# ENERGY SAVINGS TOOLBOX – An Energy Audit Manual and Tool

This manual has been developed under the auspices of the Canadian Industry Program for Energy Conservation (CIPEC), a joint initiative of Canadian industry and the Office of Energy Efficiency of Natural Resources Canada. Further, the manual was developed in conjunction with the provinces and territories. Comments, questions and requests for additional copies of this CD should be e-mailed to info.ind@nrcan.gc.ca.

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***Disclaimer:***

The information contained in *Energy Savings Toolbox – An Energy Audit Manual and Tool*, including the interactive spreadsheets in Appendix C, is intended to be used solely as an educational tool to help companies assess their energy use and identify energy-saving opportunities. This information is not intended to provide specific advice and should not be relied on as such. No action or decisions should be taken without independent research and professional advice. The information is not intended to replace the findings of a formal energy audit. Natural Resources Canada does not represent or warrant the accurateness, timeliness or completeness of the information contained in the *Energy Savings Toolbox – An Energy Audit Manual and Tool* and Natural Resources Canada is not liable whatsoever for any loss or damage caused by or resulting from any inaccuracies, errors or omissions in such information.

# A

# AN OVERVIEW OF ENERGY AUDITING

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# 1 INTRODUCTION TO ENERGY AUDITING IN INDUSTRIAL FACILITIES

## 1.1 What Is an Energy Audit?

An energy audit is key to developing an energy management program. Although energy audits have various degrees of complexity and can vary widely from one organization to another, every audit typically involves

- data collection and review
- plant surveys and system measurements
- observation and review of operating practices
- data analysis

In short, the audit is designed to determine where, when, why and how energy is being used. This information can then be used to identify opportunities to improve efficiency, decrease energy costs and reduce greenhouse gas emissions that contribute to climate change. Energy audits can also verify the effectiveness of energy management opportunities (EMOs) after they have been implemented.

Although energy audits are often carried out by external consultants, there is a great deal that can be done using internal resources. This guide, which has been developed by Natural Resources Canada, presents a practical, user-friendly method of undertaking energy audits in industrial facilities so that even small enterprises can incorporate auditing into their overall energy management strategies.

## 1.2 In-House Energy Audit

Consider the following simple definition of an energy audit:

***"An energy audit is developing an understanding of the specific energy-using patterns of a particular facility."*** – Carl E. Salas, P.ENG.

Note that this definition does not specifically refer to energy-saving measures. It does, however, suggest that understanding how a facility uses energy leads to identifying ways to reduce that energy consumption.

Audits performed externally tend to focus on energy-saving technologies and capital improvements. Audits conducted in-house tend to reveal energy-saving opportunities that are less capital intensive and focus more on operations. Organizations that conduct an energy audit internally gain considerable experience in how to manage their energy consumption and costs. By going through the auditing process, employees come to regard energy as a manageable expense, are able to analyse critically the way their facility uses energy, and are more aware of how their day-to-day actions affect plant energy consumption.

By conducting an in-house audit before enlisting outside experts, organizations will become more "energy aware" and be able to address energy-saving opportunities that are readily apparent, especially those that require no extensive engineering analysis. External experts can then focus on potential energy savings that are more complex. The in-house audit can narrow the focus of external auditors to those systems that are particularly energy intensive or complex.

## 1.3 Systems Approach to Energy Auditing

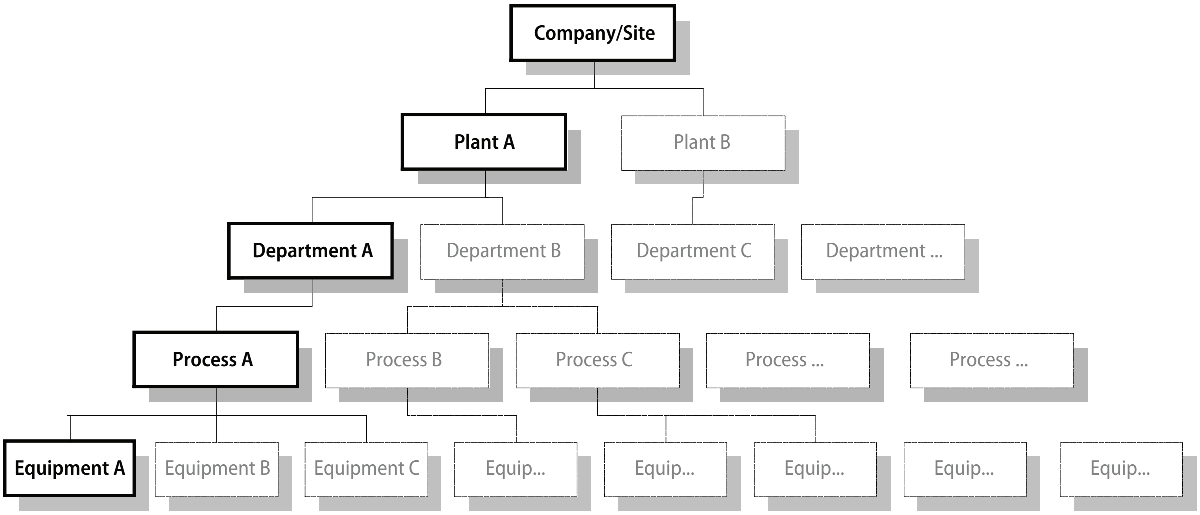
### 1.3.1 | Structure of an Energy-Consuming System

An energy-consuming system is a collection of components that consume energy. Energy audits can examine systems that may be as extensive as a multi-plant and multi-process industrial site or as limited as a single piece of equipment, such as a boiler.

Figure 1.1 illustrates the generic structure of an energy-consuming system at an industrial site.

For simplicity, Figure 1.1 shows only one branch for each subordinate level in the system hierarchy. Real systems have many branches from each component to various lower levels. The concept of an energy-consuming system can be applied to a site, plant, department, process or piece of equipment, or any combination of these.

**Figure 1.1 Structure of an Energy-Consuming System**




**Thermodynamics of Energy Systems**

Energy auditing applies a simple natural law: the first law of thermodynamics, also known as the law of conservation of energy. It simply means that we can account for energy because it is neither created nor destroyed in the facilities and systems we operate. Translated into practical terms, this law means

*What comes in = What goes out*

The challenge of an energy audit is to

- define the system being considered
- measure energy flows into and out of the system

The first of these challenges is to define a system's boundary. As already noted, by "system" we mean any energy-consuming building, area within a building, operating system, collection of pieces of equipment or individual piece of equipment. Around these elements we can place a figurative boundary. In a schematic diagram (Figure 1.1), a line drawn around the chosen elements runs inward from the facility level to specific pieces of equipment.

The second challenge is more difficult technically because it involves collecting energy flow data from various sources through direct measurement. It also likely involves estimating energy flows that cannot be directly measured, such as heat loss through a wall or in vented air. Keeping in mind that the only energy flows of concern are those that cross the system boundary, consider the following when measuring energy flows:

- select convenient units of measurement that can be converted to one unit for consolidation of data (for example, express all measurements in equivalent kWh or MJ)
- know how to calculate the energy contained in material flows such as hot water to drain, cooled air to vent, intrinsic energy in processed materials, etc.
- know how to calculate heat from various precursor energy forms, such as electricity converted to heat through the operation of an electric motor

## 1.4 Defining the Energy Audit

There is no single agreed-upon set of definitions for the various levels of energy audits. We have chosen the terms "macro-audit" and "micro-audit" to refer to the level of detail of an audit. Level of detail is the first significant characteristic of an audit.

The second significant characteristic is the audit's physical extent or scope. By this we mean the size of the system being audited in terms of the number of its subsystems and components.

- The **macro-audit** starts at a relatively high level in the structure of energy-consuming systems – perhaps the entire site or facility – and addresses a particular level of information, or "macro-detail," that allows EMOs to be identified. A macro-audit involves a broad physical scope and less detail.
- The **micro-audit**, which has a narrower scope, often begins where the macro-audit ends and works through analysis to measure levels of greater detail. A micro-audit might be a production unit, energy-consuming system or individual piece of equipment.

Generally, as an audit's level of detail increases, its physical scope decreases. The opposite is also true: if the scope is increased, the level of detail of the analysis tends to drop.

The auditing method presented in this guide applies to both the macro- and the micro-audit. Data collection and analysis steps should be followed as closely as it is possible and practical to do so, regardless of the audit's scope or level of detail. When using in-house resources, organizations are more likely to carry out macro-audits than micro-audits. Micro-level analysis can require expertise in engineering and analysis that is beyond the scope of this guide.

## 1.5 How to Use This Guide

This is a guide for self-audits of industrial facilities. It consists of three parts:

- **"Section A: An Overview of Energy Auditing"** provides an overview of energy auditing and a theoretical framework. It also defines a systematic approach to the energy audit and the steps involved.
- **"Section B: Energy Analysis Methods"** provides detailed instructions on how to carry out the 10 steps of the audit process as defined in Section A-1, page 6.
- **"Section C: Technical Supplement"** offers background information, including an overview of the basic principles involved in energy analysis and the tools used to conduct an audit. It also provides descriptions of spreadsheet tools and forms that accompany this guide and checklists and templates that will help you collect and analyse energy information.

Some readers may choose to read the guide from beginning to end; others who are carrying out an audit will find it helpful to use the audit process table on page 9 in Section A-3 as a starting point and refer to the descriptions of the audit steps in Section B, as directed by the process table.

"Energy Fundamentals" in Section C explains terms and concepts regarding energy and energy-consuming systems. The audit spreadsheets in Section B are user-friendly tools for data collection and analysis. Instructions on how to use them are provided in Section C-6, "Guide to Spreadsheet Tool."

## 1.6 A Practical Auditing Methodology

The energy audit is a systematic assessment of current energy-use practices, from point of purchase to point of end-use. Just as a financial audit examines expenditures of money, the energy audit identifies how energy is handled and consumed, i.e.

- how and where energy enters the facility, department, system or piece of equipment
- where it goes and how it is used
- any variances between inputs and uses
- how it can be used more effectively or efficiently

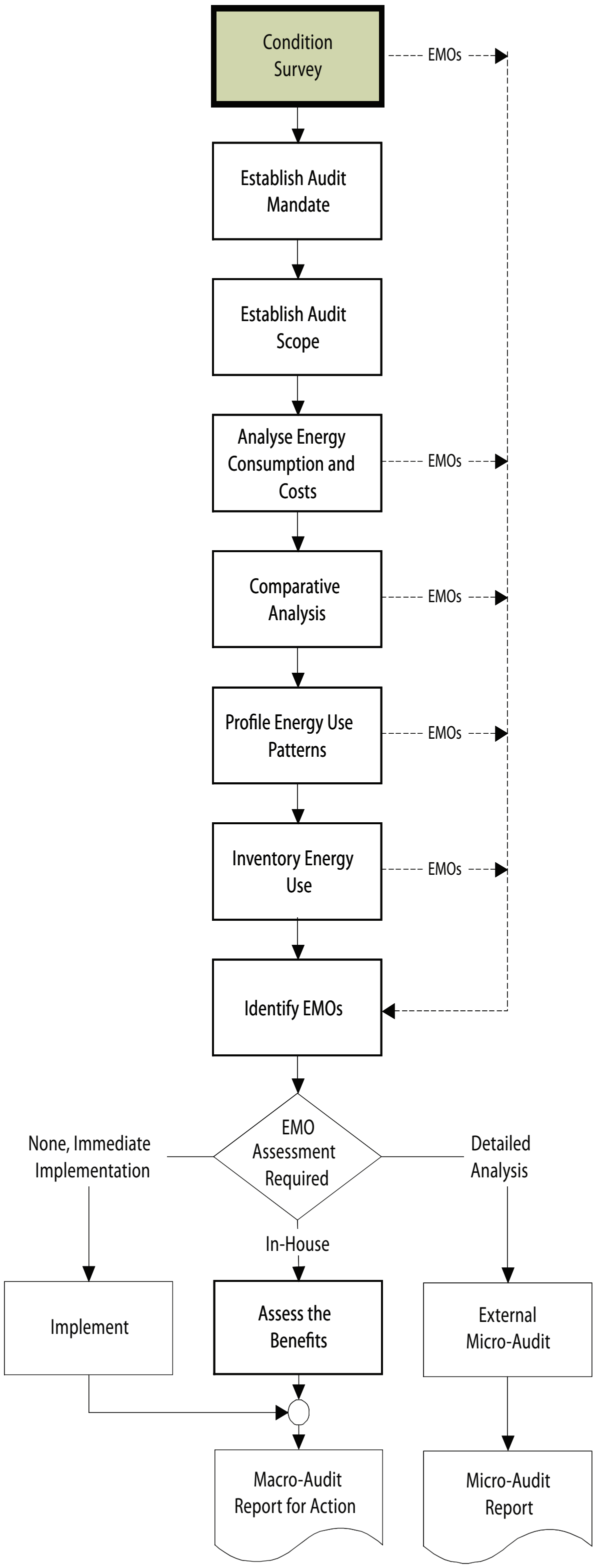
Figure 1.2 summarizes the sequence of steps as a flow chart.

