to meet its production targets on time. Also, an energy assessment can benchmark fuel and power consumption as a function of the facility's production volume. These benchmarks are vital components for the facility's planning and budgeting activities.

ment continues into the production facilities themselves, now under the purview of the operations or manufacturing department, where the steam or its heat is applied to a variety of work tasks. But here is the challenge: the top management has declared that the powerhouse superintendent's staff and budget shall take care of all steam improvements. These departmental delineations create problems. Against whose budget shall the cost of improvements be applied? To whose budget shall the energy savings accrue? What about labor hours? Who will perform the recommended tasks, and what if departments can't coordinate the recommended activities due to other crucial events on the calendar?

No wonder that less than half of energy assessment recommendations usually get implemented. In most cases, energy cost control is assigned as an "extra" function to a department that not only has other priorities, but also has limited authority and budget to generate solutions beyond its departmental boundaries.

The Logic of “Combined” Assessments

Most facilities are statutorily compelled to secure “audits” for health, safety, and environmental purposes, so these audits are paid for without question. Some clever managers have arranged for these critical audits to also encompass energy-use analysis. By doing this, the cost of the energy assessment is not perceived as an “extra” expense. Also, the audit not only fulfills legal requirements but also identifies energy savings that pay for the audit many times over. Industrial efficiency assessments can easily encompass energy, water, material utilization, safety practices, environmental impacts and related work procedures (see sidebar discussion).

Industrial assessment clients may even have specific energy improvements in mind. For them, an assessment is only a formality for securing an outside “expert opinion” needed to obtain the project’s final approval by top management. From the assessment provider’s perspective, serving the client’s immediate need is an opportunity to forge a relationship that leads to additional analysis with a broader scope. Additional improvement opportunities will become apparent over time as energy prices change and new technologies become available.

PREPARING TO CONDUCT WORLD-CLASS ENERGY ASSESSMENTS

Preparation for a successful energy assessment includes an analysis of a client company’s business procedures. The assessor will need to understand the client’s:

- **Technical review.** Who in the client company participates in evaluating and implementing changes to its operations, and what procedure does it use to accomplish these changes?
- **Fiscal calendar.** It is useful to know the client’s budget cycle. When does the company begin assembling investment proposals in anticipation of setting next year’s budget?
- **Project/investment approval.** Which of the client’s decision-makers are involved in this procedure, and what are their criteria for making decisions? The assessor should be prepared to present recommendations in a way that addresses the primary concerns of each key decision-maker.

Good communication at the outset will make the purpose of the energy assessment clear to all participants. Otherwise, an investigation performed by an “outsider” may be resisted by some individuals.

The physical examination of the client’s facility and energy-related records will require the cooperation of a number of staff, such as procurement and operations professionals. These individuals won’t always understand or agree with the assessment process and the recommendations it provides. Some people are very comfortable with “the way we’ve always done things.” To them, energy improvements suggest *change*, and change implies risk. Some of these individuals will play a role in approving—or vetoing—recommended energy improvements. For example, the client’s maintenance or engineering staff may feel that an energy assessment will be interpreted as evidence of their poor job performance.

The threat of embarrassment is very real to the client staff involved in an energy assessment. It is a good idea for the assessment to identify positives in the client’s current energy management, with credit being given to the key individuals whose support will be needed to advance new recommendations. The support of the client’s technical staff will help greatly in securing top managers’ eventual approval of forthcoming recommendations.

Departmental Issues Impacting Energy Assessments and Cost-Control

Each department in an industrial organization will have a distinct perspective on energy expenses and the strategies for energy cost control. These perspectives are a function of the professional training and objectives that characterize each department. These are some of the departments that will be impacted by energy recommendations:

- **Engineering.** The chief engineer is usually tasked with the design and installation of equipment, and may have significant influence in

ESTABLISHING AN “ENERGY CHAMPION”

Research by the Alliance to Save Energy shows that companies with a lead energy coordinator—an “energy champion”—tend to be more successful at sustained energy cost control. This is a person with the authority to coordinate energy-related decisions. The assessor should identify the client’s staff person who either does or can fulfill this role. The energy champion will be a helpful person to work with during the assessment process and during the subsequent follow-up.

developing the operating procedures for that equipment. To many engineers, energy solutions are discrete “projects” that involve capital investment for the installation of new equipment.

- **Maintenance.** These are staff charged primarily with ensuring the integrity and reliability of existing equipment. Because they usually have little involvement in capital budgeting or asset management decisions, the maintenance staff’s approach to energy cost control is to fix leaks, adjust controls, and clean or lubricate equipment. These tasks can be accomplished at little expense, but their energy savings impact is limited if the tasks are not consistently performed.
- **Procurement.** Many business leaders perceive fuel prices as the key to energy expenses. The procurement director may then be asked to take charge of energy cost control and even the energy assessment process. Procurement directors want low energy prices (or at least predictable energy bills from month to month), so they shop for the best available fuel contracts, or even switch fuels, if possible. However, procurement savings may be cancelled out by ineffective criteria for hardware purchasing. Hardware purchased from the lowest of three bidders may be cheaper to install but is often less energy efficient, therefore costing more to operate over its economic life.
- **Environmental, health, and safety (EHS) coordinators.** These are professionals who primarily administer their company’s regulatory compliance obligations. Such professionals are accustomed to data gathering, record keeping, and the documentation and monitoring of procedures. Because of the legal implications of their work, EHS professionals enjoy some authority to advise or direct staff in other departments.
- **Energy managers.** A small but growing number of organizations are developing departments for the express purpose of energy management. The effectiveness of such a position varies with the energy manager’s ability to influence or command other staff to apply energy-saving principles to their daily work.

Effective energy cost control will involve personnel from a number of departments, many of whom assume that energy cost control is “not my job.” Both the assessor and the client’s lead energy person will have their persuasive skills put to the test. Some staff will ask: “What’s in it for me?”

The answer to that question needs to be concise and in a language that is relevant to their department.

Industry clients without a clear set of energy improvement expectations may benefit by seeing case studies that describe the before-and-after impacts of energy improvements at other facilities. These case studies may describe technologies and procedures as well as information about financial incentives and utility rebates. A comprehensive case study will describe how energy improvements impact productivity, reliability, environmental compliance, safety, or other operating concerns.⁴

CONDUCTING A WORLD-CLASS ENERGY ASSESSMENT⁵

Some assessors begin the assessment process with a questionnaire or template to collect data that describes the client facility and its energy usage. This “screening tool” should include an inventory of energy-using equipment as well as the procedures and staff roles that support the operation of this equipment. Identifying the facility personnel who are involved in (or impacted by) energy improvements is important—these individuals need to understand how proposed changes may impact their daily operating concerns. The effectiveness of the energy assessment and the implementation of recommended energy improvements will depend on properly identifying the equipment, people, and organizational relationships that determine energy usage.

Observations to Make

An energy assessment should cover both mechanical and organizational attributes of a facility’s energy use.

4. The U.S. Department of Energy presents a large number and variety of technical case studies on its website:

- From *Save Energy Now* assessments in 2006:
<http://www.eere.energy.gov/industry/saveenergynow/partners/results.cfm>
- From related DOE program initiatives:
http://www1.eere.energy.gov/industry/bestpractices/case_studies.html

Both the U.S. DOE and the Alliance to Save Energy offer case studies that describe the managerial and organizational aspects of energy cost control:

- From the DOE:
http://www1.eere.energy.gov/industry/bestpractices/corporate_success.html
- From the Alliance to Save Energy:
<http://www.ase.org/section/topic/industry/corporate/cemcases>

5. It is beyond the scope of this chapter to describe in detail the mechanical aspects of energy assessments from a practitioner’s standpoint. Readers are referred to an insightful article on this topic (Knapp, 2006).

- Observations to make about equipment:
 - the general mechanical condition
 - age and repair histories
 - work capacities and tolerances
 - preventative maintenance schedules

- Observations to make about organizational attributes:
 - Were previous assessments conducted? If so, are they available to review?
 - Were any of the earlier recommendations actually implemented?
 - What kind of energy monitoring system or protocol is already in place?
 - What metrics are used for monitoring the impact of energy use on business performance?
 - How are equipment-purchasing decisions made? Do procurement criteria recognize total-costs-of-operation or simply seek the lowest initial cost?
 - Is there a protocol for making and enforcing procedural changes in maintenance and operations?
 - How do the client's in-house skills for analysis and implementation compare to what is needed to manage and evaluate energy projects or improvement programs?
 - Does the company maintain an inventory of needed skills and establish a training program to support those needs?
 - What staff, or department, is expected to accomplish energy cost control, and what is the capacity of its authority and budget?
 - Will energy improvement initiatives pose benefits to some departments while placing burdens on others? Is there a protocol for reconciling these impacts?

