HANDBOOK OF Energy Audits

9TH EDITION

Albert Thumann, P.E., C.E.M.
Terry Niehus, P.E., C.E.M.
William J. Younger, C.E.M.

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Preface

When the first edition of *Handbook of Energy Audits* was published in 1980, the field of energy auditing was in its infancy. More than 30 years since its publication, *Handbook of Energy Audits* has served as a reference to the thousands of energy auditors who are evaluating the performance of buildings. This book also serves as a reference text for the Certified Energy Auditor (CEA) examination developed by the Association of Energy Engineers.

The objectives of the Certified Energy Auditor program are:

To raise the professional standards of those engaged in energy auditing.

To improve the practice of energy auditors by encouraging energy auditing professionals in a continuing education program.

To identify persons with exceptional knowledge of the principles and practices of energy auditing through completing an examination an 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.

Increased awareness is bringing about a demand for energy audits. For example, the Better Buildings Initiative has set a target of improving energy efficiency in commercial buildings by 20 percent by 2020. As companies seek LEED certification for existing buildings, energy auditing plays a crucial role. In addition, cities such as New York are mandating energy audits of buildings.

The edition has been completely revised and includes important chapters on retro-commissioning and investment grade energy audits. The 9th is more important than any previous edition.

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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 of determining the types and costs of energy use in the building, evaluating where a building or plant uses energy, and identifying 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 four basic types or levels of energy audit, any of which may meet your requirements.

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

Type 0—The Benchmarking Audit

This audit includes performing a detailed preliminary analysis of energy use and costs, and determining benchmark indices like Btu per square foot per year and dollars of energy cost per square foot per year, based on utility bills. Very cost effective for multiple facilities. The EPA/DOE EnergyStar Portfolio Manager is one of the best and easiest tools to use—and it is free.

Type 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 averages 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.

Type 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.

Type 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.

ASHRAE DEFINITIONS OF ENERGY AUDITS

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

ASHRAE has formalized a set of energy audit definitions that are widely used by energy auditors. The source of the following definitions is the 2005 ASHRAE Handbook of HVAC Systems.

> "**Preliminary Energy Use Analysis.** This involves analysis of historic utility use and cost and development of the energy utilization index (EUI) of the building. Compare the building's EUI to similar buildings to determine if further engineering study and analysis are likely to produce significant energy savings."

We have also identified this as a Benchmark Audit.

> "**Level I: Walk-Through Analysis.** This assesses a building's current energy cost and efficiency by analyzing energy bills and briefly surveying the building. The auditor should be accompanied by the building operator. Level I analysis identifies low-cost/no-cost measures and capital improvements that merit further consideration, along with an initial estimate of costs and savings. The level of detail depends on the experience of the auditor and the client's specifications. The Level I audit is most applicable when there is some doubt about the energy savings potential of a building, or when an owner wishes to establish which buildings in a portfolio have the greatest potential savings. The results can be used to develop a priority list for a Level II or III audit."

- 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: Energy Survey and Analysis**. This includes a more detailed building survey and energy analysis, including a breakdown of energy use in the building, a savings and cost analysis of all practical measures

that meet the owner's constraints, and a discussion of any effect on operation and maintenance procedures. It also lists potential capital-intensive improvements that require more thorough data collection and analysis, along with an initial judgment of potential costs and savings. This level of analysis is adequate for most buildings."

- 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: Detailed Analysis of Capital-Intensive Modifications. This focuses on potential capital-intensive projects identified during Level II and involves more detailed field data gathering and engineering analysis. It provides detailed project cost and savings information with a level of confidence high enough for major capital investment decisions.

The levels of energy audits do not have sharp boundaries. They are general categories for identifying the type of information that can be expected and an indication of the level of confidence in the results. In a complete energy management program, Level II audits should be performed on all facilities.

A thorough systems approach produces the best results. This approach has been described as starting at the end rather than at the beginning. For example, consider a factory with steam boilers in constant operation. An expedient (and often cost-effective) approach is to measure the combustion efficiency of each boiler and to improve boiler efficiency. Beginning at the end requires finding all or most of the end uses of steam in the plant, which could reveal considerable waste by venting to the atmosphere, defective steam traps, uninsulated lines, and lines through unused heat exchangers. Eliminating end-use waste can produce greater savings than improving boiler efficiency.

A detailed process for conducting audits is outlined in ASHRAE (2004)."

- 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.

- Although not defined by ASHRAE as an Investment Grade Audit, it is often called this by many energy auditors.

- This analysis digs into the details of any large capital projects you may be considering as a result of previous, simpler audits. AEE, as well as many others, requires computer simulation to be part of an investment grade audit.

- 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 INVESTMENT GRADE ENERGY AUDIT

In most facilities, companies, and other corporate settings, upgrades to a facility's energy infrastructure must compete for capital funding with non-energy-related investments. Both energy and non-energy investments are commonly rated on a standard set of financial criteria that generally stress the expected return on investment (ROI) and often the life cycle costs. The projected operating savings from the implementation of energy projects must be developed such that they provide a high level of confidence. In fact, investors often demand guaranteed savings. The investment-grade audit expands on the detailed audit Levels II and III above, and relies on complete engineering studies in order to detail technical and economic issues necessary to justify the investment related to the transformations. In most cases, detailed hour-by-hour computer simulation modeling will be required.

The formal AEE description of the investment grade energy audit is:

Investment Grade Audit

- This audit includes weighing financial risk into the economic calculations of a type II or III energy audit.
- It will often include computer simulation and enhanced financial analysis tools such as life cycle costing. Additional requirements may be specified by individual clients.
- This audit can be utilized to obtain funding for the projects identified.

The Association of Energy Engineers has developed three certification programs for professionals practicing energy auditing: The Certified Energy Auditor (CEA) Program, The Master's Level CEA Certification Program, and the Certified Energy Manager (CEM) Program.

THE CERTIFIED ENERGY AUDITOR (CEA) PROGRAM FOR PROFESSIONAL CERTIFICATION

cea CERTIFIED ENERGY AUDITOR

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

CEM®

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 Master's Level Certified Energy Auditor (CEAM) Program

New for 2012 and developed with grant funding from the US Department of Energy, the Master's Level Certified Energy Auditor (MCEA) certification is designed to reach beyond the typical equipment replacements and develop a plan which considers additional areas of energy such as indoor air quality, code compliance, operation and maintenance, risk mitigation, commissioning, and investment grade details.

Objectives

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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

The first step in any energy audit should be to collect energy bills and perform a benchmark audit. Once you have established the level of actual 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.

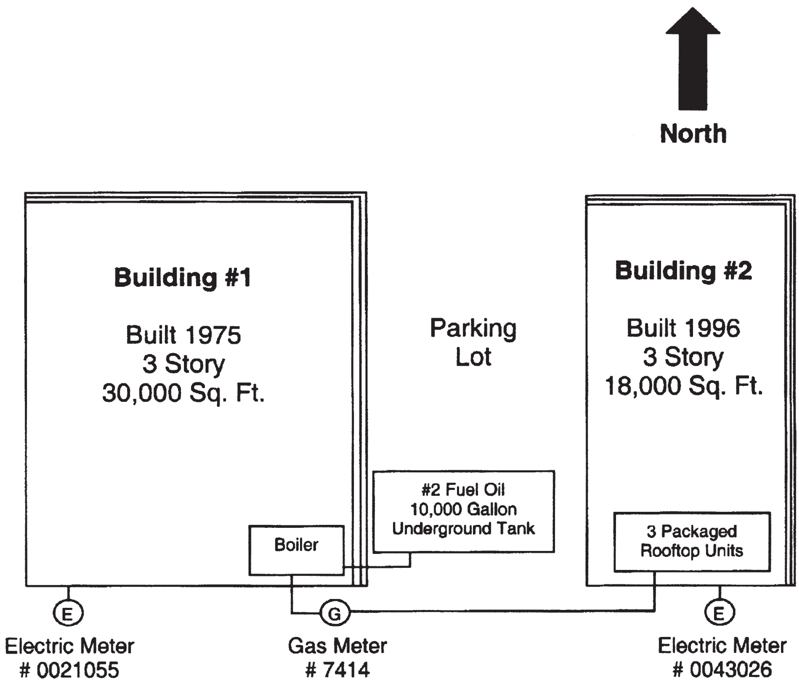
PRE-SITE WORK

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 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 one to 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



Site Sketch

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 of conditioned space 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 US Department of Energy, EnergyStar, 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.

A great, free resource is available from EnergyStar. The Portfolio Manager is an easy-to-use, free benchmarking program available from EnergyStar.gov. This process is called a benchmark audit.

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

—Binoculars

—Mini Data Loggers

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.

- Take basic measurements of light levels, temperature, relative humidity, and voltages.

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, basic measurements, 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 uses and costs, identify 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 function, 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 one to 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 electricity and 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. For electricity, include data on both energy use and peak demand.

Of increasing importance is examining the use of water and sewer in facilities. Reducing the use of water and sewer is a requirement for many facilities including federal facilities.

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, rate of return, and 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 electricity and each fuel, quantify those energy streams into discrete functions, evaluate the efficiency of each of those functions, and identify energy and cost savings opportunities. For electricity, account for both electrical energy and electrical peak demand.

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. Verify meter multipliers 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 Btu/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 Btu and then dividing by the gross square footage (conditioned space only) 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.

Use the EnergyStar Portfolio Manager to help you do this. It's free.

CONDITIONED AREA

To calculate Btu 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: ______________________________ Electric Meter # ____________ Electric Rate Schedule: ____________
Gas Utility: ______________________________ Gas Meter #____________ Gas Rate Schedule: ____________
Gross Square Footage: ______________________________

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 $\frac{kWh}{kW \times Days \times 24}$	Gas Usage Therms	Gas Cost $	Gas Unit Cost $/Therm	Gas MMBtu Therms/× .10	(A) MMBtu Consumed	(B) Cost of Energy	(C) EUI 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.

Btu/Square Foot/Year = Column A total × 1,000,000/Building Sq. Ft.

G. Calculate Dollars per Square Foot by dividing the total cost of energy (Column B) by the Building Square Footage.

Dollars/Square Foot/Year = Column B total / Building Sq.Ft.

Figure 2-1. Sample Energy Accounting Form

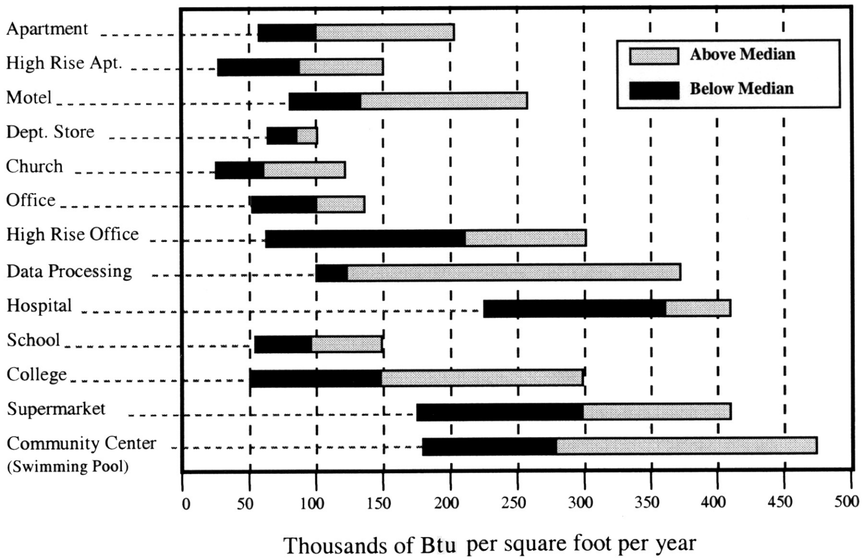


Figure 2-2. Energy Use Index by Building Type

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 (metered) demand on the utility bill. Actual demand is the figure registered

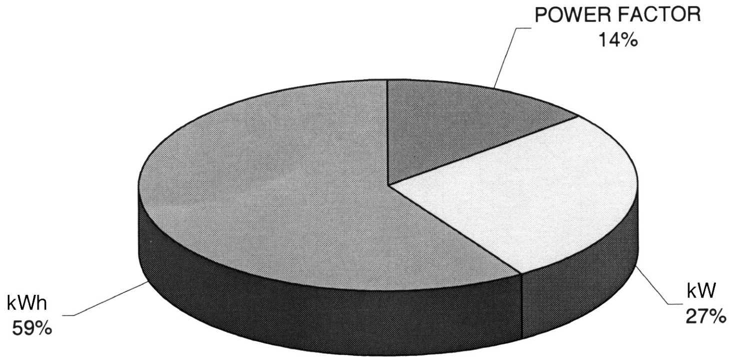


Figure 2-3. Electricity Cost Breakdown

on the meter and should be used to evaluate power requirements and the load factor (described below) 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 demand and actual demand to be different. A more detailed discussion of utility rate structures is included in Chapter 3.

Facility 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 facility load factor is kept as high as possible, thereby minimizing the impact of the demand charge by spreading it out over a relatively larger kWh base. A low facility load factor means that a high peak demand cost is being added to each kWh of electrical energy cost. 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 facility load factor. The facility 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 is called the monthly facility load factor. 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.

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

$$\text{Monthly Load Factor} = \frac{\text{kWh in month}}{\text{Peak kW} \times \text{\# hours in the month}}$$

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.

Facility load factors can be computed hourly, daily, weekly, and yearly, as well as monthly. Each of these different load factors may provide information leading to operating the facility more efficiently and/or less costly.

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 that consumed 800,000 kWh of energy during a 30-day billing period and established a peak demand of 200 kW? (Note that few utilities use a constant 30-day billing period.)

ANSWER

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

Note that if it is for a three shift a day facility, this tells us there is a lot of opportunity for peak demand savings.

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 indicate conservation efforts should be focused in these areas.

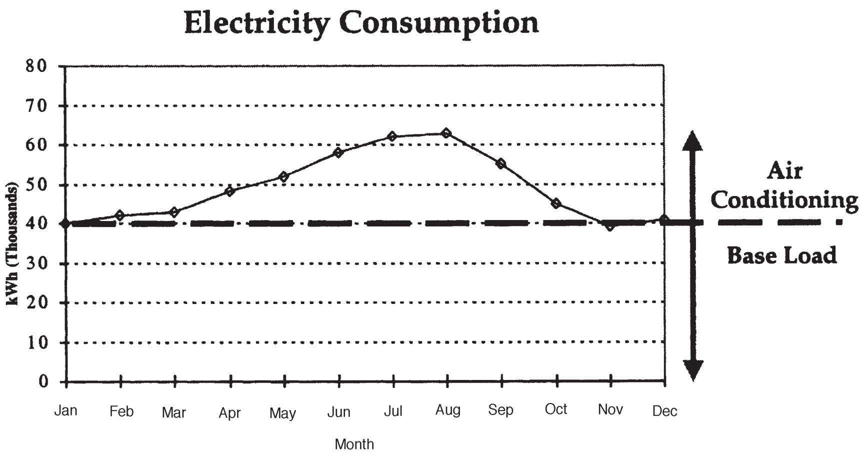


Figure 2-4. Base and Seasonal Loads

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. Since each monthly figure is an annual total, any sudden change is the result of that new 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 OF NATURAL GAS

An increase in annual natural gas consumption can be the result of several factors such as weather patterns, increased occupancy, added equipment, or increased production. Further analysis can determine which of these factors is most likely the cause of the increased consumption. Using the following steps may be helpful:

1) Determine Therms/Degree-Day consumed for previous year.
2) Multiply by number of degree-days for current year to obtain estimated natural gas consumption.

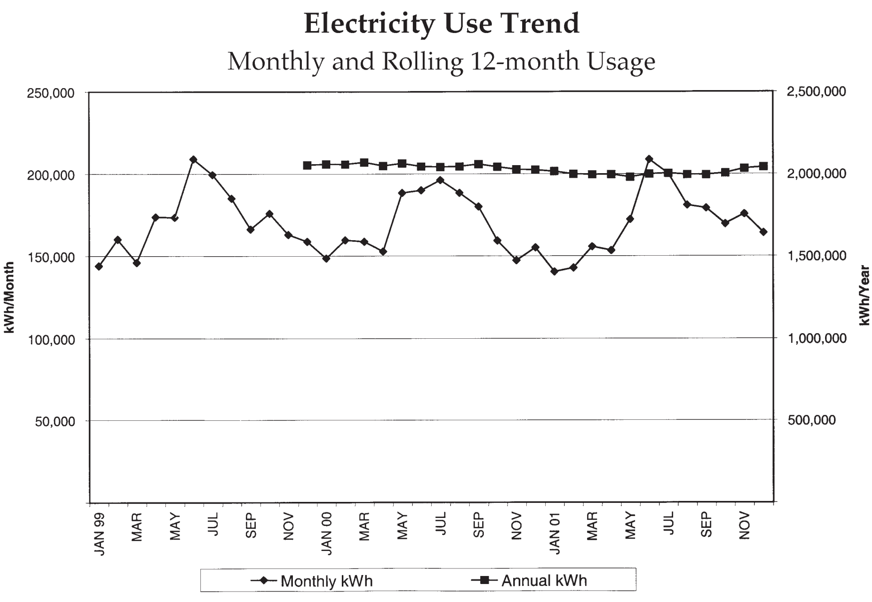


Figure 2-5.

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.

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

Energy Use in Office Buildings	*Range (%)*	*Norm (%)*
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

Energy Use in Retail Stores	*Range (%)*	*Norm (%)*
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

Energy Use in Schools	*Range (%)*	*Norm (%)*
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

Energy Use in Hospitals	*Range (%)*	*Norm (%)*
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

Energy Use in Supermarkets	*Range (%)*	*Norm (%)*
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

Energy Use in Apartment Buildings	*Range (%)*	*Norm (%)*
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

Energy Use in Hotels/Motels	*Range (%)*	*Norm (%)*
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

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

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
- Water and sewer

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), or water and sewer conservation measures.

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. This heat-of-light is a relatively expensive method of heating a building, and if this is being utilized in a building, there are much cheaper ways to accomplish space heating. 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 equipment 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 or Building Automation Systems

Energy can be saved by automating the control of energy systems through the use of energy management control systems (EMCS) or building automation systems (BAS). Rising energy costs and decreasing prices for computers and microprocessors have encouraged the use of energy management and control systems. An EMCS or BAS 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 weather stripping 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. New automatic shades and electrochromic windows are available today.

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.

Other problems can come from power quality issues like harmonics. Facilities with large numbers of VFDs or with spot welders may need harmonic correction equipment.

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. A separate power quality audit may be needed.

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. New heat pump hot water heaters are available today.

Heat Recovery Opportunities

Heat recovery is the reclamation and use of energy that is otherwise 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. Heat recovery from air conditioning units and chillers is becoming more popular for hot water production in buildings.

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 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.

- 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.

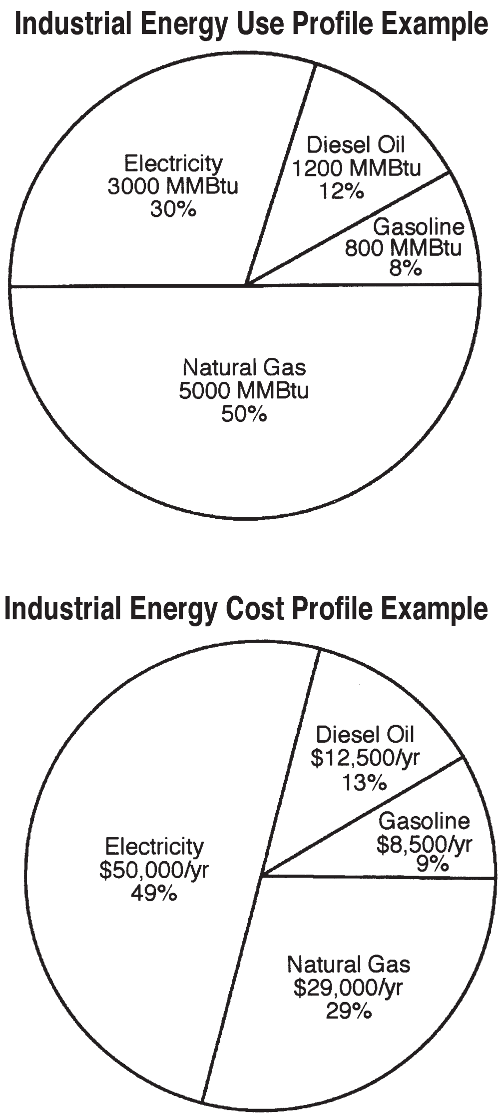


Figure 2-6. Energy Use and Cost Profile Examples

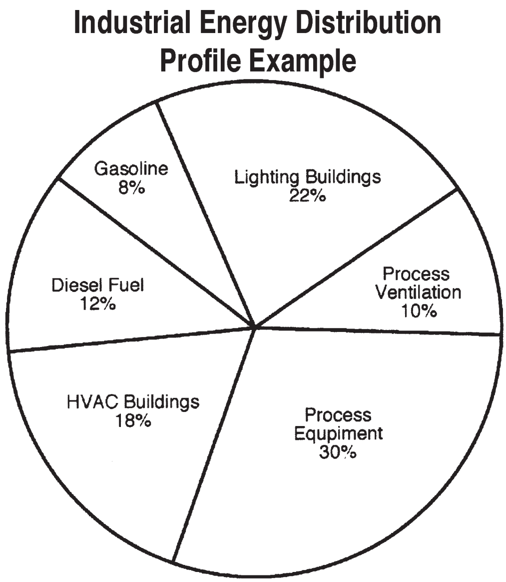


Figure 2-7. Energy Profile by Function

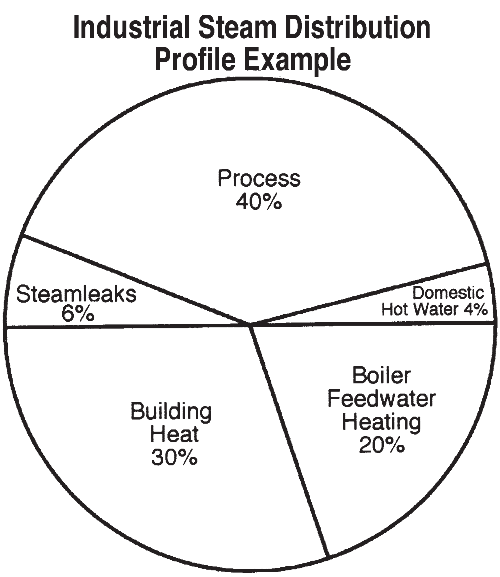


Figure 2-8. Steam Profile by Function

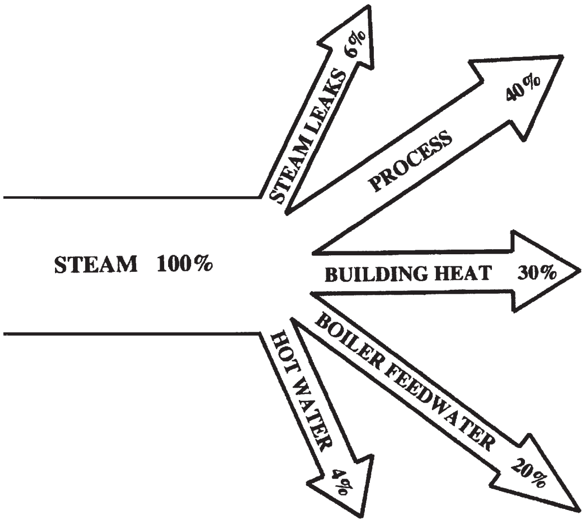


Figure 2-9. Steam Distribution Nodal Diagram Example

- 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. Water use is also examined.

- Utility Audit—This audit analyzes the daily, monthly, or annual usage for each utility including steam, compressed air, process hot water, sewer, 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

Housekeeping Energy	*Percent*
Space Heating	21.5
Air Conditioning	1.6
Lighting	1.4
Domestic Hot Water	1.8
TOTAL	**26.3**
Process Energy	*Percent*
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

Housekeeping Energy	*Percent*
Space Heating	24
Air Conditioning	2
Lighting	2
Domestic Hot Water	2
TOTAL	**30**
Process Energy	*Percent*
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

End Use	*Range (%)*	*Norms (%)*
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)

End Use	*Range (%)*	*Norms (%)**
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?
- And similar questions for water and sewer use.

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 of electrical energy. 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

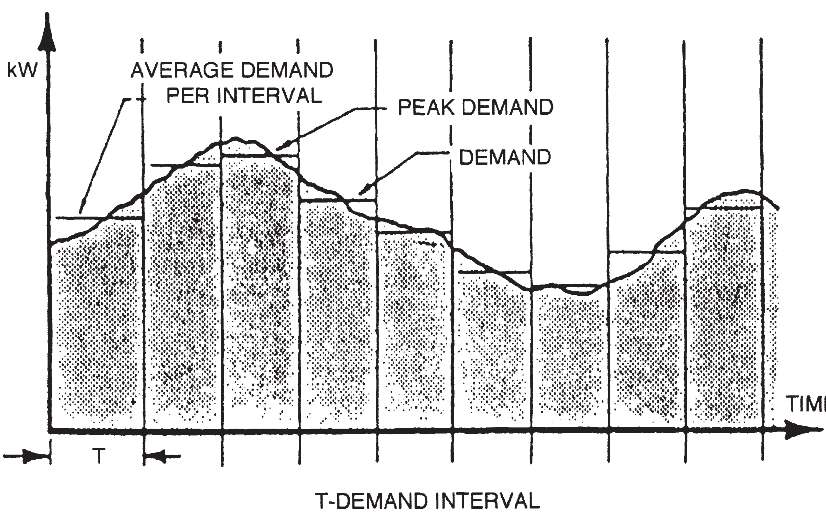


Figure 3-1. Peak Demand

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 morning 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 kWh each per month	8¢ per kWh
Next	18,000 kWh each per month	6¢ per kWh
Next	180,000 kWh each per month	4.4¢ per kWh
Etc.		

The new proposed schedule deletes price breaks for usage.

	Billing Months June-September	*Billing Months October-May*
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 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 Demand:	First 25 kW	$100	
	Next 475 kW	$1,662.50	
	Next 400 kW	$1,300	
	Total	$3,062.50	/mo
Summer Demand:		$4,037.50	/mo

Total Demand Charge:

8 mo × $3062.50/mo + 4 mo × $4,037.50/mo = $40,650

Total Usage Charge per Month:

475 kW × 330 Hours = 156,750 kWh

First	2,000 kWh @ 8¢/kWh	=	$160
Next	18,000 kWh @ 6¢/kWh	=	$1,080
Next	136,750 kWh @ 4.4¢/kWh	=	$6,017
	Total	=	$7,257

Total Usage: $7257 × 12 = $87,084

Total Charge = $40,650 + $87,084

= $127,734 = 6.8¢ per kWh average cost

Proposed Billing

Demand: 1200 kW × ($13.00/kW•mo) x 4 mo = $62,400

900 kW × ($5.00/kW•mo) x 8 mo = $36,000

Total Demand: $ 98,400

Usage: 475 kW × 330 × 5¢ × 4 = $ 31,350

475 kW × 330 × 3¢ × 8 = $ 37,620

Total Usage: $68,970

Total Charge = $98,400 + $68,970

= $167,370 = 8.9¢ per kWh = a 31% 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 Btu). 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 and changes in chemical makeup.

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, or hour, and is measured in therms/day or therms/h. 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

If 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." Not all states allow a facility to purchase its gas from a third-party supplier.

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. Recent natural gas prices are near 20-year lows, and offer substantial savings to facilities using diesel fuel.

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 Btu.

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:

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

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).

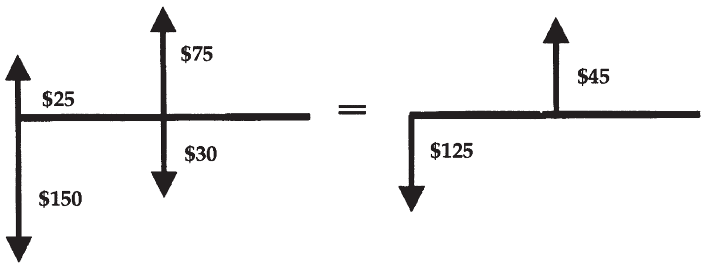
Cash Flow Diagrams

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:

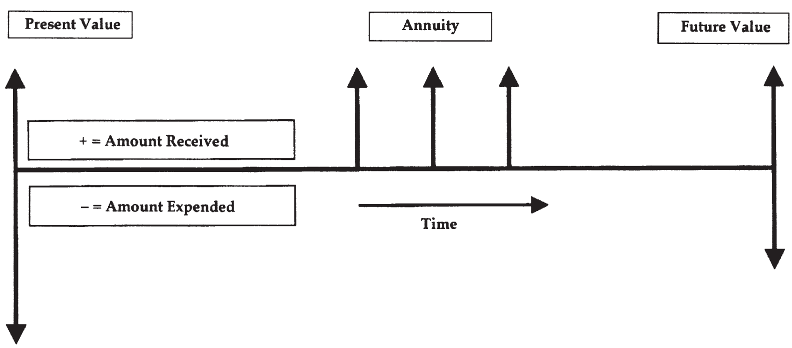
- Arrows Always Point Away from the Time Axis

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

Net present value (NPV) is found by taking the difference between the present value of the savings from a project, minus the present value of the cost of the project.

In most cases P will equal the cost of the project, so NPV = A x (P/A, I, N) – P.

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 required to implement the project, or ECM, 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
EUAC = Present Value × $(A/P, I, N)$

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 using 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 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. Alter-

	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 & Replace-ment 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 & Replace-ment 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	

native 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.

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)	$\frac{i(1+i)^n}{(1+i)^n \pm 1}$

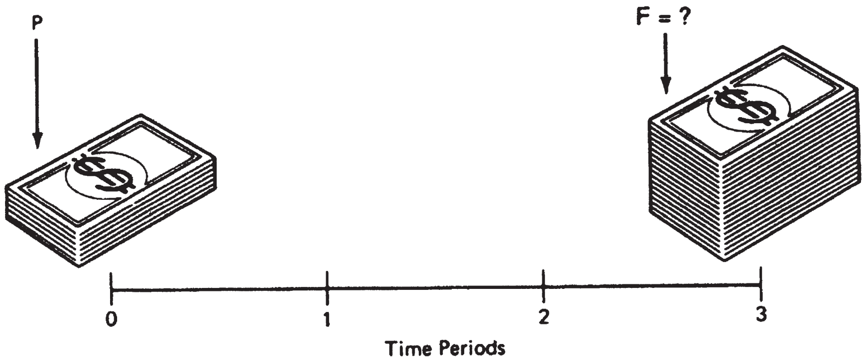


Figure 4-1. Single payment compound amount (F/P).

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.

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

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

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.

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

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

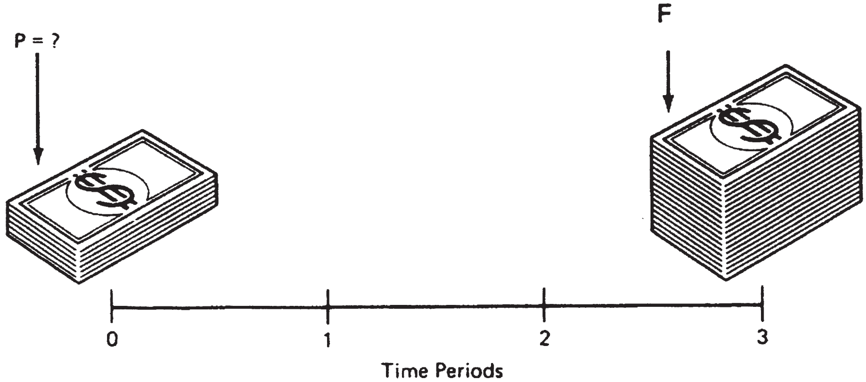


Figure 4-2 Single payment present worth (P/F).

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.

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

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

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.

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

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

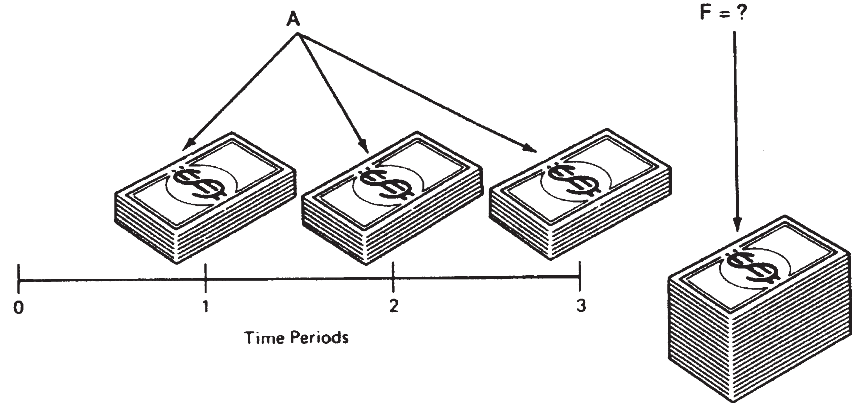


Figure 4-3. Uniform series present worth (F/A).

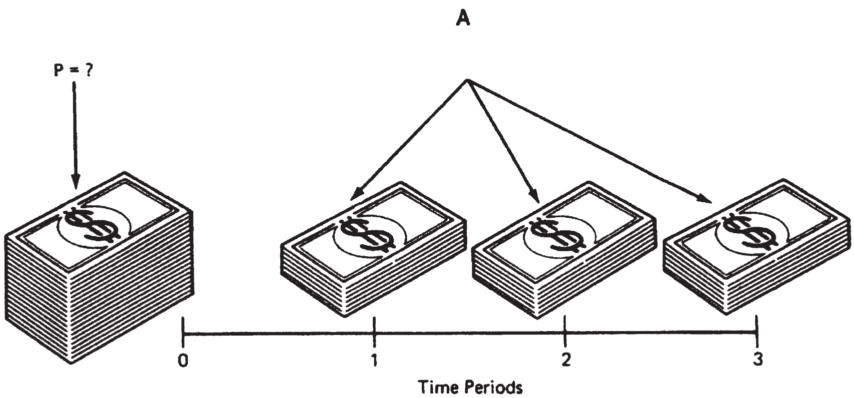


Figure 4-4. Uniform series present worth (P/A).

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

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

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

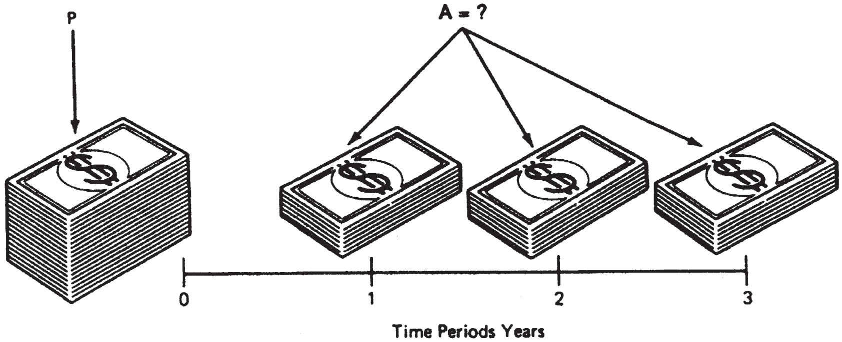


Figure 4-5. Capital recovery (A/P).

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.

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

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

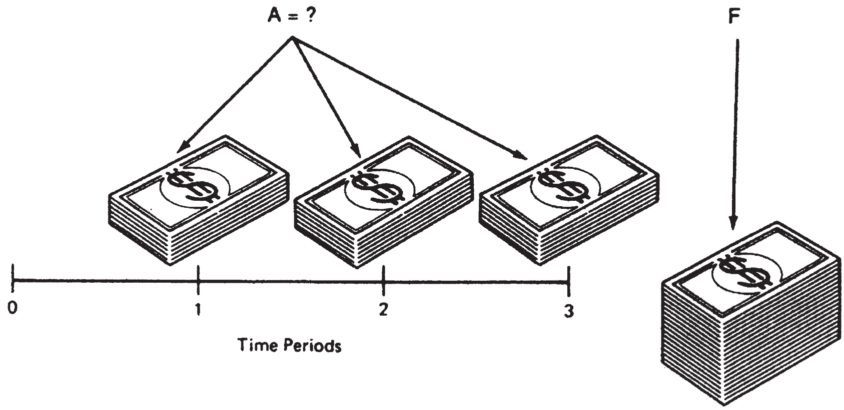


Figure 4-6. Sinking fund payment (A/F).

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.

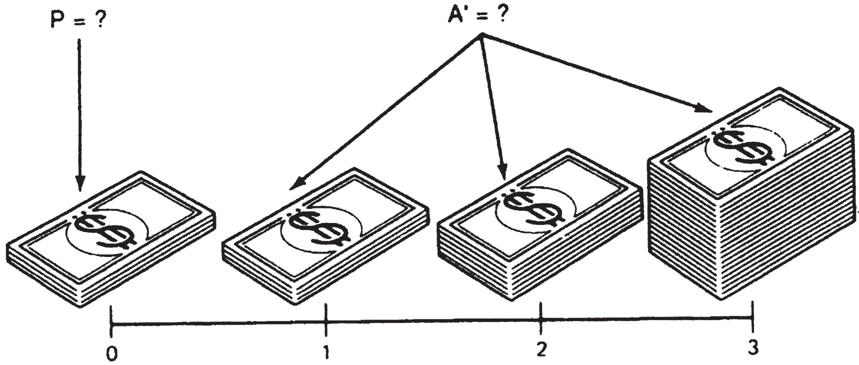


Figure 4-7. Gradient present worth

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 approximately 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

$$A = (5800\ \text{h})\ (4.8\text{W})\ (\$0.07/\text{kWh})\ (1\ \text{kWh}/1000\ \text{Wh})$$

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

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

Present Worth Method

	Alternative I *Present Method*	*Alternative 2* *Use High Efficiency Motor Spares*
(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 × 4.87 =	$1,558,400	$1,402,560
Present Worth (1) + (3)	$1,558,400	$1,402,560 ← Choose Alternate with Lowest First Cost

Annual Cost Method

	Alternative I	*Alternative 2*
(1) First Cost (P)	—	$80,000
(2) Annual Cost (A)	$320,000	$288,000
A/P (Table 4-4)	.2	.2
(3) P × .2	—	$16,000
Annual Cost (2) + (3)	$320,000	$304,000 ← Choose Alternate with Lowest First Cost

Rate of Return Method

$$A = (\$320{,}000 - \$288{,}000)$$

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

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:
$$\frac{P}{A} = \frac{20{,}000}{2{,}600} = 7.692$$

From Table 4-1, the rate of return is 10 percent. Now, with 10 percent escalation assumed, go to Table 4-11 and go to the column for 10% escalation. Find this same P/A factor for the 10% interest rate and then read the new equivalent interest rate of 21 percent. Thus, 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:

$$AC = (P - L) \times \mathrm{A/P} + iL \qquad (4\text{-}16)$$

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, i, n)		
7. $(P - L) \times$ A/P		
8. Li		
9. $AC = (P - L) \times \text{A/P} + Li + E$		

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
P	\$80,000	\$100,000		\$160,000
n	16	16		16
E	\$16,000	\$12,000		\$6,000
i	10%	10%		10%
A/P = 0.127	—	—		—
$(P - L)$ A/P	\$10,160	\$12,700		\$20,320
Li	—	—		—
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,

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

where n is the life of equipment.

Each year's depreciation rate is determined as follows.

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

Second year $$D = \frac{n - 1}{N} (P - L) \tag{4-20}$$

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

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.

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

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 modifications 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.

$$AS = (1 - \mathrm{I})E + ID \tag{4-23}$$

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 percentage rate

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					Σp

$$AS = (1 - I)\,E + ID$$

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 $AS = (1 - I)\,E + ID$

$$I = 0.34, \quad \mathrm{E} = \$1000$$

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

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:

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

In the case of escalation:

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

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

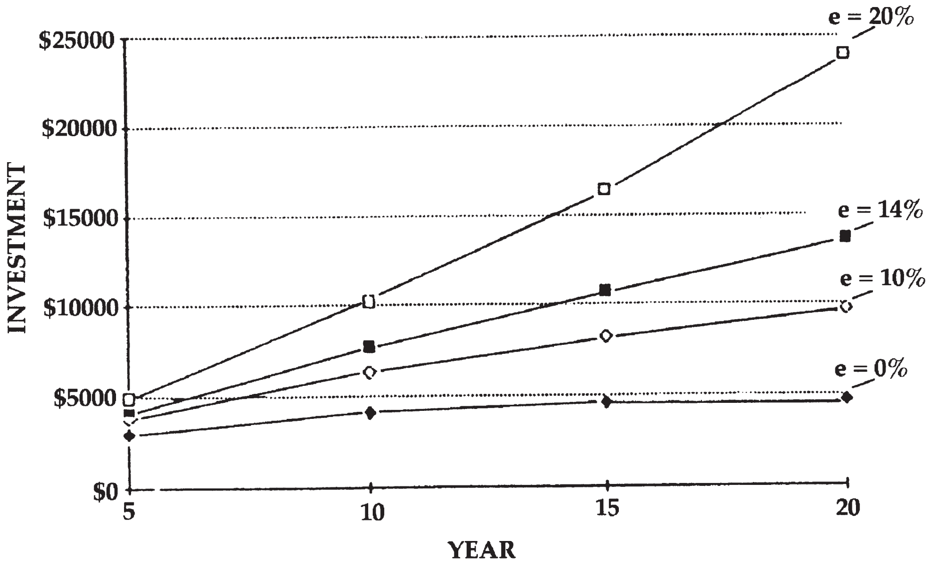
	N = 5 $*P*	*N* = 10 $*P*	*N* = 15 $*P*	*N* = 20 $*P*
e = 0	2869	4000	4459	4648
e = 10%	3753	6292	8165	9618
e = 14%	4170	7598	10,676	13,567
e = 20%	4871	10,146	16,353	23,918

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:

$$\frac{\text{PAF (unknown)}}{\text{PAF (known}} \quad \text{for example: } \frac{P}{\text{A}}$$

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

GIVEN	FIND	USE
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 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	1.100	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 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	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 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	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	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	1.200	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 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	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 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	1.300	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 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	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	1.400	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 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	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	Annual Escalation Rate					
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%	Percentiles 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 effort 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 lightweight 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

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.

activate the logger and view/analyze the collected data.