The key steps in an energy audit are as follows:

1. **Conduct a condition survey** – Assess the general level of repair, housekeeping and operational practices that have a bearing on energy efficiency and flag situations that warrant further assessment as the audit progresses.
2. **Establish the audit mandate** – Obtain commitment from management and define the expectations and outcomes of the audit.
3. **Establish the audit scope** – Define the energy-consuming system to be audited.
4. **Analyse energy consumption and costs** – Collect, organize, summarize and analyse historical energy billings and the tariffs that apply to them.
5. **Compare energy performance** – Determine energy use indices and compare them internally from one period to another, from one facility to a similar one within your organization, from one system to a similar one, or externally to best practices available within your industry.
6. **Profile energy use patterns** – Determine the time relationships of energy use, such as the electricity demand profile.
7. **Inventory energy use** – Prepare a list of all energy-consuming loads in the audit area and measure their consumption and demand characteristics.
8. **Identify Energy Management Opportunities (EMOs)** – Include operational and technological measures to reduce energy waste.
9. **Assess the benefits** – Measure potential energy and cost savings, along with any co-benefits.
10. **Report for action** – Report the audit findings and communicate them as needed for successful implementation.

Each step involves a number of tasks that are described in the following sections. As illustrated in Figure 1.2, several of the steps may result in identifying potential EMOs. Some EMOs will be beyond the scope of a macro-audit, requiring a more detailed study by a consultant (i.e. an external micro-audit). Other EMOs will not need further study because the expected savings will be significant and rapid; such EMOs should be acted on right away.

**Figure 1.2 The Audit Flow Chart**



# 2 PREPARING FOR THE AUDIT

## 2.1 Developing an Audit Plan

An audit plan is a "living" document that outlines the audit's strategy and process. Although it should be well defined, an audit plan must be flexible enough to accommodate adjustments to allow for unexpected information and/or changed conditions. An audit plan is also a vital communications tool for ensuring that the audit will be consistent, complete and effective in its use of resources.

Your audit plan should provide the following:

- the audit mandate and scope
- when and where the audit will be conducted
- details of the organizational and functional units to be audited (including contact information)
- elements of the audit that have a high priority
- the timetable for major audit activities
- names of audit team members
- the format of the audit report, what it will contain, and deadlines for completion and distribution

## 2.2 Coordinating With Various Plant Departments

Coordinating with production departments, engineering, plant operations and maintenance, etc. is critical to a successful audit. A good initial meeting with staff, representing all plant departments involved in the audit, can form a foundation for developing confidence in the process and, ultimately, the audit's findings.

Consider the following when coordinating the audit with plant departments:

- review the audit purposes (objectives), scope and plan
- adjust the audit plan as required
- describe and ensure understanding of the audit methodologies
- define communications links during the audit
- confirm the availability of resources and facilities
- confirm the schedule of meetings (including the closing meeting) with the audit's management group
- inform the audit team of pertinent health, safety and emergency procedures
- answer questions

- ensure that everyone is thoroughly familiar and comfortable with the audit's purposes and outcomes

Another option is to create an audit team at the outset, not only to solicit input at the planning stages but also to garner support and resources throughout the audit.

Whatever method you use, assure all affected departments that they will be given the audit results and encourage their involvement in the audit process.

## 2.3 Defining Audit Resources

You should decide early on whether to carry out the audit using in-house expertise or an outside consultant, as the auditor needs to be involved in the process right from the start. That person will drive work on determining the audit scope and criteria and other preparations. (Note: It is understood that the use of "auditor" in this guide can mean an entire team of auditors, as appropriate to the circumstances.)

Of course, the auditor must be a competent professional, one who is familiar with energy auditing process and techniques. When considering outside consultants, it pays to shop around and obtain references.

In order for the audit results to be credible, choose an auditor based on his or her independence and objectivity, both real and perceived. The ideal auditor will

- be independent of audited activities, both by organizational position and by personal goals
- be free of personal bias
- be known for high personal integrity and objectivity
- be known to apply due professional care in his or her work

The auditor's conclusions should not be influenced by the audit's possible impact on the business unit concerned or schedules of production. One way to ensure that the auditor is independent, unbiased and capable of bringing a fresh point of view is to use an independent consultant or internal staff from a different business unit.

## 3 A STEP-BY-STEP GUIDE TO THE AUDIT METHODOLOGY

**Table 3.1 Audit Methodology**

| | Conduct a Condition Survey | Establish the Audit Mandate | Establish the Audit Scope | Analyse Energy Consump-tion and Costs | Comparative Analysis | Profile Energy Use Patterns | Inventory Energy Use | Identify Energy Management Opportuni-ties (EMOs) | Assess the Costs and Benefits | Report the Audit's Findings for Action |
|---|---|---|---|---|---|---|---|---|---|---|
| Description | • Identifies the most likely locations for the audit<br>• Identifies EMOs that could be implemented without further analysis<br>• Helps to set priorities for the audit's mandate and scope | • Establishes and articulates the purpose of the audit<br>• Secures stakeholder input and commit-ment to the audit mandate | • Specifies the physical extent of the audit by setting the terms of the boundary around the audited energy-consuming system<br>• Identifies energy inputs that cross the boundary to be audited | • Tabulates all energy inputs – purchased and otherwise<br>• Establishes the annual pattern of energy consumption and total annual consumption | • Compares current energy performance with internal historical performance and external benchmarks<br>• Provides insight into what drives the energy consumption of a facility and what relative savings potential may exist | • Develops an understanding of the time patterns in which the system consumes energy | • Provides a clear picture of where energy is being used<br>• Helps to prioritize possible EMOs and reveal opportuni-ties for reduction by eliminating unnecessary uses | • Involves critical assessment of systems and levels of energy consumption<br>• Methods range from open-ended analyses to close-ended checklists<br>• Helps to determine whether a more detailed micro-audit is needed | • Preliminary assessment of energy savings opportunities<br>• Accounts for inter-action between EMOs when several are possible, i.e. determines net savings | • Reports the audit's findings in a way that facilitates taking action (applies to all levels of EMOs, from no-cost house-keeping items to capital-intensive retrofit EMOs) |

| | Conduct a Condition Survey | Establish the Audit Mandate | Establish the Audit Scope | Analyse Energy Consumption and Costs | Comparative Analysis | Profile Energy Use Patterns | Inventory Energy Use | Identify Energy Management Opportunities (EMOs) | Assess the Costs and Benefits | Report the Audit's Findings for Action |
|---|---|---|---|---|---|---|---|---|---|---|
| **Data Required** | • Visual inspection of representative areas and equipment | • Input from senior management and production and maintenance staff<br>• Constraints in timing, resources and access to facilities<br>• Resources | • Results from condition survey<br>• Location of all energy inputs to the system<br>• Lists of all major energy-consuming systems | • Utility bills for each purchased energy source<br>• Metered data for other energy inputs<br>• Applicable utility rate structures | • Periodic energy consumption data<br>• Periodic data for relevant consumption drivers (or impact variables) such as production, weather and occupancy | • Logged data over intervals from one minute to one hour to one day for<br>– electrical power<br>– gas flow<br>– temperature<br>– humidity<br>– light level<br>– airflow or pressure<br>– other pertinent and measurable factors | • Facility and equipment drawings and specs<br>• Equipment inventory and nameplate data<br>• Power and fuel consumption<br>• Measured flow rates, temperatures, etc.<br>• Equipment condition and performance | • Energy inventories and balances<br>• Notes from walk-through tour<br>• Selected measurements | • Existing vs. proposed energy consumption<br>• Incremental cost of energy<br>• Optional measurements of existing consumption and conditions | • Results from each preceding step, from the initial cost analysis to the EMO financial benefit |
| **Templates and Checklists** | • Condition Survey Checklists (Section C-3) | • Audit Mandate Checklist (Section B-2) | • Audit Scope Checklist (Section B-3) | • N/A | • N/A | • N/A | • Load Inventory Forms (Section C-5) | • EMO Checklists (Section C-2) | • N/A | • Report Template (Section B-10) |

| | Conduct a Condition Survey | Establish the Audit Mandate | Establish the Audit Scope | Analyse Energy Consump-tion and Costs | Comparative Analysis | Profile Energy Use Patterns | Inventory Energy Use | Identify Energy Management Opportuni-ties (EMOs) | Assess the Costs and Benefits | Report the Audit's Findings for Action |
|---|---|---|---|---|---|---|---|---|---|---|
| Spreadsheet Templates | • Condition Survey.xls | • N/A | • Condition Survey.xls | • Electricity Cost.xls<br>• Gas Cost.xls<br>• Fuel Cost.xls | • Comparative Analysis.xls | • Profile.xls | • Load Inventory.xls<br>• Thermal Inventory.xls<br>• Fuel Systems.xls<br>• Envelope.xls | • N/A | • Assess the Benefit.xls | • Assess the Benefit.xls |
| Analysis and Methods | • Condition Survey (Section B-1) | • Audit Mandate (Section B-2) | • Audit Scope (Section B-3) | • Analyse Energy Consumption and Costs (Section B-4) | • Comparative Analysis (Section B-5) | • Profile Energy Use Patterns (Section B-6)<br>• Instrumentation for Energy Auditing (Section C-4) | • Electrical Load Inventory Method (Sections B-7 and C-5)<br>• Thermal Energy Use Inventory Method (Sections B-7 and C-1)<br>• Simple Energy Balances (Section B-7)<br>• Instrumentation for Energy Auditing (Section C-4) | • Finding EMOs in the Energy Inventory (Section B-7.5)<br>• A Three-Step Approach (Section B-8)<br>• EMO Checklists (Section C-2) | • Assess the Costs and Benefits (Section B-9) | • Written Report (Section B-10)<br>• Assess the Costs and Benefits (Section B-9) |

| | Conduct a Condition Survey | Establish the Audit Mandate | Establish the Audit Scope | Analyse Energy Consump-tion and Costs | Comparative Analysis | Profile Energy Use Patterns | Inventory Energy Use | Identify Energy Management Opportuni-ties (EMOs) | Assess the Costs and Benefits | Report the Audit's Findings for Action |
|---|---|---|---|---|---|---|---|---|---|---|
| **External Resources** | • N/A | • Natural Resources Canada (NRCan) technical publications<br>• Consultants | • N/A | • Utilities often provide historical energy consump-tion data tabulation and analysis | • Consultants that specialize in energy accounting or energy monitor-ing and targeting (M&T) | • Energy consultants providing metering services<br>• Electrical utilities<br>• Gas utilities | • N/A | • Sector-specific energy efficiency guides<br>• *CIPEC Energy Efficiency Planning and Management Guide* | • External consultant | • External consultants<br>• NRCan "Dollars to $ense" workshops |
| **Results** | • A relative assessment of the condition of each energy-consuming system present in the facility | • Statement of the audit outcome:<br>– Audit location<br>– Extent and types of analysis<br>– Type of EMOs and extent of savings analysis required<br>– Other related outcomes of the audit, e.g. productivity, operations and maintenance (O&M), environmental co-benefits | • Specification of the audit boundary in terms of input energy flows, energy-consum-ing systems and, indirectly, energy outflows | • Relative annual cost of each purchased form of energy<br>• Incremental (marginal) cost of<br>– electrical demand and electrical energy<br>– natural gas<br>– other fuels | • Relationships between energy use and significant drivers<br>• Trends in consumption<br>• Preliminary reduction targets<br>• Savings potential in reducing the variability of energy consumption | • Abnormal energy use conditions not otherwise evident<br>• Dis-aggregation of energy use when combined with energy inventory<br>• Characterization of facility, system and equipment operation | • A breakdown of energy consump-tion by major area of use (e.g. gas consumption for production vs. space heat; electricity consumption for process, ventila-tion, compressed air, lighting and conveyance) | • A list of EMOs prioritized for<br>– immediate action<br>– further analysis by micro-audit and ranked to harmonize interactions between EMOs | • EMO savings<br>• EMO implementa-tion costs<br>• EMO financial benefit | • A succinct and compelling presentation of the audit findings, including<br>– Executive summary<br>– Analysis of existing energy consumption<br>– Description of EMOs identified<br>– Savings assessment for selected EMOs<br>– Action plan for implementation |

## 3.1 Digging Deeper

If a more detailed audit is being conducted, take the following points into consideration in addition to the steps outlined above.