Client staff from different departments, sections, or professional disciplines can be assigned to cooperate with the assessor in their areas of responsibility. The assessor's effectiveness will be improved by getting the cooperation of proper staff contacts. At a minimum, the client should provide a lead engineer or mechanic to assist with evaluating major equipment such as boilers, air compressors, and other large, energy-consuming equipment. Larger, more complex organizations may provide different staff contacts for each major section or department. It is also helpful to involve equipment operators when possible, since these individuals can often share with the assessor some very good energy saving recommenda-

tions that would otherwise be ignored. Support from the client's technical staff will be more forthcoming if they understand how an energy assessment and its recommendations will impact their jobs.

An energy assessment can just as easily address a client's skills and behaviors as it does the "mechanical" opportunities for energy improvements. By demonstrating diagnostic software and other useful reference material⁶, the assessor is providing the client's key staff with the skill-set needed to effectively implement and sustain energy savings. A world-class energy assessment, then, shows the client not only what can be done to improve energy performance, but also how to sustain the results.

EXPRESSING THE IMPACT OF ENERGY SAVINGS

Assessors have several options for describing the financial impact of their recommended energy improvements. "Payback," still the most widely used measure of value, describes the number of years it takes for the cost of an investment to be recovered through the annual savings that it provides. Many facilities observe a two-year payback hurdle-- in other words, the investment in an energy improvement must pay for itself in two years or less. Some facilities demand an even shorter payback. Despite the existence of more sophisticated measures of financial analysis, the majority of small to mid-sized facilities rely on payback as their primary means for evaluating investment proposals.

Industry's corporate managers are often not impressed by proposed "energy savings." Yet the same results may be enthusiastically received when impacts are related to *key performance indicators* (KPIs) of the client's business operations. This means expressing a reduction in energy use (or cost) per unit, gallon, square foot, day-of-operation, or any unit relevant to a facility's operations (see sidebar).

Outline of a World-Class Energy Assessment

To inspire action, an energy assessment report will need to resonate with the client's key decision-makers. This implies the need for an executive summary that is clearly segmented to address the concerns and goals of several audiences, as follows:

- For a corporate director or top facility manager:

6. The U.S. Department of Energy's BestPractice tools are ideal for this instruction. See <http://www1.eere.energy.gov/industry/bestpractices/resources.html>.

- How does energy—and the decisions regarding its use—impact overall business performance?
 - What are the options for taking action?
 - To what department or departments should tasks be delegated?
 - What information will assure the top manager that energy cost control is underway and sustained? In other words, how can data be converted into usable progress reports?
 - How will efforts to control energy costs require cooperation across departmental lines?
 - What changes or events must take place in the client organization before energy improvements can be realistically pursued?
 - How should the top manager foster and support the cooperation that is needed for the organization to truly control its energy costs?
- For a finance director:
 - What are the costs involved both in using energy and in controlling its waste?

**EXPRESSING THE BUSINESS
IMPACTS OF ENERGY
OPTIMIZATION**

An energy assessment will make more sense to the client's key decision-makers if its potential results are expressed in meaningful terms. Most businesses use a *key performance indicator* (KPI) to evaluate their business performance. A KPI describes financial results per some basic unit of business activity. Examples of these basic activities may be:

- Tons of product. This is typical of factories that produce bulk products by the barge-load or railroad hopper car-load.
- Barrels of product. Petroleum refining products are a good example.
- Thousand square feet of product. Many textile manufacturers use this statistic.
- Cases of product. A beer bottling plant may use this measure.
- Hours of operation. This may be suitable for a retail establishment.
- Heating or cooling degree day.⁷ This indicator is important for hotels, hospitals, offices, and classrooms, and other commercial or institutional buildings.

7. A "heating degree day" is the difference between one day's average temperature reading and the annual average temperature for the same location. This measure accounts for how cold the location is on a given day. Heating degree day measurements allow an analyst to adjust cold-weather energy consumption readings for variations in temperature. A "cooling degree day" represents a similar concept, but applies to summertime energy consumed for air conditioning purposes.

- What accounting metrics will relate energy consumption to financial performance?
- For an operations leader:
 - How can standard operating procedures be amended to minimize wasteful energy practices?
 - How can staff be held accountable for energy-smart behavior?
- For a chief of engineering:
 - What capital improvement proposals offer the most potential improvement to reliability, productivity, and cost control?

ENSURING THE CLIENT'S FOLLOW-THROUGH

All business decisions strike a balance among risk, time and money. This is especially true for energy improvement opportunities. Traditional assessments are limited to discussing the cost and payback for each recommendation. A variation to this approach would be to comment on the time and risks posed by the same improvements. The “time” discussion can cover time requirements for implementation as well as the impact on staff’s time once the improvement becomes a part of daily practice. Risk associated with certain recommendations is another discussion. Clients will want to know the probability of an initiative’s ability to reduce costs, or its potential impact on operational performance or product quality.

Scenarios: A Strategy for Presenting Assessment Recommendations

Scenarios can be used to simplify the way recommendations are presented. Different scenarios may describe the business impacts if all, some, or none of the recommendations are followed. The client should understand the benefits and limitations of each scenario. Perhaps the most important scenario is the one that illustrates the impact of “doing nothing.” For example, a two-year history of the client’s operating income shows business performance without the improvements in place. Instead of developing an energy performance forecast that looks forward (and therefore relies on more guess-work), an analysis can use historical data to “back-cast” performance to more effectively demonstrate the impact of various energy improvements. One scenario may illustrate the selective implementation of only low-cost solutions. Other scenarios may illustrate the effect of pacing improvements over time. Forecasts (or backcasts)

are never perfect at predicting *absolute* results, but they are excellent for *comparing the relative cause-and-effect* of certain energy choices.

Implementation scenarios are an opportunity to bring attention to “critical success factors.” A critical success factor is an organizational feature or attribute that must be in place if the client is to successfully implement an improvement recommendation. Some examples will help to explain:

- **Remove procurement impediments.** Requiring managers to purchase hardware from the lowest of three bidders can result in the use of lower quality equipment that fails more often, and ends up costing more in the long run.
- **Ensure that staff are properly trained.** The projected payback on a new piece of energy-using equipment may not be attained if staff continue to practice wasteful habits.
- **Remove barriers to cooperation across departmental lines.**

OPTIONS FOR ORGANIZING ASSESSMENT RECOMMENDATIONS

Some clients are overwhelmed by the sheer number and variety of energy improvement opportunities—especially when they react to the cost of all recommendations in total. Part of the assessor’s challenge is to break down a list of recommendations into manageable scenarios for implementation. Potential energy improvements can be classified in a number of ways:

- **Type of energy system.** Organize the list into distinct mechanical areas. Isolate opportunities for steam, compressed air, interior space conditioning, etc.
- **Investment impact.** Describe non-capital vs. capital investment, or quick vs. longer payback.
- **Operational impact.** Distinguish between initiatives that (1) apply to current systems and procedures and (2) those that will require capital investments or procedural changes.
- **Time.** Simply organize the list into categories that reflect the impact on people’s time, both from implementation and from operational perspectives.
- **Risk.** Categorize improvements per their relative risk of success or impact on operations.
- **Departmental impact.** Identify the energy-saving activities and investment that might clearly accrue to distinct departments in the client organization. For example, leak repair and prevention may be a duty for the maintenance department, while the assimilation of new technology may be handled by the engineering section.
- **“Make-or-buy.”** Distinguish between improvement activities for the client’s in-house staff versus those that require outside expertise.

Energy improvements probably won't be implemented when one department must pay for it, another must devote labor hours to it, and yet another gets to claim the savings.

A "Living Document"

A traditional energy assessment is a snap shot of conditions that exist at the time of the analysis. A written assessment report is a static description of the client's energy consumption, price of energy, types of fuels used, costs of specific improvement activities, financial payback, and other variables. Few clients implement all assessment recommendations all at once. As time passes, the fuel prices and other variables change, as do the relative values of individual improvement opportunities. The written report should note the "vintage" of the data used at the time of analysis. Because of the movement in these variables over time, it makes sense to provide the client with an electronic spreadsheet version of the analysis that is summarized in the written report. A world-class energy assessment would include a spreadsheet that allows the client to adjust the "model" of their facility's energy performance as energy prices and other variables change over time. Similarly, the client may arrange for the assessor to provide a periodic update of the assessment results.