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 psychometric chart to compare with ASHRAE comfort zone conditions. Many of the dataloggers previously discussed include temperature and humidity sensors.

CARBON DIOXIDE (CO_2)

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 CO_2 are typically in the 250 to 350 parts per million (ppm) range. By measuring and recording CO_2 levels over time, concentrations above ambient conditions can be used to determine when the area is actually occupied. A CO_2 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 CO_2 can be used to determine the ventilation rate in CFM/person and compared to ventilation standards (ASHRAE 62-2004). CO_2 levels above 1000 ppm can indicate that the ventilation rate is probably inadequate. CO_2 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 CO_2 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 win-

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

dows, and other zones.

In the building envelope, 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

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

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 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

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

materials 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 oat 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 unweatherstripped 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 volds and inclusions in castings

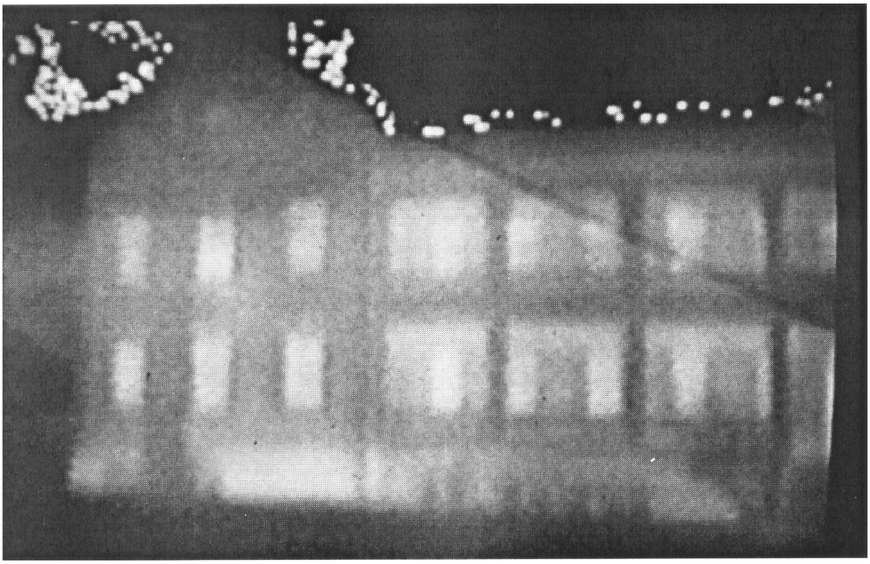


Figure 5-6. An infrared scan of the building envelope reveals substantial heat losses through the roof, windows, and foundation. Several companies offer scanning equipment for sale as well as scanning services for periodic system checks and troubleshooting.

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.

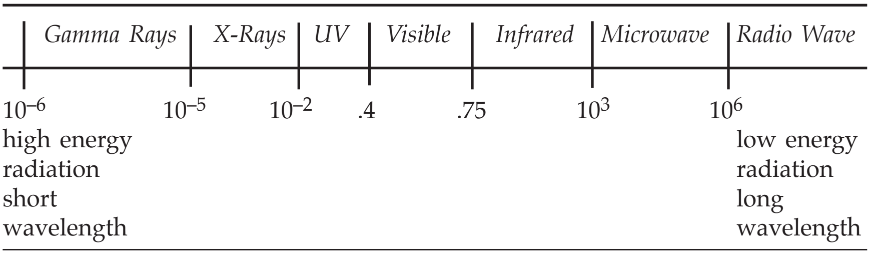


Figure 5-7. Electromagnetic Spectrum

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.

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.

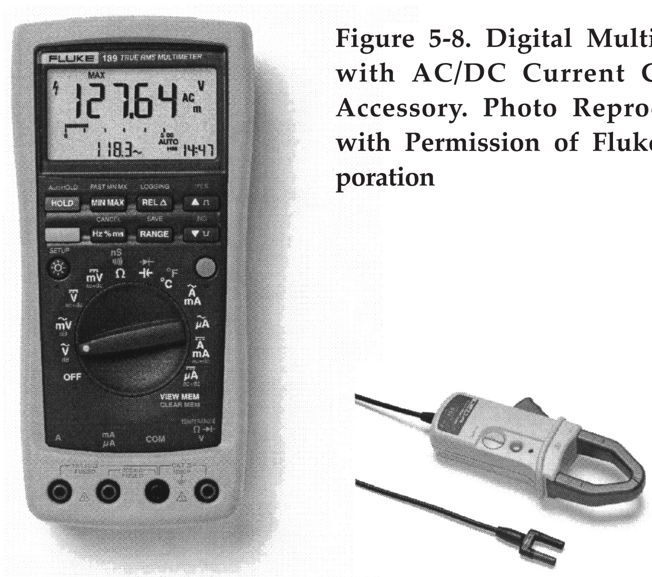


Figure 5-8. Digital Multimeter with AC/DC Current Clamp Accessory. Photo Reproduced with Permission of Fluke Corporation

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

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).

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 considered are carbon dioxide (CO_2), carbon monoxide

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

(CO). Oxygen (O_2) is also tested to assure proper excess air levels.

The typical ranges of concentrations are:

- CO_2 : 0 - 20%
- O_2 : 0 - 21%
- CO : 0 - .05%

The CO_2 or O_2 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 (CO_2), low oxygen (O_2), and little of 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 pyrogallic 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 CO_2 or O_2 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 ±1/2% CO_2 or O_2.

Fyrite absorbing fluid is selective in the chemical absorption of carbon dioxide or oxygen, respectively. Therefore, the Fyrite's accuracy,

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

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, primary and stack temperatures, draft, differential pressure, NO_x and

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

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 efficiently while environmental regulations are being met.

The combustion analyzer measures oxygen, carbon monoxide, ni-

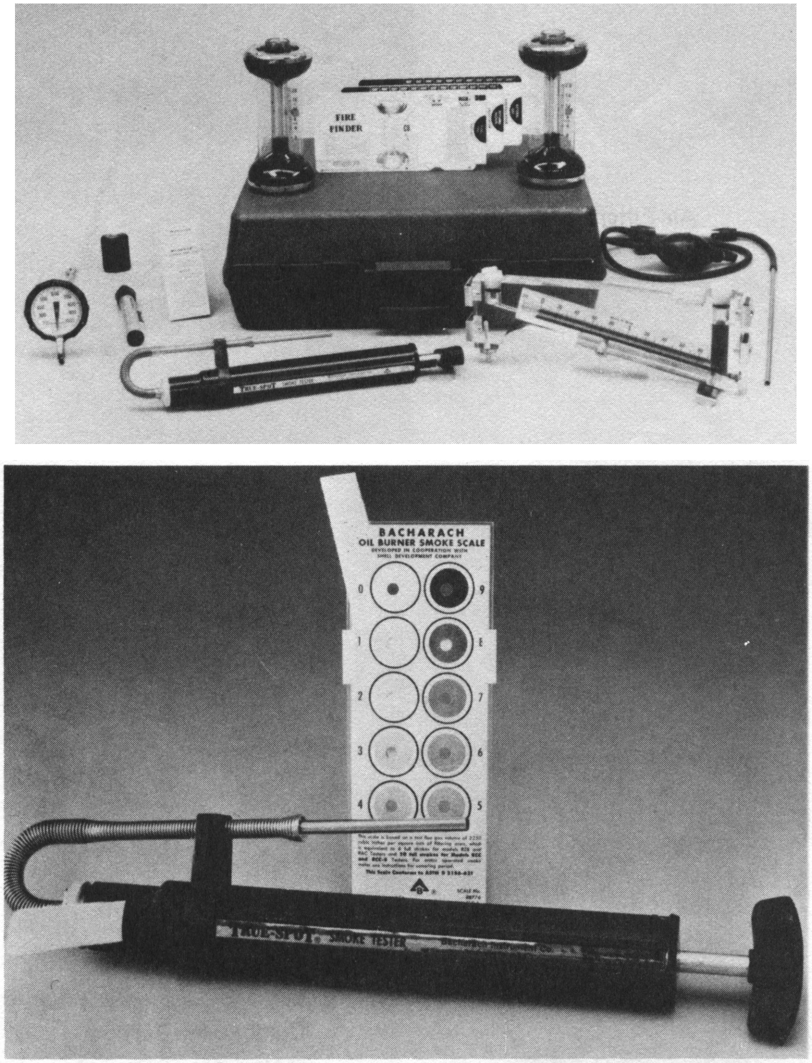


Figure 5-13. Boiler Test Kit (above) and Smoke Tester (below). (Photographs courtesy of Bacharach Instrument Company).

tric 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 other industrial combustion equipment for up to eight hours and generates combustion and environmental measurements and calculations.

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

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.
- **Anemometer** (deflecting vane)—good indication of air movement with acceptable order of accuracy. Considered useful. (Approx. $50).

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** (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.

- **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.

Table 5-3. Temperature Measurement

Device/Meter	*Application*	*Range in °F*	*Accuracy °F*	*Limitation*
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
Nickel resistance	Remote readings	–150 to 300	0.03	affected by radiation
Thermisters	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				Usually Permanent
Gas filled		–200 to 1000	2	Installations. Requires
Vapor filled	Suitable for remote reading	20 to 500	2	careful fixing and setting
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

- **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.
- **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.

Table 5-4. Pressure Measurement

Device/Meter	*Application*	*Range in FPM*	*Accuracy*	*Limitations*
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_2O	0.0005 to 0.0001 H_2O	Not easily portable, hard to use with pulsating pressures
Draft gauges	Moderately low pressure differential	0 to 10″ H_2O	0.05 H_2O	Must be leveled carefully
Manometer	Medium pressure differential	0 to 100 H_2O	0.05 H_2O	Compensation for liquid density
Swing vane gauge	Moderate low pressure differential	0 to 0.5 H_2O	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

- **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.

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 sis 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.

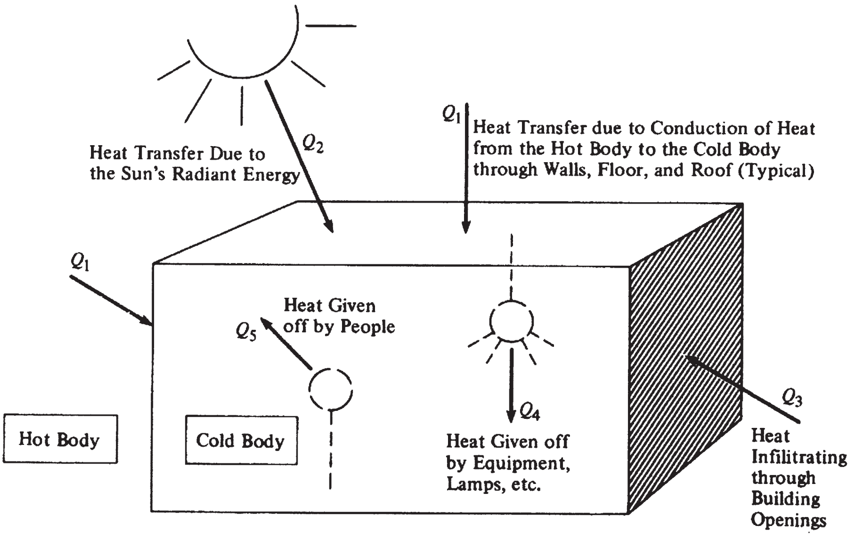
ANALYSIS

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.

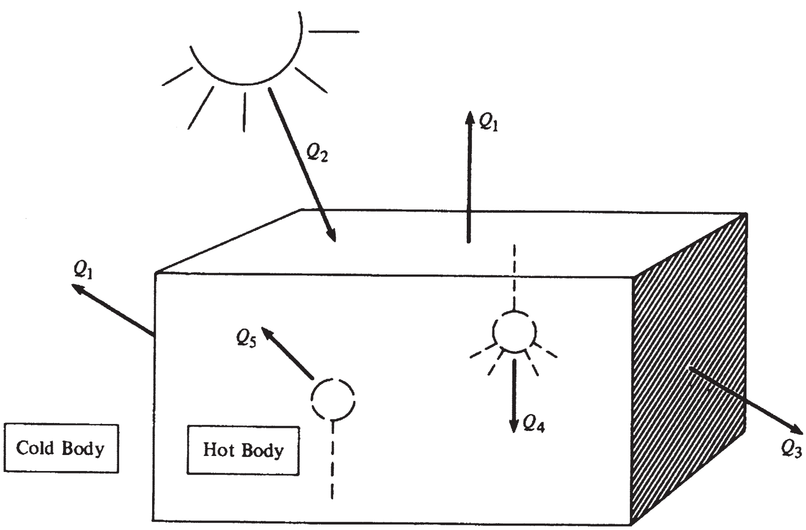
2. The solar heat gain factor is increased and if the building is air-conditioned more tons and more energy are required.

3. The excess solar heat gain during the winter months may decrease heating loads.



Heat Gain = $Q_1 + Q_2 + Q_3 + Q_4 + Q_5$

Figure 6-1. Heat Gain of a Building



Heat Loss = $Q_1 + Q_3 - Q_2 - Q_4 - Q_5$

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.

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

Where:

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

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.

$$Q = Q_1 \times \frac{d}{5} \times \frac{65 - T}{13} \quad \text{(for heat loss)} \qquad (6\text{-}2)$$

Where:

Q is the adjusted heat loss, Btu/year
Q_1 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

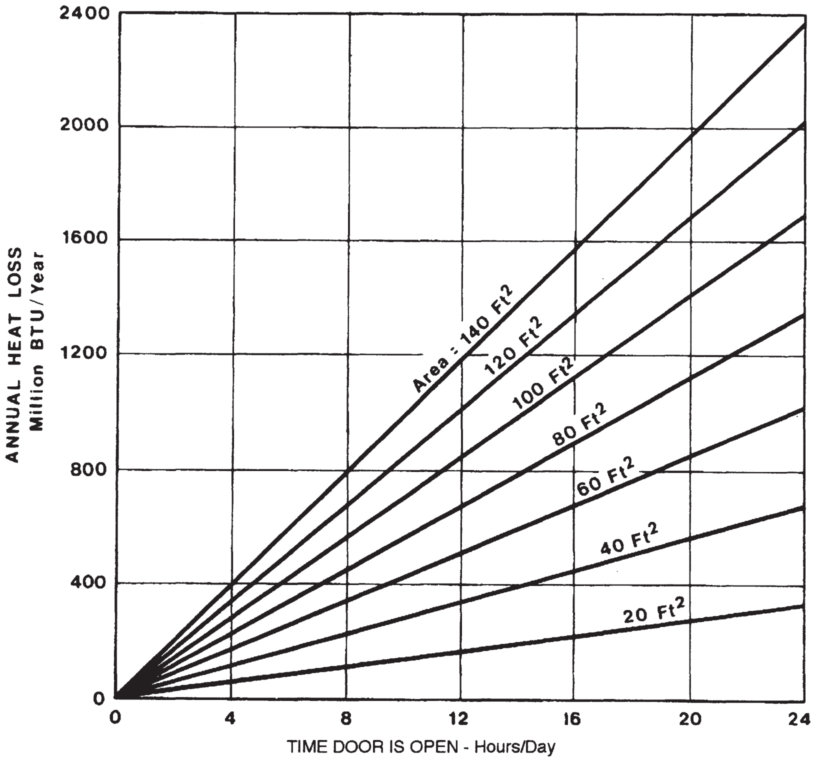


Figure 6-3. Annual Heat Loss from Doors. (Source: Georgia Tech Experiment Station)

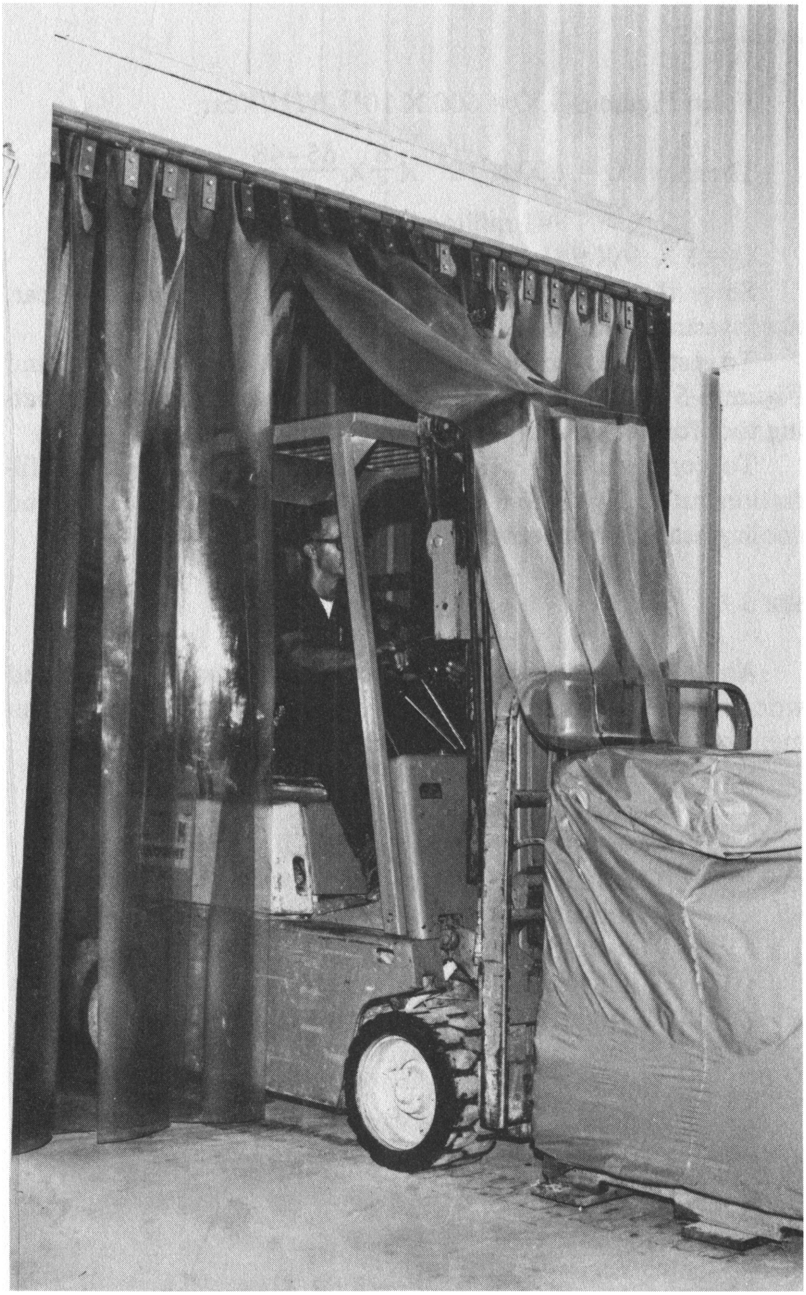


Figure 6-4. Installation of Vinyl Strips on Forklift Door. (Photograph courtesy of MetalGlas Products, Inc.)

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, $Q_1 = 600 \times 10^{12}$ Btu/Year

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

Saved Q = 3 × .9 × 941 million Btu/yr

The money saved with these vinyl strips is:

$$\frac{\$\text{saved}}{\text{yr}} = \frac{2542 \times 10^6 \text{ Btu}}{\text{yr}} \bullet \frac{\$4.00}{10^6 \text{ Btu}} \bullet \frac{1}{0.65} = \$15{,}643$$

SPP = $2,000/$15,643/yr = 0.13 years

Since the payback period before taxes is much 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.

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 wind 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:

$$V_e = \sqrt{V2 \pm 1.75a} \text{ (upper section)}$$

$$V_e = \sqrt{V2 \pm 1.75b} \text{ (upper section)}$$

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.

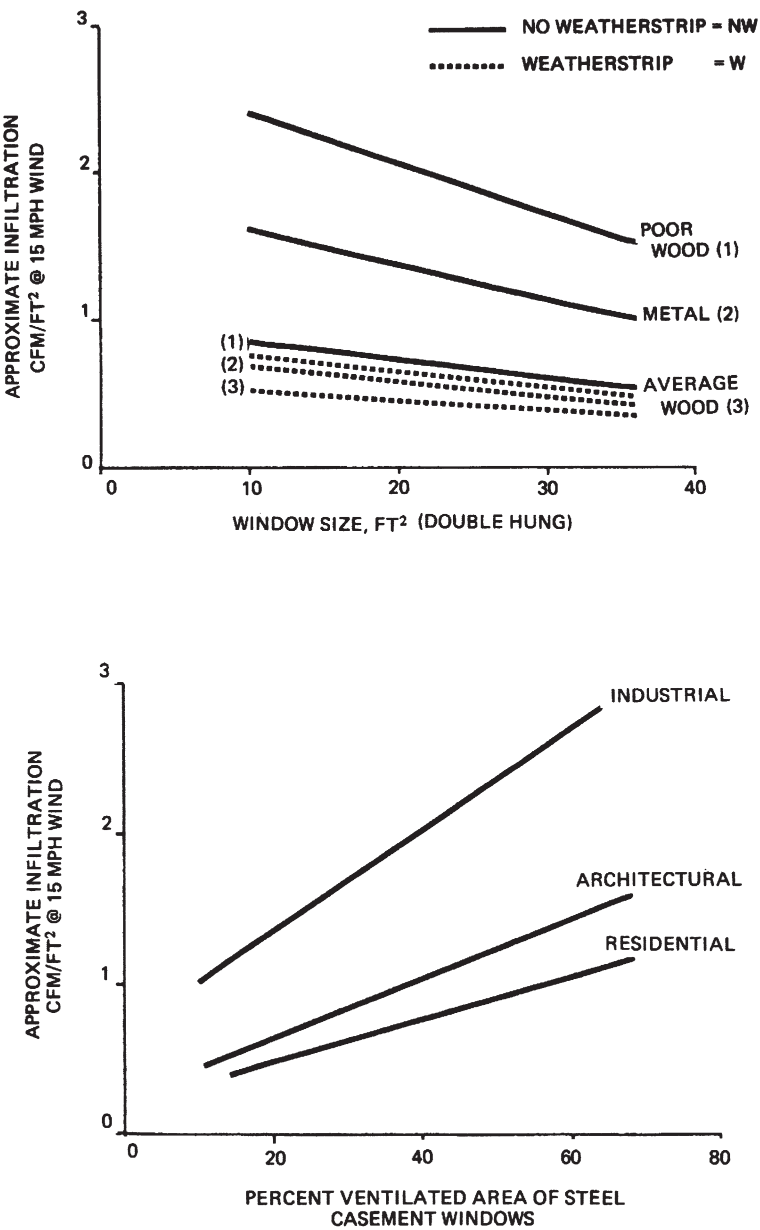


Figure 6-5. Infiltration through Windows and Doors—Winter. (Source: Instructions For Energy Auditors, Vol. II)

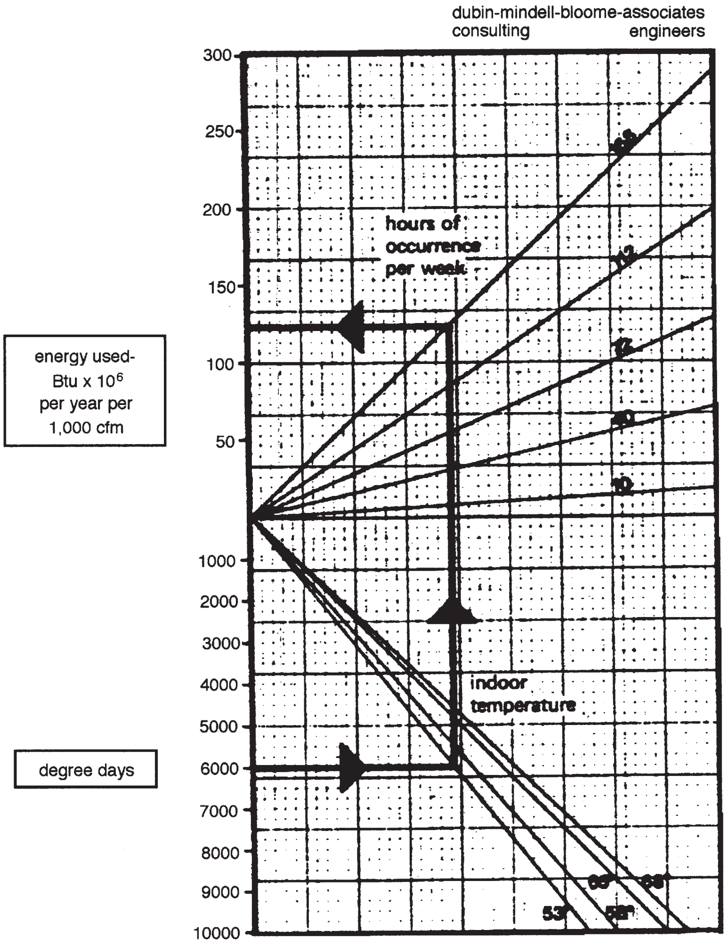


Figure 6-6. Yearly Energy Used Per 1,000 cfm Outdoor Air (Source: Guidelines For Saving Energy in Existing Buildings—Building Owners and Operators Manual, ECM-1)

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.

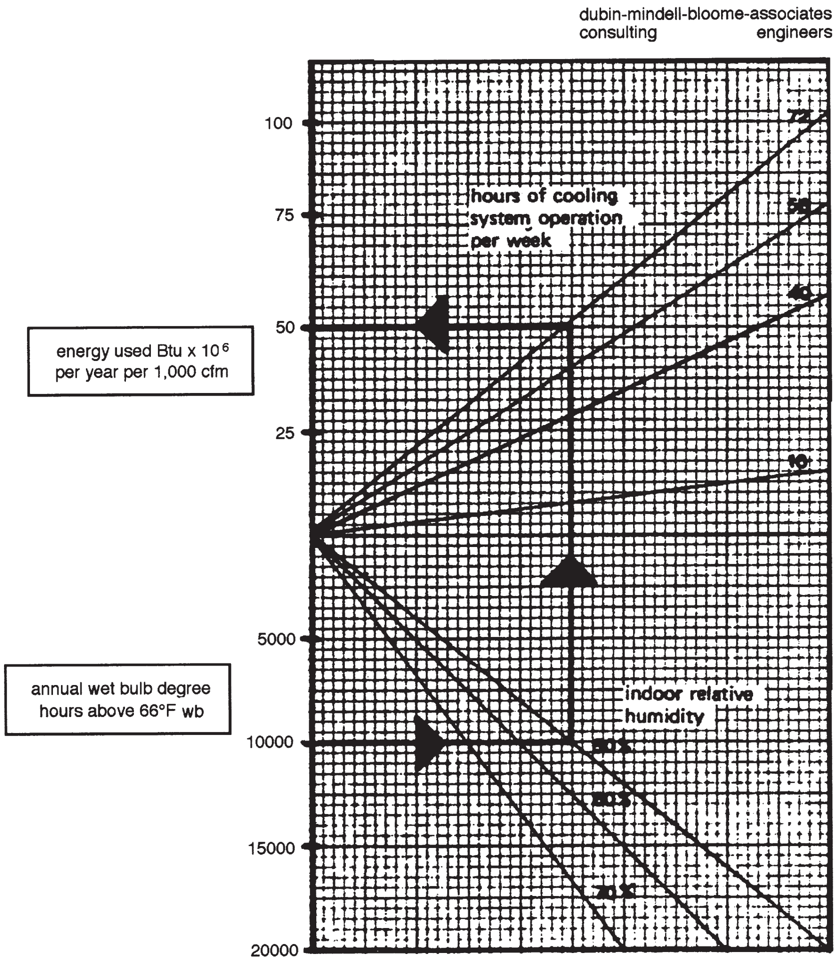


Figure 6-7. Yearly Energy Used Per 1,000 CFM to Maintain Various Humidity Conditions (Source: Guidelines For Saving Energy in Existing Buildings—Building Owners and Operators Manual, ECM-1)

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.

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"
Heating Degree-days = 8,000
Cost of heating = $4/10^6$ Btu
One-half the windows face the wind at any one time
Hours of occupation = 5760 per year
Wet-Bulb Degree-hours = 2,000 greater than 66°F
Wind velocity summer 10 mph, winter 15 mph
Refrigeration consumption = .8 kWh/Ton-Hr
Electric rate = 5¢/kWh
Hours of operation = 72 hours/week
Indoor temperature winter 68°F
RH summer 50%
Boiler efficiency = .65

ANALYSIS

$$\text{Areas of windows} = \frac{54'' \times 96''}{144\ \text{in}^2/\text{ft}^2} = 36\ \text{ft}^2 \text{ per window}$$

Coefficients from Table 6-1
With No Weather-stripping 1.52
With Weather-stripping .47
Infiltration before = 36 × 300/2 × 1.52 = 8208 cfm
Infiltration after weather-stripping = 36 × 300/2 × .47 = 2538 cfm
Savings with weather-stripping = 8208 – 2538 = 5670 cfm

First, find winter savings.

From Figure 6-6 Q = 100 × 10^6 Btu/Year/1000 cfm
(Using HDD = 8000, indoor T = 68°F, and 72 hours per week operation)

$$\frac{\$\text{savings}}{\text{year}} = \frac{5.67 \text{ thousand cfm}}{\text{year}} \bullet \frac{100 \times 10^6 \text{ Btu}}{1000 \text{ cfm}} \bullet \frac{\$4}{10^6 \text{ Btu}} \bullet \frac{1}{0.65}$$

= $3489/yr winter savings

Next, find summer savings.

From Figure 6-7 Q = 10 × 10^6 Btu/Year/1000 cfm
(Using wet bulb degree hours = 2000, indoor RH = 50%,
72 hours per week of cooling and 10 mph wind velocity.)

$$\frac{\$\text{savings}}{\text{year}} = \frac{5.67 \text{ thousand cfm}}{\text{year}} \bullet \frac{10°\text{F}}{15°\text{F}} \bullet \frac{10 \times 10^6 \text{ Btu}}{1000 \text{ cfm}} \bullet \frac{1 \text{ ton-hour}}{12{,}000 \text{ Btu}}$$

$$\times \frac{0.8 \text{ kWh}}{\text{ton-hour}} \times \frac{\$0.05}{\text{kWh}}$$

= \$126/year summer savings

Total savings = \$3615 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.)

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.)
- 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.

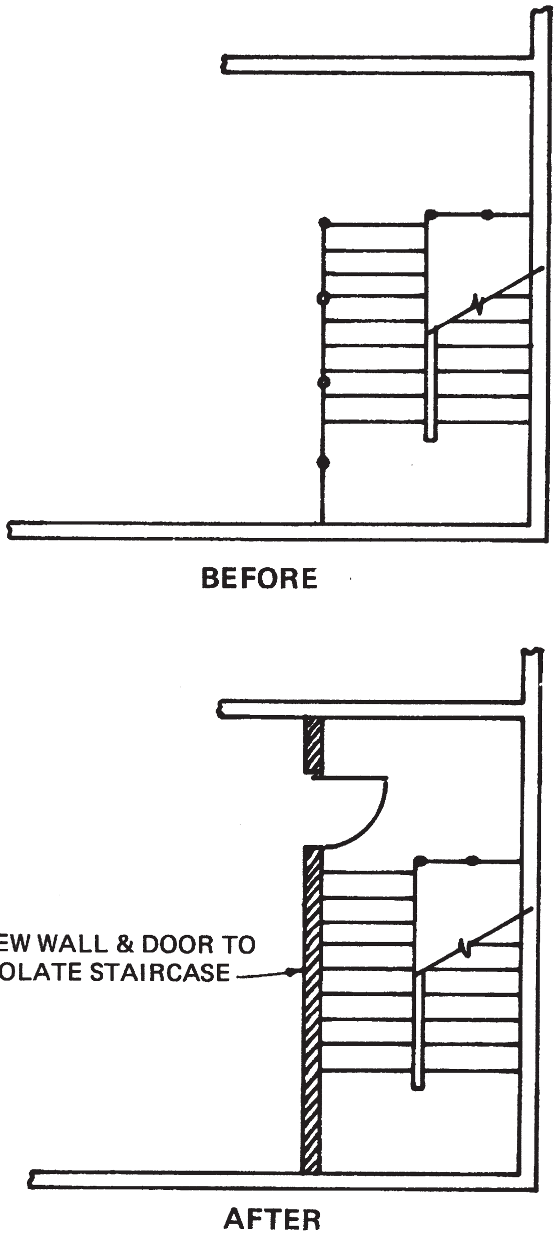


Figure 6-8.

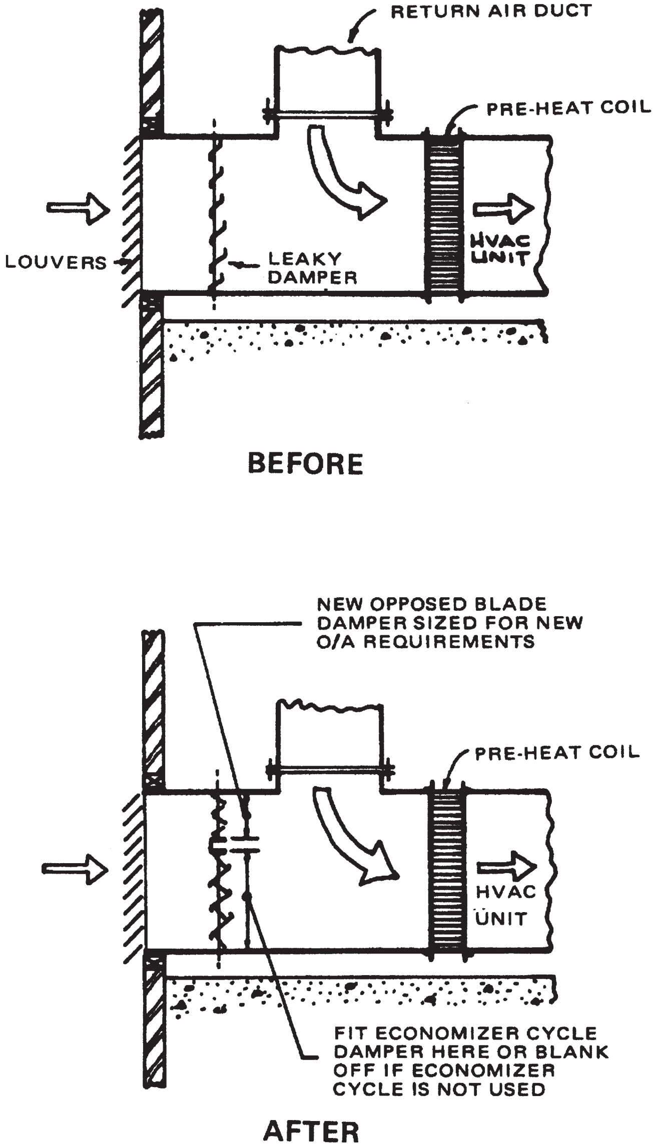

RETURN AIR DUCT
PRE-HEAT COIL
HVAC UNIT
LOUVERS
LEAKY DAMPER
BEFORE
NEW OPPOSED BLADE DAMPER SIZED FOR NEW O/A REQUIREMENTS
PRE-HEAT COIL
HVAC UNIT
FIT ECONOMIZER CYCLE DAMPER HERE OR BLANK OFF IF ECONOMIZER CYCLE IS NOT USED
AFTER

Figure 6-9.

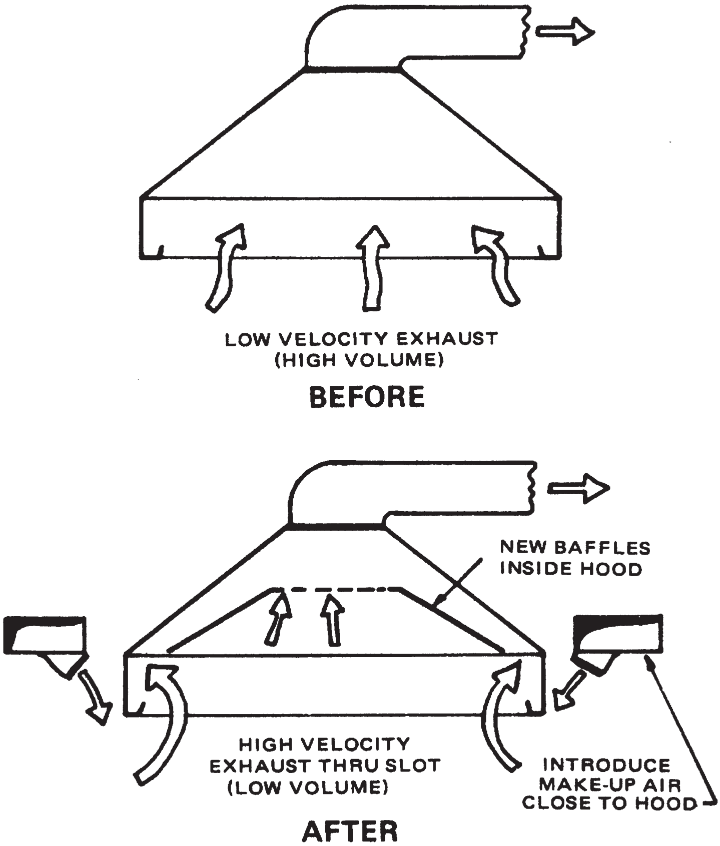


Figure 6-10.

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.

$$Q = k/d \bullet A \bullet \Delta T \quad \text{Btu/h} \qquad (6\text{-}3)$$

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

Where:

- Q is the rate of flow Btu/h
- d is the thickness of the material in inches

A is the area of the wall, ft^2
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.

$$Q = \varepsilon \, \sigma \, A \, T^4 \text{ Btu/hr} \qquad (6\text{-}4)$$

Where:

Q = rate of heat flow by radiation, Btu/h
e = emissivity of a body, which is defined as the rate of energy radiated by the actual body. $\varepsilon = 1$ for a block body.
σ = Stephen Boltzman's Constant, 1.71×10^{-9} Btu/ft^2 • hr • T^4
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 decreased 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.

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

dubin-mindell-bloome-associates
consulting engineers

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)

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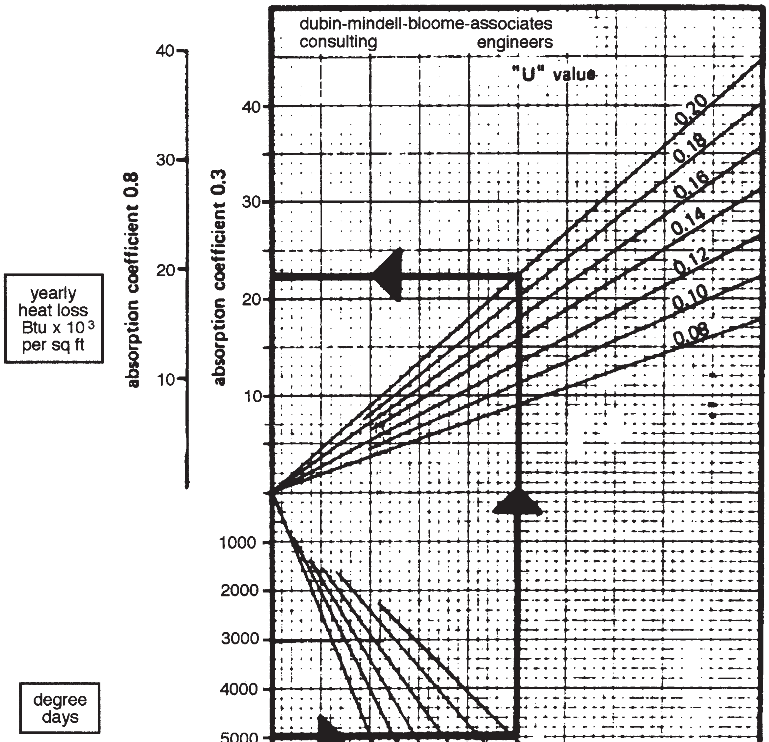
YEARLY HEAT LOSS/SQUARE FOOT THROUGH ROOF

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)

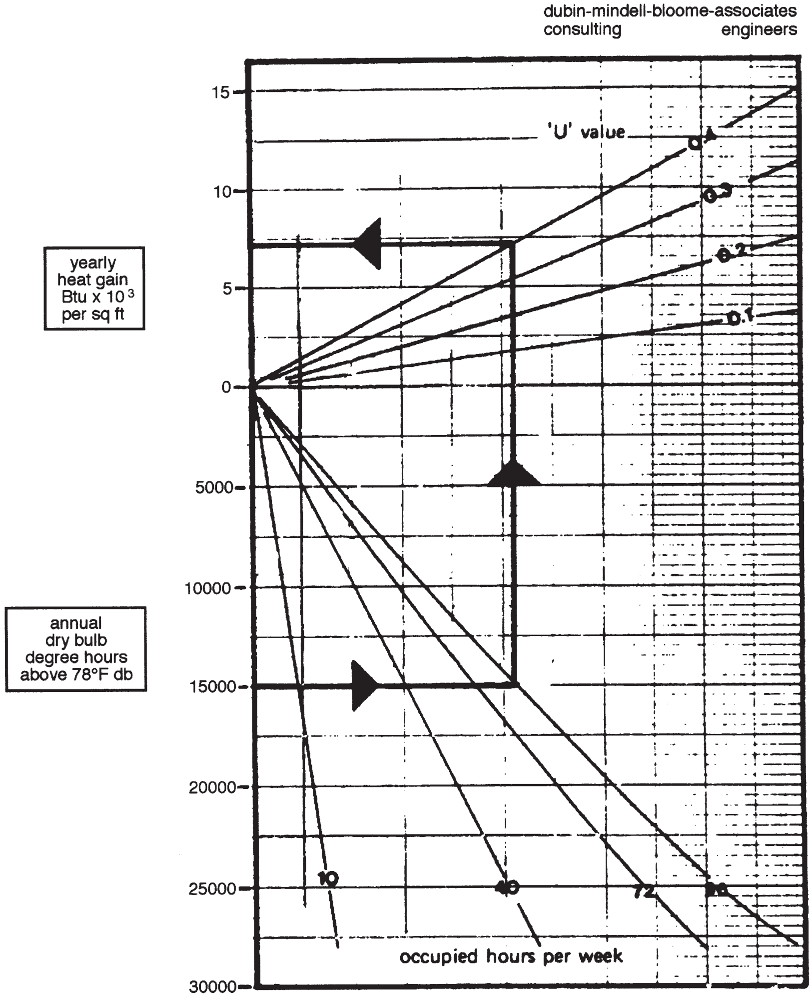


This figure is based on the "Sunset" Computer program which was used to calculate solar effect on roofs for 12 selected locations. The program calculates hourly solar angles and intensities for the 21st day of each month with radiation intensity values modified hourly by the average percentage of cloud 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/ft^2 and thermal lag averaged 3-1/2 hours. Additional assumptions were: (1) Total internal heat gain of 12 Btu/ft^2. (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.