**Condition survey**: In a more detailed audit or an equipment micro-audit, checklists with more detail than those provided in this guide will be required. It may be more effective to enlist the support of people with expertise in external systems or equipment to assess the general condition of the systems and equipment involved.

**Audit mandate**: A micro-audit involves a greater level of detail, and its mandate must define the extent of the investigation. This will be driven in part by the desired level of certainty or, conversely, the uncertainty that can be accepted in the result. The detail required in order to secure financing for proposed measures will need to be provided as well.

A micro-audit will often be carried out by an external consultant. In this case, the audit mandate and the subsequent step – developing the audit scope – form an integral part of the consultant's terms of reference.

**Audit scope**: The micro-audit will often have a scope within the boundaries of a site or within the walls of a building. The scope may be a specific process or piece of equipment. In this situation, defining the audit boundary and the associated energy inputs will be a more difficult undertaking.

**Energy consumption and cost analysis**: The boundary for a micro-audit may not include utility-metered energy inputs. In some cases, direct measurement of energy inputs may be available from sub-meters for electricity, gas, fuel or steam. In each of these cases, it will be necessary to assess an input cost for each energy form. The incremental or marginal cost may be applied to these inputs.

**Comparative analysis**: The comparative analysis performed in a macro-audit typically deals with monthly utility metered data and impact data. A micro-audit provides an opportunity to perform similar types of analysis on metered data for individual processes and equipment on a much shorter time scale, possibly weekly or daily.

**Energy use profile**: The electrical demand profile measured at the service entrance is a common profile used in a macro-audit. Such profiles can be measured for virtually any single electrical load or group of loads. The micro-audit can use detailed profiles to fully describe the operation of many processes, systems or pieces of equipment.

More detailed profiles include

- subsystem power (process system, air compressors, refrigeration, etc.)
- compressed airflow and pressure
- steam flow and pressure
- illumination level and occupancy

**Energy use inventory**: The level of detail to which the inventories are conducted will increase from the macro-audit to the micro-audit. A more detailed breakdown will require more measurements, metering equipment and expertise.

**EMO identification**: The micro-audit mandate and scope may be developed from the list of EMOs and will require further analysis. The micro-audit will further define EMO actions, costs and resulting savings.

**Costs and benefits**: A detailed assessment of savings for specific EMOs is usually the primary purpose of the micro-audit. In this case, the macro-audit may involve a cursory assessment of savings and begin to assemble the data required for more detailed analysis.

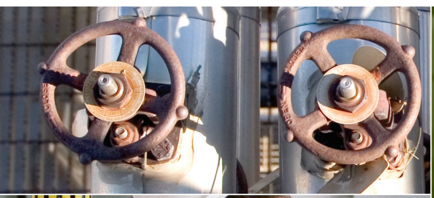
**Report for action**: Presenting audit findings in a conventional written report is more appropriate to the tightly focused micro-audit. The contents, including specific data and information arising from the audit, required in a micro-audit report may be specified by the providers of project financing.  Such requirements should be clearly specified in the micro-audit mandate.

## 3.2 Reference

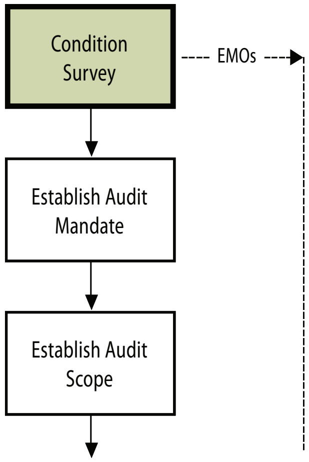
*Energy Efficiency Planning and Management Guide*, Natural Resources Canada, 2002
oee.nrcan.gc.ca/publications/infosource/pub/cipec/efficiency/index.cfm

# B

# ENERGY ANALYSIS METHODS



# 1 THE CONDITION SURVEY




## 1.1 Introduction

The Condition Survey – an initial walk-through of the facility – is essentially an inspection tour. Attention should be given to

- where energy is obviously being wasted
- where repair or maintenance work is needed
- where capital investment may be needed in order to improve energy efficiency

The Condition Survey has at least three purposes:

- It provides the auditor and/or audit team with an orientation of the entire facility to observe its major uses of energy and the factors that influence those uses.
- It helps to identify areas that warrant further examination for potential energy management opportunities (EMOs) before establishing the audit's mandate and scope.
- It identifies obvious opportunities for energy savings that can be implemented with little or no further assessment. Often these are instances of poor repair or housekeeping that involve no significant capital expenditure.

## 1.2 A Systematic Approach

It is important for the Condition Survey to be comprehensive and systematic. Although the information obtained by the survey will be primarily qualitative, it can be useful to give a numerical score to each survey observation to help determine the scope and urgency of any corrective actions.

Below is a checklist template for collecting information. It includes a point rating system. The checklist template can be readily modified and adapted to your facility; for example, in a survey of lighting, a line can be created for each room or distinct area in your facility.

The rating is based on a three-point system in which 3 represents a condition reflecting high energy efficiency and 0 represents a condition reflecting low energy efficiency. The rating indicates the urgency of corrective action.

| **Date:** 31 May 2002<br>**Auditor:** SD<br>Comments: | | Insulation Good | Insulation Average | Insulation Poor | Flanges Insulated | No Leaks | Some Leaks | Many Leaks | Automatic Controls | Standard Operating Procedure | Steam Meter | Fuel Meter | Make-up Water Meter | Preventive Maintenance | Fix as Required | Energy Recovery | Economizer Controls | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No.** | **Location/Points** | 2 | 1 | 0 | 2 | 2 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 2 | |
| | Maximum Score | 2 | | | 2 | 2 | | | 1 | 1 | 1 | 1 | 1 | 1 | | 3 | 2 | 17 |
| 1 | Main Boiler Room | | 1 | | | | 1 | | 1 | | 1 | 1 | | 1 | | 3 | | 9 |
| 2 | West Plant Boiler | | 1 | | | | | 0 | | | | | | 1 | | | | 2 |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
| **Total Points for Section** | | | | | | | | | | | | | | | | | | **11** |
| **Rating for Boiler Plant Systems** $= \dfrac{(100 \times \text{Total Points})}{\text{Number of Items} \times \text{Maximum Score}} = \dfrac{(100 \times 11)}{(2 \times 17)}$ | | | | | | | | | | | | | | | | | | 32% |

After each checklist is completed, a score is calculated [i.e. according to the formula given in the above example].

This score is then used to indicate the urgency of corrective action, based on the following scale:

| Range of 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 |

Checklists in "Part C: Technical Supplement" address the following:

1. Windows
2. Exterior Doors
3. Ceilings
4. Exterior Walls
5. Roofs
6. Storage Areas
7. Shipping and Receiving Areas
8. Lighting
9. Food Areas
10. Heating and Boiler Plant
11. Heat Distribution
12. Cooling Plant
13. Cooling Distribution
14. Electrical Power Distribution
15. Hot Water Service
16. Water Service
17. Compressed Air
18. Process Heating

In each case, only the template headings are shown, along with the scoring structure. At the end of the section, there is a blank template that can be customized to specific systems in your facility and others not included in the above list. In the latter case, consider using a scoring structure similar to the one shown above.

## 1.3 Spreadsheet Templates for the Condition Survey

"Part C: Technical Supplement" includes a spreadsheet template for the Condition Survey (Condition Survey.xls). A sample spreadsheet customized for a survey of lighting systems is shown in Figure 1.1. We suggest that the auditor create a customized spreadsheet for each of the systems and pieces of equipment in the facility. From the checklists in Section C-3, items and scores can be entered into the spreadsheet.

**Figure 1.1 Spreadsheet Template for the Condition Survey**

**The Condition Survey**

**System:** Sample Plant Lighting System

**Date:** 4-Jun-02
**Auditor:** Chase A. Watt
**Comments:**
These are sample comments for the lighting system's condition survey.

| No. | Location / Points | Excessive Illumination | Appropriate Illumination | Lights Controlled on Motion Sensors | Lights Controlled on Switches | Lights Controlled on Breakers | Incandescent (Inc) Lighting | Non-Inc Lighting (Fluroescent or HID) | Luminaires Clean | Luminaires Dirty | Room Surface Reflection Good | Room Surface Reflection Poor | Total Points | Rating for Location |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | | |
| | **Maximum Points** | | 1 | 2 | | | | 1 | 1 | | 1 | | 6 | **100%** |
| 1 | Office Area | | 1 | 2 | | | | 1 | 1 | | | 0 | 5 | **83%** |
| 2 | Production Area | | 1 | | | 0 | | 1 | | 0 | | 0 | 2 | **33%** |
| 3 | Warehouse Area | 0 | | | 1 | | 0 | | 1 | | | 0 | 2 | **33%** |
| 4 | Outside | | 1 | 2 | | | | 1 | 1 | | 1 | | 6 | **100%** |
| | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | 0 | **0%** |
| | **Total Points and Overall Rating for Sample Plant Lighting System** | | | | | | | | | | | | **15** | **63%** |

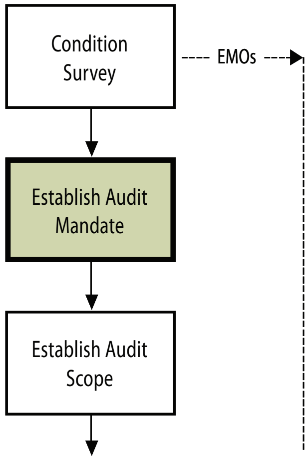
## 1.4 Finding Energy Management Opportunities (EMOs)

Although the Condition Survey precedes the main audit, it can also identify EMOs. The survey rating system helps to identify and prioritize areas of the facility that should be assessed more extensively. However, direct observations of housekeeping, maintenance and other procedures can lead to EMOs that need no further assessment and that can be acted on right away. For example, fixing leaks in the steam system, broken glazing and shipping dock doors that won't close will pay off immediately in reduced energy consumption.

## 1.5 Reference

*Energy Efficiency Planning and Management Guide*, Natural Resources Canada, 2002
oee.nrcan.gc.ca/publications/infosource/pub/cipec/efficiency/index.cfm

# 2 ESTABLISH THE AUDIT MANDATE




## 2.1 Introduction

It can be tempting to move quickly into the audit itself, especially for auditors who are technically oriented. However, knowing the "ground rules" in advance will help auditors to use their time to maximum effect and will ensure that the needs of the organization commissioning the audit are met.

The terms of reference presented to the energy auditor are as follows:

- **audit mandate** – this should make the audit's goals and objectives clear and outline the key constraints that will apply when the audit's recommendations are implemented
- **audit scope** – the physical extent of the audit's focus should be specified, and the kinds of information and analytical approaches that will comprise the auditor's work should be identified

The following checklist can help articulate a clear and concise audit mandate. A similar approach to defining the audit's scope follows in Section 3.