Documenting Assistance Resources

A valuable energy assessment will describe the local network of energy assistance providers available to the client. State energy offices, utilities, universities, and regional trade associations are the usual providers of assistance services, often at little or no cost. Available assistance might include technical troubleshooting, "how-to" reference materials, training, and project financing or rebates. A for-profit assessor serving a municipal or non-profit agency (one that is not subject to income tax) may claim the utility company rebate, and then lower the client's cost accordingly. For example, a utility might partner with a financial intermediary to establish criteria for loan eligibility, therefore giving clients a fast-track to securing loans. By assembling a list of locally-available services like this, the assessor adds great value to any assessment report.

Maintaining Momentum

Clients will usually complete recommended energy improvements over time, as opposed to all at once. While the client's energy leader may keep abreast of improvements, the top management's attention will probably move elsewhere. A well-prepared assessor will maintain a da-

tabase and calendar for managing client follow-up contacts. A reminder of energy assessment findings can be sent at the start of the client's budget development season. The completion of a major project is worthy of recognition, and a note to that effect can be sent to the client's top management. The note can elaborate on the savings that the project will generate, and how the project brings the client that much closer to capturing all the savings identified in the original assessment. These reminders are an opportunity not just to offer congratulations, but to sustain management support for pursuing additional energy improvements.

THE ROLE OF ENERGY PROCUREMENT STRATEGIES

Energy purchasing strategies are an indispensable component of energy cost control. Providing an analysis of purchasing options should be a natural extension of an energy assessor's practice. At its most basic, purchasing assistance involves helping the client to interpret current energy bills and their related tariff schedules. For facilities that have access to deregulated energy markets, assessors can assist clients in evaluating the variety of purchasing options that are available through energy marketers. Similarly, assessors may be of assistance to clients in developing bids and proposals for energy purchase. Also, many of the independent system operators that manage regional power markets have organized demand response programs. Broadly speaking, these programs allow large power users to profitably shift their electricity consumption to certain times of day. In some jurisdictions, industrial facilities that produce their own electricity can sell their surplus power back to the supply grid.

"Aggregation" activities coordinate a number of energy purchasers into a buyers' consortium. A few state energy organizations and utilities provide aggregation assistance to industries in their regions. Energy assessors need to be aware of these services and refer their clients to them accordingly.

CONCLUSION

As energy market turmoil impacts industry's business performance, more companies are becoming interested in reducing their energy waste. However, energy assessments are not often thought of as the first step in finding solutions. Education is the key to addressing industry's low awareness of energy solutions and to overcoming suspicions about the assessment process.

To a large extent, the results of an energy assessment will depend on the assessor's grasp of the client's needs and expectations. The client may simply express a need to "reduce energy costs" without fully understanding how much reduction is possible, what it takes to achieve the savings, or how the energy improvements will impact other aspects of the business. Some industrial clients know exactly what they want from an energy assessment, while others don't. Different department heads within the client organization may anticipate different energy solutions: procurement directors want lower energy prices, maintenance people may focus on the reliability of energy supply, and engineering staff want to identify new technologies. A good energy assessment will all address these areas and more. The assessor's analysis format and final report can be designed to accommodate the client's expectations.

An energy assessment is only a partial step toward the full implementation of energy improvements. To act on an assessment's recommendations, facility decision-makers will need to invest in new equipment, make changes to certain staff behaviors and procedures, or (most likely) a combination of all these activities. Many individuals in the facility are potentially impacted by recommended energy improvements. The full realization of energy cost control usually requires the support and coordination of several department leaders from within the industrial organization. This decision-making "team" will ideally include representatives from the procurement, finance, operations, maintenance, and engineering departments, acting collectively to approve or reject any of the assessor's recommendations. Very often, it may take only one person's veto to kill a project. Support for energy improvements depends largely on how well these individuals understand and support the assessor's recommendations. Assessors should be prepared to answer the "What's in it for me?" question that is implicit in each decision-maker's evaluation.

Energy consumers don't always have the time to become familiar with incentive programs and services. The success of public-sponsored energy assistance programs may rest on the assessors' efforts to maintain personal contact with key client staff. Periodic communications can announce emerging technologies as well as changes in the utility tariffs that set prices for fuel and power. For example, if a change in tariffs raises the cost of energy, the recommended energy improvements will pay for themselves more quickly through the savings they generate. The assessor can also help the client by measuring the effectiveness of early project implementation. Evidence of savings success will sustain support for future energy projects.

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Chapter 18

Water Conservation

Water usage is on the rise as the population increases. Water resources are becoming increasingly scarce. Many areas are starting to feel the impact, as indicated by the overuse of groundwater and the intrusion of saltwater into many areas. The federal government has addressed these concerns through various conservation mandates. The Energy Policy Act of 1992, the Energy Policy Act of 2005, Executive Order 13423 and Executive Order 13423 require federal agencies to install cost-effective energy and water conservation measures in their facilities. The private sector has also become focused on water conservation measures as the costs for water and sewer services have been steadily increasing. Water conservation and proper water usage management is critical to protecting the environment, ensuring that we have sufficient water available for current and future generations, and for reducing operating costs. The following chart shows how water costs have increased in the United States.

WATER AND SEWER UTILITIES AND RATES

Water and sewer utilities typically use a flat rate or a declining block rate structure. There usually is a minimum charge for each account regardless of the water usage. A typical bill can include the following components:

Customer charge—Each account will have a customer charge associated with it. This is an administration fee and is part of the monthly minimum bill.

Meter charge—based on the size of the line running to the meter; Residential meters typically are 5/8" and commercial or industrial meters 1" to 4" or larger. The larger the water line, the more expensive the meter charge. The meter charge can also be a portion of the minimum monthly bill.

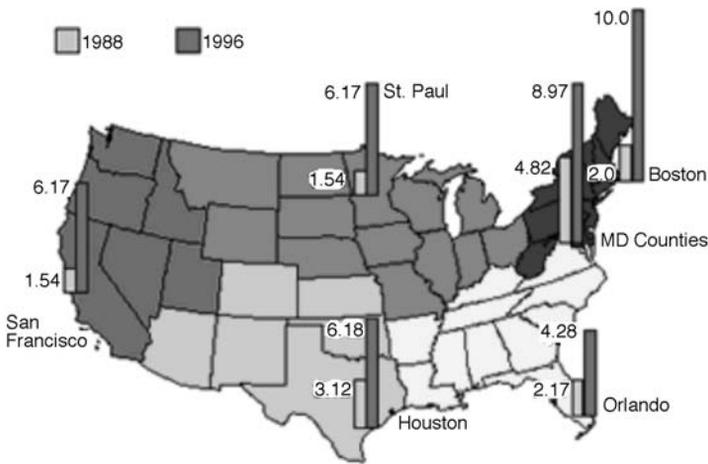


Figure 18-1. Combined Water and Sewer Rates (\$/1000 Gallons)

Source: Federal Energy Management Program

Usage charge—This is the commodity charge. It is typical based on thousands of gallons used per month. Note that the meter may read in cubic feet of water.

Sewer charge—The sewer charge is usually based upon and proportional to the amount of water used by the facility in a month.

Some water utilities have rates that promote conservation. The conservation rates usually are set up as:

- **Increasing Block Rates**—The more you use the more it costs per gallon
- **Summer Peak Demand Charges**—Used to decrease water demand in high usage months

Sample Water Bills

The following two water bills show the basic components—the commodity charge and the service charge. Note that oversizing meters can result in a significant increase in charges.

EXAMPLE #1

General Service – Metered

Quarterly Service Charges:

5/8-inch meter	\$ 13.20	3 -inch meter	\$ 57.00
3/4-inch meter	\$ 13.20	4 -inch meter	\$ 90.00
1-inch meter	\$ 18.00	6 -inch meter	\$ 144.00
1-1/4-inch meter	\$ 24.00	8 -inch meter	\$ 216.00
1-1/2-inch meter	\$ 27.00	10 -inch meter	\$ 300.00
2 -inch meter	\$ 39.00	12-inch meter	\$ 390.00

Plus Volume Charges:

First 50,000 gallons used per quarter	\$2.370 per 1,000 gallons
Next 250,000 gallons used per quarter	\$2.050 per 1,000 gallons
Over 300,000 gallons used per quarter	\$1.650 per 1,000 gallons

Billing

Bills for water service are typically rendered quarterly and become due and payable upon issuance following the period for which service is rendered. A late payment charge of 1 percent per month will be added to bills not paid within 20 days of issuance. This late payment charge will be applied to the total unpaid balance for utility service, including unpaid late payment charges. This late payment charge is applicable to all customers. The utility customer may be given a written notice that the bill is overdue no sooner than 20 days after the bill is issued. Unless payment or satisfactory arrangement for payment is made within the next 10 days, service may be disconnected.