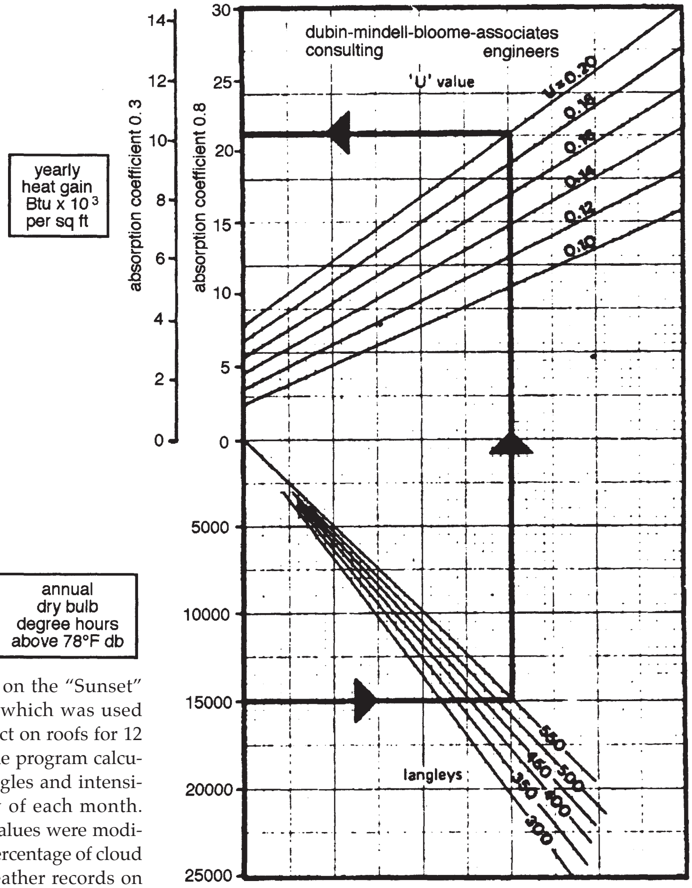
Absorption coefficients and U values were varied and summarized for the 12 locations. The data were then plotted and extrapolated to include the entire range of degree days.

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



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 × '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/ft^2 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 componant 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)

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 kWh/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

$R_T = R_1 + R_2 = 8 + 13 = 21$
$U_{Before} = 1/8 = .125$
$U_{After} = 1/21 = .047$

Savings

Winter

From Figure 6-13
$Q_{Before} = 7 \times 10^3$ Btu per square feet/yr/sq ft
$Q_{After} = 2 \times 10^3$ Btu per square feet/yr/sq ft
Savings = $(7\text{-}2) \times 10^3 \times 20 \times 10^3 \times 5/10^6/.65 = \$769/\text{yr}$

Summer

Conduction
From Figure 6-14
$Q_{Before} = 1 \times 10^3$ Btu/sq ft/yr
$Q_{After} = .4 \times 10^3$ Btu/sq ft/yr

Savings = (1 – .4) × 10^3 × 20,000 = 12,000 × 10^3 Btu/Yr

Radiation

From Figure 6-15

Q_{Before} = 8.5 × 10^3 Btu/sq ft/yr

Q_{After} = 2.5 × 10^3 Btu/sq ft/yr

$$\text{Savings} = (8.5\text{-}2.5) \times 10^3 \text{ Btu/sq ft/yr} \times 20{,}000$$
$$= 120{,}000 \times 10^3 \text{ Btu/yr}$$

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

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 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.

To reduce solar loads, several common devices are used.

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)

- 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.

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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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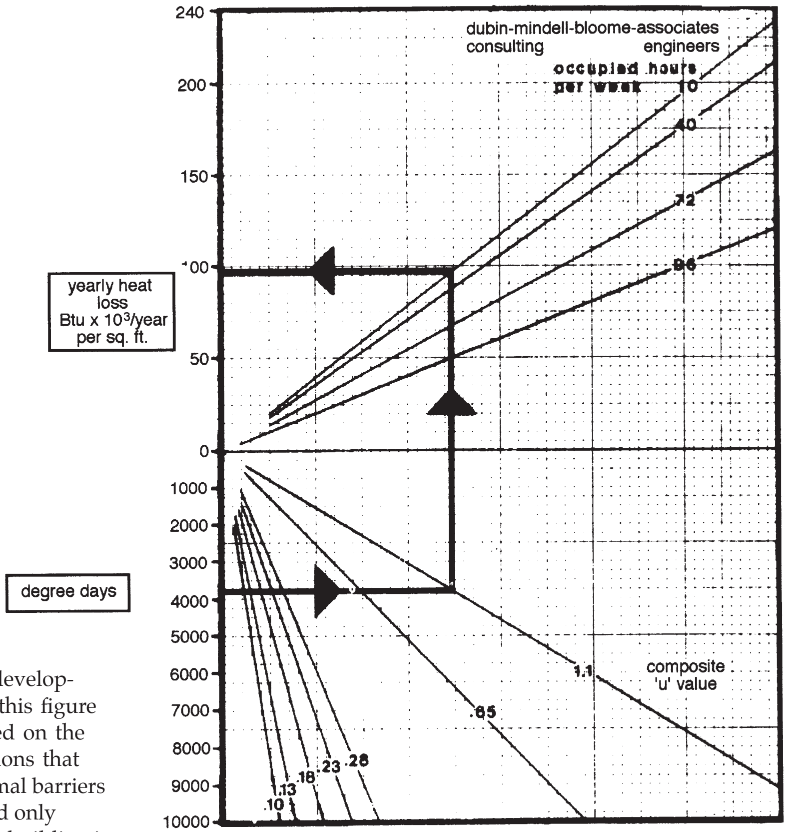
City	Latitude	Solar Radiation Langley's	D.B. Degree-Hours Above 78°F	Heat Loss Through Roof Btu/Ft^2 Year					
				North		East & West		South	
				Single	Double	Single	Double	Single	Double
Minneapolis	45°N	325	2,500	36,579	33,089	98,158	88,200	82,597	70,729
Concord, NH	43°N	300	1,750	33,481	30,080	91,684	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.

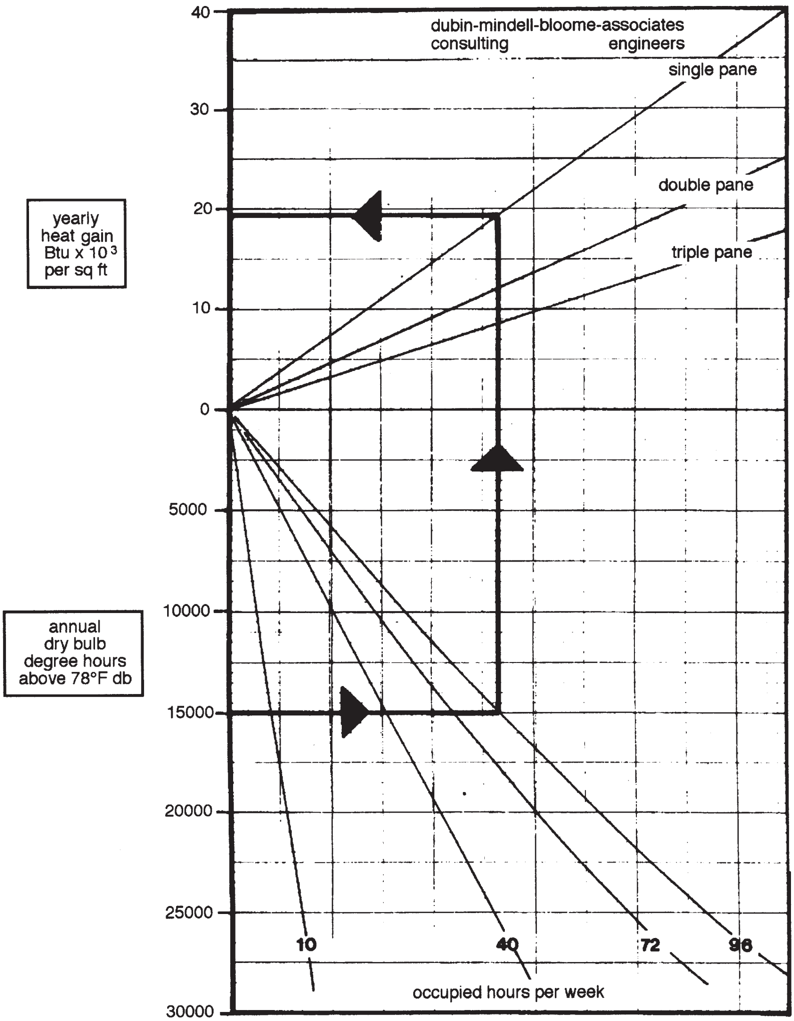
The number of degree days occurring when the thermal barriers are closed (adjusted degree-days – DO_A) were determined from the characteristic occupancy periods shown in the figure. This can be expressed as a fraction of the total degree-days (DO_T) by the relationship:

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

$$0.75DD_T\left(\frac{\text{unoccupied nighttime hours/week}}{\text{total nighttime hours/week}}\right)$$

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 × 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)

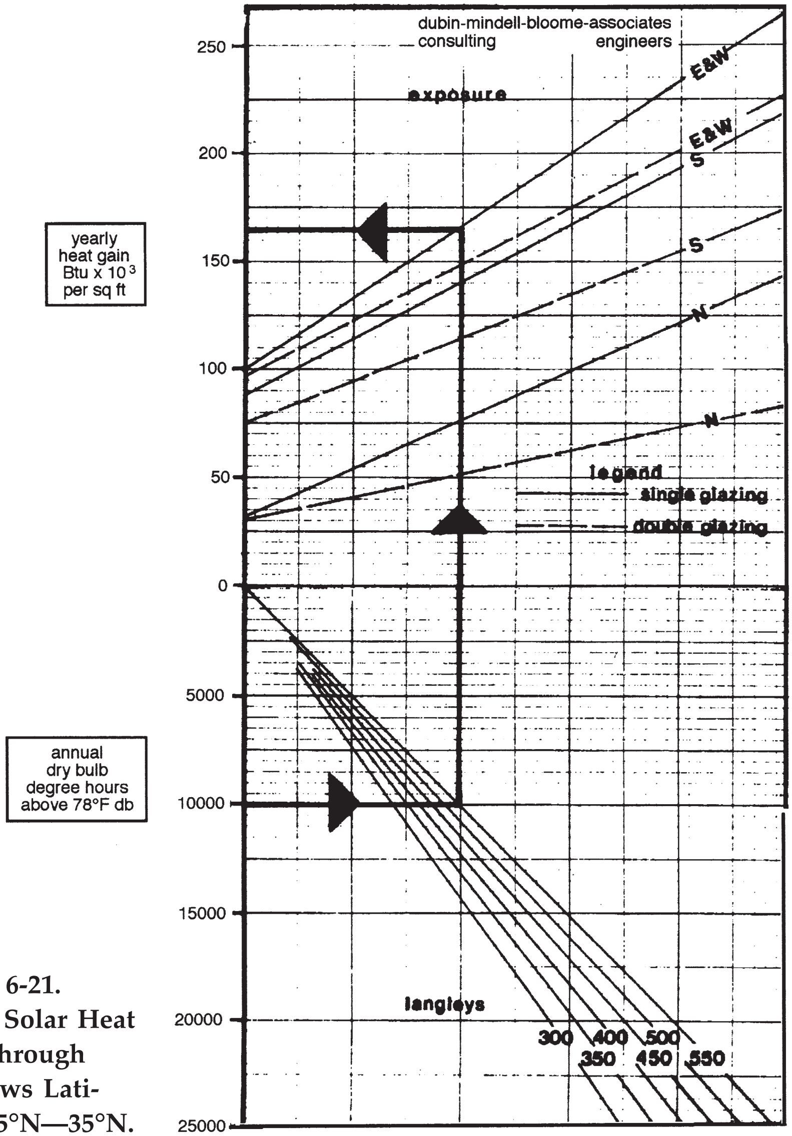


Figure 6-21. Yearly Solar Heat Gain through Windows Latitude 25°N—35°N.

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*)

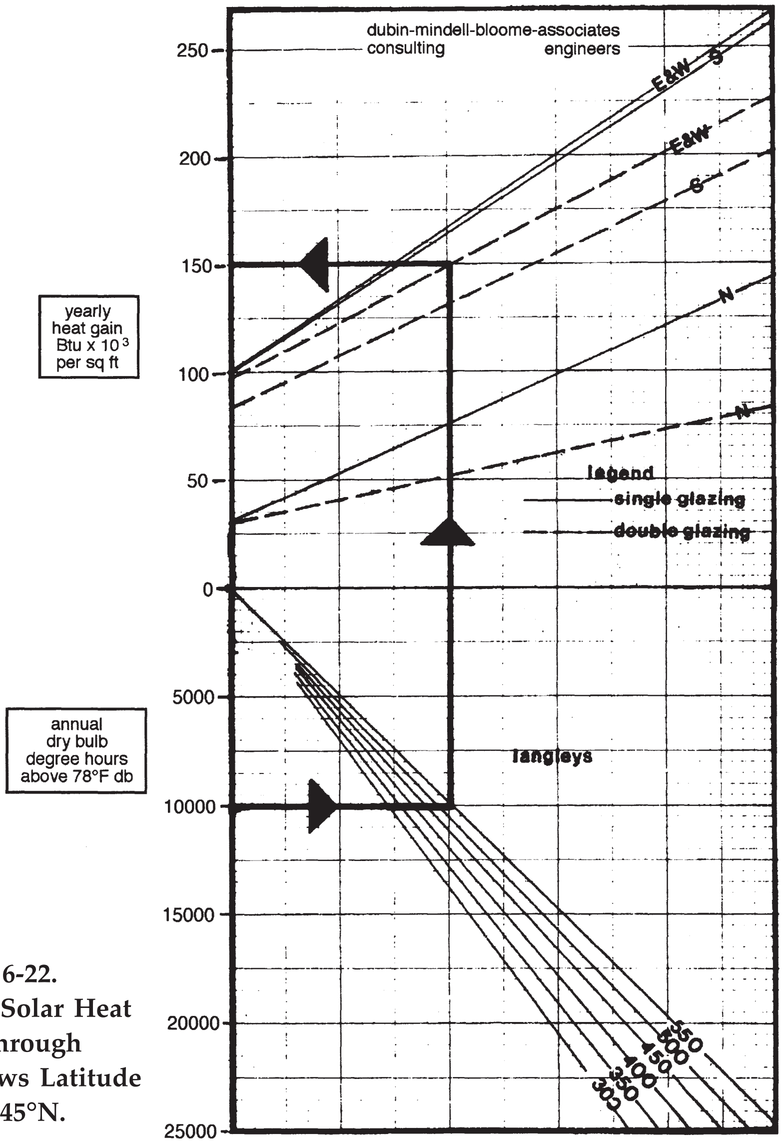


Figure 6-22. Yearly Solar Heat Gain through Windows Latitude 35°N—45°N.

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.

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. 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

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

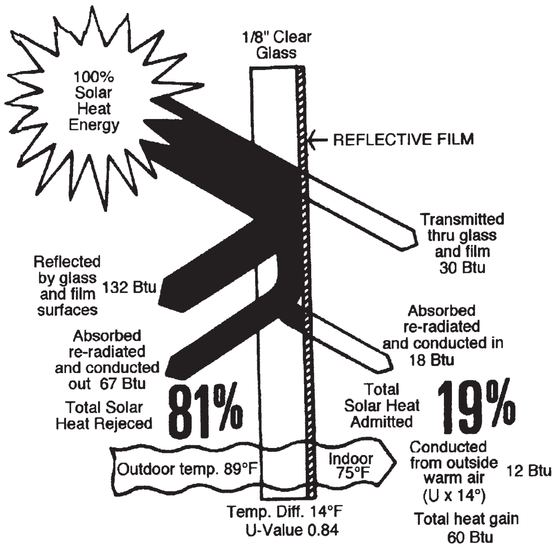


Figure 6-23. Application of Window Film. (Photograph courtesy of 3M Company)

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.

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.

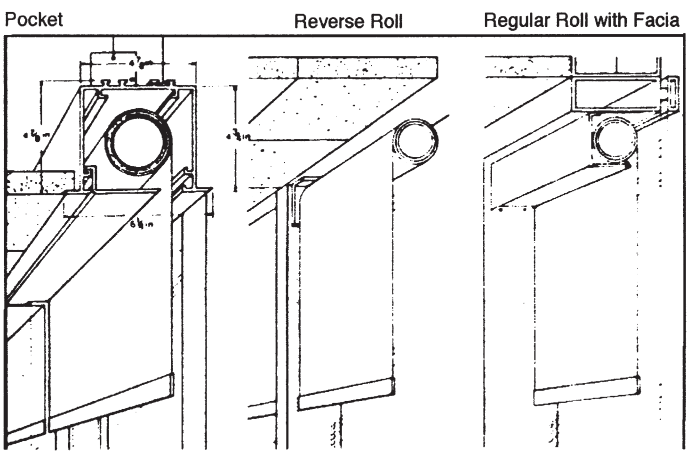


Figure 6-24. Motorized Shade System

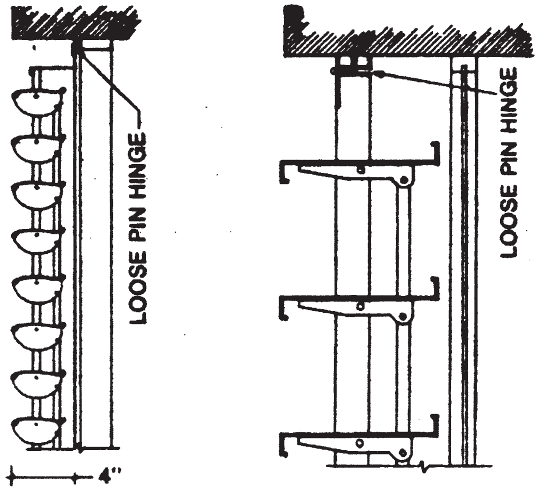


Figure 6-25. Mounting of External Louvers

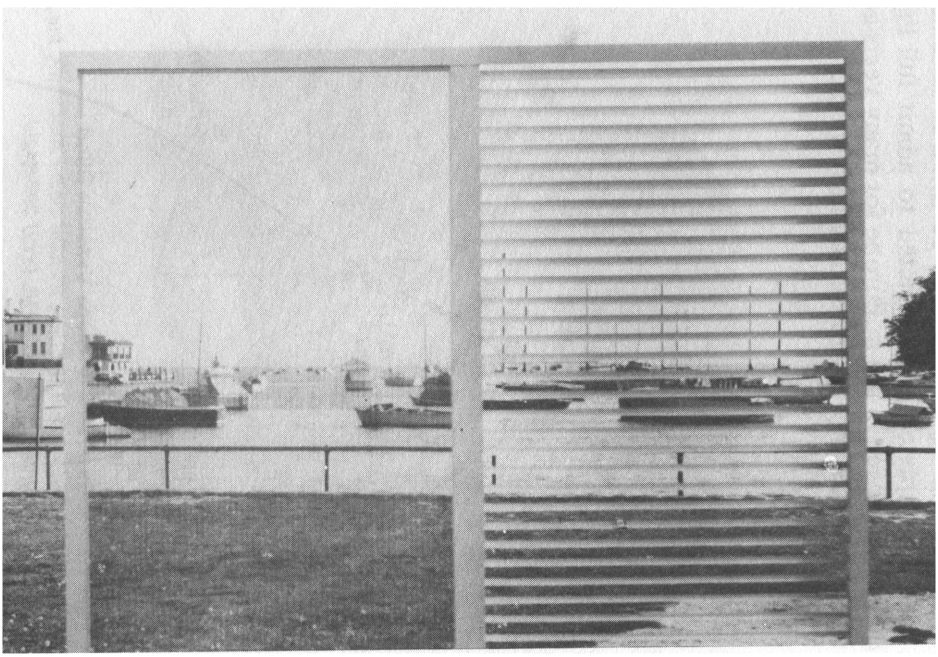


Figure 6-26. Installation of Louvered Solar Screens

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.

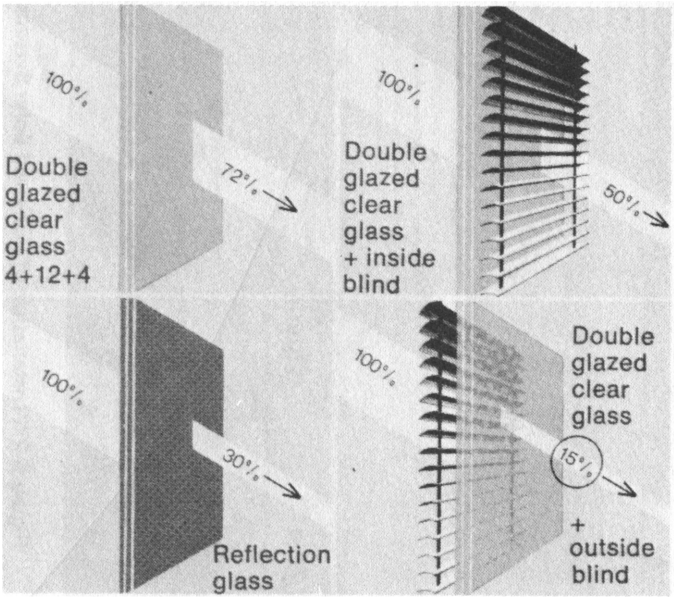
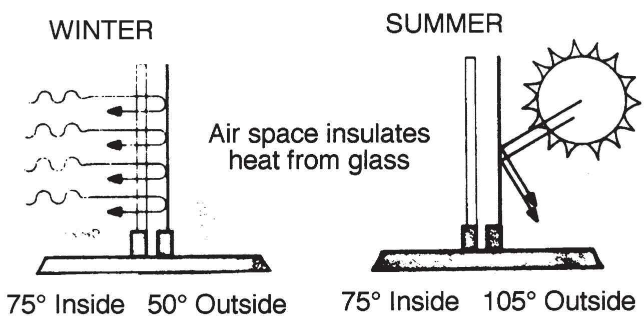


Figure 6-27. Exterior "L"—Type Venetian Blind

Reflective, Perforated Solar Control Laminate

Laminate of metalized weatherable polyester film and black vinyl which is then perforated with 225 holes/in^2, 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.



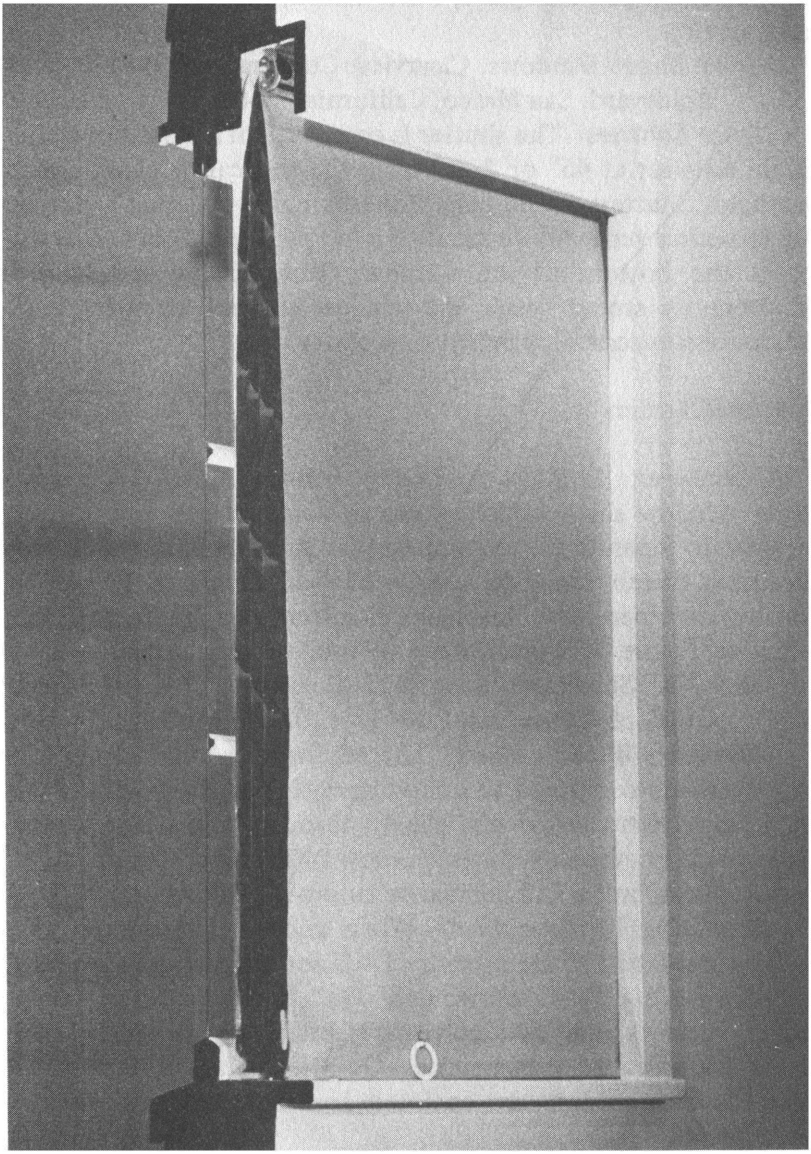
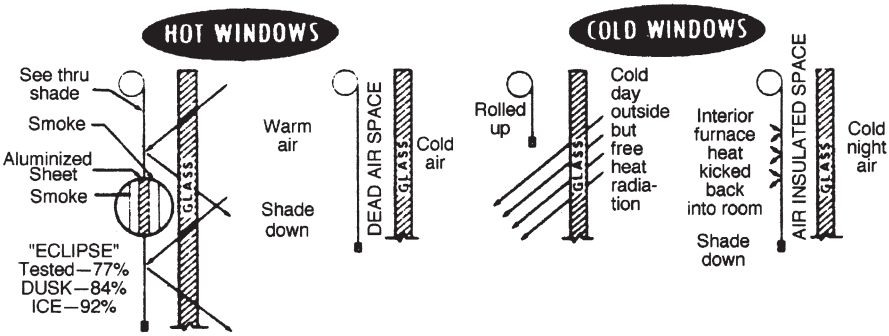


Figure 6-28. Thermal Window Shade Installation

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.

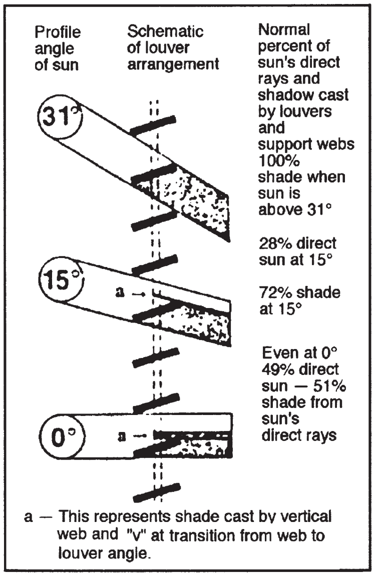


Louvered Metal Solar Screens

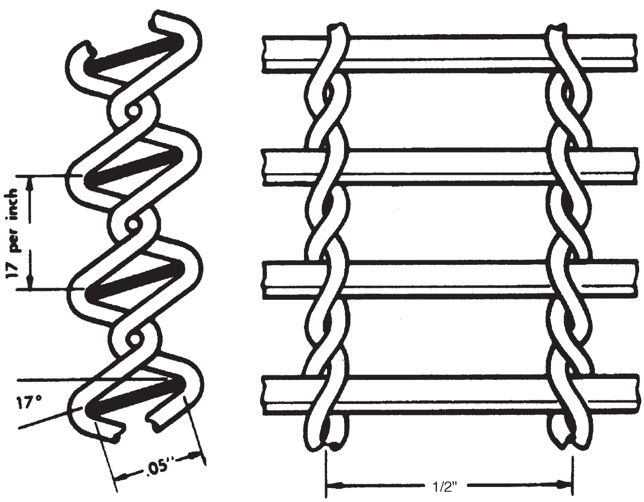
Solar screen consists of an array of tiny louvers which are formed from a sheet of thin aluminum. The louvered aluminum sheet is then installed in conventional screen frames and may be mounted against a window in place of a regular insect screen or mounted away from the building to provide free air circulation 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.



(MAGNIFIED VIEW)



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/ft^2 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.

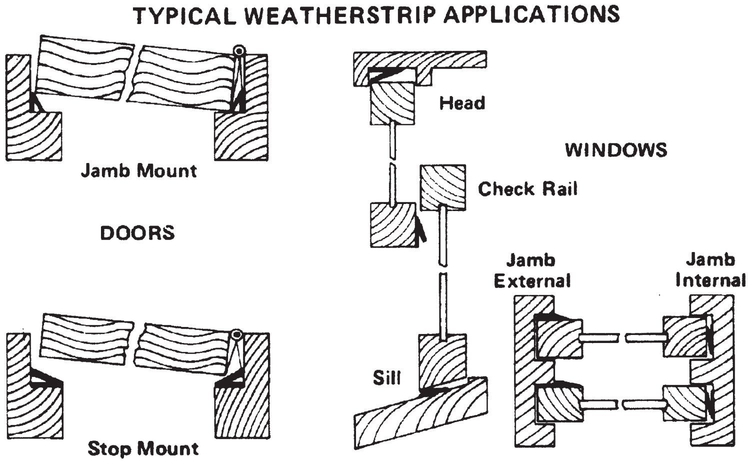
Infiltration

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:

$$Q = \text{cfm} \times 1.08 \times \Delta T \text{ Btu/h}$$

Before change

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

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

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

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

After change in stratification temperature

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

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

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

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

The heating season savings from this project is:

$$(1{,}770{,}000 - 1{,}416{,}000) \text{ Btu/h} = 364{,}000 \text{ Btu/h}$$

The percent savings is:

$$\% \text{ savings} = \frac{364{,}000}{1{,}770{,}000} \times 100 = 20\%$$

Chapter 7

The Electrical System Audit

The 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 × # of fixtures/1000 = Existing kW)
   - Calculate Power Density (kW × 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 × annual hours × $/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) × hours of operation = kWh
   - Calculate energy cost savings (kWh × $/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 candles

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.

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

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 Kelvins. Incandescents have a low color temperature (~2800K) and have a red-yellowish tone; daylight has a high color temperature (~6000K) and appears bluish. Today, the phosphors used in fluorescent lamps can be blended to provide any desired color temperature in the range from 2800K to 6000K.

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.

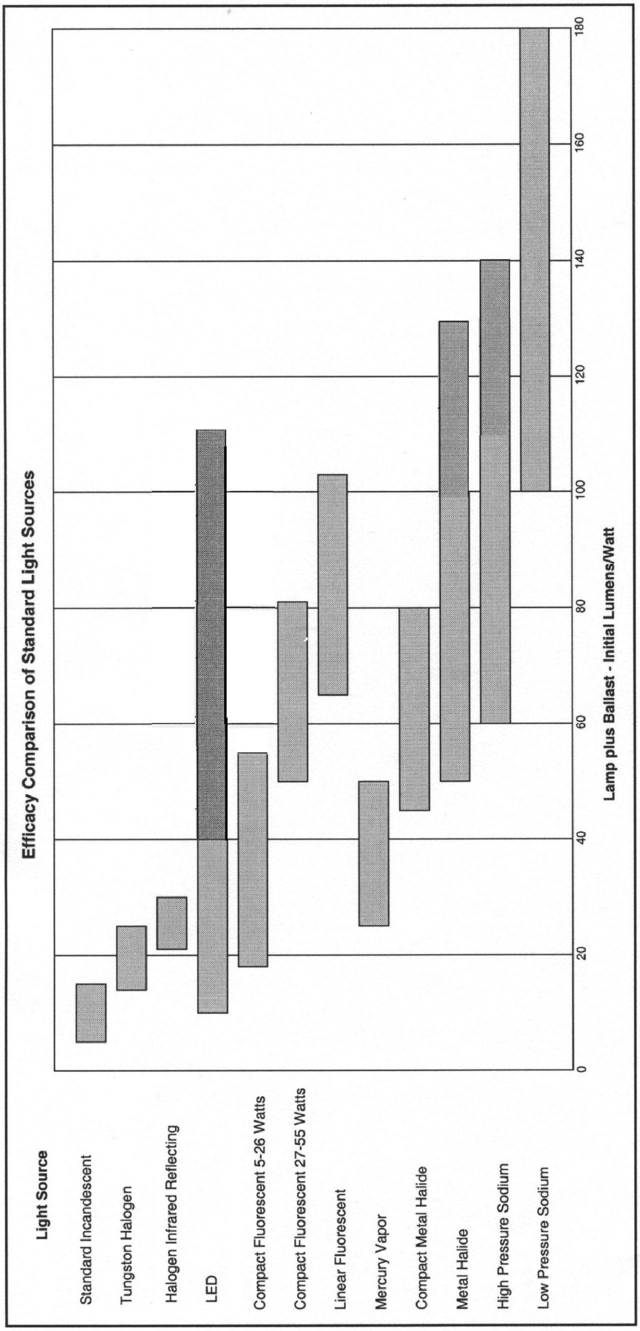

Efficacy Comparison of Standard Light Sources
Light Source
Standard Incandescent
Tungston Halogen
Halogen Infrared Reflecting
LED
Compact Fluorescent 5-26 Watts
Compact Fluorescent 27-55 Watts
Linear Fluorescent
Mercury Vapor
Compact Metal Halide
Metal Halide
High Pressure Sodium
Low Pressure Sodium
0
20
40
60
80
100
120
140
160
180
Lamp plus Ballast - Initial Lumens/Watt

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 fight 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

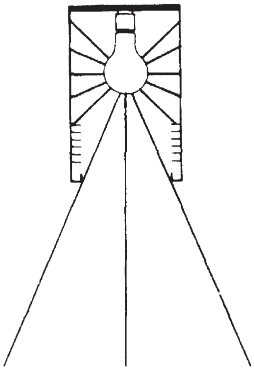
Parabolic aluminized reflector (PAR) lamps are reflector lamps with a lens of heavy, durable glass, which makes them an appropriate choice for outdoor flood and spot lighting. They are available in 75, 150, and 250 watts. They have longer lifetimes with less depreciation than standard incandescents.

ER Lamps

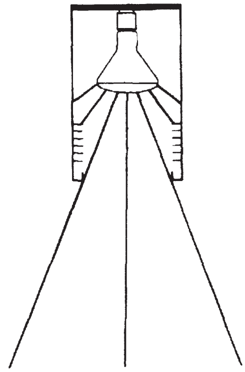
Ellipsoidal reflector (ER) lamps are ideally suited for recessed fixtures, because the beam of light produced is focused two inches ahead of the lamp to reduce the amount of light trapped in the fixture. In a directional fixture, a 75-watt ellipsoidal reflector lamp delivers more light than a 150-watt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

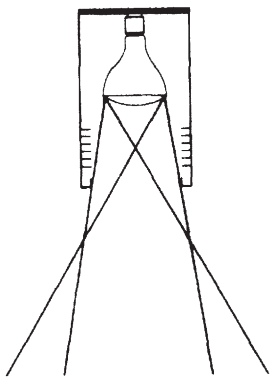
Fluorescent lamps have made dramatic advances in the last 10 years. From the introduction of reduced wattage lamps in the mid-



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 and T-5 lamps are generally considered the industry standard. Both have lumen maintenance of 90-95% at end of life, and efficacies of around 100 L/W. These lamps have steadily moved from 28 to 25W, and even lower as more recognition is made that we have too much light in many buildings and facilities. On the other hand, a common lamp in use today is the Super T-8 which is a full 32 W lamp with about 3300 lumens of light output. This lamp is often the only lamp for which a given utility might offer a rebate. The lamp is physically robust and is not significantly affected by vibration and temperature extremes. Two super T-8s will almost always replace four old T-12s, and are even used to replace three standard T-8s in cases where the light level is excessive.

New LED troffers to replace older troffers are now available. One company makes a 5000 lumen LED troffer that has an efficacy of 100 L/W, a CRI of 93, and lumen maintenance of over 80% at its end of life at 50,000 hours. Lamp efficacy now ranges from about 65 lumens per watt to over 100 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.

Recently there has been a lot of interest in induction lamps, a special form of fluorescent lamps. These lamps do not have direct electrical pin contacts, but are started and run with electromagnetic coils. This starts, and runs, the lamp more gently, and thus the lamps last much longer. Current guarantees for these lamps are for 100,000 hours of lamp and ballast life. These lamps are about 80 L/W efficiency, 80 CRI, and are quite expensive to purchase. However, user experience is showing the 100,000 hour life performance. These are clearly lamps that are very cost effective when it is difficult, expensive, or dangerous to get to the lamp to replace it. Growing applications today seem to be in the areas of parking garages, parking lots, and street lighting.

Metal halide lamps fall into a lamp efficacy range of approximately 50-130 lumens per watt. This makes them more energy efficient than mercury vapor and fluorescent lamps, 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), a pronounced tendency to shift colors as the lamp ages, and often a poor lumen maintenance of only 50%-70% at end of life. In spite of the drawbacks, this source deserves serious consideration and is used very successfully in many applications.

For quote a few years now there has been a big move to replace high bay metal halide and high pressure sodium lamps with T-5 and T-8 fluorescent lamps. Even though the initial lumens for the metal halides is much higher than the T-5s and T-8s, the lumen depreciation for many of the metal halides is very poor, being less than 50% at end of life. So, in terms of maintained lumens, the T-5s and T-8s do have an advantage. However, the main advantage of T-5s and T-8s is in their opportunities for savings through lighting control systems such as occupancy sensors, dimmable ballasts and bank switching. Just being able to turn lights off—of down—at breaks and at lunch produces significant savings. Also, being able to turn lights off in warehouses and storage areas when one is there is a huge opportunity for saving lighting energy.

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 possible 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 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.

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

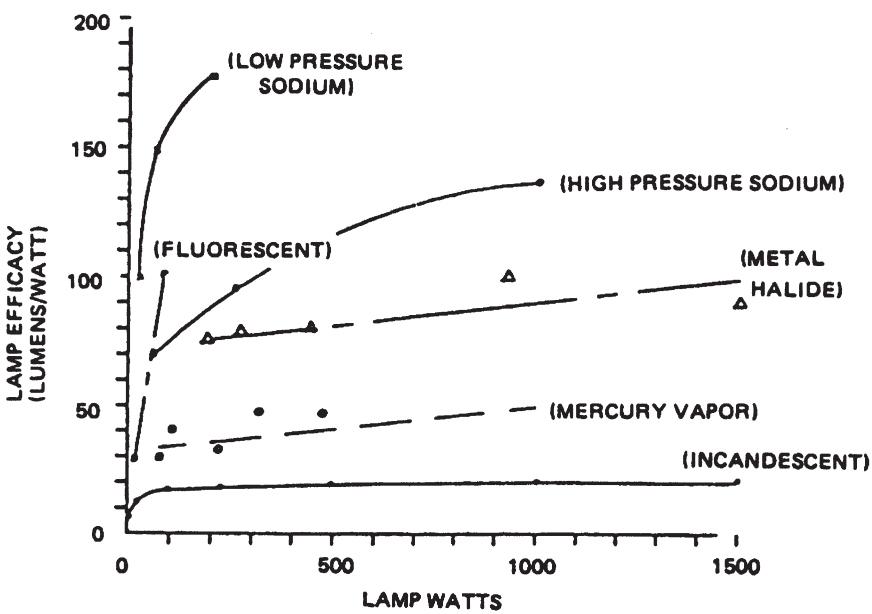


Figure 7-3. Lamp Efficacy
(Does Not Include Ballast Losses)

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 increased efficacy, longer life and reduced total cost. The circline lamps are much larger and heavier than the incandescents 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 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.

Table 7-1. Lamp Characteristics

*Lamp Type (Total Input Power)**	*Lamp Power W*	*Light Output (lumens)*	*Lamp Life (hour)*	*Efficacy (/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.

In the last few years, white LEDs have become commercially available in sizes that make them useful for typical incandescent lamp and CFL replacements. Today these white LEDs can easily replace 60 and 75 watt incandescent lamps. Also, several companies are making fluorescent tubes with LEDs in them so that a standard fluorescent tube can be replaced easily with an LED tube of the same size and length. The LED lamps have a potentially long lifetime of about 50,000 hours if they have heat dissipating designs which include some form of heat sinks. Heavy metal ceramic shells, strips of metal, metal plates, liquid cooling, heat pipes, or other devices accomplish this function. Without something of this nature, the LED is going to overheat and fail at an early age. Several LED lighting suppliers are now providing unconditional five-year guarantees for their LED lamps. This is a 43,800-hour guarantee, which is short of 50,000 hours, but not too bad. With this guarantee, you can perform your life cycle cost analysis with this lifetime assured. Just make sure you buy your lamps from a reputable dealer who you think will be around for the next five years.