## 2.2 Audit Mandate Checklist

### Audit Mandate Checklist

**Audit Objectives: Investment and Operational Needs/Desires**

- ❑ To save
  - ❑ Energy consumption/costs
  - ❑ Specific fuel type (details) ____________________
  - ❑ Maximum demand
- ❑ To accommodate increased load in the building
- ❑ To pass on energy costs directly to tenants/departments
- ❑ To limit manual operation of facility/processes
- ❑ Other (specify) ____________________

____________________

**Time Line**

Completion date required ____________________

Date preliminary findings required ____________________

**Resources**

***In-House Staff***

- ❑ Technical
- ❑ Clerical
- ❑ Other (specify) ____________________

____________________

***External***

- ❑ Consultants
- ❑ Utilities
- ❑ Government organizations
- ❑ Contractors
- ❑ Other (specify) ____________________

**Building Conditions**

Note all problems related to the following:

- ❏ Comfort
- ❏ Breakdowns
- ❏ Lack of capacity
- ❏ Appearance
- ❏ Noise
- ❏ Operational practices
- ❏ Maintenance practices
- ❏ Other (specify) ______________________________

______________________________

**Implementation Factors and Constraints**

Housekeeping EMOs time line ______________________________

Low-cost EMOs time line ______________________________

Financial constraints ______________________________

Retrofit EMOs time line ______________________________

Financial constraints ______________________________

Applicable grants, subsidies and tax advantages ______________________________

______________________________

**Possibility of Audit Recommendations Being Applied to Other Buildings/Areas**

- ❏ Yes
- ❏ No

Details ______________________________

______________________________

**Reporting Format Required**

Level of detail ______________________________

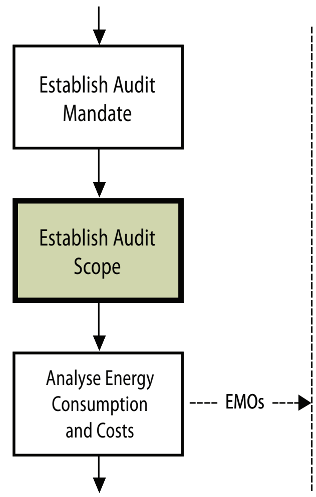
Financial analysis/criteria required ______________________________

______________________________

Payback period/criterion acceptable ______________________________

______________________________

# 3 ESTABLISH AUDIT SCOPE



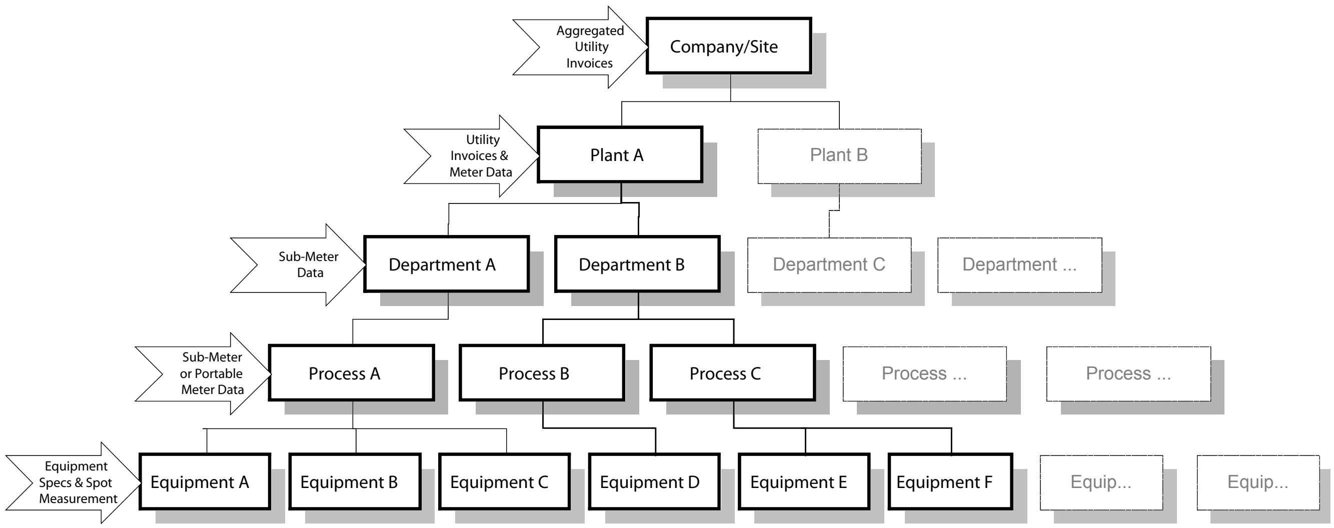

## 3.1 Introduction

A systematic approach to energy auditing specifically defines the boundaries that apply (as defined in the exploration of the thermodynamic basis for energy auditing). The audit scope provides this detailed definition of the system to be audited.

In addition, the audit scope is a "scope of work" statement; i.e. it defines the sources of information and the analysis that will be applied to them. Figure 3.1 illustrates a sample audit scope.

As noted earlier, the system may be anything from an entire plant to a piece of processing equipment. Figure 3.1 illustrates the hierarchy of an audit scope and the pertinent levels of information.

**Figure 3.1 Sample Audit Scope for a Simplified Energy-Consuming System**



### 3.1.1 | Define the System to Be Audited

This step defines the audit's boundaries and the specifics of the energy systems within those boundaries. Although details on the energy load inventory will emerge from the audit process itself, it is useful to define the areas to be examined, as outlined in the Audit Scope Checklist (see Section 3.2).

### 3.1.2 | Identify Energy Inputs and Outputs

Using a schematic diagram of the area being audited, you should be able to list energy inputs and outputs. It is important to identify all flows, whether they are intended (directly measurable) or unintended (not directly measurable). Obvious energy flows are electricity, fuel, steam and other direct energy inputs; and flue gas, water to drain, vented air and other apparent outputs. Less obvious energy flows may be heat loss though the building envelope or the intrinsic energy in produced goods.

### 3.1.3 | Identify Subsystems

Each of the systems to be considered in the audit should be identified, as outlined in the Audit Scope Checklist below.

## 3.2 Audit Scope Checklist

**Audit Scope Checklist**

**Areas to Be Examined**

- ❑ Whole site
- ❑ Individual buildings (details) ______________________________
- ❑ Department/processing unit (details) ______________________________

**External Site Subsystems**

- ❑ Lighting
- ❑ Heating mains
- ❑ Other (describe) ______________________________

### Individual Subsystems

- ❏ Boiler plant
- ❏ Steam distribution
- ❏ Domestic/process water
- ❏ Process refrigeration
- ❏ Lighting
- ❏ HVAC
- ❏ Building envelope
- ❏ Production/process operations (describe) ______________________________
- ❏ Other (details) ______________________________

### Types of Information

- ❏ Electricity billings
- ❏ Fuel billings
- ❏ Production data
- ❏ Weather data
- ❏ Facility specifications and drawings
- ❏ Sub-sector benchmarks
- ❏ Other (specify) ______________________________

### Analysis

- ❏ Correlation of consumption with production and weather
- ❏ Internal and/or external benchmark analysis
- ❏ Electrical demand analysis
- ❏ Load inventory analysis
- ❏ Payback analysis of EMOs and other financial criteria
- ❏ Other (specify) ______________________________

**Sample Energy Audit Scope of Work**

## 1 Historical Cost and Consumption Analysis

1.1 Regression analysis of gas versus weather and production

1.2 Regression of electricity versus production

1.3 Summary breakdown of energy use from historical data

## 2 Electrical Comparative Analysis

2.1 Electrical energy versus weights by batch data analysis
- 2.1.1 Monthly historical – from existing data
- 2.1.2 By batch for audit test period

2.2 Estimate potential savings from ongoing monitoring

2.3 Prepare spreadsheet for ongoing analysis

## 3 Natural Gas Comparative Analysis

3.1 Gas energy versus batch weights analysis
- 3.1.1 Monthly historical – by oven, by product
- 3.1.2 By batch for audit test period – by oven, by product

3.2 Estimate potential savings from ongoing monitoring

## 4 Oven Preheat

4.1 Combustion testing (existing gas pressure)

4.2 Energy balance

4.3 Estimate savings for appropriate final temperatures

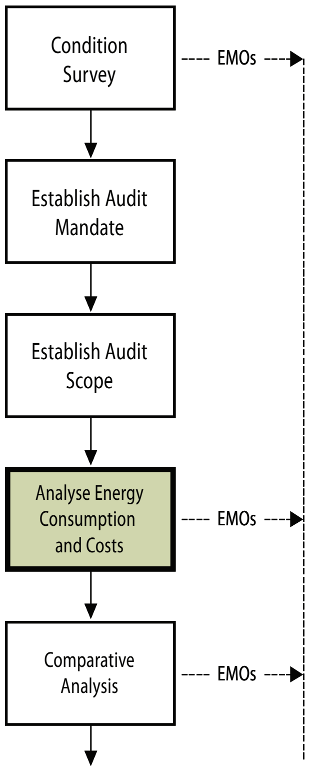
## 5 Air Exhaust/Make-up

5.1 Review air balance and determine energy and cost figures for estimated flows

5.2 Conduct combustion testing of unit heater under negative pressures
- 5.2.1 Estimate savings for operation at balanced pressures

5.3 Estimate savings for direct air make-up at workstations

# 4 ANALYSE ENERGY CONSUMPTION AND COSTS




## 4.1 Introduction

Information in energy billings and cost records can lead to EMOs, especially when it is analysed with key energy use drivers such as production. You should analyse energy consumption and costs before comparing energy performance with internal and external benchmarks. Tabulating historical energy consumption records provides a summary of annual consumption at a glance. EMOs identified in this step may involve the reduction of energy consumption and/or cost, both of which are important outcomes.

Information in energy billings begins with the rate structures or tariffs under which energy is purchased. It is important for the auditor to understand the structure of tariffs and cost components fully because these will greatly influence savings calculations when EMOs are being assessed. Because the facility may use several energy sources, it is also important to understand the per-unit energy cost of these sources and their incremental cost (as opposed to just the average cost of energy).

In this section we outline the basic terminology involved in reading energy bills and show the reader how to tabulate billings in order to quantify past consumption levels and begin to identify consumption patterns.

## 4.2 Purchased Energy Sources

Energy is purchased in a variety of commodities with varying energy content (see Table 4.1). This information is useful for analysing the unit cost of energy from various sources and making savings calculations.

**Table 4.1 Energy Content of Various Fuels**

| Fuel | SI Units | | Imperial Units | |
|---|---|---|---|---|
| Propane | 25.3 MJ/L | | 109 000 Btu/gal. (UK) | |
| Bunker C oil | 42.7 MJ/kg | 40.5 MJ/L | 18 380 Btu/lb. | 174 500 Btu/gal. (UK) |
| No. 2 oil | 45.3 MJ/kg | 38.7 MJ/L | 19 500 Btu/lb. | 166 750 Btu/gal. (UK) |
| Wood | 19.9 MJ/kg | | 8 600 Btu/lb. | |
| Natural gas | 37.6 MJ/$m^3$ | | 1 008 Btu/cu. ft. | |
| Electricity | 3.6 MJ/kWh | | 3 413 Btu/kWh | |

## 4.3 Purchasing Electrical Energy

The next step in conducting an energy audit is to understand how your organization purchases electricity. In part, this relates to metering by the supply utility. Although there are a number of metering technologies in use, the key issues for all are essentially the same:

- whether or not demand is metered
- which demand rate (kW or kVA) is measured
- how the information is measured, stored and displayed, i.e. thermal (dials) or electronic (digital display)

See "Energy Fundamentals" (Part C, Section 1) for a discussion of utility metering. The following outlines the terminology used in electric and gas bills. A basic understanding of the structure of the bill is required to extract data for tabulation.

### 4.3.1 | The Electricity Bill

The information in an electricity bill includes the following:

- **Kilowatt-hours (kWh) used**: Energy consumed since the previous meter reading (also referred to as "consumption").
- **Metered demand (kW and/or kVA)**: Actual metered values of maximum demand recorded during the billing period. If both are provided, the power factor at the time of maximum demand can be calculated and may also be provided.
- **Billing demand (kW and/or kVA)**: Demand value used to calculate the bill. It is the metered demand or some value calculated from the metered demand, depending on the utility rates.
- **Rate code or tariff**: Billing rate as applied to the energy and demand readings.
- **Days**: Number of days covered by the current bill. This is important to note because the time between readings can vary within ±5 days, making some monthly billed costs artificially higher or lower than others.
- **Reading date**: In the box called "Service To/From." The "days used" and "reading date" can be used to correlate consumption or demand increases to production or weather-related factors.
- **Load factor**: Percent of energy consumed relative to the maximum energy that could have been consumed if the maximum demand had been constantly maintained throughout the billing period.
- **Power factor**: Ratio of recorded maximum kW to kVA (usually expressed as a decimal or percentage).

### 4.3.2 | The Natural Gas Bill

Gas companies use terms that can have different meanings within different rates. The following definitions are fairly standard. For specific terms and clauses, contact your gas utility representative, or refer to the latest rate tariffs for the appropriate rate and to the contract between your company and the utility.