Metering

Volumetric meter readings will be combined for billing if the utility for its own convenience places more than one meter on a single water service lateral. Multiple meters placed for the purpose of identifying water not discharged into the sanitary sewer are not considered for utility convenience and shall not be combined for billing. This requirement does not preclude the utility from combining readings where metering configurations support such an approach. Meter readings from individually metered separate service laterals shall not be combined for billing purposes.

EXAMPLE # 2**Schedule of meter rates***Application:*

To all metered customers, for residential, commercial, industrial or public use residing in all territories.

Volume Charges:

<u>Per Month</u>	<u>Per Quarter</u>	<u>Rate Per 100</u>
Gallons: First 5,000 Gallons	15,000 Gallons	\$ 0.51368
Next 5,000 Gallons	15,000 Gallons	\$0.47581
Next 15,000 Gallons	45,000 Gallons	\$0.45282
Next 50,000 Gallons	150,000 Gallons	\$0.39021
Over 75,000 Gallons	225,000 Gallons	\$0.33681

Customer Service Charges:

<u>Meter Size</u>	<u>Per Month</u>	<u>Per Quarter</u>
5/8"	\$ 8.50	\$ 25.50
3/4"	12.75	38.25
1"	21.25	63.75
1-1/2"	42.50	127.50
2"	68.00	204.00
3"	127.50	382.50
4"	212.50	637.50
6"	425.00	1,275.00
8"	680.00	2,040.00
10"	977.50	2,932.50

EXAMPLE # 3**Schedule of Meter Rates***Application: To all large industrial customers.*

Large Industrial Tariff—All Customers Using 7 Million per Month or 84 Million on an Annual Basis Consumption Charge

Service Charge Per Month

3"	\$127.50
4"	212.50
6"	425.00
All usage per 100 gallons. \$0.2180	

STEPS TO MINIMIZE WATER AND SEWER CHARGES

1. Obtain copies of water and sewer bills for at least one year. Graph the usage and costs by month and review this graph for abnormalities.
2. Familiarize yourself with the rates schedules offered by your utility. Evaluate alternative rates if offered.
3. Meet with your water and sewer utility account manager and determine if you are on the best rate for your facility. The account manager may provide information on financial or technical assistance available to help with facility water planning and implementing water efficiency programs.
4. Separately meter cooling tower and irrigation systems to avoid paying sewer charges if economically feasible.
5. Determine if your water meter is oversized by determining the maximum water flow required. Evaluate water usage and minimum billing to determine if downsizing the water meter is a viable option.
6. If there are many facilities at on location that are separately metered, consider master metering to reduce customer charges. If some facilities need to be individually metered, consider sub-metering.
7. Perform a comprehensive water audit.

WATER AUDITS

A water audit can ensure that water is used efficiently and cost effectively. It is critical to understand where and how much water is used at each facility. A water audit can identify the changes which can be made to reduce water consumption. Economic analysis including simple payback should be performed to determine if these changes are economically viable. The water conservation opportunities determined

by the audit can be used incorporated into a *water management action plan*. Some of the water conservation opportunities identified may be implemented at no or low costs, such as leaking faucets.

Pre-audit Data Gathering

Prior to the audit, the following actions should be taken:

- Obtain copies of water and sewer bills for the facility to be audited for at least one year, preferably two. Graph the usage and costs by month and review this graph for abnormalities. Make a note of the account and water meter number for each facility.
- If you are auditing a building complex, prioritize the order of buildings to be audited; start with the largest water user first, and work towards the smaller users.
- Review plumbing blueprints if available to determine the areas of usage and the location of underground water and sewer lines. Note that blueprints are not always accurate or current.
- Ensure that the people responsible for maintenance and operations are available for the walk-through audit.
- Schedule the audit. Ensure that you have sufficient time allocated to perform the walkthrough. Water audits can take anywhere from one hour for a small facility, to a few days for a large industrial complex.
- Determine the equipment and supplies you will need to do the audit. It is suggested that at a minimum you take a notebook, a digital camera, digital thermometer and flashlight. Check sheets and a small voice recorder can also be helpful, as well as a notebook computer for larger facilities.

Perform a walk-through audit of the facility

The walk-through audit of the facility should identify all major water using processes, verify meter number and location, identify main shut off-valves, and verify operating schedules and occupancy of buildings. Hot water temperatures should be taken. Water-using equipment nameplate data should be obtained in order to evaluate more efficient

equipment options. The following are areas that should be surveyed during a water audit.

- Toilets, sinks, vanity basins, urinals
- Kitchens and restaurants—dishwashers, food and drink preparation, ice makers, wash down hoses
- Laundries – washing machines
- Cooling and heating systems—cooling towers, once through cooling systems, evaporative coolers, boilers/steam generators
- Swimming pools—evaporation, backwash, draining/filling
- Cleaning and sanitization areas—steam sterilizers, autoclaves
- Cleaning—manual washing, vehicle washing
- Process water—water used in production
- Irrigation and outdoor water use—irrigation systems, landscape areas, grass and plant types, soil type

Worksheets for the water audit

The following worksheets can be used in conducting a water audit. They can be modified to meet the auditor's requirements.

Lead Detection Program

A comprehensive water audit should also incorporate a leak detection program. Leak detection is necessary in order to ensure that water is not being wasted. These programs can be performed on a building by building basis, or done on a larger scale, going through the installation's water distribution system. Paybacks can be as fast as a few months for leak correction measures (one leaking faucet can waste up to 1,000 gallons per week). It is recommended that the following be performed as part of a leak detection program:

a) Perform a Leakage Survey

Inspect all water related equipment in the facilities being considered. Check toilets, showers, facets (inside and out), dishwashers, clothes

#1. Building Information – Water Audit

Building Information – Water Audit	
Name of building:	
Address:	
Building contact:	
Phone #:	
Water company:	
Account number:	
Meter number:	
Surveyed by:	
Date of survey:	
Comments:	
Occupancy schedule	
Daily	
Weekends	
Occupants	
Daily	
Weekends	

washers and water heaters. Toilets can be checked for leaks by placing a few drops of dye (food coloring) in the tank and observing the bowl 15 minutes later. Dye in the bowl is an indication of water leakage through the tank plunger seal. Inspect all plumbing joints and connections. Ensure that they do not drip or leak. Check irrigation systems. Be aware of outside ground wet areas that may be caused by a leaking underground water pipe.

b) Check Water Meter

This test is only possible if the building has its own water meter. During non-use hours, ensure that no water is being used in the metered building. Check the meter reading. Prior to the start of the next business day, check the meter again. A difference in the readings could mean a water leak in the facility.

#2 Water and Sewer Usage History Worksheet

Water and Sewer Usage History						
Account number:						
Meter number:						
Facility name:						
Facility location:						
Year:						
Comments:						
Month	Billing days	Water used	Avg. daily use	Water costs	Sewage costs	Total charges
January						
February						
March						
April						
May						
June						
July						
August						
Sept						
October						
November						
December						

c) Initiate a Program for Repairs

After the leaks are detected, it is recommended that a prioritization of repairs be made. A time period should be allocated to ensure that all repairs are completed by a set date. Also, an analysis should be made to determine if leaking equipment should be repaired or replaced. A good leak detection program can provide numerous benefits, such as: significant reduction in O&M costs, and prevention of costly leak-related problems, such as flooding.

Prepare the Water Audit Report

The information used in the walk through and data collection is used to write the audit report. The report should address: metering, utility information and rate analyses, current water usage at the facility, opportunities to reduce water usage, fuel switching for hot water production, simple payback for these water reducing measures, leak detection, and a water management plan.