Lumen maintenance of LEDs should be at least 70% of initial lumens at end of life. Some are even better than 80% at end of life. Many different color temperatures are now available, from warm white to cool white and above. Efficacies now range from 40 to over 100 lumens per watt. One manufacturer's LED lamp, now commercially available, produces 100-110 lumens per watt at their full power of 10 watts, and up to 160 lumens/watt at around 2 watts input power. Several manufacturers currently have LEDs with efficacies of over 200 L/W in the early stages of commercial development. This will only increase over time.

Larger LED lights are also commercially available today. Several companies make LED replacements for 250 W and 400 W metal halide lamps. These are large lamp replacements since they need large heat sinks to keep the LED lamp cool. One of the 400 W metal halide replacements uses about 180 W for the LED. There are fewer lumens produced, but they are typically higher CRI.

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, specified by IES. 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 significantly 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. Fixtures with much higher Cu's are now available, compared to older fixtures in use.

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 burn 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 (L_1) even further. If a group relamping program is used, (L_3) is assumed to be unity.

Figure 7-4 illustrates the effect of dirt build-up on (L_2) for a dust-proof luminaire. Every luminaire has a tendency for dirt build-up. 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

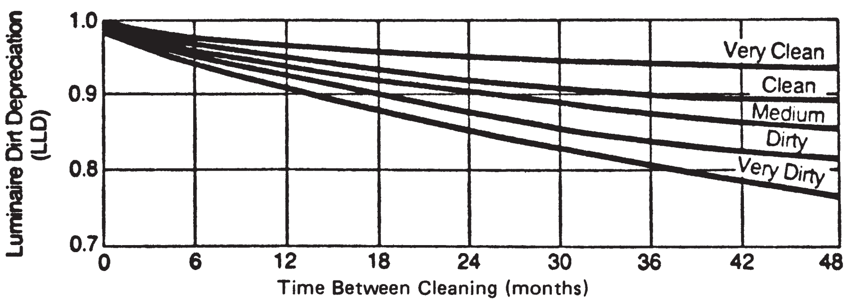


Figure 7-4. Effect of Dirt Build-Up on Dust-proof Luminaires for Various Atmospheric Conditions

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. For modern T-5s and T-8s, the efficacy is now about 100 L/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.

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.

Table 7-2. Performance of F40 Fluorescent Lamp Systems

	Core-Coil		*—Solid-State Ballasts—*				
	2 Lamps,T-12		*2 Lamps,T-12*		*4 Lamps,T-12*		*2 Lamps,T-8*
Characteristic	*40W*	*34W*	*40W*	*34W*	*40W*	*34W*	*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

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.

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.

Table 7-3. Lighting Control Equipment

System	*Remarks*
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.

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 sensored.

Switched compensators control the light level using a manually operated wall switch. These particular systems are used frequently in residential settings and are commonly known as "dimmer switches."

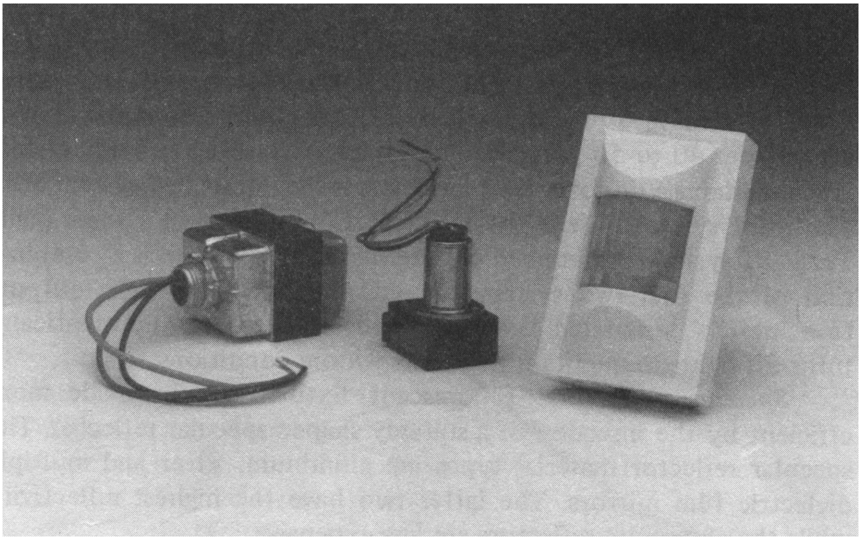


Figure 7-5. Transformer, Relay and Wide View Infrared Sensor to Control Lights (Photograph courtesy of SensorSwitch)

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.

Number of Poles	*Synchronous Speed (RPM)*
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 consists of taking multiple operating speed measurements throughout the day, month or year.

$$\textbf{Motor load in percent} = \frac{(\text{synchronous speed} - \text{measured operating speed}) \times 100}{\text{synchronous speed} - \text{nameplate speed}}$$

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:

$$kW = \frac{(HP) \times (.746\ kW/HP) \times (Motor\ Loading)}{Efficiency}$$

kWh = kW × (Operating Hours)
(If the motor runs at a constant load.)

Example:

Determine the simple payback realized by replacing the following motor with an energy efficient one. The motor load factor is 0.70.

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.

$$kW = \frac{(50) \times (.746\ kW/HP) \times .7}{.902} = 28.9\ kW$$

kWh = (28.9 kW) × (4,500 hours/year) = 130,050 kWh/year

Energy cost = (130,050 kWh/year) × ($.05/kWh) = $6,502/year

Demand charges = (28.9 kW) × ($10/kW-mo) × (12 mo/year)
= $3,468/year

Total operating cost $_{\text{existing motor}}$ = \$6,502 + \$3,468 = \$9,970/year

Calculate the operating cost of the energy efficient motor. Note that the only thing that changes is the efficiency.

$$\text{kW} = \frac{(50) \times (.746\ \text{kW/HP}) \times .7}{.945} = 27.6\ \text{kW}$$

kWh = (27.6 kW) × (4,500 hours/year) = 124,200 kWh/year

Energy Cost = (124,200 kWh/year) × (\$.05/kWh) = \$6,210/year

Demand Charges = (27.6 kW) × (\$10.00/kW-mo) × (12 mo/year)
= \$3,312/year

Total operating cost $_{\text{energy efficient motor}}$ = \$6,210 + \$3,312 = \$9,522/year

Total operating costs savings = Existing motor operating cost
– new motor operating cost
= \$9,970/year - \$9,522/year = \$448/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

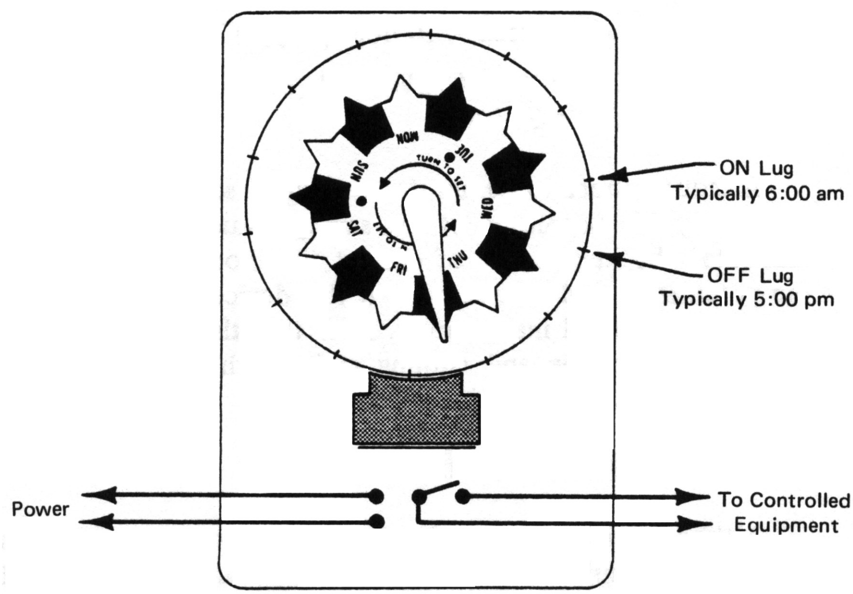


Figure 7-6. Mechanical Timeclock

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 weeks × 7 days/week × 24 hours/day = 8736 hours

Annual Operation After Timeclock =

52 × (5 days/week × 10 hours/day) = 2600 hours

Savings = 130 hp × 0.746 kW/hp × (8736-2600) hours × $0.08/kWh = $47,600

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 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 periods of time to control demand, affect productivity or comfort.

To prevent excessive cycling of equipment, most energy manage-

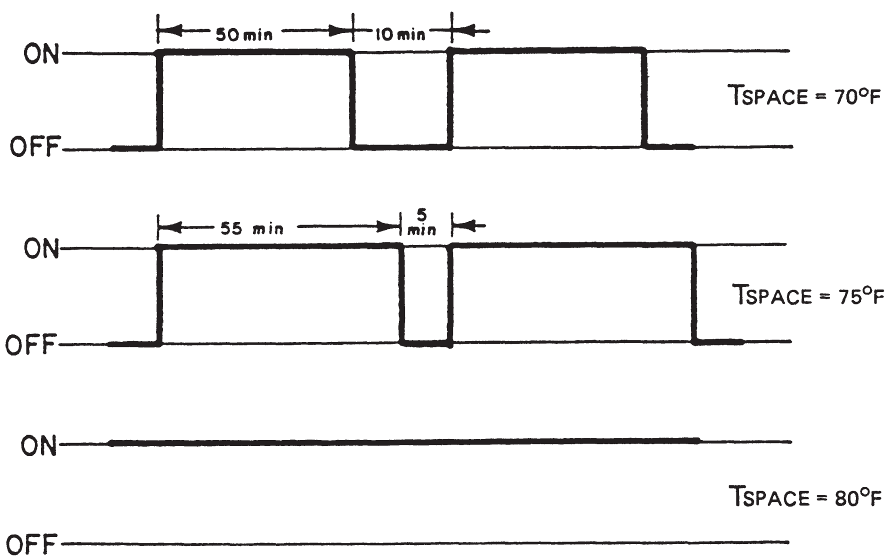


Figure 7-7. Temperature Compensated Duty Cycling

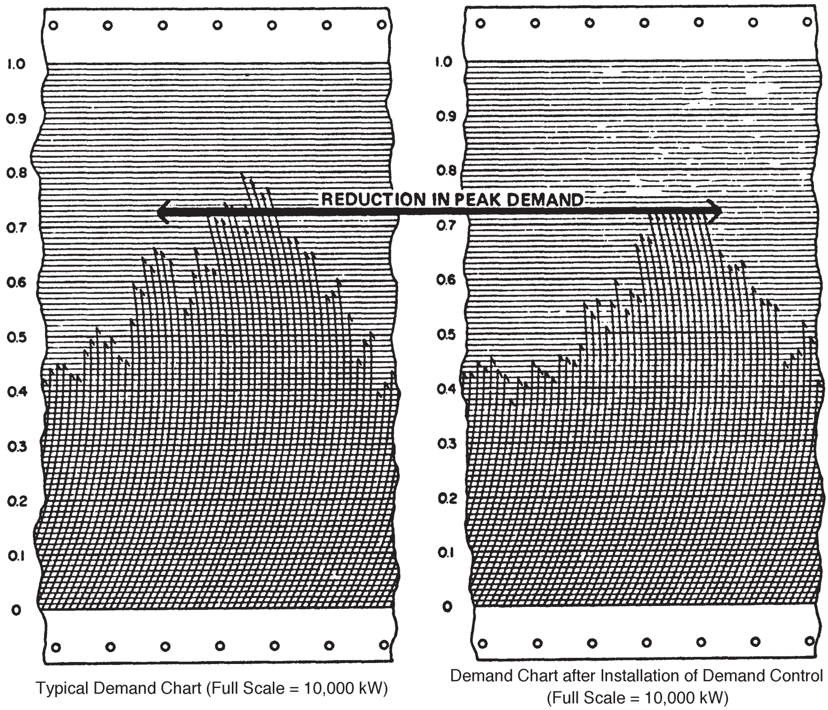


Figure 7-8. Demand Limiting Comparison

ment 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

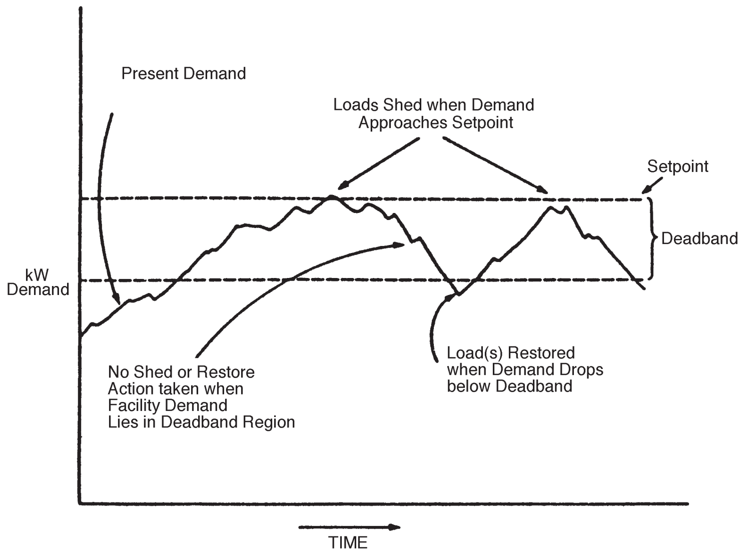


Figure 7-9. Demand Limiting Actions

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.

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 7:00 a.m. or even later, thereby saving significant amounts of energy.

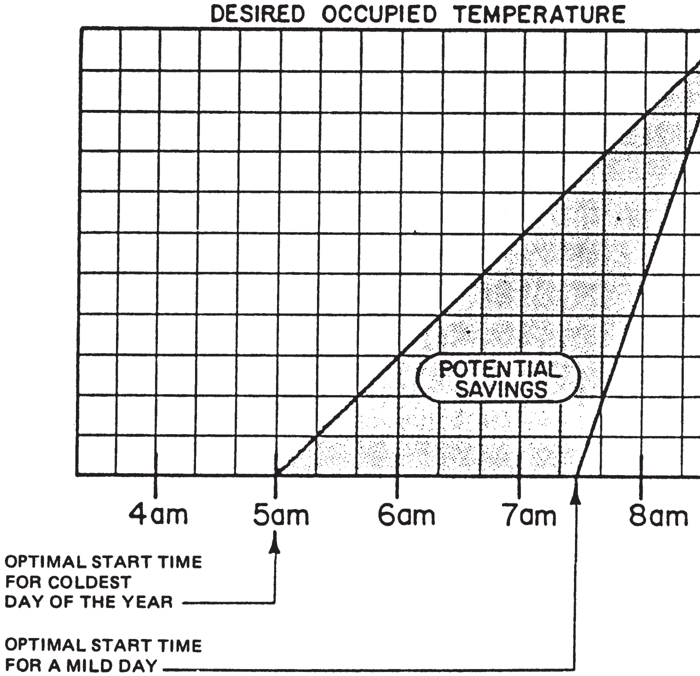


Figure 7-10. Typical Variation in Building Warm-Up Times

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.)

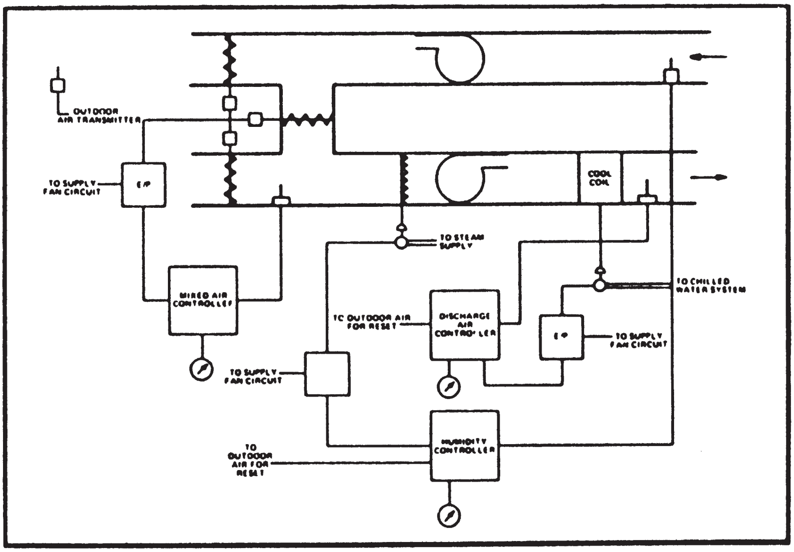
Direct digital control (DDC) has the following advantage over pneumatic controls:

- Reduces overshoot and offset errors, thereby saving energy,

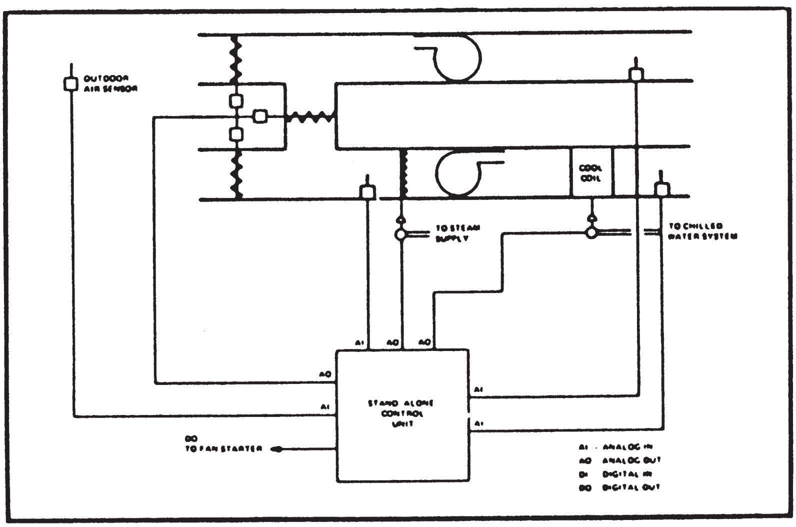
- Flexibility to easily and inexpensively accomplish changes of control strategies.

- 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.



CONVENTIONAL PNEUMATIC CONTROL SYSTEM



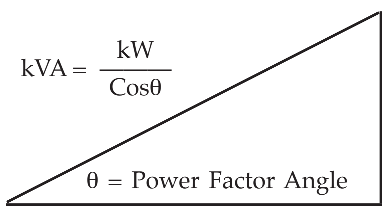
DIRECT DIGITAL CONTROL SYSTEM

Figure 7-11. Comparison of Pneumatic and DDC Controls

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	VAR = Volt Amperes Reactive		
W = Watts	θ = Angle Between kVA and kW		
VA = Volt Amperes	Cosθ = Power Factor		(7-4)

$$\tan\theta = \frac{\text{kVAR}}{\text{kW}}$$

For a balanced 3-phase load

$$\underset{\text{Watts}}{\text{Power}} = \underbrace{\sqrt{3}V_L I_L}_{\text{Volt Amperes}} \underset{\text{Power Factor}}{\text{Cos}\theta} \qquad (7\text{-}5)$$

For a 1-phase load

$$P = V_L\ I_L\ \text{Cos}\theta \qquad (7\text{-}6)$$

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.

$$\text{kVA} = \frac{\text{HP} \times .746}{\eta \times \text{P.F.}} \qquad (7\text{-}7)$$

HP = Motor Horsepower (at full load)
η = Efficiency of Motor (at full load)
P.F. = Power Factor of Motor (at full load)

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.

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

Table 7-4

HP RANGE	*3-30*	*40-100*
η% 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

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 I^2R loss through cables will also be lowered. Table 7-5 can be used to estimate the connective capacitance required. Do not install capacitor banks without first measuring power quality to insure there are no harmonic problems.

SUMMARY

The term energy management system denotes equipment whose functions can range from simple timeclock control to sophisticated building automation.

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.

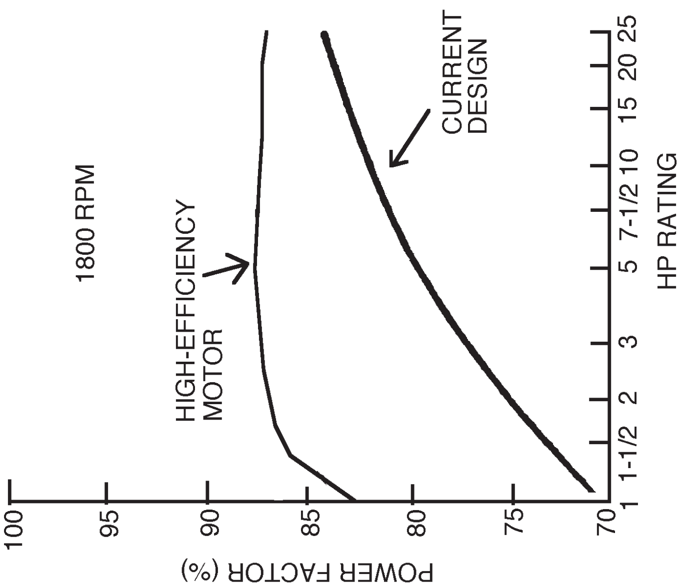


Figure 7-13.
Power Factor vs. Horsepower Rating (Dripproof Motors)

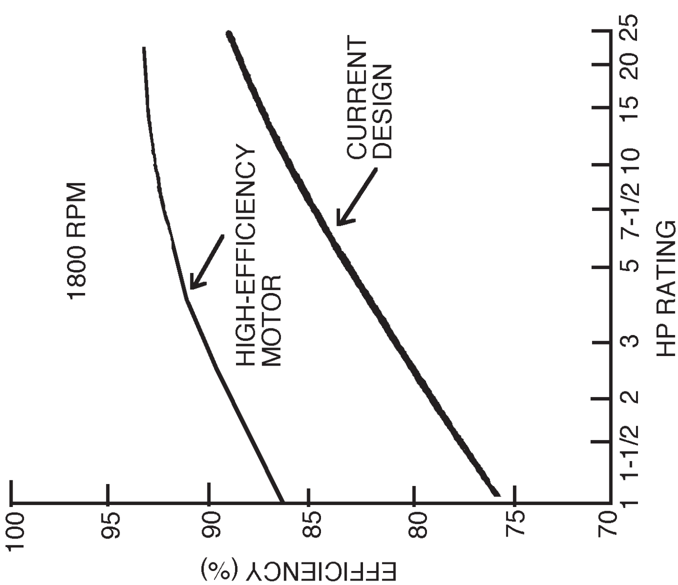


Figure 7-12.
Efficiency vs. Horsepower Rating (Dripproof Motors)

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	L090	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	.928	.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	.937	.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	.620

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 ↔ 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 older ASHRAE ventilation standard, 62-1999 requires 20 cfm/person, if the prescriptive approach is used. The current ASHRAE ventilation standard is 62.1-2010, and is now more complicated since both an occupancy related outside air requirement exists, as well as a space related outside air requirement. For the default condition of 5 occupants per 1000 square feet for an office building, this current standard requires 17 cfm/person. As more people are added to that occupancy, the cfm/person required soon becomes greater than 20 cfm/person.

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.

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) 5.0 μg/m^3 (Chlordane) 2.0 μg/m^3 () 10 μg/m^3 ()	Recommended by the National Academy of Sciences Committee on Toxicology.
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

Specific methods are available for preventing or reducing IAQ concerns. These include:

1. Providing adequate and effective ventilation. This includes complying with the current ASHRAE Standard 62.1-2010. The proper amount of outside air must be brought into the building and the air must be 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.

$$\text{hp (new)} = \text{hp (old)} \times \left(\frac{\text{cfm (new)}}{\text{cfm (old)}} \right)^3 \qquad (8\text{-}1)$$

$$\text{Q (saved)} = \frac{1.08 \text{ Btu}}{\text{Hr} \bullet \text{cfm} \bullet {}^\circ\text{F}} \times \text{cfm (saved)} \times \Delta\text{T} \; \frac{\text{Btu}}{\text{h}} \qquad (8\text{-}2)$$

$$\text{kW} = \text{hp} \times .746/\eta \qquad (8\text{-}3)$$

Where

hp = Motor horsepower (at full load)
cfm = Cubic feet per minute

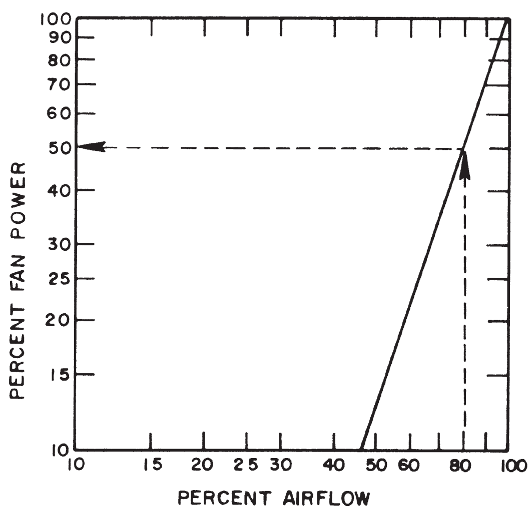


Figure 8-2. Decrease in Horsepower Accomplished By Reducing Fan Speed (Based on Laws of Fan Performance). (Source: NBS Handbook 115 Supplement 1)

ΔT = Average temperature gradient
kW = Motor kilowatts (k = 1000)
η = Motor efficiency

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 heating 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: $4/10^6$ Btu, 5¢ per kWh
- Hours of Operation 5760
- Boiler Efficiency = .65

ANALYSIS

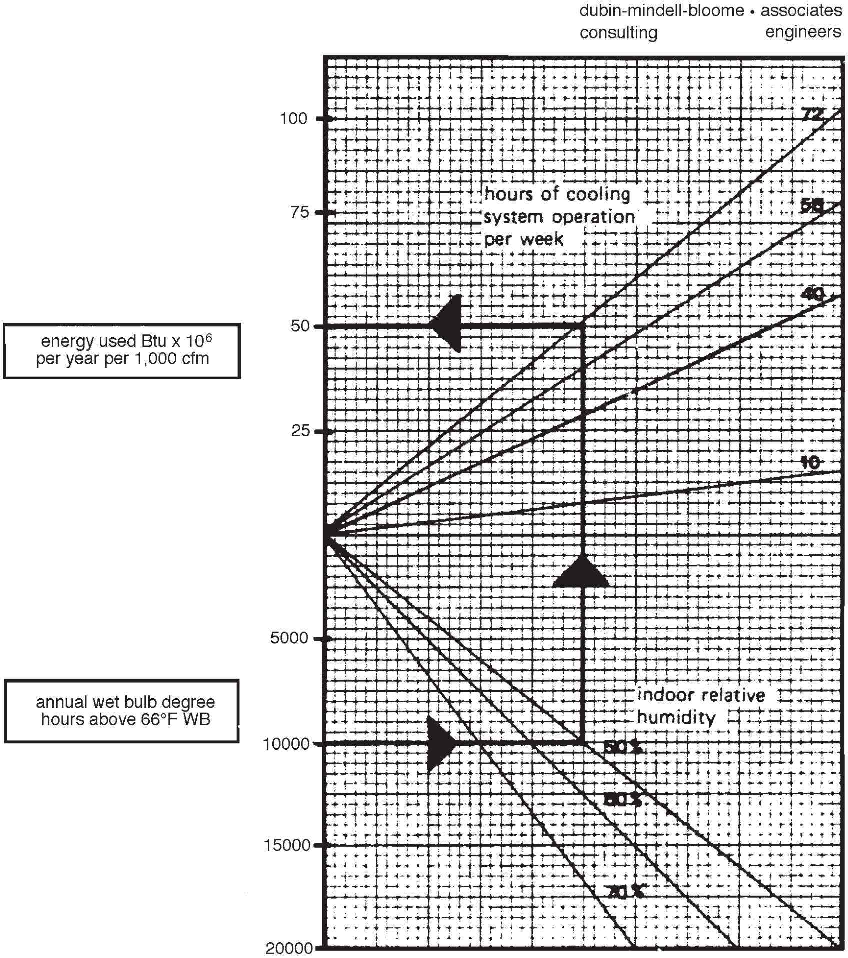
Volume of Warehouse Area = 20 × 150 × 100 = 300,000 ft^3
Present Rate: 4 × 300,000 × 1/60 = 20,000 cfm
Reduced Rate = 2 × 300,000 × 1/60 = 10,000 cfm

Savings Due to Reduced Horsepower

New Horsepower = 20 hp × $(2/4)^3$ = 2.5 hp
Savings Electricity = (20–2.5) × (.746/.8) × 5¢/kWh × 5760 = $4,699.80

Savings Due to Reduced Heat Loss

Average ΔT = 4200 degree-days/240 days = 17.5°F (from 65°F base)
Average Outdoor = 65 – 17.5 = 47.5



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)

Temperature during Heating Seasons

$$Q\ (\text{saved}) = \frac{1.08\ \text{Btu}}{\text{Hr} \bullet \text{cfm} \bullet {}^\circ\text{F}} \times \text{cfm (saved)} \times \Delta T \qquad (8\text{-}2)$$

$$1.08\ (20{,}000 - 10{,}000) \times 17.5 = 189{,}000\ \text{Btu/h}$$

Savings = 189,000 × ($4/$10^6$ Btu/.65) × 5760 = $6698
Total Annual Savings = $4699 + 6698 = $11,397/yr

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 kWh/Ton-Hr.

ANALYSIS

From Figure 8-3
Energy Used per year per 1000 cfm is 22.5 × 10^6 Btu
Energy Saved = (20,000 – 10,000 cfm) × 22.5 × 10^6 Btu
= 225 × 10^6 Btu/Yr

$$\text{Savings} = \frac{225 \times 10^6\ \text{Btu/Yr}}{12{,}000\ \text{Btu/Ton} \bullet \text{Hr}} \times .8\ \text{kWh/Ton} \bullet \text{Hr} \times 5¢/\text{kWh} = \$750/\text{Yr}$$

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.

	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

		24 Hrs or less	Greater than 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

- 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.

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.

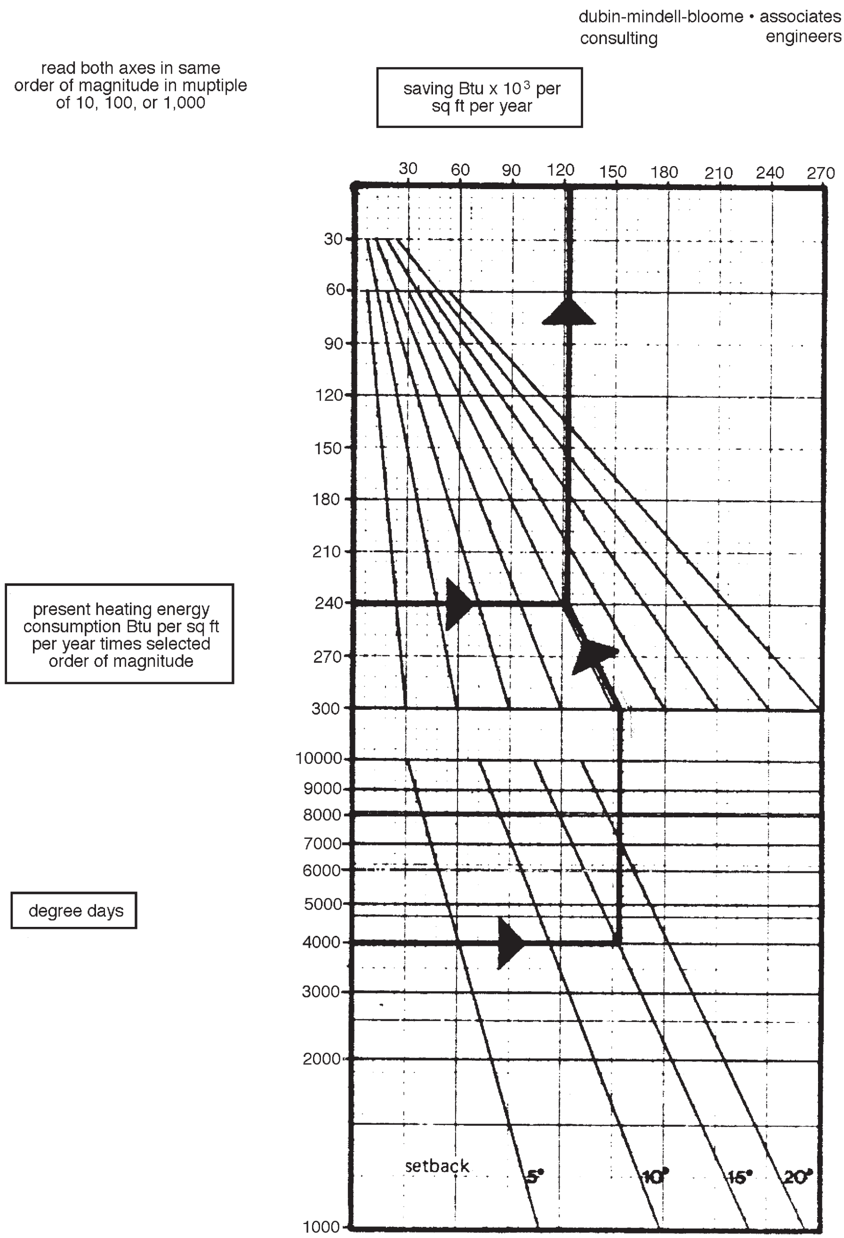


Figure 8-6. Energy Saved for Unoccupied Setback during Winter Months (Source: ***Guidelines for Saving Energy in Existing Buildings*****—Building Owners and Operators Manual, ECM-1)**

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.

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 = $4/10^6$ Btu

Boiler Efficiency = .65

ANALYSIS

From Figure 8-6

Energy Savings is 36,000 Btu/square foot/year

Savings = 36,000 × ($4/10^6$) × 100,000/.65 = $22,153/yr

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	14,656 Btu/Hour/1000 cfm

Savings: (14,656 Btu/Hour/1000 cfm) × 15,000 cfm × ($4/$10^6$ 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 heating 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 = $(65\text{-}35) \times 10^6 \times 10 = 300 \times 10^6$ Btu/Yr

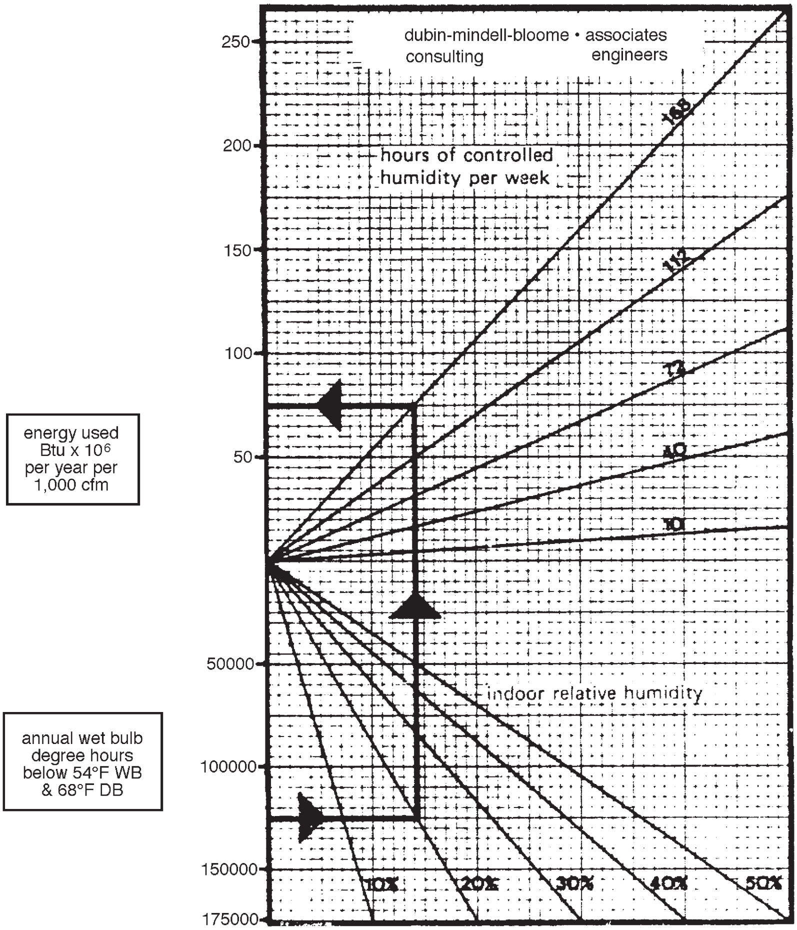
Savings = $(300 \times 10^6 \times \$4/10^6)/.65 = \$1,846$/Yr

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 air conditioning 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 kWh/Ton Hour
Electric rate	5¢ per kWh

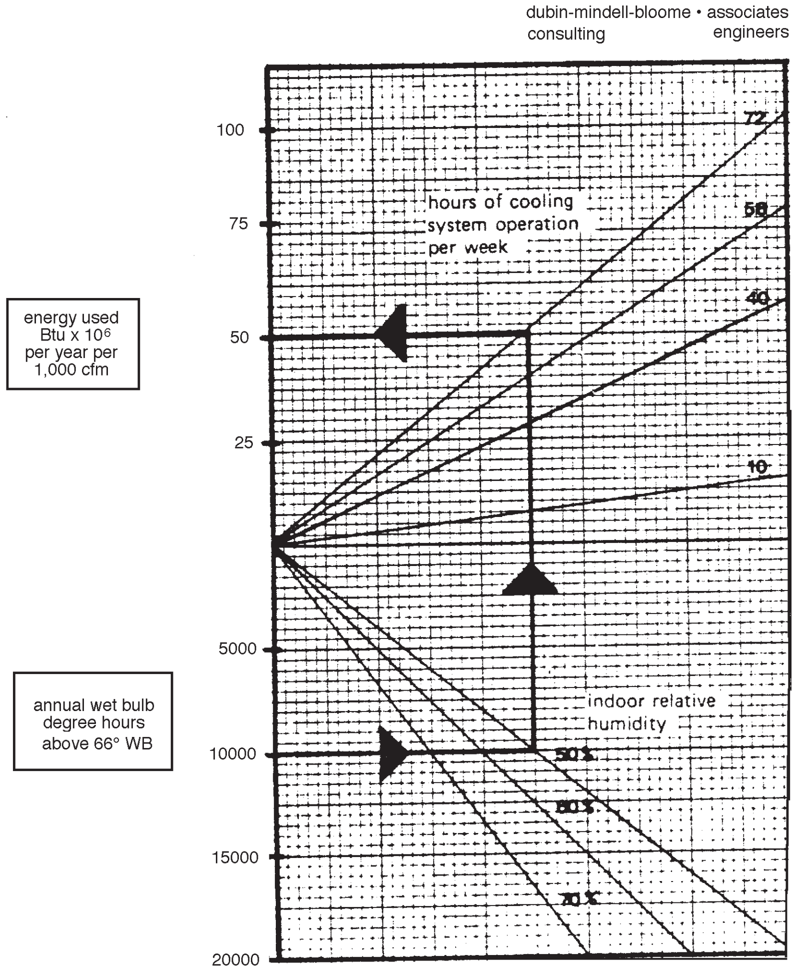


WE degree hours based on 24 hours/day, October—April.
Base Indoor condition for figure is DB=68F, WB=54F, RH=40%.

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 × 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)



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)

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) × 10^6 × 20 = 130 × 10^6 Btu/Yr

$$\text{Savings} = \frac{130 \times 10^6}{12{,}000 \text{ Btu/Ton} \bullet \text{Hr}} \times (.8 \text{ kWh/Ton} \bullet \text{Hr}) \times 5¢/\text{kWh} = \$433/\text{Yr}$$

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

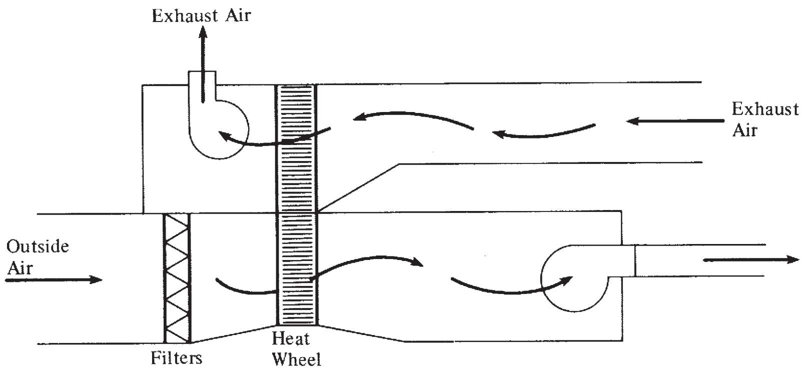
The HVAC Energy Audit should analyze opportunities for recovering energy. To recover heat from exhausts, several devices can be used including the heat wheel, air-to-air heat exchanger, heat pipe and coil run-around cycle. Examples of these systems and devices are illustrated in Figures 8-10 and 8-11.

Heat Wheels

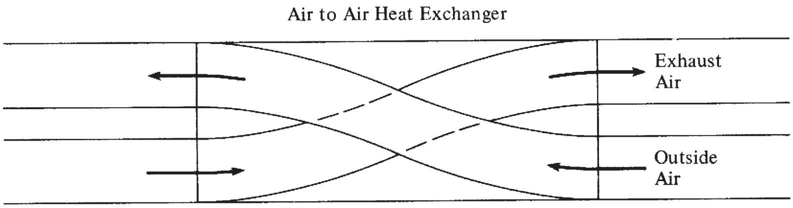
Heat wheels are motor-driven devices packed with heat-absorbing material such as a ceramic. As the device turns by means of a motor, heat is transferred from one duct to another.

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 pas-



HEAT WHEELS



AIR-TO-AIR HEAT PIPES AND EXCHANGERS

Figure 8-10. HVAC Heat Recovery

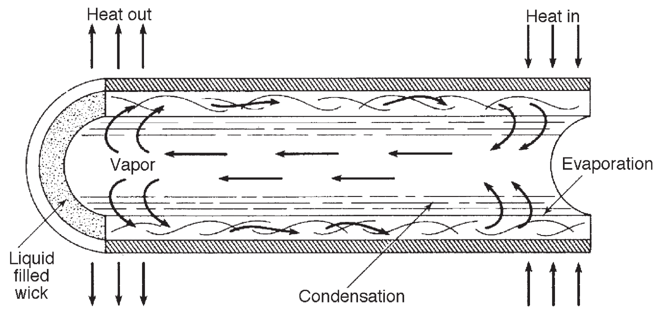
sage carries exhaust air alternating with make-up air. Energy is transmitted by means of conduction through the walls.