- **Days**: Number of days covered by the current bill. This is important to note because the time between readings can vary anywhere within ± 5 days, making some monthly billed costs artificially higher or lower than others.
- **Reading date**: In the box called "Service To/From." The "days used" and "reading date" can be used to correlate consumption or demand increases to production or weather factors.
- **Contracted demand (CD)**: The pre-negotiated maximum daily usage, typically in $m^3$/day.
- **Overrun**: The gas volume taken on any day in excess of the CD (e.g. 105%).
- **Block rate**: A rate where quantities of gas and/or CD are billed in preset groups. The first block is usually the most expensive; subsequent blocks are progressively less expensive.
- **Customer charge**: A fixed monthly service charge independent of any gas usage or CD.
- **Demand charge**: A fixed or block monthly charge based on the CD but independent of actual usage.
- **Gas supply charge**: The product charge (cents per $m^3$) for gas purchased; commonly called the commodity charge. This is the competitive component of the natural gas bill. If you purchase gas from a supplier (not the gas utility to which you are connected), this charge will be set by that contract or supplier. The gas utility will also offer a default charge in this category.
- **Delivery charge (re CD)**: A fixed or block monthly charge based on the CD but independent of actual usage.
- **Delivery (commodity) charge (for gas delivered)**: The fixed or block delivery charge (cents per $m^3$) for gas purchased.
- **Overrun charge**: Rate paid for all gas purchased as overrun.

## 4.4 Tabulating Energy Purchase Data

Energy consumption data is available from your own accounting records. Utility and fuel supplier invoices also contain valuable information about consumption that can be tabulated.

The technical supplement to this manual includes a set of spreadsheet templates for tabulating, graphing and analysing historical energy consumption and purchase data.

Templates are available for electricity, natural gas and other fuel or energy sources. See the following templates:

- Electricity Cost.xls
- Gas Cost.xls
- Fuel Cost.xls

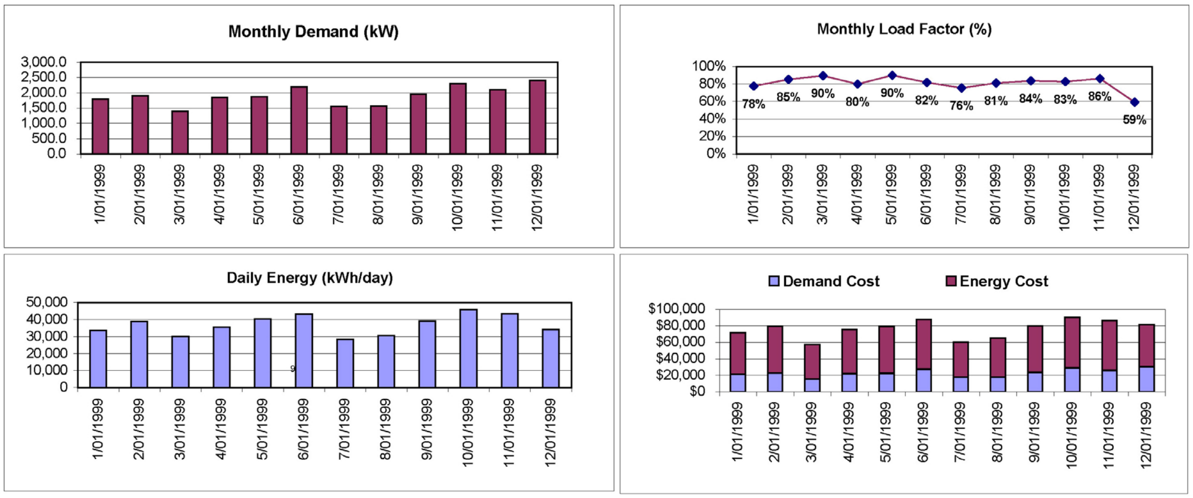
### 4.4.1 | Tabulation of Electricity Data

Figure 4.1 is a sample of the first sheet of the electricity cost spreadsheet. It contains consumption data collected from bills or invoices and derived numbers that form part of the analysis. Also illustrated is a graphical presentation of the key data and derived values.

**Figure 4.1 Sample Electricity Consumption Data Spreadsheet (from Electricity Cost.xls)**

**Electricity Consumption Data** Location: ABC Facility

| Billing Date | Metered kVA | Metered kW | Power Factor | Billed kW | Energy kWh | Days | Daily kWh | Load Factor | Demand Cost | Energy Cost | Adjust (+/-) | Sub Total | Total Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/01/1999 | | 1,800.0 | | 1,800.0 | 1,006,703 | 30 | 33,557 | 78% | $21,250 | $50,365 | ($11,147) | $71,615 | $64,701 |
| 2/01/1999 | | 1,900.0 | | 1,900.0 | 1,206,383 | 31 | 38,916 | 85% | $22,750 | $56,441 | ($13,204) | $79,191 | $70,607 |
| 3/01/1999 | | 1,400.0 | | 1,400.0 | 842,286 | 28 | 30,082 | 90% | $15,250 | $42,144 | ($9,263) | $57,394 | $51,501 |
| 4/01/1999 | | 1,850.0 | | 1,850.0 | 1,102,176 | 31 | 35,554 | 80% | $22,000 | $53,315 | ($12,132) | $75,315 | $67,606 |
| 5/01/1999 | | 1,870.0 | | 1,870.0 | 1,213,021 | 30 | 40,434 | 90% | $22,300 | $56,641 | ($13,252) | $78,941 | $70,287 |
| 6/01/1999 | | 2,200.0 | | 2,200.0 | 1,339,599 | 31 | 43,213 | 82% | $27,250 | $60,438 | ($14,716) | $87,688 | $78,080 |
| 7/01/1999 | | 1,560.0 | | 1,560.0 | 850,195 | 30 | 28,340 | 76% | $17,650 | $42,540 | ($9,438) | $60,190 | $54,304 |
| 8/01/1999 | | 1,570.0 | | 1,570.0 | 948,747 | 31 | 30,605 | 81% | $17,800 | $47,467 | ($10,429) | $65,267 | $58,677 |
| 9/01/1999 | | 1,950.0 | | 1,950.0 | 1,213,798 | 31 | 39,155 | 84% | $23,500 | $56,664 | ($13,308) | $80,164 | $71,536 |
| 10/01/1999 | | 2,300.0 | | 2,300.0 | 1,373,054 | 30 | 45,768 | 83% | $28,750 | $61,442 | ($15,111) | $90,192 | $80,337 |
| 11/01/1999 | | 2,100.0 | | 2,100.0 | 1,347,059 | 31 | 43,454 | 86% | $25,750 | $60,662 | ($14,731) | $86,412 | $76,699 |
| 12/01/1999 | | 2,400.0 | | 2,400.0 | 1,024,475 | 30 | 34,149 | 59% | $30,250 | $50,984 | ($11,685) | $81,234 | $74,418 |
| **Totals/Max** | | **2,400.0** | | **2,400.0** | **13,467,496** | **364** | | | **$274,500** | **$639,104** | **($148,415)** | **$913,604** | **$818,752** |




Starting with the basic historical billing data, a number of calculations can be performed. Here are some of the major calculations.

**kWh/day**: kWh in period ÷ days. Since reading periods can vary, kWh/day is more useful for spotting consumption trends than for determining billed kWh.

**Load factor (LF)**: kWh ÷ (kW × days × 24 hrs./day). If metered in kVA and the power factor (PF) is known, substitute kVA × PF for kW. If the PF is not known, assume 90%. LF is an indication of the percentage of time the plant is operating at peak.

Electrical LF is the energy consumed relative to the maximum energy that could have been consumed if the maximum (kW) demand had been maintained throughout the billing period. All the information required for this calculation can usually be found in the electricity bills. Mathematically, it is written as follows:

$$\text{Load factor (\%)} = \frac{\text{kWh used in period}}{\text{Peak kW} \times \text{24 hrs. per day} \times \text{No. days in period}} \times 100$$

A high, short-duration peak demand will lower the LF, whereas a more consistent rate of energy consumption will raise the LF.

Let us assume that the two sample facilities consume 25 000 kWh over a billing period of 28 days. Their respective LFs can be calculated as follows:

Facility A

$$\text{Load factor (\%)} = \frac{\text{25 000 kWh}}{\text{250 kW} \times \text{24 hrs. per day} \times \text{28 days in period}} \times 100 = 15\%$$

Facility B

$$\text{Load factor (\%)} = \frac{\text{25 000 kWh}}{\text{50 kW} \times \text{24 hrs. per day} \times \text{28 days in period}} \times 100 = 75\%$$

Facility A has an LF of 15% and an average energy cost of 10.5¢ per kWh. Facility B has an LF of 75% and an average energy cost of 6.4¢ per kWh. Thus, LF is inversely proportional to the average cost per kWh for similar facilities on the same rate.

LF can be used as a barometer of a facility's use of electricity by revealing excessive demand for the energy consumed. The following section provides more detail on how LF can be analysed with other operating characteristics of the facility.

### Load Factor vs. Utilization Factor: An Indicator of Potential

The utilization factor (UF) is the percent of use (occupancy, production, etc.) of a facility. For comparative purposes, it should be calculated over the same period of time as the electrical LF (24 hours, one week, one month, etc.). Completing this exercise is an initial step in determining the present use of electricity and is a good place to start your search for savings opportunities. If there is a significant difference between the UF and the LF, further investigation is probably warranted.

**Example**: UF/LF calculations can be made without any demand profile metering. All that is required is one or more electricity bills and knowledge of facility operations.

For example, a typical school is occupied for 11 hours per day, five days a week. The UF on a weekly basis would be 55 hrs./168 hrs., or 33%. Assume that the LF calculations yield an LF of 45%. The fact that the LF is roughly one third higher than the UF would be cause for further investigation and more questions: Are systems operating when not required? Is the school being used longer than first thought? Can system controls be adjusted or retrofitted to trim the usage closer to the occupancy hours?

### 4.4.2 | Graphical Analysis of Historical Energy Use Patterns

Tabulating historical bills also facilitates a graphical analysis of consumption patterns of all purchased energy forms. Figure 4.2 illustrates the patterns of gas and electricity use by four different buildings. The overall usage pattern should be driven to some extent by a facility's type of equipment, systems and process.

Look for these patterns in your data. Often these patterns are as expected, and this simply confirms that there are a number of drivers of energy use in a facility. This relationship is explored further in Section 5. Sometimes the patterns found are unexpected and can lead to opportunities to modify usage and save energy. For example, one might not normally expect a heavy process industry to exhibit a seasonal variation in energy use. If a seasonal pattern does exist, however, this may suggest investigating the building envelope and exhaust/make-up air systems.

**Figure 4.2 Historical Energy Use Patterns for Four Different Facilities**

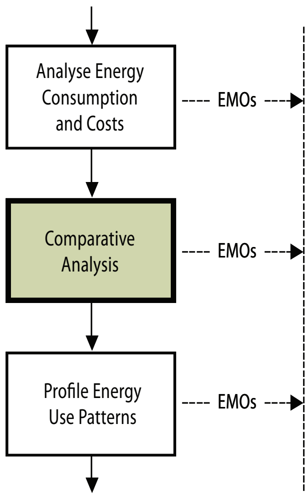
### 4.4.3 | Summary

We can use the overall patterns of consumption to help direct our focus in later stages of the audit. A basic analysis of historical energy bills provides insight into the unit cost of all purchased energy – information we will need to evaluate cost savings in the final stages of the audit.

## 4.5 Reference

For more information on gas, electricity and fuel prices and rates, contact your local utilities or suppliers.

# 5 COMPARATIVE ANALYSIS




## 5.1 Introduction

How does your organization's level of energy consumption compare with other similar industries, facilities and sites? What level of energy consumption is achievable with the best operating practices and industry benchmarks? How does your energy consumption this year compare with last year? How does the energy performance of site A compare with that of site B?

Analysing historical energy consumption and costs, as described in Section 4, is only the beginning in that it organizes billing information and provides a basis for more in-depth analysis of energy performance. In particular, it provides the data needed for comparing performance

- **internally** – period to period, site to site and/or production unit to production unit
- **externally** – to standards of performance established in the relevant industrial sub-sectors

The approach to comparative analysis outlined in this section includes monitoring and targeting (M&T). This method of statistical analysis considers energy use determinants such as production or weather factors and generates management information on energy use trends and relationships that can be used to analyse performance historically and control future performance.