Commercial—gallons/unit/per day

<i>User</i>	<i>Unit</i>	<i>Range</i>	<i>Typical</i>
Airport	Passenger	4-5	3
Apartment house	Person	100-200	100
Boarding house	Person	25-50	40
Hotel	Guest	40-60	50
	Employee	8-13	10
Lodging house and tourist home	Guest	30-50	40
Motel	Guest	25-40	35
Motel with kitchen	Guest	25-60	40
Laundry (self-service)	Machine	400-650	550
Office	Employee	8-20	15
Public Lavatory	User	3-6	5
Restaurant (including toilet)			
Conventional	Customer	8-10	9
Short-order	Customer	3-8	8
Shopping Center	Parking Space	1-3	8-13
	Employee	2	10
Open Space			
Non-turf	Acre	785	
Turf	Acre	1571	

Recreational—gallons/unit/per day

<i>User</i>	<i>Unit</i>	<i>Range</i>	<i>Typical</i>
Apartment, resort	Person	50-70	60
Bowling alley	Alley	150-250	200
Camp			
Pioneer type	Person	15-30	25
With toilet and bath	Person	35-50	45
Day, with meals	Person	10-20	15
Day, without meals	Person	8-18	13
Trailer	Trailer	75-150	125
Campground	Person	20-40	30
Country Club	Members	80-125	100
	Employee	10-15	50

Dormitory (bunk house)	Person	20-45	35
Fairground	Visitor	1-2	3
Picnic park with flush toilets	Visitor	5-10	6
Swimming Pool and Beach	Customer	5-15	10
	Employee	8-15	10
Visitor center	Visitor	4-8	5

Institutional—gallons/unit/per day

<i>User</i>	<i>Unit</i>	<i>Range</i>	<i>Typical</i>
Assembly hall	Seat	2-4	3
Medical Hospital	Bed	80-150	120
	Employee	5-15	10
Prison	Inmate	80-150	120
	Employee	5-15	10
Rest Home	Resident	5-120	90
	Employee	5-15	10

School, Day

With cafeteria, gym and showers	Student	15-30	25
With cafeteria only	Student	10-20	15
Without cafe and gym	Student	5-15	10
School, Boarding	Student	50-100	75

Conversion Factors

Volume conversion

1 gallon (gal)	=	8.34 pounds
1 cubic foot (ft ³)	=	7.48 gallons
1 unit (Ccf)	=	748 gallons
1 acre-foot (AF)	=	325,851 gallons
1 acre-foot (AF)	=	43,560 cubic feet
1 million gallons/day (MGD)	=	1121 acre feet/year

Metric conversions

1 acre	=	.4 hectares
1 gallon	=	3.8 liters
1 cubic foot	=	0.3 cubic meters

MEASURES TO REDUCE WATER USAGE

In 1992, Congress issued the initial guidelines for flow control in various plumbing products via the Energy Policy Act of 1992. This Act regulated the volume of water that could flow through residential, commercial and industrial plumbing equipment. Manufacturers of these various plumbing products worked to comply with the specific standards. The legislation also sets maximum flow rates for the following classes of products:

- Faucets and shower heads 2.5 gallons per minute (gpm) at 80 psi
- Faucet replacement aerators 2.5 gallons per minute (gpm) at 80 psi
- Pre-rinse spray valves 1.6 gallons per minute (gpm)
- Toilets 1.6 gallons per flush (gpf)
- Urinals 1.0 gallons per flush (gpf)

Manufactures are constantly developing and updating equipment that reduces water consumption. The following list includes some of these products:

Faucets and Shower Heads

The Energy Policy Act of 1992 has mandated that all faucets and shower heads use only 2.5 gallons per minute. The water used during a shower is based on the flow rate and the duration of the shower. The typical duration is 5 minutes per person per day. The actual flow rates for non-conserving shower heads is in the range of 3.4 to 8 gallons per minute, and for low flow models, 1.9 to 2.75 gallons per minute. The user can vary these numbers by adjusting the flow rate. Using these figures as a guide, the average payback for replacing these shower heads is approximately two years, with water and sewer at \$2.00 per 1000 gallon. Note that if the energy required to heat the water is taken into account, the payback will decrease.

Aerators

To maintain steady water pressure, manufacturers added aerators to shower heads and faucets. As the single-most effective water conservation product in use today, aerators can reduce both water consumption and the cost of heating by as much as 50%. It is easy to tell if the faucets in a public washroom are missing the aerators because the water spray is very erratic, and the facility is using more water than is absolutely necessary.

Toilets and Urinals

The initial EPA 1992 limited toilets to 1.6 gpf and urinals to 1.0 gpf. Manufacturers immediately developed low-flow toilets to meet or exceed the requirement. More recently, dual-flush toilets have been promoted as more practical water-saving devices. The dual-flush function provides two separate flush valves: a very low-flow flush for liquid waste and a standard flush for solid waste. The standard flush still meets the EPA requirements. Manufacturers have also developed waterless urinals, which use a cartridge to filter the urine and completely eliminates water flushes.

Dishwashers and Clothes Washers

Older dishwashers and clothes washers should be evaluated economically for both energy savings and water savings. ENERGY STAR has listings of clothes washers that save both energy and water. According to the ENERGY STAR website, qualified clothes washers can save *7,000 gallons of water a year*. Also, each ENERGY STAR qualified commercial dishwasher can save businesses energy approximately 90 MBtus, and an average of \$850/year on their energy bills. In addition, businesses can expect to save more than \$200/year and 52,000 gallons/year due to reduced water usage.

Flow Control Disc

A flow control disc maintains desired sprinkler or spray head output despite changes in supply line pressure. The flow control device consists of a flexible disc which acts as an orifice through which water is emitted. If the operating pressure is below the pressure rating of the device, the disc will remain flat and the flow rate will not be regulated. When the operating pressure is above the pressure rating of the device, the disc flexes outward, reducing the size of the opening and lowering the flow rate.

Sensor Faucets

Sensor faucets only dispense water when required. They use proximity sensors to detect motion using beams of infrared light. A disruption to the beam's path activates the water flow. The installation of sensor faucets in public washrooms has been growing steadily for several years. Manufacturers are making these faucets available for the home bathroom, adding even more cost-effectiveness to home design and construction. Sensor faucets increase water conservation, and improve sanitation.

Foot Pedal Valves

Foot pedals provide hands-free faucet control, allowing the consumer to turn the water on even when hands are full or dirty. They also can prevent water from running continuously in the kitchen or the bathroom. Restaurants, hospitals and hotels across the country are now using them, in addition to other types of commercial establishments. Foot pedals reduce water consumption and conserve the energy needed to heat those wasted water.

Ceramic Cartridges

A ceramic cartridge eliminates leaky faucets and filters the water. Because a dripping tap can waste a lot of water every year, it is important to eliminate the constant drip. The EPA estimates that a ceramic cartridge can save as much as 1,300 gallons of water each year.

Metering Cartridges

A metering cartridge acts like a timer, allowing water to flow when the cartridge is activated, and to shut off automatically at a predetermined rate or after a set time (typically 10 to 15 seconds). Current government regulations allow a maximum of only 0.25 gallons per activation, significantly limiting the volume of wasted water. The installation of metering cartridges virtually eliminates the possibility of leaving the metered faucet running.

Low-flow Pre-rinse Spray Valves

Pre-rinse spray valves are typically used in food service establishments to pre-clean dishes before they enter the wash cycle. These are the most cost-efficient energy saving devices available in the commercial food service market. Much like manufacturers responded to the 1.6 gpf regulations on toilets, they have responded to current regulations for pre-rinse sprayers to maintain water conservation. Replacing old spray valves with a low-flow unit can achieve significant water savings; however, the majority of pre-existing spray valves are not compliant, and industry experts estimate it will take up to 5 years to replace noncompliant sprayers.

WATER RECOVERY MEASURES**Rooftop Rainwater Recovery**

Rooftop recovery systems capture rainwater from the roof and

redirect it to a storage tank. This cache of water can then be used for various purposes throughout the facility, such as flushing toilets, supplying cooling towers, and irrigating the landscape. Note that some states do not allow rooftop recovery.

Air Handler Condensate Recovery

The normal operation of air conditioning equipment in warm, humid climates produces condensate water from the cooling coils. Rather than draining this water into the sewer system, this water can be captured for use in cooling towers and other various applications.

IRRIGATION AND LANDSCAPING

Another place to look for water conservation opportunities is in the areas of irrigation and landscaping. Irrigation can account for up to 50% of the water usage at some facilities. In order to reduce water usage it is recommended that you Some suggestions for irrigation and landscaping water conservation opportunities are:

Xeriscape When Possible

Xeriscaping is the efficient use of water through the appropriate selection of plants that require little water, and attractive landscaping that complements these plants.

Use Turf that Requires Less Water

Types of turf are available that use less water than conventional grasses and are more resistant to drought conditions.

Use Automatic Sprinkler Controls

Use the type of control that monitors rain and ground- moisture content.

Check the Irrigation System Layout

Ensure that water is not wasted because of mismatched sprinkler heads, broken sprinkler heads, poor water distribution, or sprinklers not even hitting the desired areas (i.e. watering a driveway).

Use Subpotable Water for Irrigation

This type of water could be treated wastewater, storm water runoff and cistern water.

Expand Use of Mulching Materials

Mulch can be used to retain moisture in the soil and to reduce the growth of weeds.