Heat Pipes

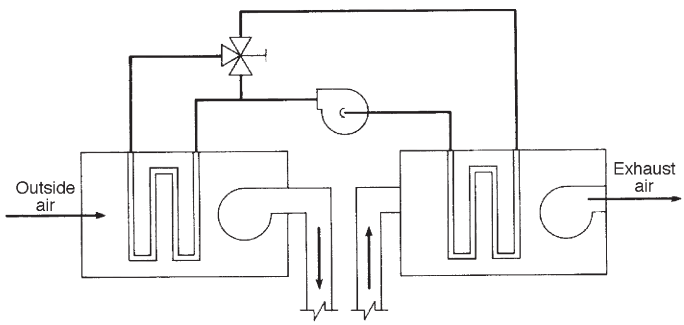
A heat pipe is installed through adjacent walls of inlet and outlet ducts; it consists of a short length of copper tubing sealed at both ends. Inside is a porous cylindrical wick and a charge of refrigerant. Its operation is based on a temperature difference between the ends of the pipe, which causes the liquid in the wick to migrate to the warmer end to 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.



HEAT PIPE



COIL-RUN-AROUND CYCLE

Figure 8-11. HVAC Heat Recovery

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.

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.

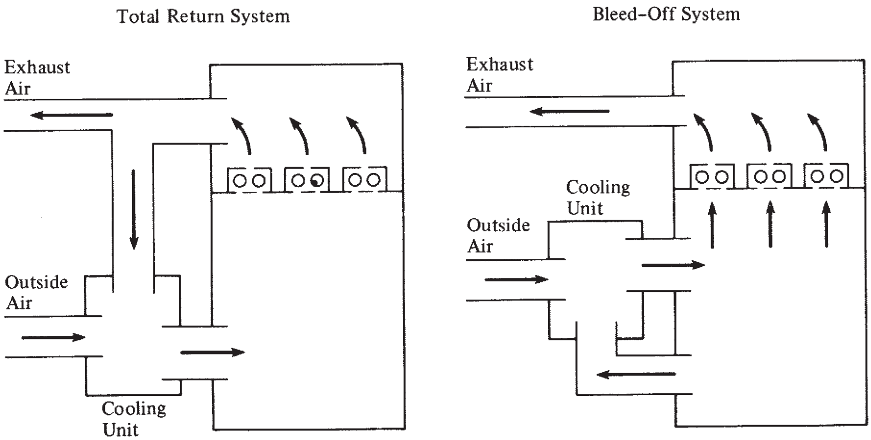


Figure 8-12. Recovery from Lighting Fixtures

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 previously dissipated to the atmosphere. This energy can be used to preheat the domestic water supply for various processes.

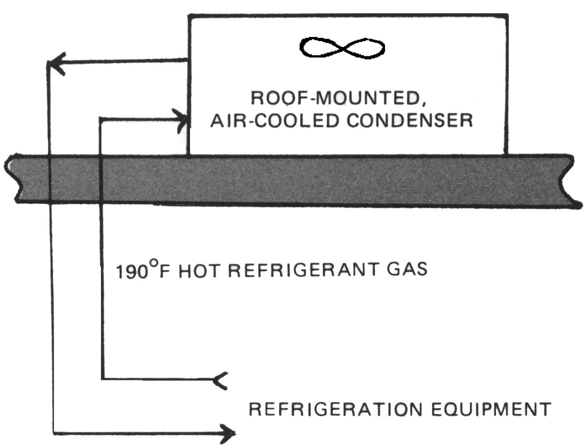


Figure 8-13.

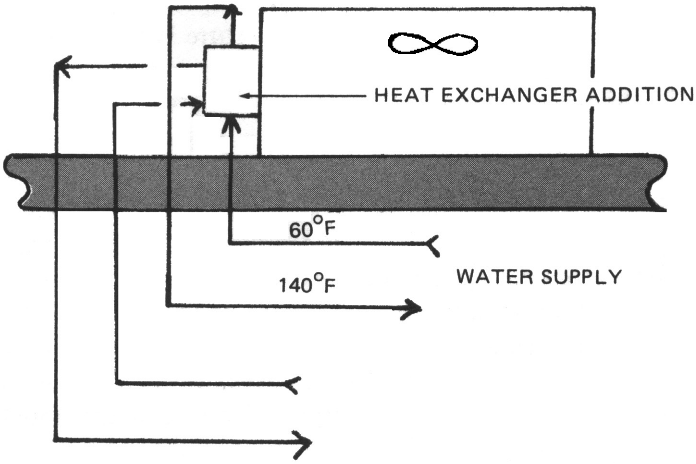


Figure 8-14.

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 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

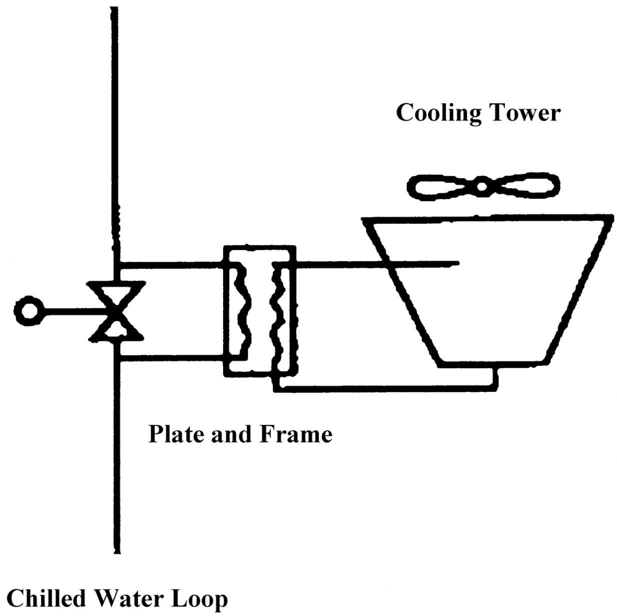


Figure 8-15.

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.

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.

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 compete 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.

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 CO_2. Incomplete combustion can be recognized by a low CO_2 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:

$$\%E = \frac{\text{Heat out of Boiler}}{\text{Heat Supplied to Boiler}} \times 100 \qquad (10\text{-}1)$$

For steam-generating boiler:

$$\%E = \frac{\text{Evaporation Ratio} \times \text{Heat Content of Steam}}{\text{Calorific Value of Fuel}} \times 100 \qquad (10\text{-}2)$$

For hot water boilers:

$$\%E = \frac{\text{Rate of Flow from Boiler} \times \text{Heat Content of Water}}{\text{Calorific Value of Fuel}} \times 100 \qquad (10\text{-}3)$$

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.

$$\text{Flue gas loss} = \frac{K\,(T - t)}{CO_2} \qquad (10\text{-}4)$$

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

CO_2 = percentage CO_2 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.

$$\text{Savings in Fuel} = \frac{\text{New Efficiency} - \text{Old Efficiency}}{\text{New Efficiency}} \times \text{Fuel Consumption} \qquad (10\text{-}5)$$

1. Overall thermal efficiency.. ______
2. Losses due to flue gases
   (a) Dry Flue Gas .... ______

The loss due to heat carried up the stock in dry flue gases can be determined, if the carbon dioxide (CO_2) content of the flue gases and the temperatures of the flue gas and air to the furnace are known.

   (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):

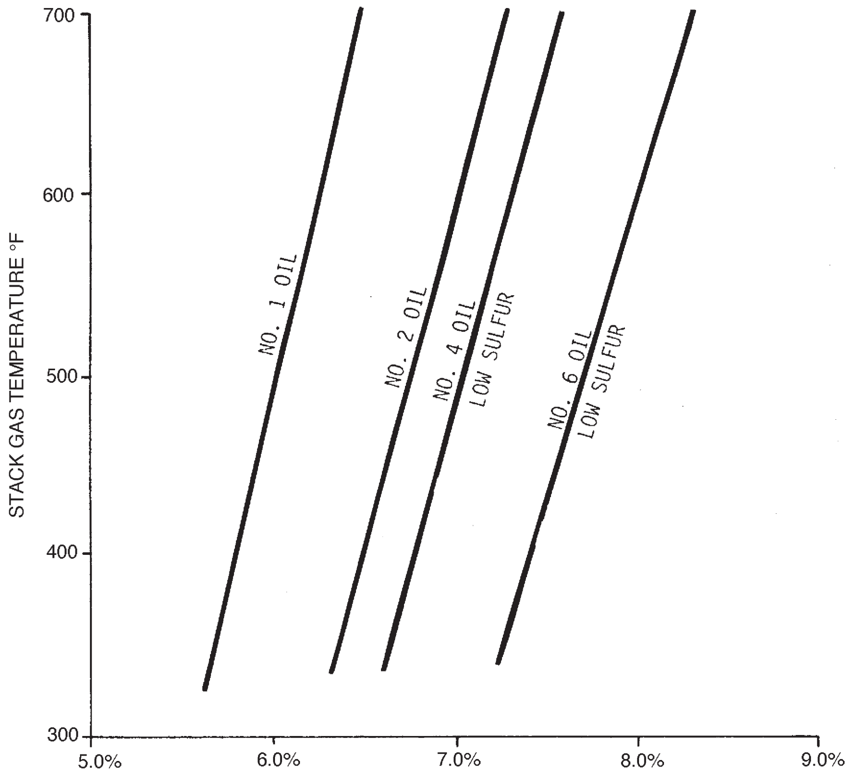
1. Enter the nomograph at the lower horizontal line at the percentage of CO_2 in the flue gas for the fuel being used.

2. Enter the lower left-hand vertical part of the nomograph at the percentage O_2 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.

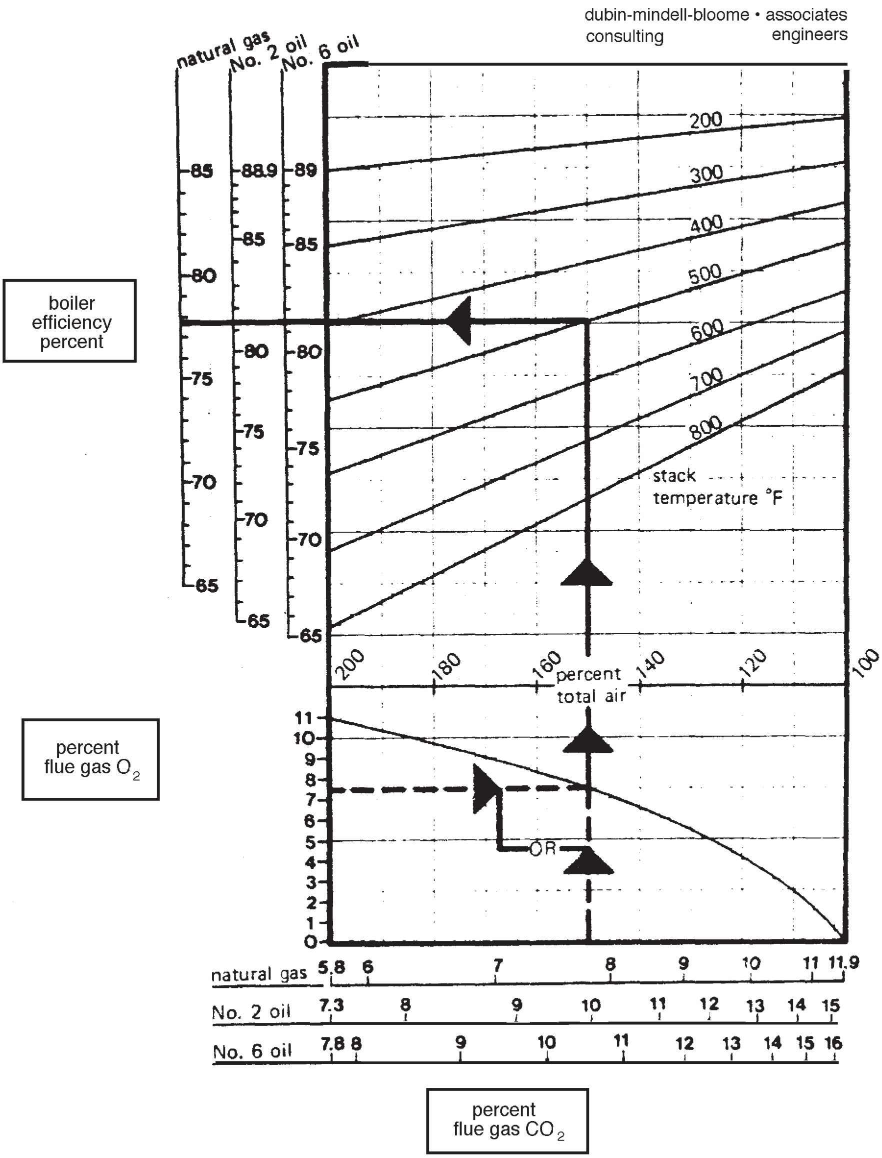


Figure 10-3. Effect of Flue Gas Composition and Temperature on Boiler Efficiency (Source: *Guidelines For Saving Energy in Existing Buildings*—Engineers, Architects and Operators Manual, ECM-21

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 CO_2 and percentage O_2.

Devices are available which continuously measure CO_2 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 O_2 concentrations is useful in judging burner performance more precisely. Due to the increasing utilization of multifuel boilers, however, O_2 analysis is the single most useful criterion for all fuels since the O_2 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 10-4, boiler efficiency will increase by approximately 2 percent for each 100°F added to combustion air tempera-

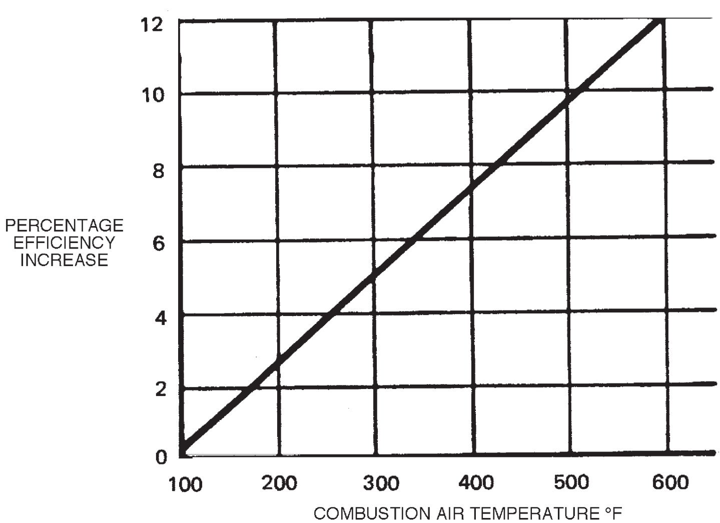


Figure 10-4. Efficiency Increase with Pre-Heated Air

ture. 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

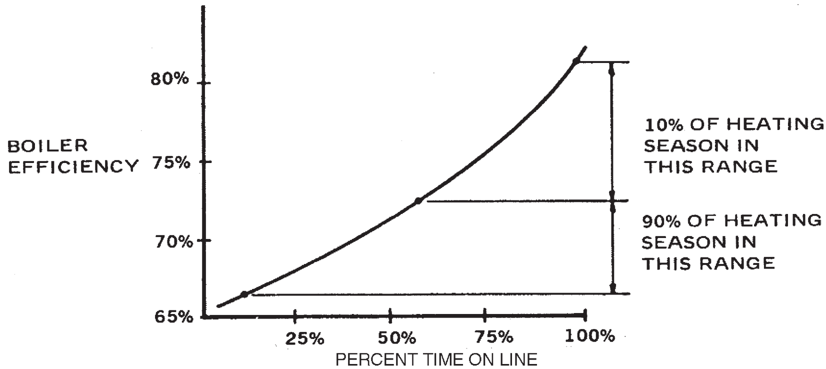


Figure 10-5. Effects of Boiler Cycling

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

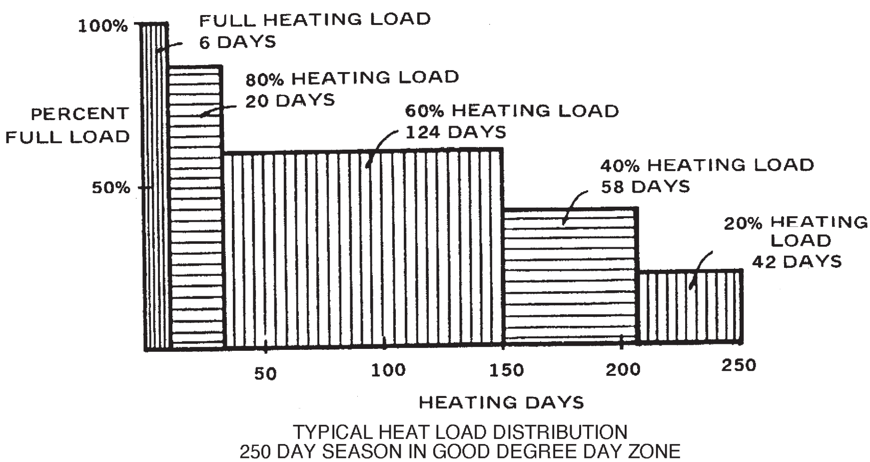


Figure 10-6. Seasonal Heat Load Distribution

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 O_2 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.

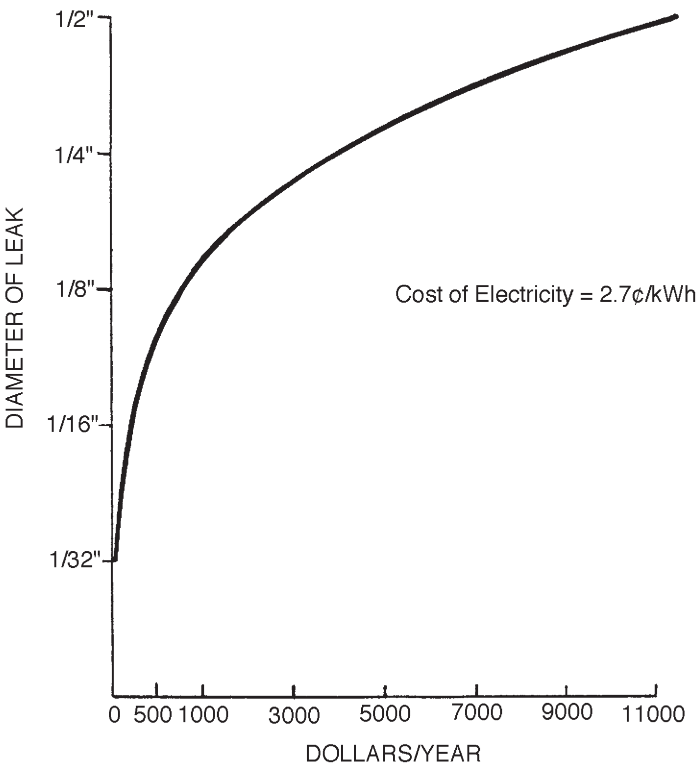


Figure 10-7. Cost of Air Leaks at 100 PSI (Source: *Instructions For Energy Auditors,* Volume II)

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.

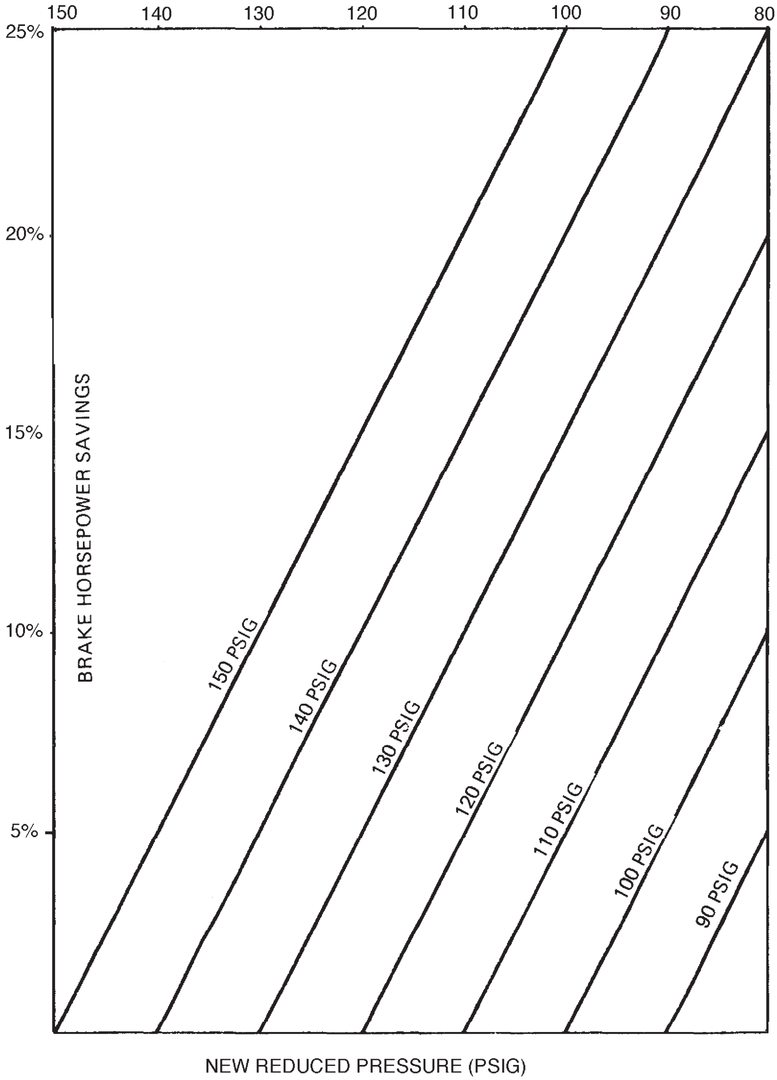


Figure 10-8. Savings with Reduction in Pressure (Source: *Instructions for Energy Auditors*, Volume I)

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

Piping System	*Temperature Range °F*	*Insulation Thickness Inches*
Heating		
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
Cooling		
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.

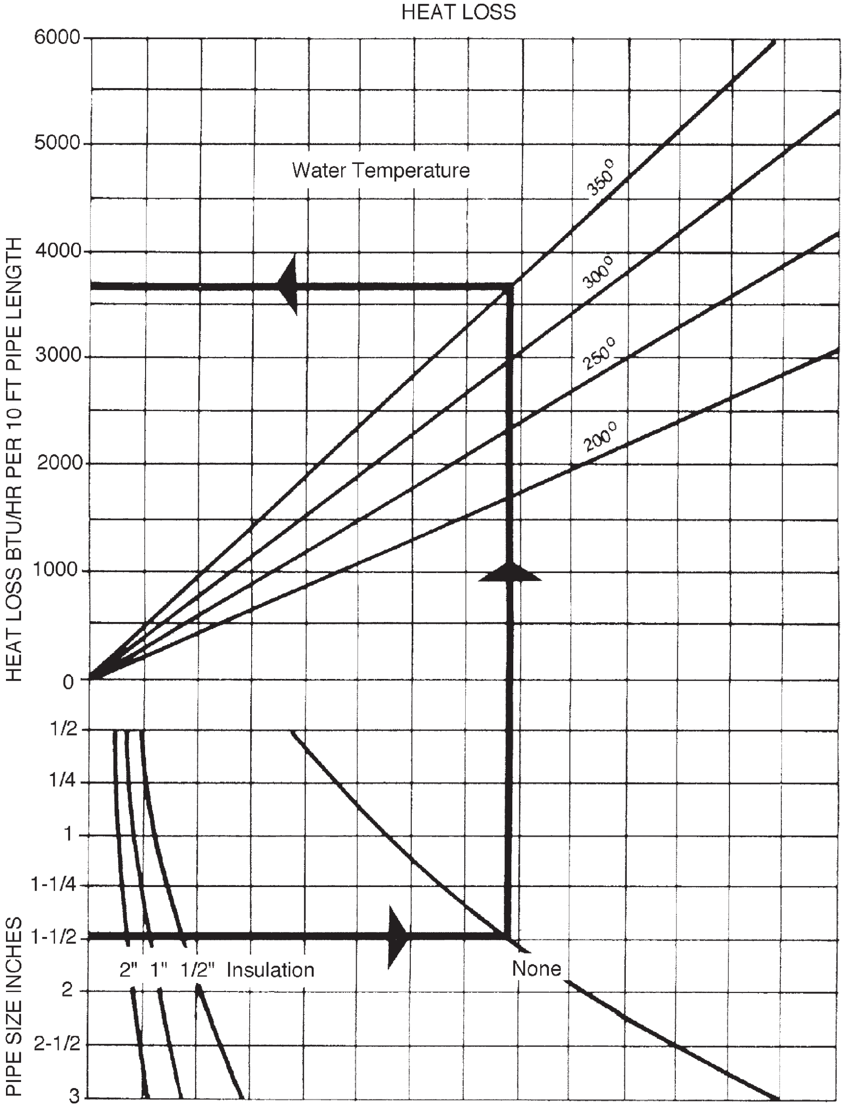


Figure 10-10. Pipe Heat Losses

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 systems 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.

Typical Manufacturer	*Equipment Type*
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 44 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

Daily Weekly Monthly 6 Months Yearly

Mechanic assigned for completion

Billet #	Amount of Time	Date

Figure 12-3. Maintenance Index Card System

	Daily Weekly Monthly 6 Months Yearly		
	Billet #	Amount of Time	Remarks
Jan			
Feb			
Mar			
Apr			
May			
Jun			
Jul			
Aug			
Sep			
Oct			
Nov			
Dec			

Figure 12-4. Recording Performance Comments 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.

	Operations Request	Maintenance			
Date		Date	Code	Billet #	Action Taken

Figure 12-5. Operations Maintenance Log Book

Operation No. ____________

Maintenance Department

Item	Location of Item	Code	Frequency of Maintenance	Est. Time Required	Time of Day	Description of Maintenance

Figure 12-6. Preventive Maintenance Survey Form

System	*Daily Requirements*	*Weekly*	*Monthly*	*Annual*
Blowdown and Water Treatment	• Check that blowdown valve does not leak. • Make sure blowdown is not excessive.		• Make sure that solids are not built-up.	
Exhaust Gases	• Check temperature at two different firings	• Measure exhaust gas temperature and composition at selected firings and adjust to recommended values.	• Same as weekly. • Compare with readings of previous months	• Same as weekly. • Record reference data
Burner	• Check controls are operating properly. • Burner may need cleaning several times daily if #6 fuel is used.	• Clean burner pilot pilot assemblies. • Check condition of spark gap, electrode, burner.	• Same as weekly.	• Same as weekly. • Clean and recondition
Feedwater Systems	• Check & correct unstable water level. • Causes of unstable conditions: contaminants, overload, malfunction.	• Check control by stopping feedwater pump and allow control to stop fuel flow.		• Clean condensate receivers, deaeration system. • Check pumps.
Steam Pressure	• Check for excessive loading on boiler which will cause excessive variations in pressure.			

Air Temperature in Boiler Rooms	• Check that temperature in boiler room is within acceptable range			
Relief Valve		• Check if relief valve leaks.		• Remove and recondition.
Boiler Operating Characteristics		• Observe flame failure system & characteristics of flame.		
Combustion Air Supply			• Check that adequate openings exist for combustion air inlet. • Clean inlet if fouled.	
Fuel System			• Check pumps, filters, pressure gauges and transfer lines. • Clean filters as required.	• Clean and recondition system.
Belts and Packing Glands			• Check belts for proper tension and damage. • Check packing glands for leakage and proper compressions.	
Air Leaks			• Check for leaks around access openings and flame scanner.	

Figure 12-7. Boiler Operations and Maintenance Requirements.

System	*Daily Requirements*	*Weekly*	*Monthly*	*Annual*
Air Leak Waterside & Fireside Surfaces				• Clean surfaces according to manufacturer's recommendations.
Refractor on Fireside				• Repair refractor.
Electrical Systems				• Clean electrical terminals and replace defective parts.
Hydraulic & Pneumatic Valves				• Check all operations and repair all leakages.
Start-Up and Operation				• Check during start-up and operation.
Records	• 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

Conditions	(1) *°F*	(2) *°F*	(3) *Tons*	(4) *%*	(5) *HP*	(6) *HP/T*	(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 prelubricated 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

Diameter	*Steam—lb/hour*		*Water —gals/hour*		*Air SCFM*
of Hole	*100 psig*	*300 psig*	*20 psig*	*100 psig*	*80 Psig*
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

Pipe Dia Inches	*Surface Temp °F*	*Insulation Thickness Inches*	*Heat Loss (Btu/Ft/Hr) Uninsulated*	*Insulated*	*Insulation Efficiency*
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

The 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 5 1 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
2. Door
3. Ceiling
4. Wall
5. Roof
6. Storage Area
7. Shipping and Receiving
8. Illumination
9. Food Area
10. Heat Generation
11. Heat Distribution
12. Cooling Generation
13. Cooling Distribution
14. Electrical Power Distribution
15. Hot Water Service
16. Laundry
17. Compressed Air
18. Water
19. Process Heating
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 NAME Anywhere

SHEET NO. 1

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
			WINDOW CONDITIONS																		
			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.

Range of Rating Score	*Action Required*
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 ______________

DATE ______________

UNIT NAME ______________

SHEET NO. ______________

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																					

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																		
				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
No.	Location		Rating Value Max. = 10	2	1	1	0	2	1	0	2	1	0	1								
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.

SELF-EVALUATING CHECKLIST FOR CEILINGS

EVALUATOR ____________

DATE ____________

UNIT NAME ____________

SHEET NO. ____________

				CEILING CONDITIONS																	
				Drop Ceiling	Insulated Drop Ceiling	Insulated Reg. Ceiling	Space Not Mech. Vented	All Panels in Place	Panels Broken	Panels Missing											TOTAL POINTS
No.	Location		Rating Value Max. = 6	1	1	1	1	2	1	0											
1																					

WALL RATING INSTRUCTIONS

3 points if wall is designed to resist outside temperature differential. Insulation is present to substantially change heat transfer time.
0 points if wall is merely a physical separation without adequate insulating qualities.
2 points if outside wall surface has solar protection such as light finish, is heavily shaded or has physical sun screens.
2 points if surfaces of walls are in good repair and not damaged.
1 point if inside is in average condition with a few small cracks in the surface and smaller plaster sections missing.
0 points if wall has openings to unconditioned space; i.e., plumbing or duct openings not closed.

SELF-EVALUATING CHECKLIST FOR EXTERIOR WALLS

EVALUATOR ____________

DATE ____________

UNIT NAME ____________

SHEET NO. ____________

				WALL CONDITIONS																	
				Insulated	Not Insulated	Solar Protection	Watertight	Cracked or Broken	Open to Noncondition Sp.												TOTAL POINTS
No.	Location		Rating Value Max. = 7	3	0	2	2	1	0												
1																					

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 ________________

DATE ________________

UNIT NAME ________________

SHEET NO. ________________

			ROOF CONDITIONS																		
			Dry Insulation	Wet Insulation	Reflective Surface	Ventilation Under Roof	No Leaks	Small Leaks	Many Leaks												TOTAL POINTS
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.

SELF-EVALUATING CHECKLIST FOR STORAGE AREAS

EVALUATOR ______________

DATE ______________

UNIT NAME ______________

SHEET NO. ______________

No.	Location	Rating Value Max. = 6	STORAGE AREA CONDITIONS: Not Conditioned	Door Closed	No Windows	One Window	Two or More Windows	Used as Designed	Not Used as Designed												TOTAL POINTS
			1	1	2	1	0	2	0												
1																					

SHIPPING AND RECEIVING AREA RATING INSTRUCTIONS

3 points	if the shipping and receiving area is well protected from outside temperature.
1 point	if the shipping and receiving area is reasonably protected from outside air entry.
0 points	if the shipping and receiving area has no protection from the ambient. This would be an open area directly exposed to the outside conditions.
1 point	if individual truck stalls exist so the unused areas can be closed.
0 points	if one large area exists and the entire dock must be exposed if a single truck is loaded or unloaded.
1 point	if the doors are closed when not in use.
0 points	if the doors are left open as a matter of convenience.
1 point	if the area does not receive conditioned air.
0 points	if the area receives conditioned air.

SELF-EVALUATING CHECKLIST FOR RECEIVING AREAS

EVALUATOR ______________

DATE ______________

UNIT NAME ______________

SHEET NO. ______________

No.	Location	Rating Value Max. = 6	SHIPPING AND RECEIVING CONDITIONS: Weather Prot. Good	Weather Prot. Average	Weather Prot. Poor	Individual Stalls	One Large Area	Doors Closed	Doors Opened	Not Temp. Cond.	Temp. Cond.										TOTAL POINTS
			3	1	0	1	0	1	0	1	0										
1																					

ILLUMINATION RATING INSTRUCTIONS

1 point	if extensive decorative fighting 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 ________________

DATE ________________

UNIT NAME ________________

SHEET NO. ________________

				ILLUMINATION CONDITIONS																		
				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
No.	Location		Rating Value Max. = 10	1	1	0	2	1	0	2	1	0	1	0	1	1	1	0				
1																						

*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

Task or area	*Foot-candle levels*	*How measured*
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.

Task or area	*Foot-candle levels*	*How measured*
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 ____________

DATE ____________

UNIT NAME ____________

SHEET NO. ____________

FOOD AREA CONDITIONS

No.	Location		Rating Value Max. = 15	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. Aver	Refrig. Equip. Poor	Heat Recovery System				TOTAL POINTS
				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 beat generation is controlled by a system using an economizer system by comparing inside and outside temperature.

SELF-EVALUATING CHECKLIST FOR HEAT GENERATION

EVALUATOR ____________

DATE ____________

UNIT NAME ____________

SHEET NO. ____________

				HEAT GENERATION CONDITIONS																	
				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
No.	Location		Rating Value Max. = 17	2	1	0	2	2	1	0	1	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
No.	Location	Rating Value Max. = 13	2	1	0	2	2	1	0	2	1	0	1	1	0	1	0	2	1	0	
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
No.	Location		Rating Value Max. = 12	2	1	0	1	1	1	1	0	3	2	1								
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. ________________

No.	Location		Rating Value Max. = 11	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																						

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 ________________

DATE ________________

UNIT NAME ________________

SHEET NO. ________________

POWER DISTRIBUTION CONDITIONS

No.	Location		Rating Value Max. = 10	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
				2	1	1	1	1	1	1	0	2										
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.

SELF EVALUATING CHECKLIST FOR HOT WATER SERVICE

EVALUATOR ________________

DATE ________________

UNIT NAME ________________

SHEET NO. ________________

HOW WATER SERVICE CONDITIONS

No.	Location		Rating Value Max. = 5	Insulation Good	Insulation Average	Insulation Poor	No Faucet Leaks	Faucet Leaks	Standard Op. Procedure	Preventive Maintenance	Fix as Required											TOTAL POINTS
				2	1	0	1	0	1	1	0											
1																						

LAUNDRY RATING INSTRUCTIONS

2 points if overall equipment is in good condition. This means all equipment is operating per manufacturers' specifications. There are no leaks; gaskets and seals are all functioning properly, nothing is "jury rigged" to enable it to work, and equipment is used for its designed function, etc.

1 point if overall equipment is in average shape. Equipment condition will deteriorate over time due to normal usage. If equipment has been in use for a few years it should be placed in this category.

0 points if equipment is in poor condition. This includes leaks, malfunctioning equipment, improperly adjusted components, bypassing manufacturers' operational procedures, etc.

1 point if faucets, valves and traps are in good condition. Faucets should not leak, valves should seal tight and traps cannot have any blow by.

3 points if energy recovery systems are used. These can be any of several systems on the market today.

1 point if the laundry hot water generator is secured during laundry off periods such as evenings and weekends. An analysis should be made of each hot water system to determine the recovery time to ensure hot water is available when required.

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.

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.

SELF-EVALUATING CHECKLIST FOR LAUNDRY

EVALUATOR ____________

DATE ____________

UNIT NAME ____________

SHEET NO. ____________

No.	Location	Rating Value Max. = 13	Equip. Condition Good	Equip. Condition Average	Equip. Condition Poor	No Leaks	Energy Recovery System	Hot Water Gen. Secured	Insulation Good	Insulation Average	Insulation Poor	Flanges Insulated	Standard Op. Procedure	Preventive Maintenance	Fix as Required						TOTAL POINTS
			2	1	0	1	3	1	2	1	0	2	1	1	0						
1																					

COMPRESSED AIR SERVICE RATING INSTRUCTIONS

1 point if outlets and valves are in good repair.
0 points if outlets and valves leak externally or internally.
1 point if compressors are properly sized to shave peak demands.
1 point if additional compressors are brought on line as demand requires and not run continuously.
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.

SELF-EVALUATING CHECKLIST FOR COMPRESSED AIR

EVALUATOR ____________

DATE ____________

UNIT NAME ____________

SHEET NO. ____________

No.	Location	Rating Value Max. = 5	No Outlet Leaks	Outlet Leaks	Compressors Sized	Compressors on Demand	Standard Op. Procedure	Preventive Maintenance	Fix as Required												TOTAL POINTS
			1	0	1	1	1	1	0												
1																					

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 ______________

DATE ______________

UNIT NAME ______________

SHEET NO. ______________

				WATER CONDITIONS																		
				No Faucet Leaks	Faucet Leaks	Standard Op. Procedure	Preventive Maintenance	Fix as Required	No Equip. Use Water Once	Equipment Off												TOTAL POINTS
No.	Location		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.

SELF-EVALUATING CHECKLIST FOR PROCESS HEATING

EVALUATOR ____________

DATE ____________

UNIT NAME ____________

SHEET NO. ____________

PROCESS HEATING CONDITIONS

No.	Location	Rating Value Max. = 6	Flue Gas Waste Heat	High Temp. Areas Insulated	Insulation Poor	Exhaust Process Air	Standard Op. Procedure	Combustion Efficiency	Preventive Maintenance	Fix as Required											TOTAL POINTS
			1	2	0	1	1	1	1	0											
1																					

VEHICLE OPERATIONS/MAINTENANCE RATING INSTRUCTIONS

2 points if a driver training course in economical operation is utilized.
2 points if the fueling of vehicles is supervised and controlled.
2 points for the maintenance of vehicles on a scheduled basis.
3 points if there is an operating program on van pool and/or car pool.
0 points if vehicles are observed operating with tires underinflated.
1 point if a vehicle operating schedule procedure is in effect.
0 points if vehicles are dispatched without regard for optimum use.
1 point if mileage and fuel consumption data is available to all drivers.

SELF-EVALUATING CHECKLIST FOR VEHICLE OPERATIONS/MAINTENANCE

EVALUATOR ____________

DATE ____________

UNIT NAME ____________

SHEET NO. ____________

VEHICLE OPERATIONS/MAINTENANCE CONDITIONS

No.	Location	Rating Value Max. = 10	Economical Training	Supervised Fueling	Scheduled Maintenance	Van/Car Pool	Underinflated Tires	Dispatch Schedules	No Display Schedules	Mileage/Fuel Data											TOTAL POINTS
			2	2	2	3	0	1	0	1											
1																					

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 &

Presented at 17th World Energy Engineering Congress by John W. Sheffield and Burns E. Hegler 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 Technologies[2], 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 *Drag-Out*
Reduction of Solid *Drag-Out*
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.

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

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,[d] F	Degree-Days Yearly Total
Ala.	Birmington	A	54.2	2551
	Huntsville	A	51.3	3070
	Mobile	A	59.9	1560
	Montgomery	A	55.4	2291
Alaska	Anchorage	A	23.0	10864
	Fairbanks	A	6.7	14279
	Juneau	A	32.1	9075
	Nome	A	13.1	14171
Ariz.	Flagstaff	A	35.6	7152
	Phoenix	A	58.5	1765
	Tucson	A	58.1	1800
	Winslow	A	43.0	4782
	Yuma	A	64.2	974
	....			
Ark.	Fort Smith	A	50.3	3292
	Little Rock	A	50.5	3219
	Texarkana	A	54.2	2533

State	Station		Avg. Winter Temp. F	Degree-Days Yearly Total
Calif.	Bakersfield	A	55.4	2122
	Bishop	A	46.0	4275
	Blue Canyon	A	42.2	5596
	Burbank	A	58.6	1646
	Eureka	C	49.9	4643
	Fresno	A	53.3	2611
	Long Beach	A	57.8	1803
	Los Angeles	A	57.4	2061
	Los Angeles	C	60.3	1349
	Mt. Shasta	C	41.2	5722
	Oakland	A	53.5	2870
	Red Bluff	A	53.8	2515
	Sacramento	A	53.9	2502
	Sacramento	C	54.4	2419
	Sandberg	C	46.8	4209

[a]Data 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.

[b]Data for airport station, A, and city stations, C, are both given where available.

[c]Data 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.

[d]For period October to April, inclusive.