Consider the following questions: How does the present level of energy consumption in your plant compare with that of last month or last year? Do you use more or less energy to manufacture your products or operate your facility than the average for your industry?

The answers to these questions will give you an initial indication of the extent of the overall energy savings potential for your plant and will allow you to set realistic savings targets for your energy management program.

The spreadsheet template "Comparative Analysis.xls" implements the analysis described in this section.

## 5.2 Tabulating Other Data

In Section 4 we discussed tabulation of energy consumption and cost data. It is also necessary to determine what factors influence energy usage and what data, if any, can be gathered regarding these factors or drivers. The factors may include those shown in Table 5.1.

**Table 5.1 Factors Influencing Energy Use**

| Factor | Data | Units |
|---|---|---|
| Product | Product quantities | Quantities, volumes, etc. |
| Weather | Outside air temperature | Degree-days |
| Occupancy | Occupied time | Hours, shifts, days, schedules, etc. |

Continuing the example of fuel consumption first used in Section 4, we can determine that weather and production are the only two factors that influence the fuel consumption tabulated. The weather (heating degree-day data from the local weather office) and production data (number of widgets) for the period corresponding to the fuel data are gathered and entered in the table (see Table 5.2).

**Table 5.2 Thermal Energy Use Data Analysis**

| ABC Widgets Inc. | | | | |
|---|---|---|---|---|
| Thermal Energy Data and Driver Data | | | | |
| Date | Purchased Natural Gas ($m^3$) | Total Energy (GJ) | Weather (heating degree-days) | Product (000 of units) |
| January 2001 | 531 000 | 20 521 | 723.2 | 48 |
| February 2001 | 559 000 | 21 599 | 658.3 | 64 |
| March 2001 | 520 000 | 20 081 | 589.6 | 59 |
| April 2001 | 420 000 | 16 609 | 379.5 | 64 |
| May 2001 | 445 000 | 17 182 | 262.8 | 89 |
| June 2001 | 237 000 | 9 137 | – | 75 |
| July 2001 | 256 000 | 9 868 | – | 81 |
| August 2001 | 284 000 | 10 964 | – | 90 |
| September 2001 | 193 000 | 7 431 | – | 61 |
| October 2001 | 354 000 | 13 651 | 280.3 | 55 |
| November 2001 | 497 000 | 19 183 | 419.8 | 79 |
| December 2001 | 507 000 | 19 557 | 678.6 | 45 |
| **Totals** | **4 803 000** | **185 783** | **3992.1** | **810** |

Weather data in this example (in the form of heating degree-days) for June to September is ignored, based on the assumption that, for a facility in the northern hemisphere, space heating is not used during this period. In this example, the effect of warm weather, which is often represented by cooling degree-days, is not considered either, because the oil consumed is used only to generate heat for process and space heating.

### 5.2.1 | Analysis of Data

The benefits of tabulating energy bills and key "drivers" over time and making these simple calculations are as follows:

- To make an initial correlation between the energy and demand figures and the operation of the plant. An example of the correlation is provided later in this section.
- To set a savings objective or target.
- To reveal and flag any unexpected increases in demand and/or consumption. Later, we can track down and, where necessary, correct the condition that is causing the increase and thereby identify an EMO.
- To confirm the savings expected from any energy conservation measures that have been implemented. For example, we should be able to ensure that new process control systems are delivering ongoing savings.
- To evaluate and compare the energy use and demand of one building to another or to standards (benchmarks) on the basis of area or energy density. Additional information must be known, such as size of heated or cooled areas (sq. ft. or $m^2$) and type of heating fuel. The types of calculations involved are also known as "energy use intensity," "energy budget" and "demand density."

### 5.2.2 | Benchmark Comparison

Consumption and production data, as in Table 5.3, can be used to calculate an important parameter: specific energy consumption (SEC). SEC is simply the relevant energy consumption divided by the production for the same period. Its units depend on the circumstances, with the production unit being characteristic of the plant and process (e.g. tonnes, kilograms or some other mass unit; units sent out for assembly; etc.). Common energy units used are kWh, MJ and GJ.

For the data in Table 5.3, specific energy consumption is as follows:

*Maximum week:* *2098 kWh/tonne*
*Minimum week:* *744 kWh/tonne*
*Average for period:* *1000 kWh/tonne*

These figures highlight the range of variation present and provide a point of comparison with an external benchmark.

For example, the following industry data may be available for this type of plant:

*Industry average:* *850 kWh/tonne*
*Best practice:* *700 kWh/tonne*

Best practice represents the specific energy use achievable with the best-known operational and equipment practices. By comparing these values with our own, we can draw simple conclusions:

- On average we may be able to achieve a 15% reduction in consumption.
- Using best practice, which may require extensive operational and technological improvements, we could achieve savings of up to 30%.

It is wise to be cautious when making this type of comparison since we don't know what the industry average practice is, and our plant may never be able to achieve best practice standards. But it does provide a starting point. On the other hand, investigating the differences between our plant and the benchmark in terms of practices and technology employed may well enable us to identify both operational and technological opportunities.

What is clearly demonstrated by both of the comparisons – internal and external – is that there is some opportunity for improvement. In this case, a modest target of 5% may be a good starting point.

**Table 5.3 Sample Energy Use and Production Data**

| Week | Production (tonnes) | Energy (kWh) | Specific Energy (kWh/tonne) |
|---|---|---|---|
| 1 | 150 | 140 726 | 938 |
| 2 | 80 | 103 223 | 1290 |
| 3 | 60 | 90 764 | 1513 |
| 4 | 50 | 87 567 | 1751 |
| 5 | 170 | 146 600 | 862 |
| 6 | 180 | 154 773 | 860 |
| 7 | 120 | 121 575 | 1013 |
| 8 | 40 | 81 436 | 2036 |
| 9 | 110 | 115 586 | 1051 |
| 10 | 90 | 105 909 | 1177 |
| 11 | 40 | 83 916 | 2098 |
| 12 | 50 | 86 272 | 1725 |
| 13 | 140 | 125 892 | 899 |
| 14 | 155 | 138 966 | 897 |
| 15 | 165 | 139 922 | 848 |
| 16 | 190 | 152 274 | 801 |
| 17 | 40 | 77 788 | 1945 |
| 18 | 55 | 82 711 | 1504 |
| 19 | 150 | 124 317 | 829 |
| 20 | 80 | 94 677 | 1183 |
| 21 | 63 | 84 628 | 1343 |
| 22 | 110 | 108 041 | 982 |
| 23 | 70 | 89 115 | 1273 |
| 24 | 170 | 136 388 | 802 |
| 25 | 190 | 141 428 | 744 |
| 26 | 160 | 141 215 | 883 |
| 27 | 120 | 118 319 | 986 |
| 28 | 190 | 152 506 | 803 |
| 29 | 80 | 99 267 | 1241 |
| 30 | 90 | 94 468 | 1050 |
| 31 | 180 | 140 188 | 779 |
| 32 | 70 | 91 262 | 1304 |
| 33 | 50 | 78 248 | 1565 |
| 34 | 155 | 128 005 | 826 |
| 35 | 167 | 131 003 | 784 |
| 36 | 120 | 109 192 | 910 |

## 5.3 Internal Comparison by Energy Monitoring

Energy monitoring serves to analyse information on energy consumption in order to identify EMOs.

By definition, **monitoring** is the regular collection of information on energy use. Its purpose is to establish a basis for management control, determine when and why energy consumption is deviating from an established pattern, and form a basis for taking management action where necessary. Monitoring is essentially aimed at preserving an established pattern.

Energy monitoring may be conducted over a short period as part of the energy audit. Subsequently, data can be analysed to help uncover opportunities (i.e. EMOs), especially those that are possible through improved operating practices and process control.

Energy monitoring can be applied to a variety of systems and types of energy and driver data:

- monthly plant gas consumption versus weather and production
- daily gas consumption versus daily production for a bakery
- electricity consumption versus tonnage melted in an electric furnace
- weekly or daily steam consumption versus fabric production for a dye-house
- daily fuel consumption versus production and weather for a cement or lime kiln

An internal comparative analysis methodology suggested for the audit would involve the following:

- **collect and record** energy and driver data
- use **regression analysis** to investigate what drives energy use and establish a baseline relationship for energy consumption
- use cumulative sum (**CUSUM**) analysis to investigate deviations in energy use from the baseline
- set a **target** for reduced energy consumption levels

The following sections give details on each step, along with samples from the comparative analysis spreadsheet template in this guide's "Technical Supplement."

### 5.3.1 | Energy Monitoring

Energy monitoring is used to find out how energy consumption relates to key "drivers" such as production or weather. It is a technique that relies on not only quantitative but also qualitative information about energy use. There are also qualitative indicators: in a building, human comfort is such a sensitive indicator of change that, if the basic energy needs of the building vary by more than a small percentage, the occupants will notice it immediately. In many manufacturing processes, the characteristics of the product are determined by the changes that the input of energy brings about – for example, the colour of a loaf of bread or the dryness of ink.

These qualitative indicators are sensitive and detectable, but they are not easily quantified and often depend on subjective impressions. Energy monitoring requires quantitative information, usually measured, such as

- energy billing data, including electrical demand and consumption, fuel consumption and costs
- consumption measurements at some level (e.g. the entire building, a production department or an individual energy-consuming system, such as a furnace)
- key independent variables that influence energy consumption, such as production of a manufacturing system, occupancy of a building in terms of persons and hours, and/or weather factors such as heating degree-days

In essence, energy monitoring as a technique entails quantitatively relating consumption information to the critical independent variables.

### 5.3.2 | Energy Use and Production

Energy used in production processes typically heats, cools, changes the state of, or moves material. Obviously, it is impossible to generalize because industrial processes are complex and vary widely. However, a theoretical assessment of specific processes that is similar to the one carried out for degree-days will yield a similar conclusion – that is, there is reason to expect that energy plotted against production will also produce a straight line of the general form

$y = mx + c$ *(Equation 5.1)*

where *c*, the intercept (and no-load or zero-production energy consumption), and *m*, the slope, are empirical coefficients, characteristic of the system being analysed.

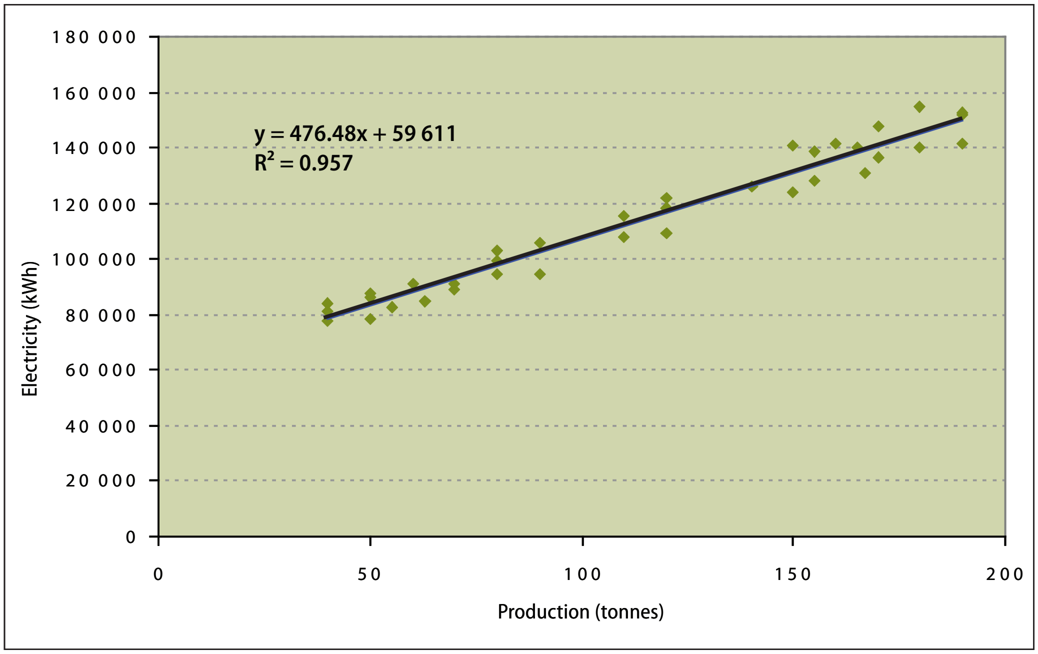
We have established the principle that energy use data by itself is of limited use in understanding the nature of the energy system, in identifying opportunities for efficiency improvement or in controlling future energy use. Refining data to obtain information that facilitates these functions involves analysis following the steps described here.