Use Proper Maintenance

Limit use of water and fertilizers to the amount needed for healthy plants. Mowing only when the grass reaches 2 to 3 inches in height will make the turf more resistant to drought conditions.

Use Drip Irrigation Systems for New Installations

These systems deliver water directly to the root zone, avoiding evaporation experienced by conventional sprinkler systems.

Evaluate Roof Rainwater Reclamation Systems

Rain water can be collected from the roof and recycled for non-potable irrigation.

COOLING TOWERS

Cooling towers use water in three ways: evaporation, drift, and bleed off (also known as blowdown). Evaporation is influenced by weather conditions—the lower the humidity, the higher the evaporation rate. As the water evaporates, dissolved solids and other material left behind need to be removed. This is done by discharging a percentage of the water continuously (blowdown) and replenishing this with relatively pure make-up water. Drift losses are typically a function of tower design. Most of today's tower designs reduce drift to about 0.05 to 0.2%. Make-up water replaces water lost because of evaporation, drift, and bleed-off. The following should be considered to reduce cooling tower water usage:

Control Blowdown Using Automatic Controls

Use automated controls such as a conductivity controller. You can also improve on this method by operating the bleed-off on a more continuous basis, maintaining the conductivity of the tower closer to its limits.

Ensure Drift Eliminators are Installed and Functioning Properly

Drift eliminators are used to reduce the amount of water removed from the system because of wind.

Establish an Effective Scale, Corrosion and Bio-fouling Protection Plan

Work with the heat exchanger manufacturer and your tower chemical treatment vendor to develop the proper program. A clean tower uses water more efficiently.

Ensure Cooling Towers are Appropriately Sized for the Cooling Load

Many sites have two towers that when combined, make up the peak load for the building. When the demand is reduced, one tower can be shut down. This enables the system to operate at a higher overall energy efficiency when using a single large tower and operating it at half load during low demand periods.

Use Two-speed or Variable Frequency Drives on Tower Fans

These devices match air requirements to load more effectively and reduce the overall energy consumption of a tower as well as reducing water use.

Use an Automatic Shutoff Control

Shut off the cooling tower during unoccupied periods such as nights or weekend hours, or to operate it concurrently with chillers.

Submeter Make-up Water

The use of submeters allows the operator to monitor the volume of water being used in the tower and can eliminate sewer charges.

EPA WaterSense PROGRAM

WaterSense, a partnership program sponsored by the U.S. Environmental Protection Agency (EPA), makes it easier to save water and protect the environment. Its mission is to protect the future of our nation's water supply by promoting and enhancing the market for water-efficient products and services. The EPA has developed water saving criteria, and has applied these criteria to products. Products meeting or exceeding these standards receive the WaterSense label. To learn about WaterSense labeled products, saving water, and how businesses and organizations can partner with WaterSense, visit the EPA WaterSense website at:

<http://www.epa.gov/watersense/>

WaterSense shows products that meet their conservation standards—these products include:

- Sink fixtures
- High efficiency toilets
- Landscape irrigation services
- Shower heads
- Urinals
- Weather/sensor based irrigation control technologies

WATER MANAGEMENT PLAN

A comprehensive water management plan should be developed to ensure that water is being used efficiently, and to determine progress in reducing overall water usage. In order to create a proper facility water management plan, it is important to include the following sections:

- Water accounting
- Utilities
- Water conservation measures performed
- Water conservation opportunities
- Progress towards goals
- Future action items

1. **Water Accounting**

The water accounting section should document water and sewer usage for each account for the prior twelve month period. Graphs of monthly water usage, sewer usage and costs for each facility should be plotted. A baseline water usage should be determined for evaluating water conservation progress.

2. **Utilities**

This section should list water utility contacts with phone numbers for future reference and contact information for the agency or office that pays the water/sewer bills. Water rate analysis for each facility should be included with recommendations for changes if beneficial. Also included should be information on financial or technical assistance available from the utilities to help with facility water planning and implementing water efficiency programs.

3. Water Conservation Measures Performed

This section should show the water conservation measures and activities that have been done to date, or that are in progress. The water usage can be compared to the baseline in order to evaluate water conservation progress.

4. Water Conservation Opportunities

This information can be taken from the water audit and should include at a minimum a description of the water saving measure, capital costs and simple payback. These measures can then be prioritized according to the company criteria. In some cases a life cycle costing analysis may be performed to determine a more detailed cost/benefit of a project.

5. Progress Towards Goals

This section should compare the baseline data to the current year in order to ascertain the effectiveness of the water conservation program. This information may also be required for reporting purposes.

6. Future Action Items

This section will help in allocating money and resources for future conservation activities.

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Glossary

Absorption Chiller—A refrigeration machine which uses heat as the power input to generate chilled water.

Actual Demand—The amount of kW demand registered on the electric meter during the billing cycle.

AFUE—Annual Fuel Utilization Efficiency.

Air Handling Unit (AHU)—Draws return air from the conditioned space, mixes it with outside air, filters it, adds or withdraws heat, and returns it to the conditioned space. Normally comprised of a fan, cooling/heating coils, and filters.

Ambient Temperature—Normally the temperature outside or the temperature of air surrounding a building. Also refers to the temperature of the immediate surrounding environment of a device.

Ancillary—Miscellaneous energy consuming equipment.

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

Atmospheric Burner—A burner in combustion furnaces or boilers that works on atmospheric pressure only, unassisted by induction or forced draft fans.

Average Occupancy—The average number of people in a building or area over a 24-hour period.

Balance Point Temperature—The outside temperature when no heating or cooling is required (thermally neutral). The point at which the internal heat gains of a building from lighting, people, machines, etc. equals the losses through walls, roof, and windows.

Ballast—A device used with fluorescent and HID lamps to obtain the necessary starting and operating circuit conditions by modifying the incoming voltage and current.

Base Load—Energy requirements of a facility that are unaffected by weather. The minimum amount of electricity or natural gas delivered or required over a given period of time at a steady rate.

Baseline—Energy consumption or costs for a specified time period to which future usage or costs are compared.

Billing Cycle—The regular periodic interval used by a utility for reading the meters of customers for billing purposes.

- Block Rate Schedule**—Rate schedule that provides different unit charges for various blocks of demand or energy.
- Blowdown**—Discharge of water from a boiler or cooling tower sump to control level of dissolved solids. May be continuous or cyclic.
- Boiler Capacity**—Rate of heat output in Btu/h measured at the boiler outlet at the design pressure and/or temperature.
- Boiler Economizer**—The term “economizer” is sometimes applied to a boiler device that recovers heat from the exhaust stack to preheat the feedwater.
- Btu**—British thermal unit. A standard unit for measuring the quantity of heat energy equal to the quantity of heat required to raise the temperature of 1 pound of water by 1 Fahrenheit (from 59°F to 60°F) at sea level.
- Btu/h**—British thermal units per hour. Many aspects of a building, heat load calculations, and HVAC systems are expressed in terms of how many Btus are transferred in a one hour period.
- Building Envelope**—The external surfaces of a building including the roof, walls, windows, floor, which separate the conditioned space from the external ambient environment.
- Capacitor**—Electrical appliance working on the condenser principle. Two conducting plates are separated by an insulating layer. When alternating current is applied, the capacitor is adjusted so that its leading current balances the lag of the circuit giving a high-power factor.
- Capital Cost**—The total investment needed to complete a project and bring it to a operable status.
- CDD (Cooling Degree Day)**—The difference of the mean daily temperature above a base temperature of 65°F.
- Celsius (C)**—A thermometric scale in which the melting point of ice is zero and the boiling point of water is 100° above zero ($^{\circ}\text{C} = [^{\circ}\text{F} - 32] \div 5/9$).
- CFM (Cubic feet per minute)**—A measurement of a volume of air movement over time.
- Chiller**—A central plant refrigeration device that produces chilled water for use in cooling coils.
- Cogeneration**—Generating electricity using a waste heat fuel source (full or partial) which comes from another industrial process.
- Coil**—A cooling or heating element made of pipe or tubing.
- Color Rendering Index (CRI)**—A measure of the degree of color shift objects undergo when illuminated by a light source as compared