State	Station	Avg. Winter Temp,[d] F	Degree-Days Yearly Total
Calif.	San Diego ... A	59.5	1458
(*Cont'd*)	San Francisco ... A	53.4	3015
	San Francisco ... C	55.1	3001
	Santa Maria ... A	54.3	2967
Colo.	Alamosa ... A	29.7	8529
	Colorado Springs ... A	37.3	6423
	Denver ... A	37.6	6283
	Denver ... C	40.8	5524
	Grand Junction ... A	39.2	5641
	Pueblo ... A	40.4	5462
Conn.	Bridgeport ... A	39.9	5617
	Hartford ... A	37.3	6235
	New Haven ... A	39.0	5897
Del.	Wilmington ... A	42.5	4930
D.C.	Washington ... A	45.7	4224
Fla.	Apalachicola ... C	61.2	1308
	Daytona Beach ... A	64.5	879
	Fort Myers ... A	68.6	442
	Jacksonville ... A	61.9	1239
	Key West ... A	73.1	108
	Lakeland ... C	66.7	661
	Miami ... A	71.1	214
	Miami Beach ... C	72.5	141
	Orlando ... A	65.7	766
	Pensacola ... A	60.4	1463

State	Station	Avg. Winter Temp. F	Degree-Days Yearly Total
Iowa	Burlington ... A	37.6	6114
	Des Moines ... A	35.5	6588
	Dubuque ... A	32.7	7376
	Sioux City ... A	34.0	6951
	Waterloo ... A	32.6	7320
Kans.	Concordia ... A	40.4	5479
	Dodge City ... A	42.5	4986
	Goodland ... A	37.8	6141
	Topeka ... A	41.7	5182
	Wichita ... A	44.2	4620
Ky.	Covington ...- A	41.4	5265
	Lexington ... A	43.8	4683
	Louisville ... A	44.0	4660
La.	Alexandria ... A	57.5	1921
	Baton Rouge ... A	59.8	1560
	Lake Charles ... A	60.5	1459
	New Orleans ... A	61.0	1385
	New Orleans ... C	61.8	1254
	Shreveport ... A	56.2	2184
Me.	Caribou ... A	24.4	9767
	Portland ... A	33.0	7511
Md.	Baltimore ... A	43.7	4654
	Baltimore ... C	46.2	4111
	Frederich ... A	42.0	5087

Table 15-1. Degree Day Data (*Cont'd*)

State	*Station*	*Avg. Winter Temp,[d] F*	*Degree-Days Yearly Total*
	Tallahassee........................A	60.1	1485
	Tampa................................A	66.4	683
	West Palm Beach ....A	68.4	253
Ga.	Athens...............................A	51.8	2929
	Atlanta ....A	51.7	2961
	Augusta ....A	54.5	2397
	Columbus ....A	54.8	2383
	Macon ....A	56.2	2136
	Rome ....A	49.9	3326
	Savannah ....A	57.8	1819
	Thomasville.......................C	60.0	1529
	....		
Hawaii	Libue ....A	72.7	0
	Honolulu ....A	74.2	0
	Hilo...................................A	71.9	0
Idaho	Boise ....A	39.7	5809
	Lewiston ....A	41.0	5542
	Pocatello ....A	34.8	7033
Ill.	Cairo.................................C	47.9	3821
	Chicago(O'Hare) ....- A	35.8	6639
	Chicago(Midway) ....A	37.5	6155
	Chicago C	38.9	5882
	Moline ....A	36.4	6408
	Peoria ....A	38.1	6025
	Rockford ....A	34.8	6830
	Springfield.........................A	40.6	5429
	....		

State	*Station*	*Avg. Winter Temp. F*	*Degree-Days Yearly Total*
Mass.	Boston ....A	40.0	5634
	Nantucket..........................A	40.2	5891
	Pittsfield............................A	32.6	7578
	Worcester ....A	34.7	6969
Mich.	Alpena..............................A	29.7	8506
	Detroit(City).....................A	37.2	6232
	Detroit(Wayne) ....A	37.1	6293
	Detroit(Willow Run)........A	37.2	6258
	Escanaba C	29.6	8481
	Flint ....A	33.1	7377
	Grand Rapids ....A	34.9	6894
	Lansing ....A	34.8	6909
	Marquette C	30.2	8393
	Muskegon.........................A	36.0	6696
	Sault Ste. Marie..............A	27.7	9048
Minn.	Duluth..............................A	23.4	10000
	Minneapolis ....A	28.3	8382
	Rochester ....A	28.8	8295
Miss.	Jackson.............................A	55.7	2239
	Meridian ....A	55.4	2289
	Vicksburg.........................C	56.9	2041
Mo.	Columbia ....A	42.3	5046
	Kansas City ....A	43.9	4711
	St. Joseph.........................A	40.3	5484
	St. Louis...........................A	43.1	4900
	St. Louis...........................C	44.8	4484
	Great Falls........................A	32.8	7750

Ind.	Evansville	A	45.0	4435
	Fort Wayne	A	37.3	6205
	Indianapolis	A	39.6	5699
	South Bend	A	36.6	6439
Mont. (*Cont'd*)	Havre	A	28.1	8700
	Havre	C	29.8	8182
	Helena	A	31.1	8129
	Kalispell	A	31.4	8191
	Miles City		31.2	7723
	Missoula	A	31.5	8125
Neb.	Grand Island	A	36.0	6530
	Lincoln	C	38.8	5864
	Norfolk	A	34.0	6979
	North Platte	A	35.5	6684
	Omaha	A	35.6	6612
	Scottsbluff	A	35.9	6673
	Valentine	A	32.6	7425
Nev.	Elko	A	34.0	7433
	Ely	A	33.1	7733
	Las Vegas	A	53.3	2709
	Reno	A	39.3	6332
	Winnemucca	A	36.7	6761
N.H.	Concord	A	33.0	7383
	Mt. Washington Obsv		15.2	13817
N.J.	Atlantic City	A	43.2	4812
	Newark	A	42.8	4589
	Trenton	C	42.4	4980
	Springfield	A	44.5	4900
Mont.	Billings	A	34.5	7049
	Glasgow	A	26.4	8996
	Columbus	A	39.7	5660
	Columbus	C	41.5	5211
	Dayton	A	39.8	5622
	Mansfield	A	36.9	6403
	Sandusky	C	39.1	5796
	Toledo	A	36.4	6494
	Youngstown	A	36.8	6417
Okla.	Oklahoma City	A	48.3	3725
	Tulsa	A	47.7	3860
Ore.	Astoria	A	45.6	5186
	Burns	C	35.9	6957
	Eugene	A	45.6	4726
	Meacham	A	34.2	7874
	Medford	A	43.2	5008
	Pendleton	A	42.6	5127
	Portland	A	45.6	4635
	Portland	C	47.4	4109
	Roseburg	A	46.3	4491
	Salem	A	45.4	4754
Pa.	Allentown	A	38.9	5810
	Erie	A	36.8	6451
	Harrisburg	A	41.2	5251
	Philadelphia	A	41.8	5144
	Philadelphia	C	44.5	4486
	Pittsburgh	A	38.4	5987

Table 15-1. Degree Day Data (*Cont'd*)

State	*Station*	*Avg. Winter Temp,*[d] *F*	*Degree-Days Yearly Total*
N.M.	Albuquerque...A	45.0	4348
	Clayton...A	42.0	5158
	Raton...A	38.1	6228
	Roswell...A	47.5	3793
	Silver City...A	48.0	705
N.Y	Albany...A	34.6	6875
	Albany...C	37.2	6201
	Binghamton...A	33.9	7286
	Binghamton...C	36.6	6451
	Buffalo...A	34.5	7062
	New York (Cent. Park)...C	42.8	4871
	New York (LaGuardia)...A	43.1	4811
	New York (Kennedy)...A	41.4	5219
	Rochester...A	35.4	6748
	Schenectady...C	35.4	6650
	Syracuse...A	35.2	6756
N. C.	Asheville...C	46.7	4042
	Cape Hatteras...	53.3	2612
	Charlotte...A	50.4	3191
	Greensboro...A	47.5	3805
	Raleigh...A	49.4	3393
	Wilmington...A	54.6	2347
	Winston-Salem...A	48.4	3595
N.D.	Bismarck...A	26.6	8851
	Devils Lake...C	22.4	9901
	Fargo...A	24.8	9226
	Williston...A	25.2	9243

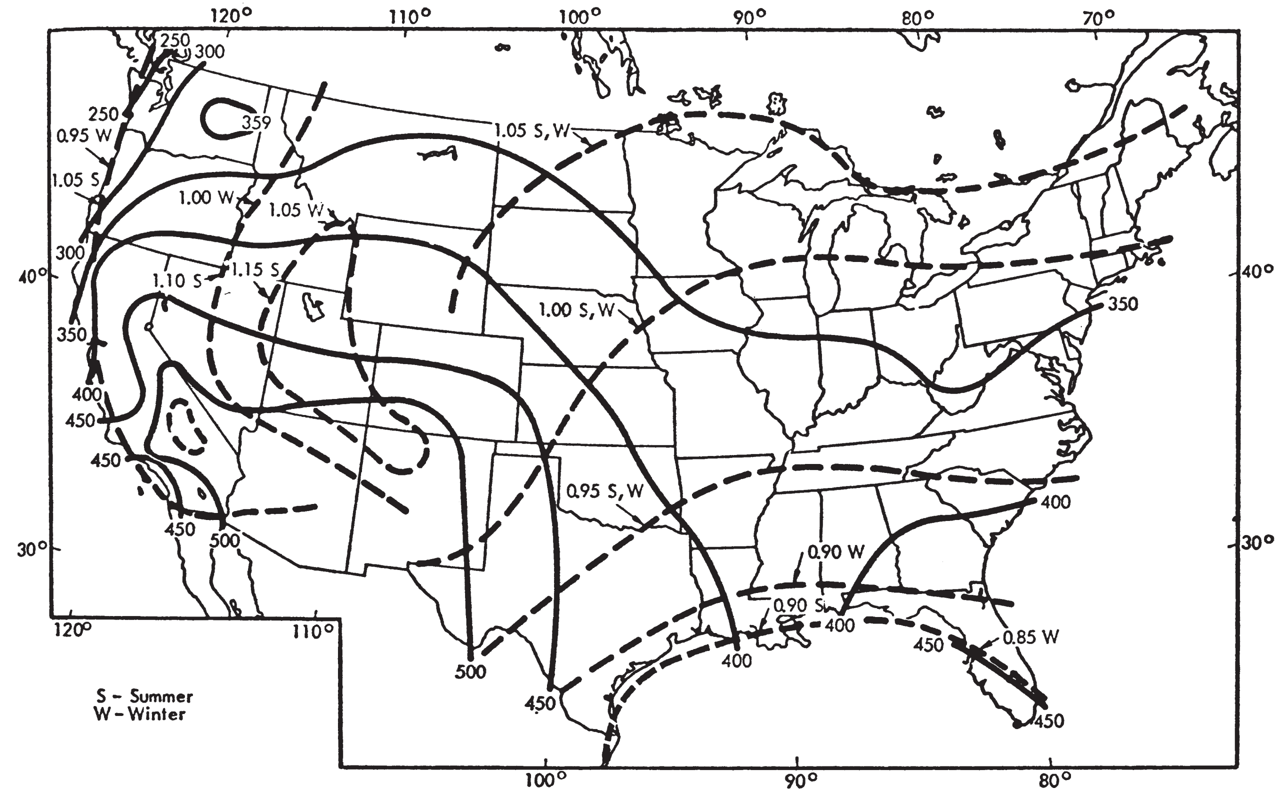
State	*Station*	*Avg. Winter Temp. F*	*Degree-Days Yearly Total*
	Pittsburgh...C	42.2	5053
	Reading...C	42.4	4945
	Scranton...A	37.2	6254
	Williamsport...A	38.5	5934
R.I.	Block Island...A	40.1	5804
	Providence...A	38.8	5954
S.C.	Charleston...A	56.4	2033
	Charleston...C	57.9	1794
	Columbia...A	54.0	2484
	Florence...A	54.5	2387
	Greenville-Spartenburg...A	51.6	2980
S.D.	Huron...A	28.8	8223
	Rapid City...A	33.4	7345
	Sioux Falls...A	30.6	7839
Tenn.	Bristol...A	46.2	4143
	Chattanooga...A	50.3	3254
	Knoxville...A	49.2	3494
	Memphis...A	50.5	3232
	Memphis...C	51.6	3015
	Nashville...A	48.9	3578
	Oak Ridge...C	47.7	3817
Tex.	Abilene...A	53.9	2624
	Amarillo...A	47.0	3985
	Austin...A	59.1	1711
	Brownsville...A	67.7	600
	Corpus Christi...A	64.6	91

Ohio	Akron-Canton..................A	38.1	6037
	Cincinnati.........................C	45.1	4410
	Cleveland..........................A	37.2	6351
Texas (*Cont'd*)	Galveston..........................A	62.2	1274
	Galveston..........................C	62.0	1235
	Houston............................A	61.0	1396
	Houston............................C	62.0	1278
	Laredo...............................A	66.0	797
	Lubbock............................A	48.8	3578
	Midland............................A	53.8	2591
	Port Arthur.......................A	60.5	1447
	San Angelo.......................A	56.0	2255
	San Antonio.....................A	60.1	1546
	Victoria.............................A	62.7	1173
	Waco.................................A	57.2	2030
	Wichita Falls....................A	53.0	2832
	Dallas...............................A	55.3	2363
	El Paso.............................A	52.9	2700
	Fort Worth........................A	55.1	2405
Utah	Milford.............................A	36.5	6497
	Salt Lake City..................A	38.4	6052
	Wendover.........................A	39.1	5778
Vt.	Burlington........................A	29.4	8269
Va.	Cape Henry......................C	50.0	3279
	Lynchburg........................A	46.0	4166
	Norfolk.............................A	49.2	3421
	Richmond.........................A	47.3	3865
	Roanoke...........................A	46.1	4150
Wash.	Olympia...........................A	44.2	5236
	Seattle-Tacoma.................A	44.2	5145
Alta.	Banff.................................C	—	10551
	Calgary.............................A	—	9703
	Edmonton.........................A	—	10268
	Lethbridge........................A	—	8644
B.C.	Kamloops.........................A	—	6799
	Prince George*.................A	—	9755
	Prince Rupert...................C	—	7029
	Vancouver*.......................A	—	5515
	Victoria*...........................A	—	5699
	Victoria.............................C	—	5579
Man.	Brandon*..........................A	—	11036
	Churchill...........................A	—	16728
	The Pas............................C	—	12281
	Winnipeg..........................A	—	10679
N.B.	Fredericton*......................A	—	8071
	Moncton............................C	—	8727
	St. John.............................C	—	8219
Nfld.	Argentia............................A	—	8440
	Corner Brook...................C	—	8978
	Gander..............................A	—	9254
	Goose*..............................A	—	11887
	St. John's*.........................A	—	8991
N.W.T.	Aklavik,............................C	—	18017

Table 15-1. Degree Day Data (*Concluded*)

Days *State*	*Station*	*Avg.* *Winter Temp,*[d] *F*	*Degree-Days* *Yearly Total*	*State*	*Station*	*Avg.* *Winter Temp. F*	*Degree-* *Yearly Total*
Seattle	C....................46.9	4424		Fort Norman	C	—	16109
	Spokane ....A	36.5	6655		Resolution Island C	—	16021
Wash.	Walla Walla C	43.8	4805		Fort William....................A	—	10405
(*Cont'd*)	Yakima ....A	39.1	5941		Kapuskasing C	—	11572
					Kitchner C	—	7566
W. Va.	Charleston ....A	44.8	4476		London....................A	—	7349
	Elkins....................A	40.1	5675		North Bay....................C	—	9219
	Huntington....................A	45.0	4446		Ottawa C	—	8735
	Parkersburg....................C	43.5	4754		Toronto....................C	—	6827
Wisc.	Green Bay....................A	30.3	8029	P.E.I.	Charlottetown....................C	—	8164
	La Crosse....................A	31.5	7589		Summerside C	—	8488
	Madison....................A	30.9	7863				
	Milwaukee....................A	32.6	7635	Que.	Arvida C	—	10528
	....				Montreal*....................A	—	82033
	....				Montreal C	—	7899
Wyo.	Casper ....A	33.4	7410		Quebec*....................A	—	9372
	Cheyenne....................A	34.2	7381		Quebec C	—	8937
	Lander....................A	31.4	7870				
	Sheridan....................A	32.5	7680	Sasks	Prince Albert....................A	—	11630
					Regina. ....A	—	10806
N. S.	Halifax C	—	7361		Saskatoon....................C	—	10870
	Sydney ....A	—	8049				
	Yarmouth....................A	—	7340	Y.T.	Dawson....................C	—	I5067
					Mayo Landing....................C	—	14454
Ont.	Cochrane....................C	—	11412				

*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)

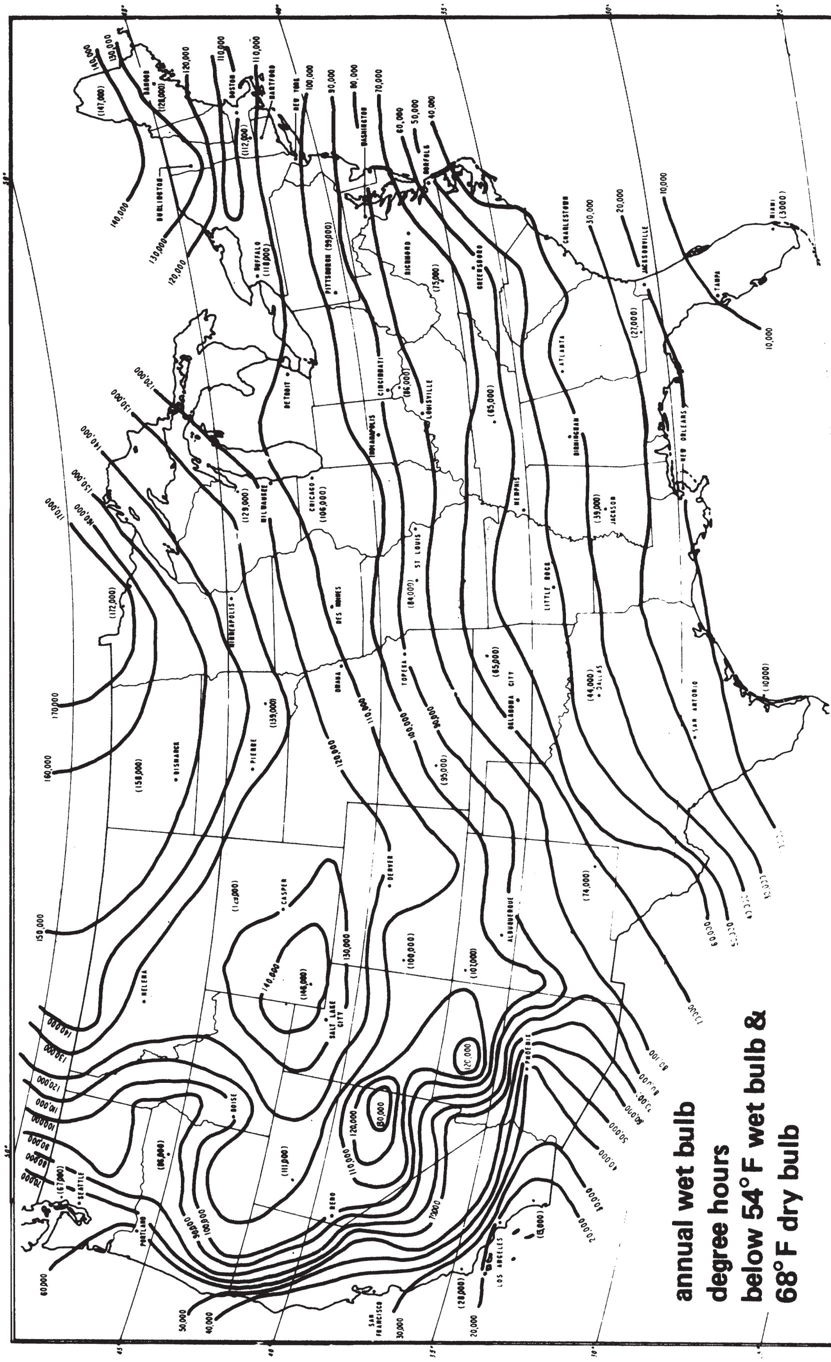


Figure 15-2
(Source: AFM 88-8, U.S. Government Printing Office, June 15, 1967)

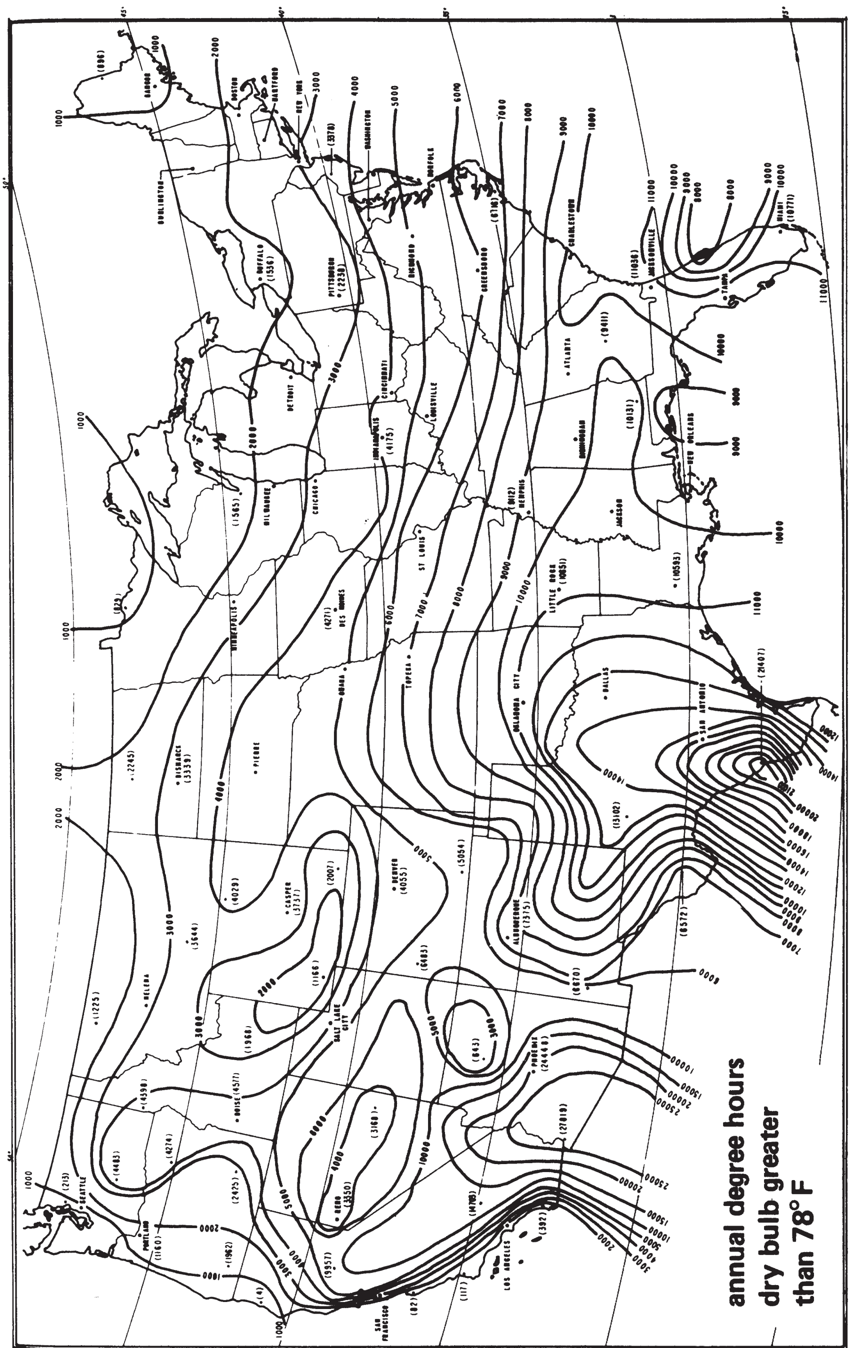


Figure 15-3
(Source: AFM 88-8, U.S. Government Printing Office, June 15, 1967)

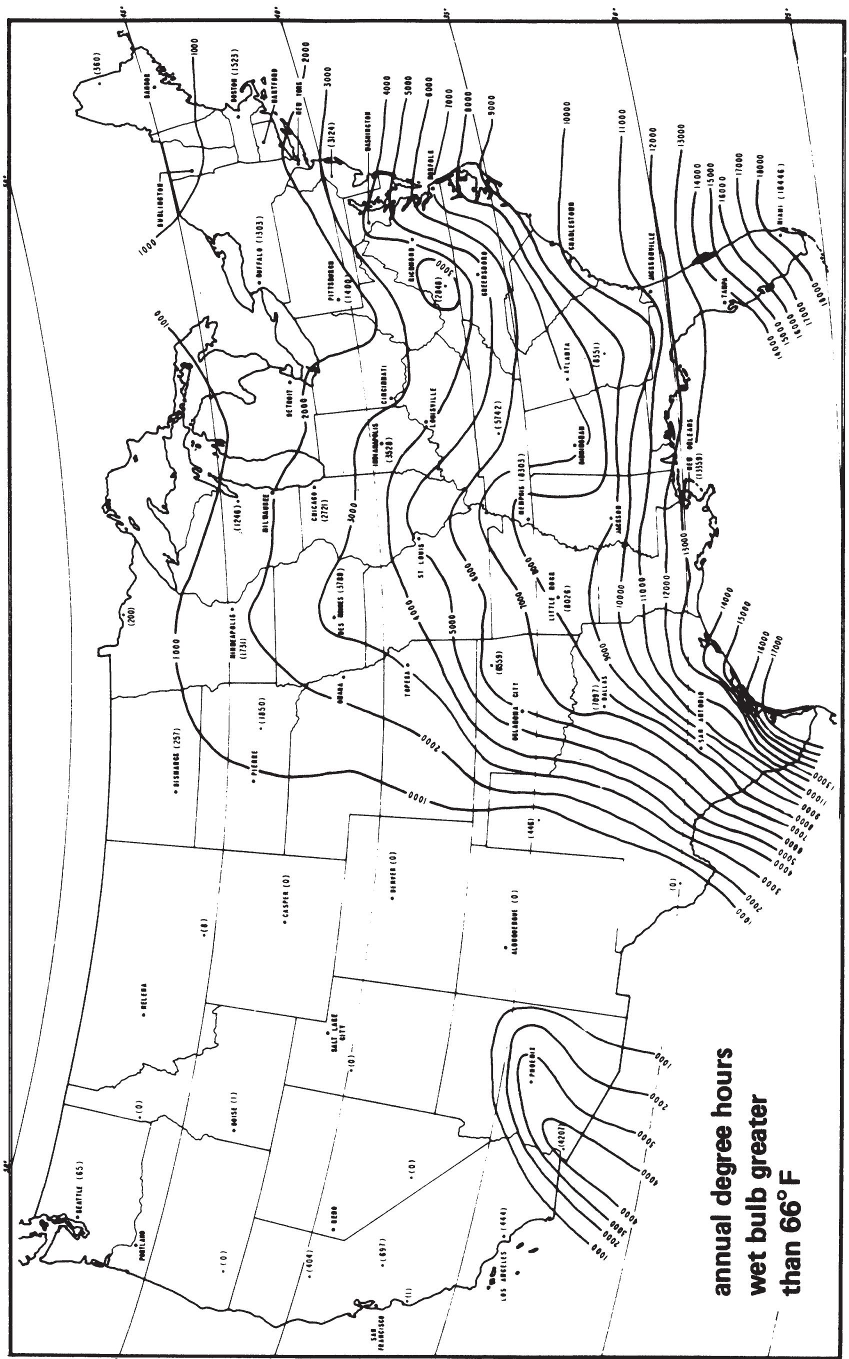


Figure 15-4
(Source: AFM 88-8, U.S. Government Printing Office, June 15, 1967)

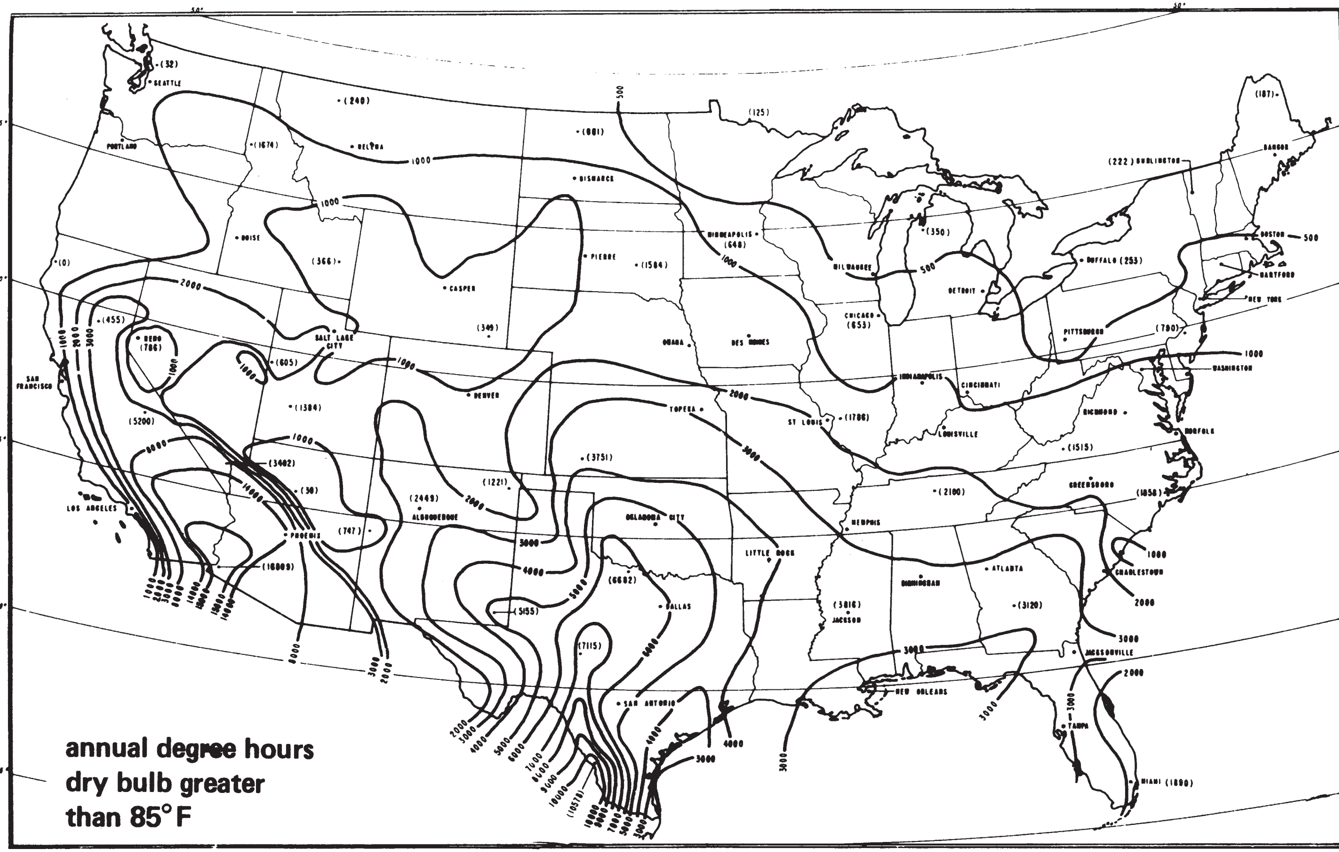


Figure 15-5
(Source: AFM 88-8, U.S. Government Printing Office, June 15, 1967)

Building ____________________ ____________________ Year

Month*	Heating Degree Days	Cooling Degree Days	electricity				Oil					Natural Gas			Coal ☐ Wood ☐	Purchased Steam ☐ Other ______			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/gas

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)

Line No.		*A*	*B* Conversion Factor		*C* Thousands of Btus/yr
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 × 10^3Yr/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) if absorption cooling*	*A*	*B* Conversion Factor		*C* Thousands of Btus/yr
		________	× 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) if absorption cooling*	*A*	*B* Conversion Factor		*C* Thousands of Btus/yr
34.	kWh Fig. 10, Line 3 × Fig. 10, Line 33 (1)	________	× 3.413	=	________
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 H_2O)

   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)			Z_1 ________	Z_2 ________
....	Z_3 ________	Z_4 ________	Z_5 ________	Z_6 ________
....	Z_7 ________	Z_8 ________	Z_9 ________	Z_{10} ________

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 ________ Ft^2	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)

Control Dampers
(Leakage in closed position).. High __________ Normal __________ Low __________
Belts.. Tight __________ Loose __________ Worn __________ Good __________

5. AIR DISTRIBUTION
Is ductwork leaking? .... Heavy __________ Medium __________ Light __________
Is ductwork insulated/lined?..................................... Interior __________ Exterior __________ No __________
Is ductwork accessible to repair leaks?... Yes __________ No __________
Does system have manual balancing dampers at zones or mains? .... Yes __________ No __________
Do supply outlets have dampers?... Yes __________ No __________
Do return outlets have dampers? .... Yes __________ No __________

6. REMARKS:

Figure 15-8. HVAC System Data (*Concluded*)

Project No. ________

Job Name ______________________________ Date ____________________

System No. ______________ Location ______________

O.A.T. ______________

Tested by ____

EWT.......................... Actual ____________ Design ____________

LWT.......................... Actual ____________ Design ____________

Coil No.	Area Served	Actual				Design			
		CFM	EAT	LAT	Air PD	CFM	EAT	LAT	Air PD

REMARKS:

Figure 15-9. Reheat Coil Data

(Source: Certified Test & Balance Company, Inc., Chicago, Illinois)

DATE ____________________ PREPARED BY: ____ PROJECT NO. ____________

JOB NAME:			WEEKDAYS			SATURDAY			SUNDAYS/HOLIDAYS		
AREA SERVED	GROSS SQ. FEET	SYSTEM SERVING	NO. OF OCCU-PANTS	OCCUPANCY TIME A.M.	P.M.	NO. OF OCCU-PANTS	OCCUPANCY TIME A.M.	P.M.	NO. OF OCCU-PANTS	OCCUPANCY TIME A.M.	P.M.

Figure 15-10. Building Occupancy Schedule
(Source: Certified Test & Balance Company, Inc., Chicago, Illinois)

JOB NAME ______________________ DATE ______________________

PREPARED BY ______________________ PROJECT NO. ______________________

SYSTEM NUMBER	DESIGN		ACTUAL		REMARKS:
	TOTAL CFM	OUTSIDE AIR	TOTAL CFM	OUTSIDE AIR	

NOTE: These readings should be obtained by traverse and O.S. setting kept on minimum position ONLY.

Figure 15-11. CFM Audit

(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 Convertor 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 ☐ Manual ☐ Other ☐

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/ft^2: 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/Ft^2 Offices ______________ Other ______________

   Total Install kW ______________ Foot Candies ______________

   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 ____________

How Started: Manual ❐ Auto Switchover ❐

Equipment/Systems Operated: ______________________________

____

____

CHECK LIST

	Due Date	Date Complete	By
1. HVAC Survey	________	________	________
2. Lighting & Misc. Survey	________	________	________
3. Utility Bill Analysis	________	________	________
4. Recommendation	________	________	________

Date ______________________________

Figure 15-14. Building Information (*Concluded*)

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 2-F40T12 3-F40T12 4-F40T12	50 92 142 184
8 Ft Slimline Instant Start	1-F96T1 2 2-F96T1 2 3-F96T12 4-F96T1 2	100 170 270 340
8 Ft High Output	1-F96T12/HO 2-F96T12/HO 3-F96T12/HO 4-F96T12/HO	140 252 392 504
8 Ft 1500 ma Power Grove, SHO or VHO	1-F96PG17 1-F96T12/SHO or VHO 2-F96PG17 2-F96T12/SHO or VHO 3-F96PG17 3-F96T12/SHO or VHO 4-F96PG17 4-596T12/SHO or VHO	230 450 680 900

II. HIGH INTENSITY DISCHARGE

Lamp Type	Lamp Designation	Fixture Watts	Wattage*
Mercury	MV 100 MV 175 MV 250 MV 400 MV 1000	100 175 250 400 1000	118 200 285 450 1075
Metal Halide	MH 175 MH 250 MH 400 MH 1000	175 250 400 1000	210 292 455 1070
High Pressure Sodium	HPS 70 HPS 100 HPS 150 HPS 250 HPS 400 HPS 1000	70 100 150 250 400 1000	88 130 188 300 465

*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

Source	*Initial Lumens Watt*
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

Surfaces	*Reflectance (Percent)*
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.	LIGHT# FIXTURE	LOCATION	NO.	WATTS PER FIXTURE	LUMENS	Hrs. Operated Per Day	Days Operated Per Week	kWh Per Per Week	COMMENTS

Figure 15-16. Energy Survey—Lights

OPERATION ______________ LOCATION ______________ DATE ______________

MFG'R.	EQUIPMENT ITEM	LOCATION	ELECTRICAL EQUIPMENT RATED INPUT 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	COMMENTS

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 ____________________

Month	Consumption kWh	Demand kW	Rate	Fuel Adj. Rate/kWh	Cost	65° Heating Days	65° Cooling Days	kWh 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 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 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	COMMENTS

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 ± ______________________________________ in. H_2O

Location of measurement:

______________ Over-the-fire ______________ Breaching

Type of draft: ______________ Forced______________ Induced

Acceptable draft pressure ± ______________ in. H_2O

(Refer to table at end of form)

Measured smoke density reading

(For oil burners only)

Measured CO_2 concentration ______________ %

Acceptable CO_2 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. H_2O) FOR COMBINATION SYSTEMS

	Location	
Gas or Oil Burners	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 CO_2 CONCENTRATIONS FOR VARIOUS FUELS

	% CO_2	
Gases	*Stoichiometric*	*Recommended Value*
Natural	12	7-10
Propane or Butane	14	8.5-11.5
Fuel Oils		
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).

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 printouts 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 complex 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/ft^2 figure. The result was that supply air was calculated by the program at something like 0.2 cfm/ft^2, the outside air was 0.1 cfm/sf^2 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

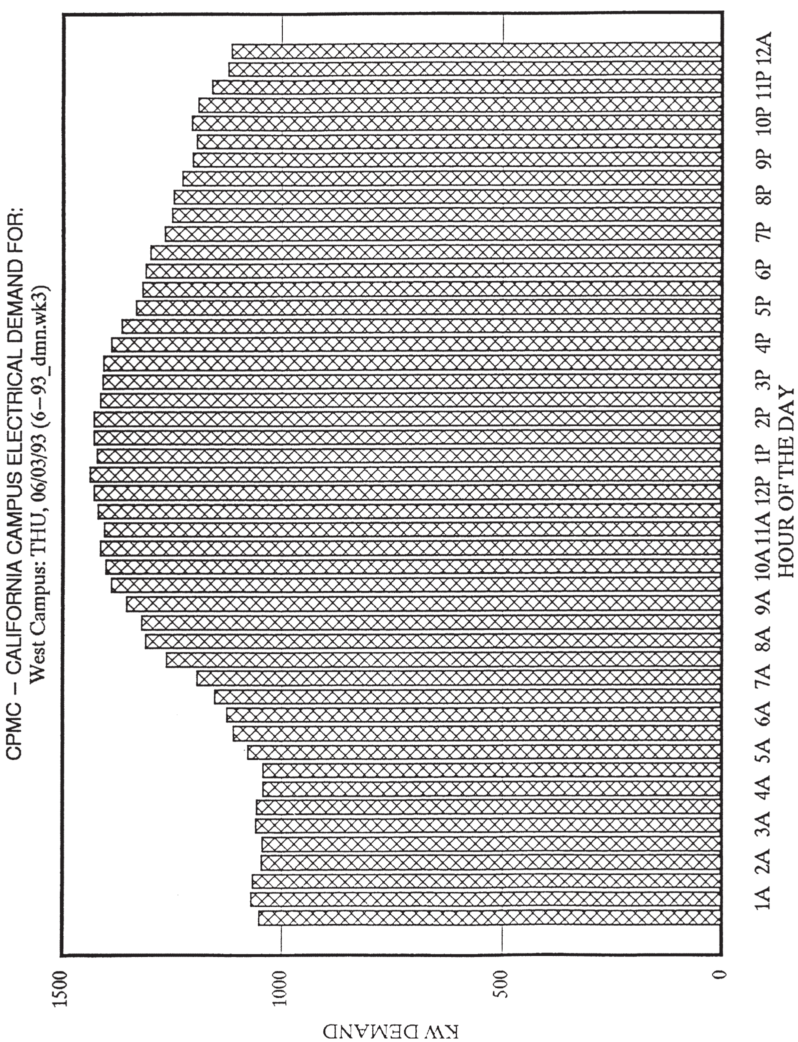


Figure 16-1. Example of analysis of utility company demand interval records.

Table 16-2.
Example of comparison of field-measured electrical loads to peak demand recorded by the utility company.

——CALCULATION SHEET——
(PRE-MODL)

DATE: 10/29/94
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

——ENERGY RESOURCE ASSOCIATES——

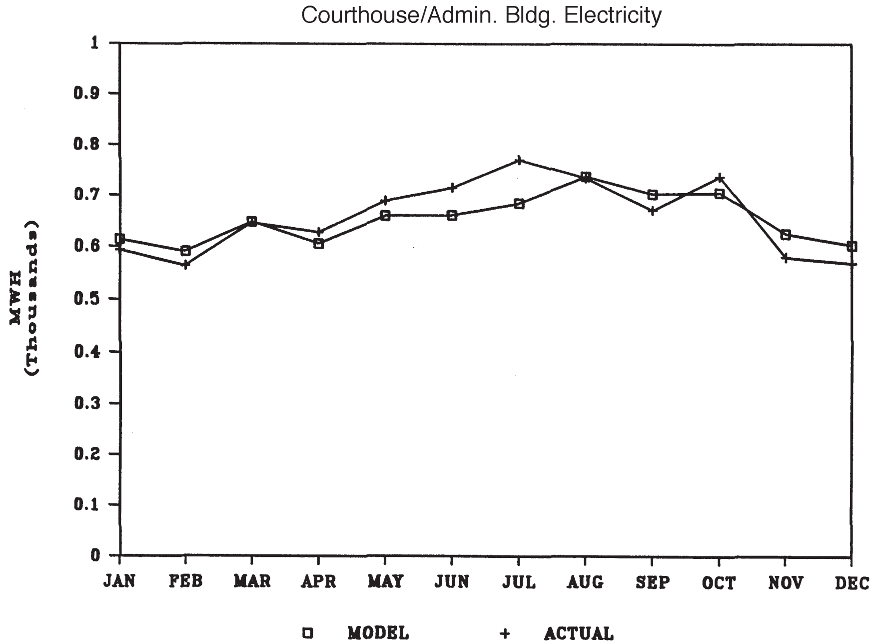


Fig. 16-2. Comparison of model and actual annual electrical use profile.