The first step is to determine the functional relationship between energy consumption and the key determining parameters, a relationship of the form of equation 5.1. This is illustrated with reference to the production situation for which data was given in Table 5.3.

### 5.3.3 | Regression Analysis

The functional relationship between production and energy consumption can usually be determined by linear regression, i.e. by finding the best fit of a straight line using the least squares method to the plot of energy consumption vs. production. Figure 5.1 shows the regression plot for the sample production situation.

**Figure 5.1 Regression Analysis**




For the entire data set, the functional relationship that we are looking for is

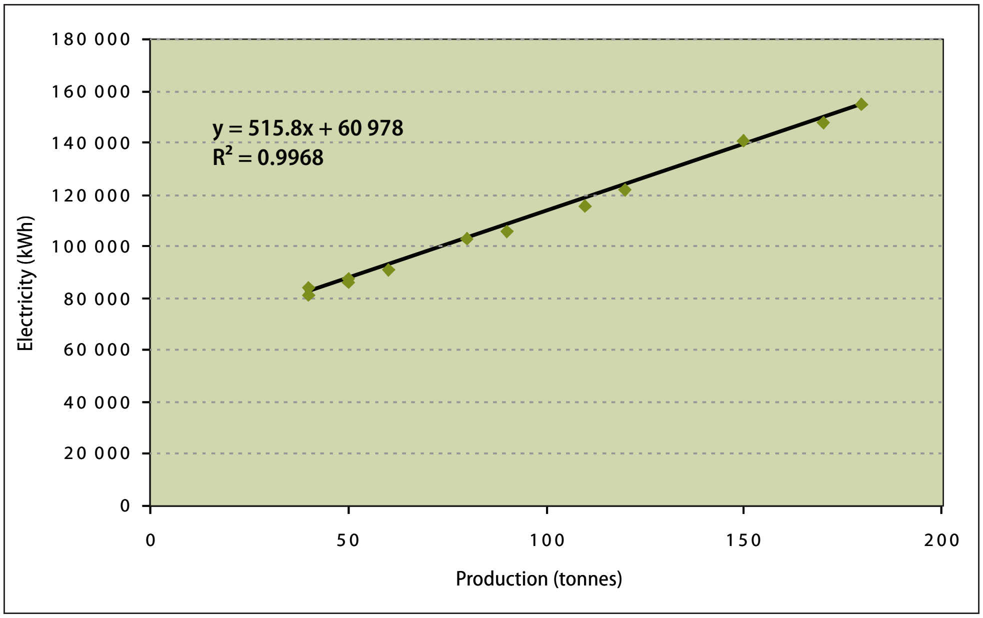
*Electricity (kWh) = 476.48 × production (tonnes) + 59 611 (Equation 5.2)*

However, this relationship may or may not represent consistent performance that is unaffected by improvements or breakdowns. What is needed is a baseline against which all other performance can be measured.

In the example, the first 12 weeks are just such a case: the performance was consistent, no improvements were installed, and no breakdowns occurred. (Without information on performance, finding the baseline is a trial-and-error process.) When a linear regression is done for the first 12 points, Figure 5.2 results, and the functional relationship is

*Electricity (kWh) = 515.8 × Production (tonnes) + 60 978 (Equation 5.3)*

**Figure 5.2 Regression on the Baseline Period**




It is this relationship that can be used as a "standard" of performance against which subsequent and future performance can be compared.

**Figure 5.3 Regression Analysis Spreadsheet Template (from Comparative Analysis.xls)**

**Regression Analysis of Baseline**

Menu

| Measured Data | | Variables | |
|---|---|---|---|
| Period Weeks | Date (Optional) | Driver Tonnes | Energy kWh |
| 1 | 1/7/2002 | 150 | 140,726 |
| 2 | 1/14/2002 | 80 | 103,223 |
| 3 | 1/21/2002 | 60 | 90,764 |
| 4 | 1/28/2002 | 50 | 87,567 |
| 5 | 2/4/2002 | 170 | 146,600 |
| 6 | 2/11/2002 | 180 | 154,773 |
| 7 | 2/18/2002 | 120 | 121,575 |
| 8 | 2/25/2002 | 40 | 81,436 |
| 9 | 3/4/2002 | 110 | 115,586 |
| 10 | 3/11/2002 | 90 | 105,909 |
| 11 | 3/18/2002 | 40 | 83,916 |
| 12 | 3/25/2002 | 50 | 86,272 |
| 13 | 4/1/2002 | 140 | 125,892 |
| 14 | 4/8/2002 | 155 | 138,966 |
| 15 | 4/15/2002 | 165 | 139,922 |
| 16 | 4/22/2002 | 190 | 152,274 |
| 17 | 4/29/2002 | 40 | 77,788 |
| 18 | 5/6/2002 | 55 | 82,711 |
| 19 | 5/13/2002 | 150 | 124,317 |
| 20 | 5/20/2002 | 80 | 94,677 |
| 21 | 5/27/2002 | 63 | 84,628 |
| 22 | 6/3/2002 | 110 | 108,041 |
| 23 | 6/10/2002 | 70 | 89,115 |
| 24 | 6/17/2002 | 170 | 136,388 |
| 25 | 6/24/2002 | 190 | 141,428 |
| 26 | 7/1/2002 | 160 | 141,215 |
| 27 | 7/8/2002 | 120 | 118,319 |
| 28 | 7/15/2002 | 190 | 152,506 |
| 29 | 7/22/2002 | 80 | 99,267 |
| 30 | 7/29/2002 | 90 | 94,468 |
| 31 | 8/5/2002 | 180 | 140,188 |
| 32 | 8/12/2002 | 70 | 91,262 |
| 33 | 8/19/2002 | 50 | 78,248 |
| 34 | 8/26/2002 | 155 | 128,005 |
| 35 | 9/2/2002 | 167 | 131,003 |
| 36 | 9/9/2002 | 120 | 109,192 |


| Baseline Period | |
|---|---|
| Start | 1 |
| End | 11 |

| Baseline Regression Model | | R²= | 0.996 |
|---|---|---|---|
| Slope | 511.059 | kWh/Tonnes | |
| Intercept | 61,366 | kWh | |

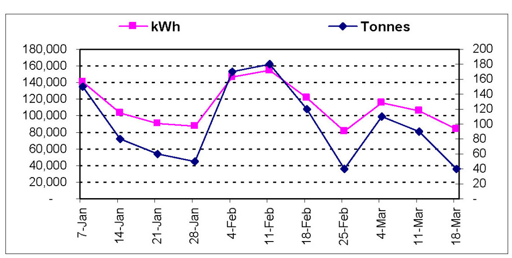



Figure 5.3 shows the regression analysis spreadsheet from the Comparative Analysis template.

The data set in Table 5.3 can be expanded by predicting consumption based on this relationship and the variance between the actual and calculated predicted values, as Table 5.4 shows.

**Table 5.4 Comparison of Predicted to Actual Consumption**

| Week | Production (tonnes) | Energy kWh | Specific Energy (kWh/tonne) | Predicted Energy (kWh) | Difference (kWh) |
|---|---|---|---|---|---|
| 1 | 150 | 140 726 | 938 | 138 020 | 2 706 |
| 2 | 80 | 103 223 | 1290 | 102 250 | 973 |
| 3 | 60 | 90 764 | 1513 | 92 030 | −1 266 |
| 4 | 50 | 87 567 | 1751 | 86 920 | 647 |
| 5 | 170 | 146 600 | 862 | 148 240 | −1 640 |
| 6 | 180 | 154 773 | 860 | 153 350 | 1 423 |
| 7 | 120 | 121 575 | 1013 | 122 690 | −1 115 |
| 8 | 40 | 81 436 | 2036 | 81 810 | −374 |
| 9 | 110 | 115 586 | 1051 | 117 580 | −1 994 |
| 10 | 90 | 105 909 | 1177 | 107 360 | −1 451 |
| 11 | 40 | 83 916 | 2098 | 81 810 | 2 106 |
| 12 | 50 | 86 272 | 1725 | 86 920 | −648 |
| 13 | 140 | 125 892 | 899 | 132 910 | −7 018 |
| 14 | 155 | 138 966 | 897 | 140 575 | −1 609 |
| 15 | 165 | 139 922 | 848 | 145 685 | −5 763 |
| 16 | 190 | 152 274 | 801 | 158 460 | −6 186 |
| 17 | 40 | 77 788 | 1945 | 81 810 | −4 022 |
| 18 | 55 | 82 711 | 1504 | 89 475 | −6 764 |
| 19 | 150 | 124 317 | 829 | 138 020 | −13 703 |
| 20 | 80 | 94 677 | 1183 | 102 250 | −7 573 |
| 21 | 63 | 84 628 | 1343 | 93 563 | −8 935 |
| 22 | 110 | 108 041 | 982 | 117 580 | −9 539 |
| 23 | 70 | 89 115 | 1273 | 97 140 | −8 025 |
| 24 | 170 | 136 388 | 802 | 148 240 | −11 852 |
| 25 | 190 | 141 428 | 744 | 158 460 | −17 032 |
| 26 | 160 | 141 215 | 883 | 143 130 | −1 915 |
| 27 | 120 | 118 319 | 986 | 122 690 | −4 371 |
| 28 | 190 | 152 506 | 803 | 158 460 | −5 954 |
| 29 | 80 | 99 267 | 1241 | 102 250 | −2 983 |
| 30 | 90 | 94 468 | 1050 | 107 360 | −12 892 |
| 31 | 180 | 140 188 | 779 | 153 350 | −13 162 |
| 32 | 70 | 91 262 | 1304 | 97 140 | −5 878 |
| 33 | 50 | 78 248 | 1565 | 86 920 | −8 672 |
| 34 | 155 | 128 005 | 826 | 140 575 | −12 570 |
| 35 | 167 | 131 003 | 784 | 146 707 | −15 704 |
| 36 | 120 | 109 192 | 910 | 122 690 | −13 498 |

### 5.3.4 | CUSUM

CUSUM is a powerful technique for developing management information on, for example, a building, a plant or an energy-consuming system, such as an oven or furnace. It distinguishes between significant events that affect performance (i.e. faults or improvements) and noise.

CUSUM stands for "CUmulative SUM of differences," where "differences" refers to the discrepancy between actual consumption and the consumption expected in light of an established pattern. If consumption continues to follow the established pattern, the differences between the actual consumption and the established pattern will be small and be randomly positive or negative. The cumulative sum, or CUSUM, of these differences over time will stay near zero.

Once a change in pattern occurs because of a fault or an improvement in the process being monitored, the distribution of the differences above or below zero becomes less symmetrical, and their cumulative sum – CUSUM – increases or decreases with time. The CUSUM graph therefore consists of straight sections separated by kinks; each kink shows a change in pattern, and each straight section indicates a time when the pattern is stable.

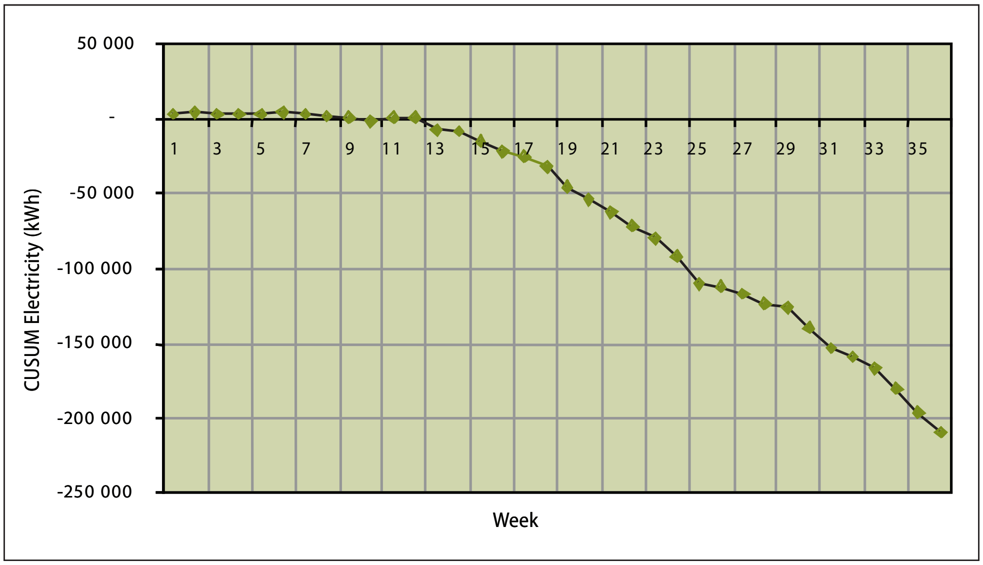
CUSUM is calculated by accumulating the differences between predicted and actual performance, as shown in the final version of the sample data set (see Table 5.5). The CUSUM values are then plotted as a time series, yielding a graph as shown in Figure 5.4.