- with the color of those same objects when illuminate by a reference source comparable color temperature. Based on a scale of 100.
- Combustion Efficiency**—Ratio of heat obtained from the combustion of a fuel to the theoretical heat content of the fuel.
- Commercial Sector**—The commercial sector is generally defined as nonmanufacturing business establishments, including hotels, restaurants, wholesale businesses, retail stores, and health, social, and educational institutions.
- Conduction**—Heat transfer or transmission through a solid.
- Convection**—Heat transfer by the motion of a fluid or gas, usually air.
- Cooling Tower**—The condensing unit of a central chiller plant which uses evaporation and air movement to provide cooling.
- COP (Coefficient of Performance)**—Ratio of heat produced (including circulating fan heat but not supplemental or backup heat) divided by the total electric energy input (Btus) including condenser fan and defrost.
- Condensate**—Liquid water after it had condensed from vapor.
- Condenser**—The outdoor coil of a cooling system which condenses the refrigerant back into a liquid.
- Damper**—A device used to vary the volume of air passing through and air outlet, inlet, or duct.
- Daylighting**—Using natural light through windows and skylights. Ideally used in conjunction with dimming controls to reduce amount of electrical light input to maintain constant lighting levels.
- DDC (Direct Digital Control)**—Usually refers to a computer based control system that can evaluate several conditions and provide a more complex response than a simple solid-state control. It is often referred to as a “distributed control unit” of a larger computerized system to provide localized control independently of the main data storage and analysis system.
- Deadband**—In a thermostat, the difference in degrees between the point where heating shuts off and the cooling mode comes on.
- Degree Days**—The difference between the average daily temperature (°F) and a standard temperature of 65°F. Degree days are used to indicate patterns of deviation from a given temperature standard. Average daily temperatures above 65°F are cooling degree days and average daily temperatures below 65°F are heating degree days.
- Dekatherm**—The quantity of heat energy which is equivalent to one million (1,000,000) Btus.

- Demand**—The rate of electrical usage over a specified period of time, usually 15 or 30 minutes. Measured in kilowatts (kW).
- Demand Limiting**—A technique to reduce demand by measuring incoming electrical power and turning off specified loads to keep the rate of electrical usage under a preset level.
- District Heating**—A system that involves the central production of hot water, steam, or chilled water and the distribution of these transfer media to heat or cool buildings. Steam or hot water from an outside source used as an energy source in a building. The steam or hot water is produced in a central plant and piped into the building. The district heat may be purchased from a utility or provided by a physical plant in a separate building that is part of the same facility, such as a hospital complex or university.
- Duty Cycling**—A method of reducing peak demand and energy consumption by cycling motors in a lead/lag fashion. It can reduce accumulated run times but may impact equipment life and maintenance by frequent starts.
- DX (Direct Expansion)**—Refers to cooling systems that use a refrigerant coil directly in the air stream to transfer energy.
- EAHR (Exhaust Air Heat Recovery)**—A system designed to recover energy from an exhaust air stream and utilize the energy for another purpose such as preheating ventilation air or domestic hot water.
- ECM (Energy Conservation Measure)**—A building modification or equipment change to reduce energy consumption. Usually refers to a capital improvement project with a payback longer than one or two years.
- Economizer Cycle**—A method of operating a ventilation system to reduce refrigeration load. Whenever the outdoor air conditions are more favorable (lower heat content) than return air conditions, outdoor air quantity is increased to provide “free” cooling.
- ECO (Energy Conservation Opportunity)**—Usually refers to opportunity to save energy through implementation of and operation and maintenance O&M measure or installation of an energy conservation measure (ECM).
- EMCS (Energy Management Control System)**—Some type of computer based control system whose primary function is the control of energy using equipment to reduce the amount of energy consumed.
- Efficacy**—The luminous efficiency of a lamp expressed as the ratio of total lumens produced to the watts consumed.
- Efficiency**—The ratio of the useful energy (at the point of use) to the

- thermal energy input for a designated time period, expressed in percent.
- Emissions**—Waste substances released into the air or water.
- End-use Sectors**—The residential, commercial, industrial, and transportation sectors of the economy.
- Energy**—The capacity for doing work as measured by the capability of doing work (potential energy) or the conversion of this capability to motion (kinetic energy). Energy has several forms, some of which are easily convertible and can be changed to another form useful for work. Most of the world's convertible energy comes from fossil fuels that are burned to produce heat that is then used as a transfer medium to mechanical or other means in order to accomplish tasks. Electrical energy is usually measured in kilowatt-hours, while heat energy is usually measured in Btus.
- Energy Accounting**—A formal process of providing long term organization and monitoring of utility costs and consumption data for a facility.
- Energy Audit**—An assessment of the energy flows in a building or process, usually with a view to identify opportunities to reduce consumption.
- Energy Balance**—The accounting of energy inputs and outputs in any process.
- Energy Charge**—That portion of the charge for electric service based upon the electric energy (kWh) consumed or billed.
- Energy Consumption**—The use of energy as a source of heat or power or as an input in the manufacturing process.
- Energy Content**—The intrinsic energy of a substance, whether as gas, liquid, or solid, in an environment of given pressure and temperature.
- Energy Use Index**—A representation of annual energy usage per square foot of a facility. May appear in any basic or common unit such as Btu, kWh, or therms per square foot per year.
- ESCO (Energy Service Company)**—A company that offers to reduce a client's energy consumption with the cost savings being split with the company to pay for installation costs of energy conservation measures.
- Evaporator**—A heat exchanger which adds heat to a liquid changing it to a gaseous state. In a refrigeration system, it is the component which absorbs heat.
- Excess Air**—Air which passes through an appliance and the appliance

flues in excess of that which is required for complete combustion of the gas. Usually expressed as a percentage of the air required for complete combustion of the gas.

Exfiltration—Air leakage out of the building.

Exhaust Air—Air removed from the conditioned space to the outdoors by a dedicated exhaust fan or by the ventilation system.

Fahrenheit—A thermometric scale in which the melting point of ice is 32° above zero and the boiling point of water is 212° above zero ($^{\circ}\text{F} = 9/5 \text{ }^{\circ}\text{C} + 32$).

Firm Service—Gas of electric service offered to customers under schedules or contracts which anticipate no interruptions, even under adverse conditions.

Fixture—A complete lighting unit, or luminaire, consisting of one or more lamps, ballast if needed, and elements necessary to position and protect lamps, distribute light, and connect to a power supply.

Flue—The exhaust stack of a combustion boiler or other combustion. A device to convey products of combustion to the outside.

Fluorescent Lamp—Low-pressure electric discharge lamp in which a phosphor coating transforms some of the ultraviolet energy generated by the discharge into light.

Foot-candle—Measure of luminance or light. The illumination of one lumen uniformly distributed on a one foot square surface.

Forced Draft—A fan on the intake side of a combustion furnace or boiler burner that forces combustion air into the burner.

Generator—A machine that converts mechanical energy into electrical energy.

Glare—Any excessive brightness from a direct or reflected source that annoys, distracts, or reduces visibility.

HDD (Heating Degree Day)—The difference of the mean daily temperature below a base temperature of 65°F. A relative measure of how weather imposes a heating load on a building which assumes that the building will not require heating until the outdoor temperature drops below 65°F.

Heat Pump—A DX cooling system that can operate in the reverse mode and be used as a heating unit as well as a cooling unit.

HID (High Intensity Discharge)—High intensity discharge lighting including mercury vapor, metal halide, and high pressure sodium light sources. Light is produced by a high pressure gas discharge at high temperatures requiring protective sealed arc tubes.

Horsepower (HP)—A unit of power where 1 horsepower equals 746

watts or 42.4 Btu per minute.

HVAC (Heating, Ventilation, and Air-Conditioning)—A system that provides the process of comfort heating, ventilating, and/or air conditioning within a building.

Hydronic System—A heating and/or cooling system that uses a liquid, usually water, as the medium for heat transfer.

IES—Illuminating Engineering Society

Illuminance—Lighting level measured in foot-candles or lux on a working surface such as a desktop or floor.

Induced Draft—A fan on the flue side of the burner which draws combustion air into the combustion chamber through negative air pressure.

Industrial Sector—The industrial sector is generally defined as manufacturers who are primarily engaged in a process which creates or changes raw or unfinished materials into another form or product.

Infiltration—The process by which outdoor air leaks into a building through cracks and holes in the building envelope.

Inlet Vanes—Damper vanes located at the intake of a fan to reduce the total air flow (CFM) the fan will produce.

Interruptible Service—Low priority service offered to customers under schedules or contracts which anticipate and permit interruption on short notice, generally in peak-load seasons, by reason of the claim of firm service customers and higher priority users. Gas is available at any time of the year if the supply is sufficient and the supply system is adequate.

kVa (Kilovolt-ampere)—The unit used to express apparent power. It is a measure of the total electrical power capacity of a distribution system or component equipment. In addition to Watts, it includes the contributions of VARs and harmonic currents from equipment that is not resistive such as motors, computers, and most non-incandescent lighting.