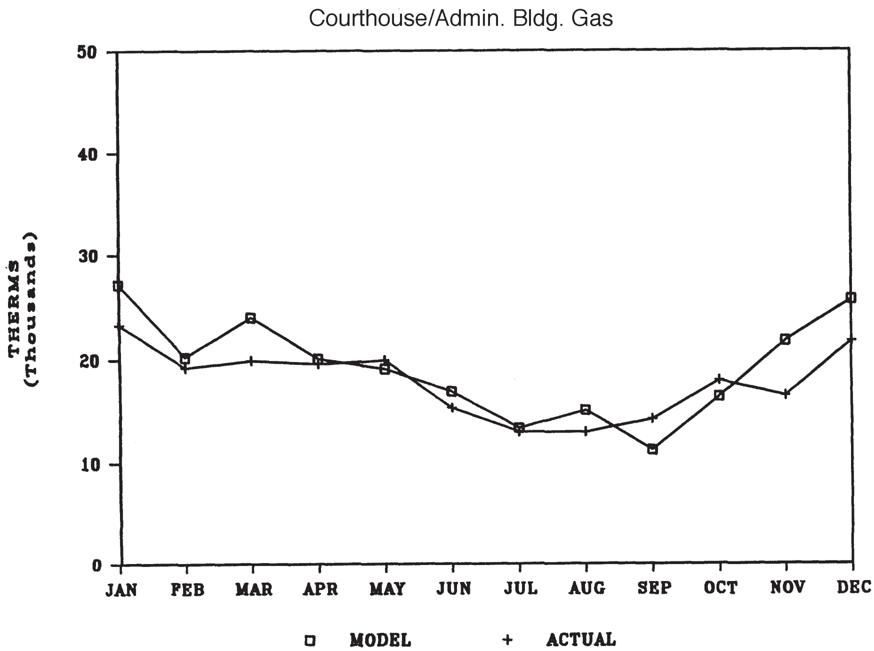


Figure 16-3. Comparison of model and actual annual gas use profile.

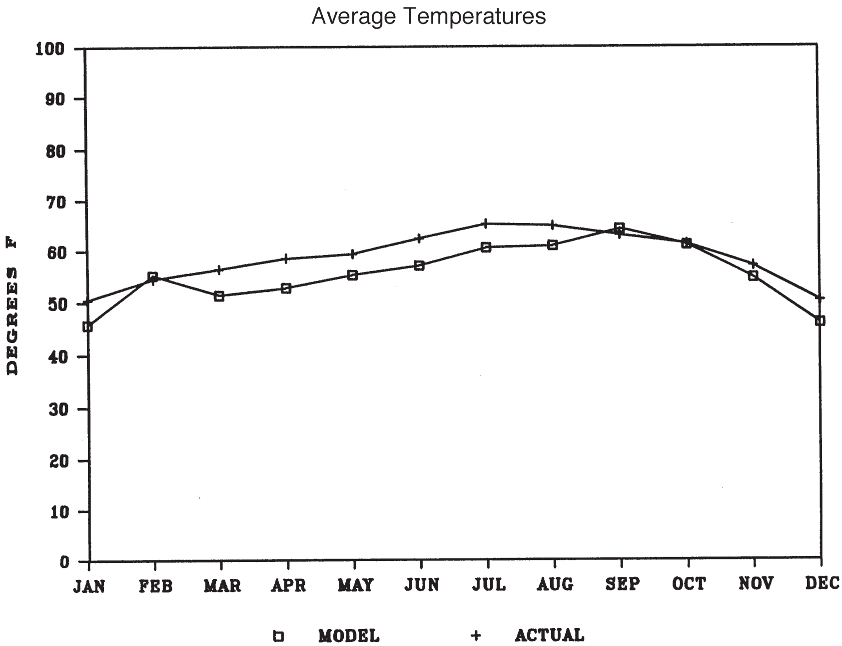


Figure 16-4. Comparison of model and actual weather data.

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 modeled 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 neighbor hood 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	‘652192	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 (WCT-ECM2) — DATE: 10/29/94, 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.

CALCULATION SHEET — DATE: 4/5/89

(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	$62,246
3. ADMIN COURTROOM MULTIZONES TO VAV	37124	3589	$4,415
4. CONVERT JAIL MULTIZONES TO VAV	53579	0	
&			
7. LARGE COURTHOUSE MULTIZONES TO VAV	127761	36682	
SUB TOTAL	181340	36682	$27,696
5. SUPERVISOR'S AHU CONTROL MOD	12372	332	$1,195
6. LIGHTING RETROFIT	448987	–1946	$38,888
8. COURTHOUSE SMALL MZ'S TO VAV			
&			
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	$178,960
	PLAUSIBILITY FACTOR		0.95	0.95	
	NET SAVINGS	41496	1404617	145018	$170,012
	EXISTING CONSUMPTION	104035	7896022	214272	$763,417
	PERCENT REDUCTIONS	39.9	17.8	67.7	22.3
	RETROFIT BTU/SF/YR	60355			

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-

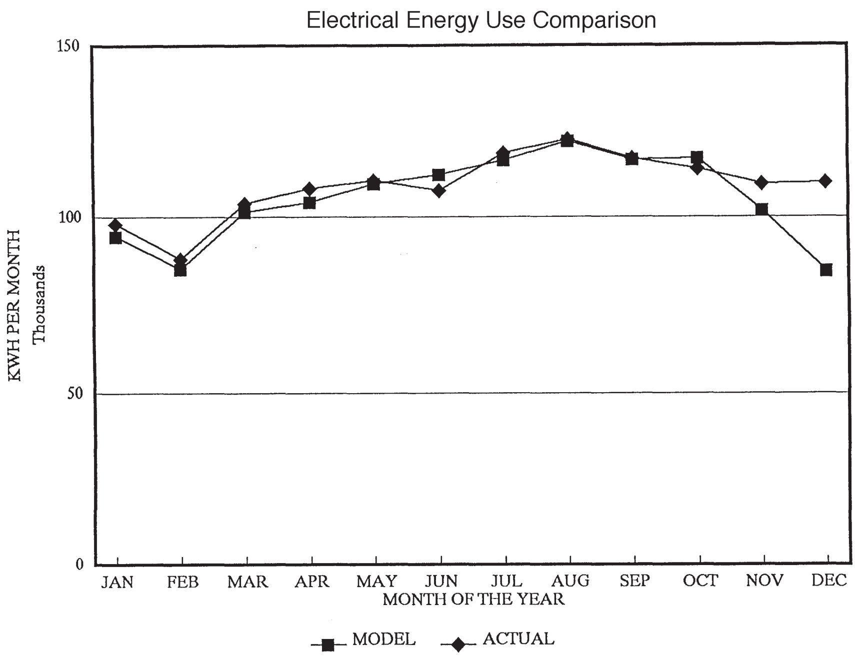


Figure 16-5. Example of complex spreadsheet simulation results.

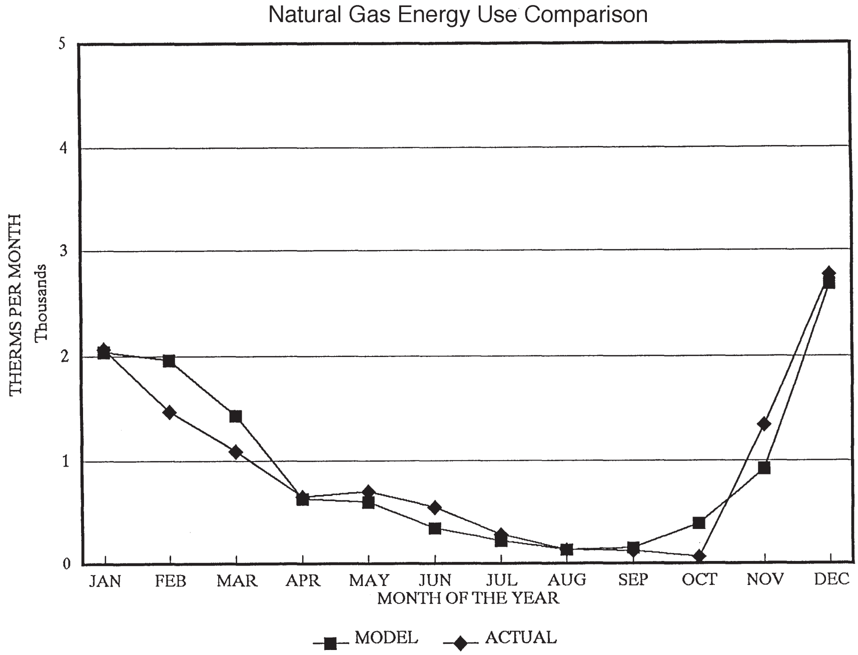


Figure 16-6. Example of complex spreadsheet simulation results.

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.

SWEENY COMMUNITY HOSPITAL ENERGY USE TEMPLATE
FOR NON-MIXING SYSTEMS

ENERGY UNITS>>>> UNIT # TYPE

UNIT #	TYPE
1	ELEC, KWH
2	GAS, MBTU
3	STEAM, MBTU
4	CHW, MBTU

INPUT BY [M. MUNIZ] DATE [9/7/89]

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 >	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. LO%>	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 LO%>	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

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

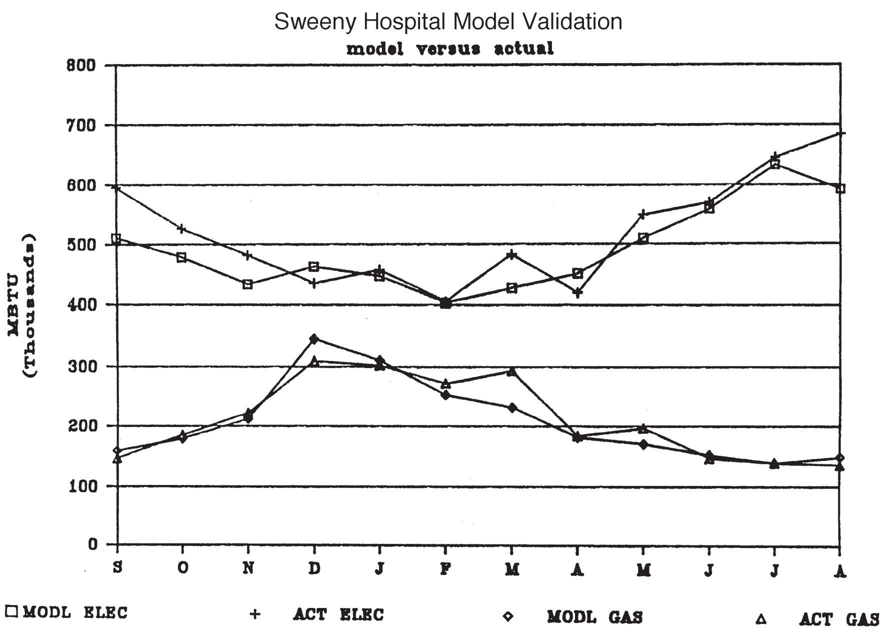


Figure 16-7. Example of simple spreadsheet simulation results.

(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

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"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://appsl.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.

This directory also notes all of the software that is available free. Going to this website will allow you to see detailed descriptions of the software tools, and to see the latest information available on those tools.

Tool	Applications	Free	Recently Updated
1D-HAM	heat, air, moisture transport, walls		
3E Plus	insulation, insulation thickness	✓	
AAMASKY	skylights, daylighting, commercial buildings		
ABACODE	Residential code compliance, IECC	✓	
ACOUSALLE	acoustics, codes and standards		
Acoustics Program	HVAC acoustics, sound level prediction, noise level		
Acuity Energy	energy efficiency software; customized business recommendation;		
Platform	commercial and industrial energy use comparisons		
ADELINE	daylighting, lighting, commercial buildings buildings		
AEPS System Planning	electrical system, renewable energy system, planning and design software, modeling, simulation, energy usage, system performance, financial analysis, solar, wind, hydro, behavior characteristics, usage profiles, generation load storage calculations, on-grid, off-grid, residential, commercial, system sizing, utility rate plans, rate comparison, utility costs, energy savings		
AFT Fathom	design, pump selection, pipe analysis, duct design, duct sizing, chilled water systems, hot water system		
AFT Mercury	optimization, pipe optimization, pump selection, duct design, duct sizing, chilled water systems, hot water systems		
AGI32	lighting, daylighting, rendering, roadway		
AIRWIND Pro	Air Conditioning Load Calculation		
AkWarm	home energy rating systems, home energy, residential modeling, weatherization		
Analysis Platform	heating, cooling, and SWH equipment, commercial buildings		
Animate	animated visualization of data, XY graphs, energy-use data		
AnTherm	Thermal heat bridges, heat flow, steady state, 2D, 3D, transfer coefficients, thermal conductance, visualization, simulation, European standards, EPBD, temperature distribution, vapor transfer, vapor diffusion, avoiding moisture, avoiding mould, energy performance, linear thermal transmittance, point thermal transmittance,vapor pressure, surface condensation, thermal comfort, dew point		

Tool	Applications	Free	Recently Updated
Apache	thermal design, thernal analysis, energy simulation, dynamic simulation, system simulation		
ApacheCalc	heat loss, heat gain, load calculation		
ApacheHVAC	buildings, HVAC, simulation, energy performance		
ApacheLoads	heat loss, heat gain, load calculations		
ApacheSim	thermal simulation, energy consumption		
ArchiWIZARD	energy performance; 3-D graphics interface; solar and lighting simulation; real time updated results and changes; thermal calculation; building performance; heat balance; thermal regulation		
Athena Model	life cycle assessment, environment, building materials, buildings	✓	
AUDIT	operating cost, bin data, residential, commercial		
Autodesk Green Building Studio	building information modeling, interoperability, energy performance, DOE-2, EnergyPlus, CAD	✓	
AWDABPT	building temperature simulation, thermal performance		
Awnshade	solar shading, awnings, overhangs, side fins, windows		
BE$T	electric motors, energy efficiency		
Be06	energy performance, building regulations, house, office, commercial and institutional		
BEAVER	energy simulation, thermal analysis		
BEES	environmental performance, green buildings, life cycle assessment, life cycle costing, sustainable development	✓	
Benchmata	Automated Benchmarking System Automation Portfolio Manager		
BESTEST	exterior envelope simulation program capability tests	✓	
BinMaker Pro	weather data, binned weather data, design weather data		
BLCC	economic analysis, ESPCs, federal buildings, life-cycle costing	✓	
BSim	building simulation, energy, daylight, thermal and moisture analysis, indoor climate		
BTU Analysis Plus	HVAC, heating, cooling, heat load studies		
BTU Analysis REG	HVAC, heating, cooling, heat load studies		

Tool	Applications	Free	Recently Updated
Building Design Advisor	design, daylighting, energy performance, prototypes, case studies, commercial buildings	✓	
Building Energy Analyzer	air-conditioning, heating, on-site power generation, heat recovery, CHP, BCHP.		
Building Energy Modelling and Simulation: Self-Learning Modules	energy simulation, buildings, courseware, self-learning, modeling, simulation	✓	
Building Greenhouse Rating	operational energy, greenhouse performance, national benchmark	✓	
Building Performance Compass	Commercial Buildings, Multi-family Residence, Benchmarking, Energy Tracking, Improvement Tracking, Weather Normalization		
BuildingAdvice	Whole building analysis, energy simulation, renewable energy, retrofit analysis, sustainability / green buildings		
BuildingSim	thermostat, simulation, energy cost	✓	
BUS++	energy performance, ventilation, air flow, indoor air quality, noise level		
BV2	annual energy use, durational diagram		
C-MAX	pumps, fans, chillers, compressors, energy conservation, facility design		
CAMEL	load estimation, psychrometrics, plant sizing		
Carbon Estates	Energy Benchmarking; Retrofitting Simulation; Energy Management; Carbon Management		
CATALOGUE	windows, fenestration, product information, thermal characteristics	✓	
CELLAR	cellar, heat loss, design rules		
Cepenergy Management Software for Buildings	Energy management, energy efficiency, energy evaluation, energy simulation, energy modeling, environmental performance, sustainable development, CO2 footprint.		
CHP Capacity Optimizer	CHP, cogeneration, capacity optimization, distributed generation	✓	
CHVAC	commercial hvac, load calculations, CLTD		

Tool	Applications	Free	Recently Updated
CL4M Commercial Cooling and Heating Loads	cooling loads, heating loads, commercial buildings		
CLIMATE 1	climate data, climatic maps, sun chart		
Climate Consultant	climate analysis, psychrometric chart, bioclimatic chartm wind wheel	✓	
Climawin 2005	building thermal regulations		
CoDyBa	Energy simulation, energy efficiency, building performance, renewable energy, comfort, thermal analysis, indoor air temperature, dynamic simulation.		
Cold Room Calc	refrigeration load, heat gains, heat loads, cold room, cooler, freezer, refrigerated warehouse		
COLDWIND Pro	Refrigeration, Heat Load Calculation		
COMcheck	energy code compliance, commercial buildings, codes training, energy savings	✓	
COMFIE	energy performance, design, retrofit, residential buildings, commercial buildings, passive solar		
COMIS	multizone airflow, pollution transport	✓	
Commodity Server	energy database server, time series energy, portfolio management		
CompuLyte	lighting, daylighting, rendering	✓	
COMSOL	Multiphysics, simulations, modeling, heat transfer, finite element		
Construction R-value Calculator	R-value, thermal bridging	✓	
CONTAM	airflow analysis; building controls; contaminant dispersal; indoor air quality, multizone analysis, smoke control, smoke management, ventilation	✓	
Cool Roof Calculator	reflective roof, roofing membrane, low-slope roof	✓	
Cool Room Calc	cooling load, heat gains, heat loads, air-conditioned room, air conditioner, HVAC, air conditioning		
CPF Tools	Solar Sales, Quoting Tool, Proposal Tool, Solar Financing, Leads, Auto-Populate, Rebate Form, CRM software, Customer and Financing Dashboard		

Tool	Applications	Free	Recently Updated
CtrlSpecBuilder	HVAC controls, specifications, CSI Section 15900 HVAC Instrumentation and Controls	✓	
Cymap Electrical	BS 7671 Main/Sub Main and Final Circuit distribution, generators, UPS, lighting design, emergency lighting, daylighting, floodlighting, cable sizing, discrimination studies, LV and HV capabilities, fire alarm, CAD symbol library based small power design, Cable Tray/Basket/Raceways/Conduit. Lightning protection risk assessment to EN62305 in 10 languages.		
Cymap Mechanical	Load calculation, Pipe sizing & Radiator selection, Duct sizing, Hot and cold water design, SAP, iSBEM, EPCs, Psychrometrics.		
CYPE-Building Services	building services, single model, energy simulation, sizing, HVAC, plumbing, sewage, electricity, solar, analysis of acoustic behavior		
Czech National Calculation Tool	EPBD, Energy Performance Certificate, Delivered energy, Energy Demand Calculation	✓	
D-Gen PRO	distributed power generation, on-site power generation, CHP, BCHP		
Data Center Efficiency Savings Calculator	Energy Efficiency Calculator for Data Centers.		
Dataplus-online	monitoring and targeting, energy management, self-billing		
DAVID-32	Thermal bridges, temperatures, heat flows, computer program, freeware	✓	
Daylight	daylighting, daylight factor	✓	
DAYSIM	annual daylight simulations, electric lighting energy use, lighting controls	✓	
DD4M Air Duct Design	duct design, air-conditioning, heating		
Degree Day.Net	degree days, HDD, CDD	✓	
Degree Day Forecasts	degree days, historical weather, mean daily temperature	✓	
Degree Day Reports	degree days, historical weather, mean daily temperature	✓	
Delphin Reports	Coupled heat, air and moisture transport, porous materials, building envelope		

Tool	Applications	Free	Recently Updated
Demand Response Quick Assessment Tool	demand response, load estimation, EnergyPlus	✓	
DEROB-LTH	energy performance, heating, cooling, thermal comfort, design		
DesiCalc	desiccant system, air-conditioning, system design, energy analysis, dehumidification, desiccant-based air treatment		
Design Advisor	whole-building, energy, comfort, natural ventilation, double-skin facade	✓	
DesignBuilder	Building energy simulation, visualisation, CO2 emissions, solar shading, natural ventilation, daylighting, comfort studies, CFD, HVAC simulation, re-design, early-stage design, building energy code compliance checking, OpenGL EnergyPlus interface, building stock modelling, hourly weather data, heating and cooling equipment sizing		
DeST	building simulation, design process, calculation, building thermal properties, natural temperature, graphical interfaces, state space method, maximum load.	✓	
Diag DPE	energy performance directive		
DIALux	lighting design, daylight and artificial lighting, emergency lighting, road lighting	✓	
DIN V 18599	DIN V 18599, EPBD, energy performance of buildings directive	✓	
Discount	present value, discount factors, future values, life-cycle cost	✓	
DOE-2	energy performance, design, retrofit, research, residential and commercial buildings		
DOLPHIN	duct sizing, duct and fitting pressure loss, fan pressure		
DONKEY	duct sizing, equal friction, static regain, balanced pressure drop, duct acoustics, self generated noise, room sound pressure level		
DPClima	thermal load calculation, equipment sizing		
Duct Calculator	duct-sizing, design, engineering, calculation		
DUCTSIZE	duct sizing, equal friction, static regain		
e-Bench	energy benchmarking, environmental benchmarking, energy audit, invoice verification and reconciliation, performance contract verification		

Tool	Applications	Free	Recently Updated
e-Sankey	Sankey diagram, flow chart, energy efficiency, visualization		
E-Z Heatloss	heat loss, heat gain, residential calculation		
E.A.S.Y. - Energy Accounting System for Your Buildings	Energy Accounting, OMV System, Building baseline development, Energy and Emissions Savings		
EA-QUIP	building modeling, energy savings analysis, retrofit optimization (work scope development), investment analysis, online energy analysis tool, multifamily building analysis		
Easy EnergyPlus	N/A	✓	
EASY: Whole House Energy Audit	energy audit, residential buildings, retrofit, economic evaluation, DSM		
EBS	utility billing, energy management		
ecasys	energy program management		
Eco Lumen	lighting design, energy efficient		
ECO-BAT	environmental performance, life cycle assessment, sustainable development		
EcoAdvisor	online interactive training, online multimedia training, sustainable commercial buildings, lighting, HVAC	✓	
EcoDesigner	for architects, integrated in BIM software, one click evaluation		
ecoInsigh Energy Audit & Analysis Software	Retrofit Analysis, Energy Audit Software, Building Analysis, Lighting Retrofit		
ECOTECT	environmental design, environmental analysis, conceptual design, validation; solar control, overshadowing, thermal design and analysis, heating and cooling loads, prevailing winds, natural and artificial lighting, life cycle assessment, life cycle costing, scheduling, geometric and statistical acoustic analysis		
eDNA	energy data management, on-line data archive		
EE4 CBIP	whole building performance, building incentives	✓	
EE4 CODE	standards and code compliance, whole building energy performance	✓	

Tool	Applications	Free	Recently Updated
EED	Earth energy, boreholes, ground heat storage, ground source heat pump system (GSHP)		
EEM Suite	energy management, energy accounting, bench-marking, energy use analysis, energy forecasting		
EffTrack	chiller efficiency, chiller performance		
EMISS	atmospheric pollution, energy-related pollution emissions	✓	
EN4M Energy in Commercial Buildings	energy calculation, commercial buildings, bin method, economic analysis		
ENER-WIN	energy performance, load calculation, energy simulation, commercial buildings, daylighting, life-cycle cost		
EnerCAD	Building Energy Efficiency; Early Design Optimization; Architecture Oriented; Life Cycle Analysis		✓
EnerCop Energy Benchmarking and Accounting Software	energy accounting		
Energy Estimation Software with Carbon Footprint Calculation	Variable frequency drive, energy savings, fans, pumps, carbon footprint		
Energy Expert	energy tracking, energy alerts, wireless monitoring		
Energy Lens	energy management, half-hourly data analysis, business energy saving, monitoring and targeting		
Energy Profile Tool	benchmarking, energy efficiency screening, end-use energy analysis, building performance analysis, utility programs		
Energy Profiler	load profiles, rate comparisons, data collection		
Energy Profiler Online	online, energy usage, load profiles, bill estimation		
Energy Scheming	design, residential buildings, commercial buildings, energy efficiency, load calculations		
Energy Trainer for Energy Managers HVAC Module	training, HVAC, operation and maintenance, existing buildings		

Tool	Applications	Free	Recently Updated
Energy Usage Forecasts	degree days, historical weather, mean daily temperature, load calculation, energy simulation		
Energy WorkSite	energy benchmarking, facility checklist, utility bill manager		
Energy-10	conceptual design, residential buildings, small commercial buildings		
EnergyAide	Energy audits, home energy analysis, retrofit		
EnergyCAP Enterprise	energy information, energy accounting, energy tracking, energy efficiency, utility bill management, energy management, utility bill accounting, benchmarking, degree days, M&V, energy measurement, FASER		
EnergyCAP Professional	energy information, energy accounting, energy tracking		
EnergyGauge Summit Premier	Building simulation, energy simulation, building energy modeling, ASHRAE Standard 90.1, commercial code compliance, LEED NC 2.2 EA Credit 1, federal commercial building tax deductions, EPACT 2005 qualified software, Florida code compliance, ASHRAE Standard 90.1 Appendix G, DOE 2.1E, AHSRAE advanced building design guidelines, automatic reference building generation, automatic EA Credit 1 PDF generation, buildings research		
EnergyGauge USA	residential, energy calculations, code compliance		
EnergyPeriscope	Renewable energy performance analysis, financial analysis, sales proposals		
EnergyPlus	energy simulation, load calculation, building performance, simulation, energy performance, heat balance, mass balance	✓	
EnergyPro	California Title 24, LEED, ASHRAE 90.1, compliance software, energy simulation, commercial, residential		✓
EnergySavvy	efficiency calculation, energy rebates, home contractor search	✓	
EnergyShape	energy load, end-use, energy profile		
EnergyWitness	large building; energy efficiency		
ENERPASS	energy performance, design, residential and small commercial buildings		
ENFORMA	data acquisition, energy performance, building diagnostics, HVAC systems, lighting systems		

Tool	Applications	Free	Recently Updated
Engineering Toolbox	Refrigerant line sizing, air properties, fluid properties, power factor correction, duct sizing		
Envest	sustainable design, green buildings, life cycle analysis, environmental impact analysis		
EPB-software	EPBD implementation, Flemish region, primary energy consumption	✓	
EQUER	life cycle assessment, design, retrofit, residential and commercial buildings, simulation		
eQUEST	energy performance, simulation, energy use analysis, conceptual design performance analysis, LEED, Energy and Atmosphere Credit analysis, Title 24, compliance analysis, life cycle costing, DOE 2, PowerDOE, building design wizard, energy efficiency measure wizard, eem		
ESP-r	energy simulation, environmental performance, commercial buildings, residential buildings, visualisation, complex buildings and systems	✓	
Evergreen LED	LED lighting energy savings calculator		
EXTREMES	extreme weather, weather sequences, simulation, energy calculation		
EZ Sim	energy accounting, utility bills, calibration, retrofit, simulation		
EZDOE	energy performance, design, retrofit, research, residential and commercial buildings		
FASER	energy information, resource accounting		
FEDS	single buildings, multibuilding facilities, central energy plants, thermal loops, energy simulation, retrofit opportunities, life cycle costing, emissions impacts, alternative financing		
FENSIZE	fenestration, solar heat gain coefficient, thermal transmittance, visible transmittance, windows, skylights, code compliance		
FENSTRUCT	structural performance, fenestration, deflection, stress, moment of inertia, centroids, AAMA		
flixo	2D heat transfer, cold bridge, fenestration, frame U-value, thermal bridge		
FLOVENT	airflow, heat transfer, simulation, HVAC, ventilation		

Tool	Applications	Free	Recently Updated
Flownex	gas flow; liquid flow; dynamic; heat transfer; two phase; slurry		
FLUCS	illumination, daylighting		
FlucsDL	daylight simulation		
FlucsPro	luminaires, lighting design, lighting analysis, photometric data, radiosity		
foAudits	Energy audit; Android; iOS; Windows Mobile; WinCE; Web browser		
Frame Simulator	2D, heat transfer, thermal analysis, thermal transmittance, thermal conductance, building energy analysis, fenestration, window, U-value, EN ISO, surface condensation, moisture, dew point, frame, glazing, spacer, therm		
FRAME4	fenestration, framing, heat transfer, building components, thermal characteristics		
FRAMEplus	windows, fenestration, framing, building components, thermal characteristics, optical characteristics		
FRESA	renewable energy, retrofit opportunities	✓	
FSEC 3.0	energy performance, research, advanced cooling and dehumidification		
GaBi 4	environment, life cycle assessment, LCA, ecoprofiles, system analysis, design, research		
Gas Cooling Guide PRO	gas cooling, hybrid HVAC systems		
Genability	power tariff, energy tariff, energy pricing, energy bill, electricity tariff, power bill, electricity bill, electricity pricing, time of use, real time, utilities, critical peak, pricing, peak pricing, demand side management, high load factor, curtailment, interruptible, standby service, supplemental service, electric vehicle charging, electric rate plan, power rate plan, electric rate, power rate, energy rate, energy rate plan, electricity api, power api, energy api, electricity rate api, power rate api, energy rate api, utility pricing, utility price, utility rate		
GenOpt	system optimization, parameter identification, nonlinear programming, optimization methods, HVAC systems	✓	

Tool	Applications	Free	Recently Updated
GIHMS	industrialized housing production operations		
GLASTRUCT	structural performance, fenestration, deflection, stress, ASTM		
GLHEPRO	ground heat exchanger design, ground source heat pump system, geothermal heat pump system		
GPM PV+	energy management, energy accounting, benchmark, energy analysis, alert system		
Green Energy Compass	Single-family Residence, Benchmarking, Energy Tracking, Improvement Tracking, Weather Normalization		
Ground Loop Design	geothermal, borehole, heat exchanger design		
HAMLab	Heat air and moisture, simulation laboratory, hygrothermal model, PDE model, ODE model, building and systems simulation, MatLab, SimuLink, Comsol, optimization	✓	
HAP	energy performance, load calculation, energy simulation, HVAC equipment sizing		
HAP System Design Load	Cooling and heating load calculation, HVAC equipment sizing, zoning and air distribution		
HBLC	heating and cooling loads, heat balance, energy performance, design, retrofit, residential and commercial buildings		
HEAT Energy Audit Tool	energy efficiency program, auditing, reporting		
Heat Pump Design Model	heat pump, air conditioner, air-to-air heat pump, equipment simulation	✓	
HEAT2	heat transfer, 2D, dynamic, simulation		
HEAT3	heat transfer, three-dimensional heat conduction, transient heat flow, steady-state heat flow		
HEED	whole building simulation, energy efficient design, climate responsive design, energy costs, indoor air temperature	✓	
Home Energy Saver	internet-based energy simulation, residential buildings	✓	

Tool	Applications	Free	Recently Updated
Home Energy Tune-uP	Home energy audit, energy efficiency, administration, conservation, consulting, energy savings, home performance, inspection, low income, renewable energy, residential retrofit, training, weatherization, whole house		
HomeEnergy Suite	Energy use and savings analysis.		
HOMER	remote power, distributed generation, optimization, off-grid, grid-connected, stand-alone	✓	
HOT2 XP	energy performance, design, residential buildings, energy simulation, passive solar	✓	
HOT2000	energy performance, design, residential buildings, energy simulation, passive solar	✓	
HPSIM	heat pump, research	✓	
HVAC 1 Toolkit	energy calculations, HVAC component algorithms, energy simulation, performance prediction		
HVAC Solution	boilers, chillers, heat exchangers, cooling towers, pumps, fans, expansion tanks, heat pumps, fan coils, terminal boxes, louvers, hoods, radiant panels, coils, dampers, filters, piping, valves, ductwork, schedules		
HVACSIM+	HVAC equipment, systems, controls, EMCS, complex systems	✓	
Hydronics Design Studio	hydronic heating, radiant heating, simulation, design, piping		
I-BEAM	indoor air quality, IAQ education, IAQ management, energy and IAQ	✓	
IAQ-Tools	indoor air quality, ‘sick’ buildings, ventilation design, contaminant source control design, tracer gas calculations		
ID-Spec Large	Electrical installation design, power losses assessment, CO2 emissions, quantity of conductors		
IDA Indoor Climate and Energy	design, energy performance, thermal comfort, indoor air quality, commercial buildings		
IDEAL	electric utility analysis, electricity costs, bill analysis		
Indoor Humidity Tools	indoor air humidity, dryness, condensation		

Tool	Applications	Free	Recently Updated
INDUS	ductwork sizing, ductwork design, HVAC		
InterLane Power Manager	energy metering, monitoring, power management		
ION Enterprise	energy management, power quality, power reliability, cost allocation		
IPSE	solar architecture, passive solar, residential buildings, primer, introduction, educational, reference	✓	
ISE	thermal model, building zone simulation, MatLab/SimuLink	✓	
ISOVER Energi	energy performance, heat loss, U-value, profitability, Danish building regulations		
IWEC	international weather, weather data, climate data, energy calculations		
IWR-MAIN	water demand analysis, municipal and industrial water demand, water conservation, water resource planning		
IWRAPS	water planning, water management, water use forecasting, water conservation, water rights, military installations		
J-Works	load calculation, commercial buildings, residential buildings		
KCL-ECO	life cycle, inventory, assessment, LCA		
kW-Field	Commercial Energy Auditing Field Software		
LESO-COMFORT	thermal comfort, load calculation, energy		
LESO-SHADE	shading factors, solar shading, building geometry		
LESOCOOL	airflow, passive cooling, energy simulation, mechanical ventilation		
LESODIAL	Daylighting, early design stage, user-friendliness		
LESOKAI	thermal tranmission, water vapor, building envelope		
LESOSAI	heating energy, cooling energy, energy simulation, load calculation, standards, life cycle analysis, gbxml		
LifeCycle	life-cycle cost, economics		
LightPro	luminaires, lighting analysis, photometric data		
LISA	life cycle analysis, sustainability, utilisation, embodied energy	✓	

Tool	Applications	Free	Recently Updated
Load Express	Design, light commercial buildings, heating and cooling loads, HVAC		
Look3D	three-dimensional, full-color surface plots from columnar data, energy-use data		
LoopDA	airflow analysis, indoor air quality, multizone analysis, natural ventilation		
Louver Shading	window, overhang, blinds, louvers, louvres, trellis, shading, solar	✓	
Macromodel for Assessing Residential Concentrations of Combustion Generated Pollutants	indoor air quality, research		
Maintenance Edge	CMMS, Maintenance, Work Order, Planned Maintenance, LEED, ENERGY STAR®, benchmarking, Critical Alarm		
ManagingEnergy	building energy management; energy efficiency strategies, energy accounting		
MarketManager	building energy modeling, design, retrofit		
MC4Suite 2009	HVAC project design, sizing, calculations, energy simulation, commercial, residential, solar		
METEONORM 6	weather data, solar radiation, temperature, typical years, climate analysis		
METRIX4	monitoring and verification, utility bill analysis, utility accounting		
MHEA	retrofit opportunities, audit, mobile homes		
Microflo	CFD, airflow, air quality, thermal performance		
Micropas6	energy simulation, heating and cooling loads, residential buildings, code compliance, hourly		
ModEn	object-oriented simulation, energy simulation, controls, energy audit, energy-saving, energy performance, dynamic simulation, research, education, heating, air conditioning		
MOIST	combined heat and moisture transfer, envelope	✓	
MotorMaster+	motors, premium efficiency, motor management, industrial efficiency	✓	

Tool	Applications	Free	Recently Updated
myupgrades.com	HVAC updates, HVAC equipment selection, energy savings, up-sell		
National Energy Audit (NEAT)	retrofit, energy, audit, efficiency measures		
NewQUICK	Passive simulation, load calculations, natural ventilation, evaporative cooling, energy analysis.		
OHVAP	venting design, oil-fired equipment		
OnGrid Tool	solar, financial, payback, analysis, sales, tool, software, economics, proposal		
Opaque	wall thermal transmission, U-value	✓	
OptiMiser	weatherization, customizable, audit, retrofit, analysis, payback, utility bill, disaggregation, cost database, contractor		
OptoMizer	Lighting audit retrofit software, Lighting retrofit rebate programs, Lighting design and analysis		
Overhang Annual Analysis	window, overhang, shading, solar	✓	
Overhang Design	solar, window, overhang, shading		
Panel Shading	solar panels, pv, photovoltaics, solar collectors, solar thermal, shading, solar	✓	
ParaSol	solar protection, solar shading, windows, buildings, solar energy transmittance, solar heat gain coefficient, energy demand, heating, cooling, comfort, daylight	✓	
PASSPORT	heating requirements, passive solar, residential buildings, standards		
PEAR	design, retrofit, residential buildings		
Pervidi	building systems, performance, preventative maintenance, analysis, residential and commercial buildings		
PHOENICS	computational fluid dynamics, air pollution, s moke and fire, air flow		
Photovoltaics Economics Calculators	solar, photovoltaic, economic	✓	
PHPP	energy balance, high-performance houses, passive houses		

Tool	Applications	Free	Recently Updated
Physibel	heat transfer, mass transfer, radiation, convection, steady-state, transient, 2-D, 3-D		
Pipe Designer	fluid systems, piping design, existing systems		
Pipe Flow Expert	pipe flow, pipe pressure loss		
Pipe-Flo	piping analysis, pump selection, piping design, hydraulic analysis, pump sizing, pressure drop calculator, hydraulic modeling, steam distribution, chilled water, sprinkler system		
Pisces	pipework, heating, cooling		
PocketControls	PDA, controls, front end, handheld		
Polysun	Solar System Design Simulation Software (and Heat Pump)		
Popolo Utility Load Calculation	Heat transfer, load calculation, BESTEST, GPL, Free source		
Power Calc PaK	power distribution, panelboard, NEC, electrical, energy savings, buildings		✓
PRISM	utility billing data, demand-side management, statistical energy savings		
Prophet Load Profiler	energy analysis, load profiling, cost comparison, energy budgeting, rate analysis, data collection, real-time monitoring, load shedding		
PsyCalc	psychrometric, temperature, moisture content, atmospheric pressure		
PsyChart	Moist air state, dry bulb, wet bulb, relative humidity, sensible heat, moisture content.		
Psychrometric Analysis	psychrometric analysis, HVAC	✓	
PUtility Psychrometric	Moist air, Psychrometric chart, GPL, Free source		
PV*SOL	photovoltaic systems simulation, planning and design software, grid connected systems, stand-alone systems		
PV-DesignPro	photovolatiac design, tracking systems, solar, electrical design		
PVcad	photovoltaic, facade, yield, electrical	✓	
PVSYST	PV system sizing, PV system simulation, grid-connected PV systems, stand-alone PV systems, shading, solar tools		

Tool	Applications	Free	Recently Updated
PYTHON	pipe sizing, pump sizing, control valve selection		
Quick Calc	lighting design, 3d drawing, indoor lighting	✓	
Quick Est	lighting, 3d drawing, indoor lighting	✓	
QwickLoad	Design, residential to large commercial buildings, heating load, cooling load, HVAC		
Radiance	lighting, daylighting, rendering	✓	
Radiance Control Panel	radiance, lighting, daylighting, ray tracing, glare	✓	
Radiance Interface	Lighting, daylighting, ray tracing, glare		
RadOnCol	solar radiation, solar collector	✓	
RadTherm	convection, conduction, radiation, weather, solar, transient		
Recurve	energy simulation, home performance, estimates, energy audit		
REEP	energy- and water-efficiency strategies, economic analysis, pollution abatement, DOD installations	✓	
Rehab Advisor	high performance housing, single family, multifamily, housing renovation, energy efficiency	✓	
REM/Design	energy simulation, residential buildings, code compliance, design, weatherization, equipment sizing, EPA Energy Star Home analysis		
REM/Rate	home energy rating systems, residential buildings, energy simulation, code compliance, design, weatherization, EPA Energy Star Home analysis, equipment sizing		
REScheck	energy code compliance, residential buildings, codes training, energy savings	✓	
RESEM	retrofit, institutional buildings	✓	✓
RESFEN	fenestration, energy performance	✓	
RETScreen	renewable energy screening, feasibility studies for energy efficiency	✓	
RHVAC	residential HVAC, residential load calculations, ACCA, Manual J		
Right-Suite	residential loads calculations, duct sizing,		

Tool	Applications	Free	Recently Updated
Residential for Windows,	energy analysis, HVAC equipment selection system design		
RIUSKA	Energy calculation, heat loss calculation, system comparison, dimensioning, 3D modeling		
Roanakh	photovoltiac system design, grid-tie, grid-interactive, solar electric system design	✓	
Room Air Conditioner Cost Estimator	air conditioner, life-cycle cost, energy performance, residential buildings, energy savings	✓	
SBEM	energy consumption/performance, carbon dioxide emissions, UK building regulations, compliance checking, non-residential buildings	✓	
Shading II	Geometrical Shading/Insolated Coefficient, Sun view, shadow calculation		
ShadowFX	shading calculations, sun modelling, solar shading		
SIMBAD Building and HVAC Toolbox	transient simulation, control, integrated control, control performance, graphical simulation environment, modular, system analysis, HVAC		
SIP Scheming	stressed skin insulating core panels		
SkyVision	Skylight, light well, fenestration, glazing, optical characteristics, daylighting.	✓	
SLAB	slab on the ground, heat loss, design rules		
SMILE	object-oriented simulation environment, building and plant simulation, complex energy systems, time continuous hybrid systems	✓	
Sol Path	solar, sun, sun path		
solacalc	passive solar, house design, building design, building services, design tools		
Solar Rater	solar power, solar energy, solar calculator, solar app, android solar app, renewable energy, pv, photovoltaic		✓
Solar Tool	overhang sizing and position, shading devices, louvers,		
SOLAR-2	windows, shading fins, overhangs, daylight	✓	
SOLAR-5	design, residential and small commercial buildings	✓	
SolArch	thermal performance calculation, solar architecture, residential buildings, design checklists	✓	

Tool	Applications	Free	Recently Updated
SolarDesignTool	photovoltaic, PV system design, grid-tie PV systems, grid-tied pv systems, string sizing, array layout design		
SolarPro 2.0	solar water heating, thermal processes, alternative energy, simulation		
SolarShoeBox	Direct gain, passive solar	✓	
SolDesigner	design, solar thermal, solar hot water, solar heating plants, solar design		
Sombrero 3.01	Solar shading, solar radiation, building geometry, solar systems		
SPACER	fenestration, spacer, THERM, thermal modeling, IGU, sealants		
SPARK	object-oriented, research, complex systems, energy performance, short time-step dynamics	✓	
SPOT	daylighting, electric lighting, photosensor, energy savings	✓	
Star Perfomer	energy performance diagnostic, energy audit, office building	✓	
STE	thermal regulations, residential and commercial buildings, energy certification		
STREAM	Computational fluid dynamics, CFD, ventilation, airflow, temperature distribution, humidity distribution, contaminant distribution, thermal comfort, air quality		
SunAngle	Solar, sun, angle		
SunAngle Professional Suite	sun angle, solar calculator		
Suncast	solar shading, insolation		
SUNDAY	energy performance, residential and small commercial buildings		
SUNDI	solar shading, solar irradiance, solar patterns	✓	
SunPath	solar geometry, sun position		
SunPosition	solar angle design, solar altitude, solar design		
SunPosition online	sun position, solar angle design, solar azimuth, solar altitude, sun path	✓	
SUNREL	design, retrofit, research, residential buildings, small office buildings, energy simulation, passive solar		

Tool	Applications	Free	Recently Updated
Sunspec	solar radiation, illuminance, irradiance, luminous efficacies, solar position		
SunTools	Sun Path, Sun Views, Solar Access, Sun Penetration		
SUN_CHART Solar Design Software	sunchart, solar position, sun path, shading		
SuperLite	daylighting, lighting, residential and commercial buildings	✓	
System Analyzer	Energy analyses, load calculation, comparison of system and equipment alternatives		
T*SOL	solar thermal heating, swimming pool heating, solar planning and design		
TAPS	pipe sizing		
Tariff Analysis Project	bill calculator, utility bills, tariff, schedules, rates, rate schedules, utility rates, utility tariffs, cost savings, energy savings analysis, investment analysis	✓	
TAS	Building dynamic thermal simulation, building simulation , comfort, CFD, thermal analysis, energy simulation		
Tetti FV	photovoltaic, PV, energy performance, design, PV system sizing, PV system simulation, grid-connected PV systems		
Therm	two-D heat transfer, building products, fenestration	✓	
Thermal Comfort	thermal comfort calculation, comfort prediction, indoor environment		
ThermoSim	dynamic heat transfer, wall systems, simulation algorithms, interactive simulation, Java	✓	
Toolkit for Building Load Calculations	building loads, energy calculations, heat balance model, heat transfer		
TOP Energy	Energy Efficiency Optimization, Simulation, Variant Comparison, Visualization of energy flows	✓	
TownScope II	solar energy, urban design, visual reasoning		
TRACE 700	Energy performance, load calculation, HVAC equipment sizing, energy simulation, commercial buildings		

Tool	Applications	Free	Recently Updated
TRACE Load 700	Heating and cooling load calculation, air distribution simulation, HVAC equipment sizing, commercial buildings		
TRANSOL	Powerful, flexible, complete		✓
TREAT	weatherization auditing software, BESTEST, Home Performance with ENERGY STAR® auditing tool, retrofit, single family, multifamily residential, mobile homes, HERS ratings, load sizing.		
Trend Importer	trend, importer, data, spreadsheet, UTF		
TRNSYS	energy simulation, load calculation, building performance, simulation, research, energy performance, renewable energy, emerging technology		
tsbi3	energy performance, design, retrofit, research, residential and commercial buildings, indoor climate		
UM Profiler	utility metering, utility accounting		
Umberto	material and energy flow analysis, process optimization, environmental impact assessment, material flow cost accounting, life cycle assessment (LCA), life cycle costing (LCC)		
UMIDUS	moisture calculation, latent and sensible conduction loads, heat and mass transfer through building envelopes	✓	
United Resources Group Lighting Conservation	Quantify, Lighting Conservation, Cost and Savings		
UNorm	U-values, thermal bridges, temperatures, heat flows, computer program, freeware	✓	
UrbaWind	CFD, wind simulation, wind energy, natural ventilation, pedestrian comfort		
USai	inhomogeneous thermal transmission coefficient, Dynamic characteristics, condensation risk		
Utility Manager	Central capture of utility data for cost and energy usage reporting and reduction		
UtilityTrac	energy tracking, LEED, ENERGY STAR, utility bill management, M&V, benchmarking		
Varitrane Duct Designer	duct sizing, static regain, equal friction, fitting loss		

Tool	Applications	Free	Recently Updated
VentAir 62	ventilation design, ASHRAE Standard 62		
VIP+	energy performance, code compliance, design, research, residential and commercial buildings, costs, environmental sustainable		
VIPWEB	energy performance, code compliance, design, research, residential and commercial buildings, costs, environmental sustainable	✓	
Virtualwind	wind simulation, virtual wind tunnel, microclimate simulation, wind flow in urban environments, advanced wind flow visualization		
VISION4	fenestration, solar optical characteristics, thermal performance, windows, glazing		
Visual	lighting, lighting design, roadway lighting, visual, lumen method	✓	
Visual TTH	thermal regulation, compliance, EN 12831, RT 2000, RT 2005		
VisualDOE	energy, energy efficiency, energy performance, energy simulation, design, retrofit, research, residential and commercial buildings, simulation, HVAC, DOE-2		
Visualize-IT Energy Information and Analysis Tool	energy analysis, rate comparison, load profiles, interval data		
WaterAide	water audits, water analysis, water end-use allocation, retrofits, domestic hot water		
Weather Data Viewer	weather, climate, extreme weather, design data, design temperature, humidity, dew point, dry bulb, wet bulb, temperature, enthalpy, wind speed		
Weather Tool	weather data visualization, psychrometry, passive design analysis, optimum orientiation, data synthesis		
Weather Year for Energy Calculations 2	weather data, energy calculations, simulation data		
Window	fenestration, thermal performance, solar optical characteristics, windows, glazing	✓	
Window Heat Gain	Solar, window, energy		

Tool	Applications	Free	Recently Updated
WISE	hygrothermal model, building simulation, MatLab/SimuLink Tool	✓	
WUFI-ORNL/IBP	moisture modeling, hygrothermal model, combined heat and moisture transport, building envelope performance	✓	✓
ZEBO	design decision support; zero energy building; sensitivity analysis; energy simulation; thermal comfort; hot climate		
ZIP	economic insulation level, residential buildings	✓	
¡Get Psyched!	psychrometric chart, moisture, humidity, dry bulb temperature, wet bulb temperature		

Chapter 17

Retro-commissioning

Jim Brown

Energy auditing, in its most basic form, has been a part of the engineering world since Americans first felt the inconveniences associated with a shortage of energy supply; an inconvenience forced upon us by other oil producing nations in the early 1970s. Because it is an industry that has been with us for 40 years, we often assume that we have perfected the process, but because it has *only* been with us for 40 years, we continually see it change and improve. As a result, this ninth edition of the *Handbook of Energy Audits* (The Fairmont Press and CRC Press) is now being published with two new chapters, one focused upon the art of creating an Investment Grade Energy Audit (Chapter 18), and this chapter, which attempts to explain a relatively new process for gathering and analyzing energy data, "Retro-commissioning or RCx."

RETRO-COMMISSIONING (RCx) DEFINED

Although retro-commissioning is normally viewed as a form of energy auditing, its usefulness isn't necessarily limited to energy. The techniques utilized by the experienced RCx agent can serve equally well for those searching for the source of room comfort problems, or those involved in a forensics effort to discover why a system isn't operating properly. However, the most common application of this "backward looking" commissioning process is to discover why energy parameters, like energy use index (*EUI* = Btu/sf-year) or energy cost index (*ECI* = Cost/sf-year), within a specific facility or system are higher than they should be.

Let's clarify some basic concepts and delineate specific differences, just to make sure we are operating under the same set of definitions:

Commissioning (Cx) is a process of documentation, adjustment, testing, verification and training performed specifically to ensure that the finished systems operate in accordance with the owner's stated project requirements and the designer's construction documents.

The 2011 ASHRAE Handbook on *HVAC Applications* adds that **commissioning** is a

"quality-oriented process for achieving, verifying and documenting that the performance of facilities, systems and assemblies meets defined objectives and criteria."

Generally, the word commissioning is used in connection with new building construction projects. As a result, there are myriad codes, standards and permitting requirements that must be integrated into the Cx process that have nothing to do with energy and everything to do with handing the building owner a set of keys to a building or system that performs as it should.

Re-Commissioning or **Continuous Commissioning** (**Re-Cx** or **CCx**) is the process of adjusting, revising and improving the operation of systems and equipment within a previously commissioned facility.

Obviously, re-commissioning refers to checking out an existing, previously commissioned facility. In fact, it normally refers to a process that is frequently repeated. In some circles, the Re-Cx process is referred to as continuous commissioning (CCx). In general, the intent is to ensure that the originally designed operation for a system or a specific piece of equipment is being followed. If not, adjustments are made to bring the equipment back in line with its original purpose and operating sequence. The frequency of this CCx process depends upon the hours of system operation, the environment the systems operate within, the sensitive nature of the area served by the equipment, the quality of maintenance performed, and other conditions totally dependent upon the building owner/occupants needs.

Sometimes a facility can be re-commissioned to improve the systems beyond the original design. For example, adding new sensors to areas that had no original CO_2 (carbon dioxide) measurement in the conditioned space. With today's technology, we are able to re-commission the system to utilize this new technology to save energy and make sure that the indoor air quality is maintained. Re-commissioning can incorporate new strategies that were not available when the building was first commissioned. Buildings do not remain static, they either deteriorate or they are frequently re-evaluated and improved. Re-commissioning should be considered to be a significant tool toward continuous facility and systems improvement.

> **Retro-commissioning** (**Retro-Cx** or **RCx**) is the application of the commissioning process in a facility that has never been commissioned.

It is safe to say that a building that has never been professionally commissioned offers significant opportunities for a retro-commissioning agent. In fact, it is fairly safe to say that, unless professionally commissioned, virtually every building suffers from incomplete setup during the construction process, especially the ones with highly technical controls and operating systems. Consequently, the Retro-Cx industry is growing at a significant pace and doing a tremendous amount of good in the field of energy efficiency and reduced energy expense.

Whether providing a CCx or RCx service, one of the most significant tasks for the energy engineer is to determine the current space function and occupancy, as opposed to the usage at the time of original operation. Facility usage changes, sometimes frequently. Areas within the facility are re-configured for vastly different service than originally intended. In fact, change is even necessitated by moving different occupants with different personal comfort requirements into a specific space. As a result, it is incumbent upon the commissioning agent to know the end result required today and revise system operation to meet the current needs. Retro-commissioning agents must resist the tendency to rely solely upon as-built drawings and original equipment submittals as the source of information for appropriate system operation.

Although there are much more elaborate definitions for each of these terms floating around the energy audit world, I believe they are simple enough to offer the insight we need into the variance between the three commissioning classifications. So with the basic definitions established, we can now focus on the central theme of this chapter, i.e., the commissioning steps taken within existing buildings. At this point, however, I would really like to drill a bit deeper and insert a few more characteristics of existing building commissioning into our definition:

> **Retro-commissioning** (**RCx**) includes implementation of low cost measures taken to obtain appropriate operating conditions within the facility and attain maximum efficiency from existing systems, given the current circumstances.

A breakdown of this definition is appropriate:

- A "low cost measure" does not equate to "no cost measure," unless you overlook the fact that the energy auditor is getting paid! CenterPoint Energy, the electric utility company serving Houston and southeastern Texas, pays around $35,000 for a thorough RCx report. Other utility providers around the country pay as much as $60,000… it's not a "no cost" program. However, there is potential for the *end-user* to spend nothing and yet obtain significant energy cost savings. There are grants and rebates across the nation financed through federal, state or utility provider programs that will supply (and sometimes train) the RCx agent, assure his/her qualifications, and set up a program aimed at minimizing the end-user energy consumption or electrical demand without requiring a single dime from the building owner or tenant who benefits from the lower energy bill. Even those utility suppliers that do require the building owner to agree to spend a certain amount of money for mutually beneficial projects will often refund those expenses after the renovation has been completed and the savings are being realized. The bottom line is that RCx, when done correctly and thoroughly, significantly reduces the amount of power that must be generated by the electric supplier. It's a win-win for both the supplier and the end user. It isn't "no cost," but it is quite possibly the best investment that can be secured by utility suppliers and utility bill payers alike. From our last survey of websites and state/federal agency offerings, we discovered at least fifty-two different programs established to assist in the funding of a RCx project.

  A good RCx program requires a lot of high quality (and therefore expensive) research including, but certainly not limited to:

  — utility bill analysis,
  — rate schedule analysis,
  — consideration of system operating parameters,
  — metering and the coincident data analysis to determine actual operation,
  — line-by-line investigation of the energy management control system programming.

  There is certainly a cost associated with the final product, but that expense is normally a relatively small investment when compared to the final financial return. Continuing with our analysis of the RCx definition:

- "appropriate operating conditions—RCx agents beware: don't get so focused on energy savings that you overlook the most important factor within the business of energy conservation—client satisfaction! The greatest of energy audit reports lie dormant on bookshelves because they didn't address new codes/standards, didn't correct existing comfort problems, didn't integrate funding for life safety issues (such as asbestos removal from the boiler they recommended for replacement), and didn't adjust operating hours or temperatures for spaces providing different services today than they did when originally designed. There are far too many "one-for-one" replacements of packaged and split system DX systems that didn't account for new standards necessary to meet today's stringent indoor air quality requirements. RCx agents must determine what is "appropriate" for current operation and offer solutions that provide these much needed updates and/or upgrades.

- 'attain maximum efficiency"—studies differ, but on the whole, it seems that most polls and surveys proclaim that RCx offers up to 80% of the energy savings available within buildings less than 5 years old. Even more specific than that, RCx focused on waste elimination programming within the energy management system and control point calibration/operation are by far the most productive retrofit measures within these newer facilities. There are, no doubt, significant energy savings available within older buildings, especially those that have never been commissioned (a vast majority of the buildings in the United States), but do not overlook the newer buildings with the sophisticated HVAC systems and digital control systems. In a recent study of one of the country's largest school districts, we discovered a large number of campuses built since 1992 that had significantly higher EUIs than campuses built 20 to 30 years earlier.

  Why did the newer buildings with the expensive HVAC systems and elaborate control systems consume more energy than the older buildings? We drew several truly interesting conclusions regarding this question, but the most commonly discovered reason is one that today's energy auditor cannot afford to overlook. It was discovered that even the most expensive equipment must be operated correctly if it is to produce maximized efficiency.

  At the end of the day, the results of our study spurred the school district to invest a great deal of time and money in retro-commissioning their newer facilities.

- "given the current circumstances"—We said it before, and it doesn't hurt to say it again: RCx'ing systems to operate as they did when originally designed makes no sense if the function of the facility or area served has changed or when the new owner/administration wants a change now, or is considering one within the near future.

STEPS WITHIN THE RCX PROCESS

What are the specific steps that make up a good RCx study? Well, every program is different and every engineer has his or her own opinion, but the most frequently used process we have seen follows a similar course of actions that can be outlined as follows:

Preliminary Assessment

Application Completion (if funded by third-party utility supplier or state energy agency)

Utility Data Collection—

Monthly TDSP from Utility Suppliers
IDR 15-minute Data
Monthly Electric Bill from Owner
Monthly Gas Bill from Owner

Time Line/RCx Schedule—Develop a realistic timeframe for analysis of the systems/processes the owner wants evaluated

Task Order/Contract—Heed the voice of experience: don't jump in too deep until this step is completed.

As with any energy audit, there is a preliminary "needs assessment" that should be completed before getting too involved in the program. There are almost always qualifying requirements applied by the funding agency which must be verified before getting started. In addition, there are general indications that point toward success that may be discovered fairly quickly at the outset of an RCx project. Utility data holds a vast amount of useful information and should be surveyed before entering any agreement with an owner who holds a certain expectation of results.

Just an example: Years ago, our firm was asked to provide an energy study for a growing client. Because it was our policy to review energy bills before entering any client agreement, we discovered the electric bills increasing from $8,000/month, to $9,000, to $9,500… then suddenly the bill dropped down to $875 the next month and slowly began climbing again. As it turns out, the utility provider was a local municipality and they had an antiquated printer that provided only six-digit printouts! So, when the monthly bill went beyond $9,999.99, the ten thousand dollar column was left off. This error had been on-going for over a year. As a result, we had a client that could save a significant amount of energy… but no money!

If the project still looks like it has potential after the Preliminary Assessment, then the next step is the Planning Phase.

Planning Phase

Report & Calculations

Planning Phase Report
Project Workbook

Measurements & Field Notes

Photographs
Screen Captures
Scanned Floorplan & Field Notes

This phase varies significantly from program to program. However, experience tells us that this step should be a very cursory analysis. It is true that energy auditors tend to believe that they can find energy savings in any building at any time! However, building operators are becoming wiser and many have people on staff who have attained a variety of energy management credentials. So, the RCx agent needs to be careful that he isn't forced to look beyond the low cost, low hanging fruit, and end up recommending only the higher capital cost projects that are normally associated with the Investment Grade Energy Audit.

The Planning Phase report should be basic and to the point. It should contain a list of potential projects selected from a checklist of normally discovered projects for the specific type facility surveyed. It should also contain a list of discoveries that disqualify the typical project (e.g., large areas requiring 100% outside air; or major portions of the building required to operate around the clock, 7 days per week, etc.)

It is always a good idea to document the preliminary findings with actual site photographs, EMCS screenshots and simple floorplans pinpointing the location of the item found. This documentation can serve of great value if the project is allowed to proceed into the next phase.

During the planning phase, there is a collaboration between the auditor and the building owner focused upon the creation of a plan, i.e., the retro-commissioning plan. This plan will include the future elements involved within the investigation phase, along with a schedule for the more significant deliverables. At this point the owner is asked to supply information that will be valuable during the investigation phase such as existing test and balance reports, service logs, building equipment upgrades, and pertinent data.

Investigation Phase

Report & Calculations

Investigation Phase Report
Project Workbook

Measurements & Field Notes

Photographs
Screen Captures
Scanned floorplan & field notes
Measurements and logged data

Measurement & Verification Methodology

Agree upon an appropriate M&V program for post-construction verification

This is the phase where all your engineering credentials come in to play. Specific projects selected from the Planning Phase checklist should be thoroughly analyzed during the Investigation Phase of the program. Where measurements are needed to ensure accurate calculations, those measurements should be taken; where metering is needed to isolate a specific system, those meters should be installed; when the EMCS suggests that an area isn't operating within programmed parameters, those specific points should be inspected and corrected, if possible.

Many times a RCx agent suspects the existence of a problem such as excessive introduction of outside air or too much chilled water flow through an air handler coil. These parameters must be verified with measurements made either by the RCx agent, the owner's technician, or a qualified test and balance firm. These measurements become hard data to measure changes and quantify energy saving results.

It is not uncommon for this phase of the program to take several weeks to complete. In fact, the tendency to relax the technicality of the final product offered to the owner simply because the program is a "low cost" program should be consciously avoided. The Investigative Phase of a well defined retro-commissioning program offers every bit as much potential for energy savings as the most expensive, large capital expense audit that could be produced.

Anyone with a few years experience in the energy auditing world knows that it takes significant savings from the low cost, low hanging fruit projects to finance the higher cost, longer payback projects. Those lower cost projects are the ones found during these Investigative Phases of RCx reports, and they should be pursued with utmost diligence. From a philosophical standpoint, the energy auditor needs to be able to explain to the facility owner the need for combined short and long term payback projects to justify funding for the high cost problems commonly found in older buildings. That's one of the primary reasons for assigning RCx to newer facilities. However, it is very possible to convince an owner to use the savings provided from the low cost options like RCx reports toward replacement of old chillers, boilers and other primary energy consumers when real life energy savings can be verified from implementation of low cost RCx recommendations.

NOTE: There is an Implementation Phase that fits into the program at this point. This step falls within the general purview of a typical Energy Audit and an explanation of the process is not included in this chapter.

Verification Phase

Report & Calculations

Final Report

Project Workbook

Measurements & Field Notes

Photographs

Screen Captures

Measurements and logged data

This is the rubber-meets-the-road phase of a retro-commissioning program. The recommendations save money, *or they don't*. As a result, it is no less important to create a verification process that the owner agrees to at the beginning of the RCx Investigation Phase than it is for the Investment Grade Energy Audit program.

The procedure for verification should be kept as simple as possible. If measurements at specific locations will tell the tale, then those measurements should be made in the presence of the owner or his designated representative. If it takes sub-metering to certify the savings, then that metering expense should be included in the cost of the renovation. If the final results are more complicated, then energy modeling should be provided.

The bottom line is simply this: professional energy auditors, including RCx agents, should not attempt to avoid the final litmus test. In the end, the anticipated savings should be pursued. If you don't get them the first time, try again. If you still can't attain them, be honest about the reason and negotiate a suitable resolution for both your firm and the client. These may be tough meetings, but experience tells us that your best *future* client is the one sitting across the table during these discussions.

One final point is simply this: clients almost always regret agreeing to "stipulated savings." As a result, we suggest that even the no-brainer projects be provided some form of proven savings methodology; some type of evidence that the savings is real and is being obtained. Even if all you did was change out a light bulb, show the client the reduced amperage flow.

Before leaving this chapter, we offer the following format for specific project explanation. It is essential that the client understand what you are about to do, before you begin the renovation. We have found this project description to work quite well when explanations are offered up in a language the owner can understand.

A SUGGESTED ECM TEMPLATE

1.1 Energy Conservation Measure (ECM) title

Description—*Describe the existing conditions using as many details as possible (whatever has been gathered in the survey such as photographs, screenshots, trend data, observations, etc) to support the claim, (remember that at the Planning Phase the opportunity does not have to be completely verified.)*

INSERT PHOTO REPRESENTATIVE
OF OPPORTUNITY

FIGURE x.x: Show photographs representative of the opportunity

Proposed Solution—*Describe the proposed solution here. Also describe how the solution will impact operations, occupant comfort, energy consumption, and peak demand.*

Tasks for Future Phases of the Program—*Describe any measurements, observations, trending, testing or other investigative tasks that will be performed to verify the opportunity and improve the accuracy of the quantified savings. Remember to weigh the cost of such tasks with the potential opportunity, the higher the projected savings then the more investigative efforts are warranted.*

Savings Calculation—*Describe the savings calculation methodology used. These can be sorted in to two basic types: Time of Use (used for constant load consumers such as lighting or constant volume motors) and Variable Load (used for load-dependent savings calculations such as chiller efficiency improvements or VAV operation strategy changes). In every case, the baseline consumption should be calculated and the after-case consumption calculated with the difference between the two providing the savings quantity.*

Measure Persistence—*Brief description of requirements to ensure savings persist over time.*

Owner Buy-in—*Brief description of the Owner's willingness or ability to pursue this opportunity.*

Technical & Physical Feasibility—*Brief description of any known technical or physical feasibility issues associated with this measure.*

Measure Cost—*Brief description of the implementation cost components and any assumptions associated with the cost estimate, such as equipment, materials, labor, engineering, etc.*

SUMMARY

Remarkable annual utility cost savings have been achieved as a result of the retro-commissioning process that has evolved over the last few years. The relatively low implementation costs borne by building owners to install the low-cost improvements discovered by retro-commissioning professionals have resulted in a typical simple payback period of less than three years.

As the demand for RCx grows, the industry must be able to respond with qualified personnel that meet the growing demand. Our firm has learned that RCx requires a special skill set that mixes solid knowledge of systems maintenance and operations with a working command of the primary principles of facility energy consuming processes (heat transfer, fluids, psychrometrics, photometrics, etc.), not to mention the diligence it takes to ensure project success. Any plan to meet the growing demand for RCx assistance must include a plan to be sure that those being employed to perform RCx services have the knowledge, tools, and skill to do it effectively.

As with most energy conservation efforts, RCx must include follow-up checks to ensure savings persistence. While certain measures, such as de-lamping have little risk of savings degradation over time, many others will degrade if they are not periodically checked for proper operation. One way to achieve that goal is to monitor utility consumption, using analytical tools that detect "significant" changes, such as error bands or other means of detecting a significant change.

At final glance, retro-commissioning should be viewed not as a one-time effort, but rather a continuous process of re-evaluating the operation of equipment within a building for the life of the building. The concept of Continuing Commissioning (CCx) was briefly discussed at the beginning of this chapter, and should become the standard for our industry. These on-going evaluations can provide valuable information that will not only identify low cost improvement opportunities but also discover information that will aid in capital planning and budgeting for the higher capital projects that are identified along the way.

Chapter 18

Investment Grade Energy Audits

In chapter one of the eight edition of this *Handbook of Energy Audits*, there is discussion of a "Level III—Advanced" energy audit which refers to something called the "investment grade audit." The sub-points listed under that heading lay out a pretty good description of an energy audit that goes beyond other energy audits, accumulating information previously gathered from lower level audits, proving/disproving previous assumptions, and generally ratcheting up the assessment process to minimize doubt about the potential for success of the recommended savings projects in the minds of the energy auditor and building owner alike. That definition seemed to satisfy the technically minded people within the energy industry, but it didn't really address the financial side of the house.

As a result, Dr. Shirley Hansen and I to co-authored a book that would be titled *Investment Grade Energy Audit: Making Smart Energy Choices* (The Fairmont Press, 2004; Hansen and Brown.) Within the pages of that book, we attempted to declare the need for energy auditors to think outside the energy-box by including within their analyses things like human behavior, the health/environmental (in addition to energy) side of indoor air quality, measurement & verification techniques that were as convincing to the banker as they were to the engineer, and risk-minimizing methodologies that didn't just reduce the auditor's risk, but offered up truly predictable risk levels that were believable and acceptable to financiers.

Now as we move toward the ninth edition of this "handbook," we are prepared to offer an update on the energy industry's definition of the investment grade energy audit (IGA.) It is an evolving definition because we have an evolving industry with changing fuel sources (e.g., a viable renewable energy industry), higher quality system control capabilities, a political climate mandating sustainable credentials (e.g., federal LEED Gold requirements), and energy modeling programs that make it possible to evaluate any energy saving idea that anyone could possibly envision. This being said, there is yet another variable within this IGA evolution process that may be providing more "energy" toward change than anything mentioned thus far: there is more demand upon the available capital previously set aside for energy efficiency than we have ever experienced before.

IT'S STILL GOOD BUSINESS

A recent article in "The Air Conditioning, Heating and Refrigeration NEWS," (January 16, 2012, Volume 245, Number 3) entitled "Energy Efficiency Loans Have Low Default Rate," a report created by the American Council for an Energy-Efficient Economy (ACEEE), showed the results of an analysis of twenty-four energy efficiency loan programs from around the country. The analysis determined that there is an extremely low default rate on energy related loans, and the basic conclusion of the study was that "energy efficiency is proving to be a winning investment in a time of economic uncertainty. Based on these findings, now is the time to scale-up to serve many more homeowners and businesses." In fact, it is clear from the underlying premise of the article that investments made toward improved energy efficiency are having significant *verifiable* impacts of the client's bottom line. One final note from this analysis: The programs reviewed for this study represented the largest energy-efficiency financing efforts in the nation, yet client participation rates are less than 0.5% of the targeted customer class. What that means is that 99.5% of financial institutions targeted client base for energy efficient programs, those offering the greatest potential from an investors point-of-view, is still waiting for someone to convince them that the end-result of their *energy efficiency* investment will prove to be a good financial investment.

That's good news for the energy auditing industry. It tells us that opportunities abound and the future is bright for those who know how to produce a convincing energy analysis worthy of a client's investment. If there is a generic definition of an IGA, that has to be it!

As a result, we look toward the energy auditing industry. Are today's IGA auditors up to the task?

THE NEW ENERGY AUDITOR

In September, 2011, the US Department of Energy's EERE (Energy Efficiency & Renewable Energy) group distributed a Job/Task

Analysis for a Commercial Building Energy Auditor. It was specifically designated as a draft version and included a comment at the bottom of each page stating "*DRAFT, for Comment Only—Do Not Cite*." As a result, I won't. However, we can draw some pretty clear conclusions regarding the professional level expected from today's energy auditing profession.

The goal of the document, as I understand it, is to create a Job/Task Analysis (JTA) which is the process of determining what a person who wants to do the subject task needs to know, and what skills and abilities he or she needs to have. After reading the extremely detailed and elaborate requirements listed for a commercial building energy auditor, I realized that I may not know any! I do know several people who could do all the items listed within this document, but I don't know anyone who actually does them all in the preparation of their analyses and IGA reports. I can see where the document could provide a valuable plumb-line for evaluation of an energy auditor's credentials, but to suggest that all the talents, experience, physical and social capabilities itemized in this extensive manual should be wrapped up within one human body is a bit over the top. (I did find it humorous that the document lists "brevity" as one of the required skills we must have in order to provide commercial building energy audits, and it only took them 42 pages to say it!)

It is possible, however, to envision an energy auditing firm that can assemble a team with all the desired skills laid out in this analysis. And that brings us to the point at hand: energy auditing, especially audits to be used as evidence for substantial capital investments, require far more than technical engineering knowledge. Today's energy audits require administrative skills, communication skills, professional report writing skills, interpersonal skills, interviewing skills…

The purpose of pointing out this document is to identify the maturity of the energy auditing profession today. When Dr. Hansen and I authored the previously referenced IGA book seven years ago, we began the book with a chapter that chronicled the history and evolution of the energy audit in America, ending the chapter with the challenge that future energy audits would have to "stand up to the careful scrutiny of owners (but) the scrutiny of bankers and other investors will be even more demanding." We continued by stating "An IGA is at the heart of a "bankable project." Hence the term, INVESTMENT GRADE energy audit." Our challenge was for energy auditors to "raise the bar." I now believe we have advanced far beyond our modest beginnings some thirty years ago. Although the majority of EERE's energy auditor task description revolved around the technical side of the business, I was happy to see that attention is now being given to skills such as: observation, organization, presentation, writing, verbal communication, written communication, and even social skills. It is these qualities that have been sorely missing within our industry, and it is due to the lack of these skills that a significant number of good projects *don't get installed*!

WE ARE GETTING BETTER

At least some evidence of our advancement can be discovered from information presented in the 2011 ASHRAE *Handbook on HVAC Applications*, Chapter 36, "Benchmarking" and "Surveys and Audits." Table 2 in Chapter 36 tabulates energy usage per square foot per year (Energy Use Index or EUI) from 2003 energy consumption data for a variety of publicly and commercially owned facilities. The information is of great interest to anyone wanting to know if all our intensive energy auditing efforts have produced overall savings, making us relatively more efficient, or are we still losing ground to the energy consuming forces in the country.

As a contractor to the Texas State Energy Conservation Office for the last 29 years, we have gathered a great deal of information about public schools within our state, especially from utility bill tracking and region-by-region EUI comparisons. Our school focused information shows the following comparison between the national school EUI averages in 2003 found in the ASHRAE manual versus Texas school districts through our most recent data gathering efforts which include data through 2011.

Building Use	**ASHRAE 2003 50th Percentile**	**Texas Schools 50th Percentile**
Elementary School	54,000 Btu/sf-yr	48,297 Btu/sf-yr
Middle School	54,000 Btu/sf-yr	51,391 Btu/sf-yr
High School	65,000 Btu/sf-yr	54,838 Btu/sf-yr

Since the early 1970s, the State of Texas has spent a lot of effort and money in the attempt to implement energy efficiency within every public sector facility. From the comparison made in the above table, we can presume that Texas schools, when compared to the nation as a whole, have succeeded in reducing energy consumption by around 10% in Elementary Schools, 5% in Middle Schools, and 15% in High Schools above the national average. Yes, this little analysis requires that we assume that Texas schools were "average" in 2003. But even if their EUIs were slightly higher or lower than the nation's typical public school, it isn't too much of a stretch to believe that the energy efficiency industry is making progress.

DEFINING AND RE-DEFINING THE ENERGY AUDIT

Probably the most common definition of an energy audit is "to identify opportunities that will reduce energy consumption and/or cost." This identifying process requires several steps such as historical utility data (consumption and tariff) analysis, a study of the building and its operational characteristics, an identification of potential energy and cost saving opportunities, and some level of technical and financial analyses to determine the true value of the opportunity.

As the energy auditing world has matured, we have come to accept the fact that not all energy saving opportunities require an enormous amount of effort to justify. On the other hand, we have also come to the reality that some opportunities require a massive amount of technical analysis, and even then there may remain lingering questions that will not have answers until the project has been implemented and operated for a while. As a result, we have been offered definitions of three levels of audit technicality by ASHRAE:

Level I: Walk-through Analysis

This level requires an analysis of utility bills and a brief survey of the building. The audit does produce recommendations for energy savings and does offer very preliminary cost estimates. According to ASHRAE, this level is most applicable when there is doubt about the energy savings potential within the building, or when the owner is attempting to prioritize which buildings have the most potential for savings.

This is the level of energy audit that most state energy offices, municipal government agencies and utility suppliers offer their citizens and clients. Its purpose is to uncover the most basic opportunities available and present preliminary cost savings and implementation expense predictions associated with the measures discovered.

In the past, this level of study has been presented in very cursory format, generated with the obvious intent of finding only the major projects with the most prominent potential savings, (a technique known as cherry-picking or searching for low-hanging-fruit.) This is an incorrect use of the Level I tool. In fact, audits provided at this level should make it a point to locate every viable energy saving opportunity in the facility and to list them in a Program Master List for discussion with the facility owner. While developing the list, there should be little intent to implement all the projects discovered. However, at this point within the process, the auditor should not presume that he or she knows what is best for the client. In fact, it is quite possible that the client has some significant, non-energy related reasons for implementing items on your Master List that you would never have included on your low-hanging-fruit project list.

Level II: Energy Survey and Analysis

This level is a more detailed energy audit which includes a breakdown of energy usage within each facility (answering the question: "Where is the energy being consumed?"), a detailed savings and cost analysis of all practical measures, and discussion of any effect on M&O within the facility. This level provides the owner with an informed estimate of the effort it will take to produce the final recommendations, a more detailed look into the true estimated cost to implement the projects, and a higher quality projection of potential savings. According to the 2011 ASHRAE handbook, "this level of analysis is adequate for most buildings."

Level III: Detailed Analysis of Capital-intensive Modifications

This level requires more detailed field data gathering and engineering analysis. Again quoting ASHRAE, this level audit "provides detailed project cost and savings information with a level of confidence high enough for major capital investment decisions."

Although there have probably been thousands of Level II and III audits that resulted in investments in major capital expense projects, there is no mention within these definitions of sub-metering, trending, energy modeling or many other highly reliable tools that have become available over the years that add to the quality and the confidence associated with the final recommendations and reports.

As a result, we now attempt to take the next step in defining that somewhat nebulous term heard almost daily around the energy auditing world: how should we define the Investment Grade Energy Audit.

To do that, we will rely upon a typical report format that we judge as one of the higher quality reports that has been developed within the Energy Performance Contracting world as it exists today. Because performance contracting, as an industry, forces the energy auditor to take a portion of the "risk of failure," it has become extremely important for those firms to mold the energy audit into a report they can rely upon. Although that has always been the case in the performance contracting industry, the truth is that those firms that have not been consistently accurate in their predictions are no longer around to muddy the waters. Today's performance contracting firms have, for the most part, evolved into a very professional and highly competent field whose calculations can be trusted to fall within acceptable ranges of accuracy.

It would take a full week seminar to present the intricacies of the individual components within this report, so we will simply address the overall contents and make a few comments regarding each section.

INVESTMENT GRADE AUDIT REPORT CONTENTS:

Summary

1. Program Background
2. Project Goals
3. Program Benefits
4. Financial Analysis Overview including Financial Summary Table
5. Measurement and Verification Plan
6. Grants, Rebates, Utility Incentives and Tax Deductions
7. Cost Estimating Procedure and Itemization
8. Recommended Steps

This section is used to reiterate the primary focus of the audit. It is advisable to re-state the overall objective of the agreement between your firm and the client within this section of the report. Typically, the client is reminded of specific goals of the audit including the desire to list, prioritize, rank and financially evaluate each recommended project.

It is a good idea to rehearse the steps that led up to this report, the sequential steps of the process to date, and a commitment to meet any important deadlines implemented by the client.

Because the reader of this section includes the upper administration within the clients organization, it is important to discuss the financial model methodology used to determine the projects value, noting any outside income source that may be available through grants, rebates, incentives and tax deductions.

Although it is called the "Summary" section, it is not too early to present specific cost data and verification procedures. Just remember, unless the report involves his or her specific job or daily activities, a typical executive reads about five to ten pages of any report. So this is where you tell them what they need to know to make a decision going forward.

Client Needs Assessment

1 Client Goals/Preference Documentation
2 Occupant Discussions
3 End-Use Best Practices
4 Facility Adaptability to Client Desires/Needs

This is where that "perfect" EERE defined energy auditor would fit in. If you don't have this guy in your office, then this is the reason you put a diverse team together. The goal is to discover the best end-result possible for the client. The IGA auditor (or audit team) must recognize that the client has more issues to deal with than the energy bill. If you can help him fix the other problems along with a lower utility bill, you get the job.

Interviews and occupant discussions are the key here. After spending a little time analyzing the comments made by the top administrators, take some time to develop a list of key questions to ask the staff. The results from these interviews and discussions make a strong impression when presented within the final IGA report, and may give the final impetus needed for the owner to move forward with the overall program.

Facility Assessment

1 Facility Assessment Methodology
2 Individual Facility Overview with Recommended Renovations

3 Base Year Data and Tabulation
4 Utility Rate Schedule Analysis
5 Environmental Impact

These Facility Assessments are a part of every level of energy audits, from the most basic to the most complex. As a result, most energy auditors who view themselves as IGA level auditors need no additional instruction regarding this section of the report. The facility is what it is, so present the overall building and it's energy related components truthfully and in a language that the client can understand.

It is important at this point in the report to discuss areas of the facility that are not operating according to current codes and/or standards, and address the methodology used within your report to manage the base year data to represent a base model of a properly operating facility. Much energy related work cannot be incorporated in a renovation program unless the facility is brought up to current standards. However, that code-compliance portion of the work may not produce energy savings. So, it is important to show the client what his energy bill would have been if the building had been functioning correctly, then use that revised base year as a comparison for future energy savings.

Measurement & Verification Procedure

1 Measurement and Verification Discussion
2 IPMVP Procedure and Suggested Options

Read the International Performance Measurement and Verification Protocol (IPMVP). It is the standard used by a majority of countries in the industrialized world to provide credible verification of savings attained by energy related projects.

It is highly recommended that all IGA auditors spend the time necessary to decide what level of verification is really needed for specific project types. There will be disagreement between different engineers and analysts, so it is imperative that you know which option your firm wants to use, and be able to present acceptable rationale for your decisions.

This may only be my personal opinion, but I believe that more damage has been done to client relationships due to selection of an inappropriate verification procedure, or due to inadequate communication of the selected option, than any other component of the energy efficiency industry.

Calculations

1 O&M Savings—Detailed
2 Capital Expense Projects—Detailed
3 Comparison to Alternate Investment ROI

The energy industry has been around long enough and has matured to the point where our clients can understand what we are doing. If they can't, there are third-party consultants for hire that can understand and are more than willing to evaluate calculations leading to investment decisions. As a result, it is suggested that you generate and make available your detailed calculation process for every predicted savings.

In reality, the IGA auditor should be the one to suggest that the client bring in an outside consultant to review the calculation procedures and check the credibility of the results. Energy analysis processes have been in place for a long time and you aren't going to be giving away proprietary information. Your process may be different, but your equations and the available range of values are pretty well established. The bottom line is that you are asking someone to invest their finances on your predictions, and they deserve to know precisely how you arrived at your conclusions.

Appendices

Supporting Documentation (as needed)

Back it up. Energy models, utility bill tabulations, utility meter data, equipment inventories, all this and more could be inserted in the appendices.

Let's bring this chapter to a close. At the end of the day, when we finally send this ninth *Handbook of Energy Audits* edition to the presses, we will have made it quite clear that today's IGA must place more emphasis upon weighing financial risks for the client, combining improved economic evaluation methods with technically improved ASHRAE Level II or III audit reports. In fact, this is precisely what you will hear if you attend one of AEE's upcoming Fundamentals of Energy Auditing—Masters Level seminars.

Because the reader of this book is from the more technically oriented side of our profession, you will more than likely walk away with the commitment to improve your computer simulation skills and learn more about building energy modeling tools. But before you go on to the next chapter, allow me to attempt to plant the seed for what I hope to be the most evolutionary idea included in this updated IGA definition.

An IGA report should be viewed as a two-sided investment, an investment that produces an investment of capital from the end client based upon a significant investment of professional integrity by the IGA auditor. The day of an IGA report whose one-and-only end goal is to convince an owner to spend money is over (hopefully), and will certainly be considered a disservice by tomorrow's client. Economic conditions today require clients to direct their money toward that which produces the most pervasive and inclusive value for the company. Lower energy cost is one of those highly valued end results. But the most effective IGA going forward will have to consider best practices within the clients industry, and must address both the needs of the occupants and the human impact upon the success of the IGA's recommended installations and renovations.

My prediction is that tomorrow's IGA report will not be so focused on legal small print and risk-diluting savings verification formulae, and will actually be a tool that discovers the client's real needs and invests in projects that meets his or her true priorities.

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 rhermal 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 degrees and the boiling point of water is 100 degrees above zero (°C = [°F-32] 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 average rate of electrical energy 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) that 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 (°F = 9/5 °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. VARs represent the magnetizing energy in loads such as induction motors.

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.

Lumiaire—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.

Mcf—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, kW/kVA. 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 rebuild 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 Btu/h.

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 bee 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 rate 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 Btu/h.

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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