KVAR (Kilovolt Amperes Reactive)—The unit used to express reactive power. VARs are the reactive component of VA (Apparent Power), caused by a phase shift between AC current and voltage in inductors (coils) and capacitors. In inductors, current lags voltage (in time), while in capacitors, current leads voltage. VARs are typically first present in a distribution system as a result of inductive loads such as motors, reactors and transformers. VARs are then used in sizing power factor correction capacitors, which are used to offset the effects of these inductive loads.

- kW (kilowatt)**—Active power, also known as Real/True Power. Watts measure that portion of electrical power which does work. Kilo is from the metric system and means 1,000.
- kWh (kilowatt hour)**—A unit of electrical energy equivalent of 1000 watts of power provided for one hour. One kWh equals 3,413 Btus.
- Lamp**—A light source, commonly called a bulb or tube.
- Latent Heat**—The amount of energy required to cause a liquid to change its physical state to a vapor. When a vapor condenses back into a liquid, it releases the same amount of energy without any change in temperature.
- Life Cycle Cost**—The cost of owning, operating, and maintaining a piece of equipment over its entire useful life.
- Lighting Power Budget**—The total amount of power that may be utilized by a lighting system in a given space or building.
- Load**—The amount of demand or required energy to satisfy the need of any system.
- Load Factor**—The relationship between the peak rate of consumption to the total consumption for the period. For electricity, it is the relationship between kWh and kW demand. The ideal load factor is as close to 1.00 as possible.
- Load Shedding**—The process of turning off electrical loads under specified conditions, primarily to reduce demand.
- Luminaire**—See fixture
- Lumen**—A measure of the quantity of light produced by a light source.
- Make-up Air**—Outdoor air supplied to a building to compensate for air exhausted from the building.
- Make-up Water**—Water supplied to a system to replace water lost by blowdown, leakage, and evaporation.
- vMcf**—One thousand cubic feet.
- Mixed Air**—Mixture of return air and outside air before it has been conditioned.
- MMBtu**—Typically used to represent one million British Thermal Units.
- Nameplate Rating**—The full-load continuous rating of a piece of equipment under specified conditions as designated by the manufacturer, and written on the nameplate.
- Night Cycle**—Also referred to as the unoccupied cycle. A unique cycle of an HVAC control system that distinguishes between occupied and unoccupied operation. A common night cycle mode may include closing of outside air dampers, lowering of space temperatures, and reduced fan operation.

- Night Setback**—A different setpoint during the night or unoccupied periods.
- O&Ms (Operation and Maintenance Measures)**—Low cost or no cost energy efficiency opportunities involving changes in the operation and maintenance practices taken to improve equipment or building efficiency.
- Occupied Hours**—The time when a commercial, industrial, or institutional building is normally occupied by people functioning in their jobs.
- Off-peak**—Generally refers to designated periods of relatively low system demand. NERC has defined these periods as 10 p.m. until 6 a.m., Monday through Saturday and all day Sunday.
- On-peak**—The time of day and week when demand for electricity in a region is high.
- Outside Air**—Air taken from the outdoors and therefore not previously circulated through the HVAC system.
- Payback Period**—The length of time necessary to recover the initial investment of a project through energy or maintenance savings.
- Peak Load or Peak Demand**—The electric load that corresponds to a maximum level of electric demand in a specified time period.
- Plenum**—A large duct or area above a dropped ceiling used to distribute conditioned air or collect return air from a conditioned space.
- Power**—The rate at which energy is transferred. Electrical energy is usually measured in watts. Also used for a measurement of capacity.
- Power Factor**—The ratio of real power to apparent power. Devices that need an electromagnetic field to operate, such as motors and fluorescent lighting ballasts, tend to lower the power factor within a facility. Many utilities impose cost penalties for low power factor. Low power factors can be corrected by installing power capacitors or by other measures.
- Predictive Maintenance**—Using historical maintenance and breakdown information to forecast or predict when a particular piece of equipment will need to be rebuilt or replaced.
- Present Value**—The present worth of a dollar saved or spent at a determined point of time in the future. This concept reflects the time value of money.
- Preventive Maintenance (PM)**—A system of prescheduling adjustment, cleaning, calibration, lubrication, component replacement, repairs or whatever is necessary to eliminate minor equipment problems before they become major.

- Radiation**—The transfer of heat from one body to another by heat waves without heating the air between the bodies.
- Ratchet Clause**—A clause in the rate schedule of some electric utilities that bases a customer's demand charges on a specified percentage of the highest kW Demand usage during the proceeding eleven months.
- Rate Schedule**—The rates and conditions set by the utility for the use of electricity and natural gas.
- Reactive Power**—Power used by induction motors and transformers to excite magnetic fields. Measured in kVARs (kilovolt amperes reactive).
- Real-time Pricing**—The pricing of electricity based on the actual (as opposed to forecast) prices which fluctuate many times a day and are weather-sensitive, rather than varying with a fixed schedule (such as time-of-use pricing).
- Reheat**—The application of sensible heat to supply air that has been previously cooled below the temperature of the conditioned space by mechanical refrigeration or the introduction of outdoor air to provide cooling or ventilation.
- Remedial Maintenance**—Troubleshooting or making repairs as breakdowns occur.
- Residential Sector**—The residential sector is defined as private household establishments that consume energy primarily for space heating, water heating, air conditioning, lighting, refrigeration, cooking, and clothes drying. Apartment houses are also included.
- Retrofit**—The addition or replacement of equipment or alteration of an existing building to make it more energy efficient.
- Return Air**—Air that is drawn back into the ventilation system from the conditioned space.
- R-Value**—Term used to measure a given thickness of an insulating material's resistance to the flow of heat.
- Seasonal Loads**—Energy loads that vary seasonally due to such factors as changes in weather, operation, or other seasonal occupancy variations.
- Sensible Heat**—The heat which, when added or subtracted, causes a temperature change.
- Simple Payback**—The length of time required for an investment to pay for itself determined by dividing the initial investment by the annual savings.
- Supply Air**—Conditioned air going to a conditioned space. The end product of the HVAC system.

- Tariff**—A document, approved by the responsible regulatory agency, listing the terms and conditions, including a schedule of prices, under which utility services will be provided.
- Task Lighting**—Lighting directed to a specific surface or area used for performing individual tasks.
- Therm**—A unit of energy content equal to 100,000 Btus. Used primarily for natural gas.
- Time-of-use (TOU) Rates**—The pricing of electricity based on the estimated cost of electricity during a particular time block. Time-of-Use rates are usually divided into three or four time blocks per 24-hour period (on-peak, mid-peak, off-peak and, sometimes, super off-peak) and by seasons of the year (summer and winter).
- Thermostat**—A temperature sensitive device that turns heating and cooling equipment on and off at a set temperature.
- Time-of-day Metering**—A method of measuring and recording a customer's use of electricity by the time of day it was consumed. Generally used to establish maximum demand for specified periods of time for on-peak and off-peak energy charges.
- Tons of Cooling**—A way of expressing cooling capacity or how much heat the equipment can remove from the air. One ton of cooling equals 12,000 Btuh.
- U-Value**—The thermal transmittance or overall coefficient of heat transmission expressed in Btus per square foot per hour per degree F. The lower the U-value, the less heat is transferred.
- Unoccupied Hours**—The time when a commercial, industrial, or institutional building is normally empty of people, except for a few attendants or maintenance personnel.
- Useful Life**—That period of time for which a modification used under specific conditions is able to fulfill its intended function and which does not exceed the period of remaining use of the building being modified.
- Ventilation**—Usually refers to the introduction of outdoor air into a building to replace exhaust air and air exfiltration.—Changing the air in an enclosed space by removing the existing air and replacing it with air introduced from another environment, usually the outdoors.
- VAV (Variable Air Volume)**—Air flow is varied to match the heating or cooling loads.
- Visual Task**—Those details and objects which must be seen for the performance of a given activity, including the immediate background

of details or objects.

Visible Spectrum—The range of light waves detectable by human eyes.

Watt—A unit of power which is the level of energy either produced or used. The rate of energy transfer equivalent to 1 ampere flowing under a pressure of 1 volt at unity power factor. One watt equals 3.413 Btus.

Work Plane—Plane at which work is usually performed and at which illumination is specified and measured. Unless otherwise indicated, the work plane is assumed to be a horizontal plane 30 inches above the floor.

Zone—A space or group of spaces within a building with heating and/or cooling requirements sufficiently similar so that comfort conditions can be maintained throughout by a single controlling device.

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