Table 5.5 Production Data with CUSUM

| Week | Production (tonnes) | Energy kWh | Specific Energy (kWh/tonne) | Predicted Energy (kWh) | Difference (kWh) | CUSUM (kWh) |
|---|---|---|---|---|---|---|
| 1 | 150 | 140 726 | 938 | 138 020 | 2 706 | 2 706 |
| 2 | 80 | 103 223 | 1290 | 102 250 | 973 | 3 679 |
| 3 | 60 | 90 764 | 1513 | 92 030 | −1 266 | 2 413 |
| 4 | 50 | 87 567 | 1751 | 86 920 | 647 | 3 060 |
| 5 | 170 | 146 600 | 862 | 148 240 | −1 640 | 1 420 |
| 6 | 180 | 154 773 | 860 | 153 350 | 1 423 | 2 843 |
| 7 | 120 | 121 575 | 1013 | 122 690 | −1 115 | 1 728 |
| 8 | 40 | 81 436 | 2036 | 81 810 | −374 | 1 354 |
| 9 | 110 | 115 586 | 1051 | 117 580 | −1 994 | −640 |
| 10 | 90 | 105 909 | 1177 | 107 360 | −1 451 | −2 091 |
| 11 | 40 | 83 916 | 2098 | 81 810 | 2 106 | 15 |
| 12 | 50 | 86 272 | 1725 | 86 920 | −648 | −633 |
| 13 | 140 | 125 892 | 899 | 132 910 | −7 018 | −7 651 |
| 14 | 155 | 138 966 | 897 | 140 575 | −1 609 | −9 260 |
| 15 | 165 | 139 922 | 848 | 145 685 | −5 763 | −15 023 |
| 16 | 190 | 152 274 | 801 | 158 460 | −6 186 | −21 209 |
| 17 | 40 | 77 788 | 1945 | 81 810 | −4 022 | −25 231 |
| 18 | 55 | 82 711 | 1504 | 89 475 | −6 764 | −31 995 |
| 19 | 150 | 124 317 | 829 | 138 020 | −13 703 | −45 698 |
| 20 | 80 | 94 677 | 1183 | 102 250 | −7 573 | −53 271 |
| 21 | 63 | 84 628 | 1343 | 93 563 | −8 935 | −62 206 |
| 22 | 110 | 108 041 | 982 | 117 580 | −9 539 | −71 745 |
| 23 | 70 | 89 115 | 1273 | 97 140 | −8 025 | −79 770 |
| 24 | 170 | 136 388 | 802 | 148 240 | −11 852 | −9 122 |
| 25 | 190 | 141 428 | 744 | 158 460 | −17 032 | −10 854 |
| 26 | 160 | 141 215 | 883 | 143 130 | −1 915 | −11 069 |
| 27 | 120 | 118 319 | 986 | 122 690 | −4 371 | −11 440 |
| 28 | 190 | 152 506 | 803 | 158 460 | −5 954 | −12 094 |
| 29 | 80 | 99 267 | 1241 | 102 250 | −2 983 | −12 377 |
| 30 | 90 | 94 468 | 1050 | 107 360 | −12 892 | −13 669 |
| 31 | 180 | 140 188 | 779 | 153 350 | −13 162 | −14 931 |
| 32 | 70 | 91 262 | 1304 | 97 140 | −5 878 | −15 509 |
| 33 | 50 | 78 248 | 1565 | 86 920 | −8 672 | −16 481 |
| 34 | 155 | 128 005 | 826 | 140 575 | −12 570 | −17 751 |
| 35 | 167 | 131 003 | 784 | 146 707 | −15 704 | −19 255 |
| 36 | 120 | 109 192 | 910 | 122 690 | −13 498 | −20 653 |

The critical points on the CUSUM graph are the changes in the slope of the line. These can be easily seen – and more precisely located – by laying straight lines over the sections that have a more or less constant slope. We see that these slope changes occurred at weeks 12, 18, 25 and 30.

**Figure 5.4 Example of CUSUM Graph for Production**




Specifically, in terms of the process being analysed, the graph indicates the following:

- There have been two measures to reduce consumption; one took effect in week 12, the other in week 18.
- The first measure had saved 73 500 kWh, and the second measure had saved 36 800 kWh by the time it broke down in week 25.
- The second measure was restored in week 30; and by the end of data series, the combined measures had saved 201 300 kWh.

The Comparative Analysis spreadsheet (Comparative Analysis.xls) provides CUSUM analysis tools that can be adapted to virtually any data set similar to the preceding example.

## 5.4 Target Setting

In the context of an energy audit, a reduction target may have been established at the outset, with the audit being undertaken to find ways to achieve it. Alternatively, the information derived from the audit may provide a basis for setting a realistic target.

Target setting is more of an art than a science, but there are techniques that can be used to ensure that targets are not trivial but are still achievable.

***Performance Benchmarks***

Earlier, we saw that internal and external comparisons of energy performance can be used to set performance targets. The comparative analysis of processes or the buildings in the owner's portfolio – i.e. the comparison of current and past energy consumption – is a form of benchmarking in which the standard is an internal one rather than a sectoral or industry-wide one. This approach is suitable for buildings and industry. It is usually taken in graphical format, where a bar graph or column chart is used to compare the data from the current period with a similar previous period.

***Normalized Performance Indicator (NPI)***

Knowing how the industry at large performs may lead to more aggressive energy-reduction targets. Unfortunately, benchmarks of this kind may not be available, although some industry associations accumulate and communicate sectoral performance information. Data on the performance of specific kinds of buildings is generally available for comparison.

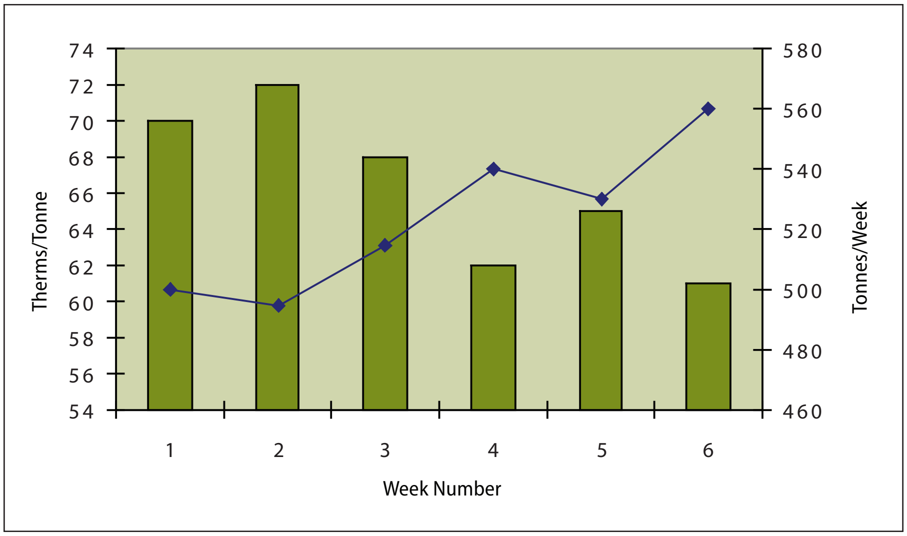
The NPI is a technique for quantifying building energy performance. It provides a yardstick figure for energy consumption, such as kWh/m$^2$/year (although, in the case of the health care sector, it is more usually based on building volume, i.e. m$^3$). The calculation requires a total annual energy consumption figure and a floor area or building volume. The energy ratio can then be normalized by referring to tables that indicate operating hours, weather, etc. NPIs are used to indicate performance on the basis of the facility's total energy consumption, individual energy source (e.g. natural gas, electricity, fuel oil) or use in the facility (e.g. space heating, process heat).

***Specific Energy Consumption***

Specific energy consumption (SEC) applies to industry. It is simply the energy used divided by an appropriate production measure (e.g. tonnes of steel, number of widgets). It can be calculated for any fixed time period or by batch. SECs need to be treated with care because their variability may be due to factors such as economies of scale or production problems rather than energy management as such.

There are many process benchmarking methods based on SECs, and their ease of use makes them attractive to many companies. However, some practitioners regard SECs as too simplistic and flawed. An illustration of SEC for glass melting is shown in Figure 5.5.

**Figure 5.5 SEC for Glass Melting**




***Preliminary Targets***

When setting up M&T, it is often appropriate to use standard consumption as the target, at least for the first few weeks.

Standard consumption represents historical average performance; therefore, continuously achieving standard consumption will not generate savings. Because standard performance represents an average, it follows that actual performance exceeds this level of efficiency for a significant fraction of the time, thus maintaining utility users' motivation to achieve savings. The target is felt to be realistic, and, in addition, high consumption is corrected. Points on the scatter plot above the line of best fit are collapsed toward the line, and savings are achieved. Figure 5.6 – a sheet from the Comparative Analysis template – shows a preliminary target based on historical average performance.

**Figure 5.6 Target-Setting Spreadsheet (from Comparative Analysis.xls)**

## Setting a Target for Reduced Consumption

Menu

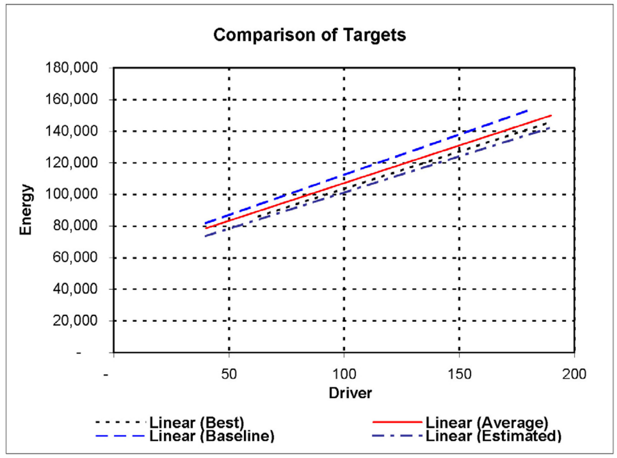
### Comparison on Possible Targets

| Baseline Regression Model | | | $R^2$= | 0.996 |
|---|---|---|---|---|
| Slope | 511.059 | kWh/Tonnes | | |
| Intercept | 61,366 | kWh | | |

| Best Performance Model | | | $R^2$= | 0.970 |
|---|---|---|---|---|
| Slope | 473.844 | kWh/Tonnes | | |
| Intercept | 56,160 | kWh | | |

| Estimated Performance Model | | |
|---|---|---|
| Slope is | 90% | of baseline |
| Slope | 459.953 | kWh/Tonnes |
| Intercept is | 90% | of baseline |
| Intercept | 55,229 | kWh |

| Estimated Performance | Tonnes | kWh |
|---|---|---|
| At Minimum Value | 40 | 73,627 |
| AtMaximum Value | 190 | 142,620 |




### Annualized Estimate of Savings

| | | |
|---|---|---|
| Weeks per year | 52 | |
| Annual Tonnes | 6,000 | Tonnes |
| Average Performance | 999.553 | kWh/Tonnes |

| | kWh/Year | Projected Savings | |
|---|---|---|---|
| At Average Performance | 5,997,318 | | |
| At Baseline Performance | 6,257,361 | (260,043) | -4.3% |
| At Best Performance | 5,763,396 | 233,921 | 3.9% |
| At Estimated Performance | 5,631,625 | 365,693 | 6.1% |

Also shown in Figure 5.6 are targets based on the following:

- the baseline model – maintaining the status quo
- the period of best performance – a selected period from the historical or monitored period
- estimated performance – based on an arbitrary or estimated incremental performance from the average performance

### *Revision of Targets*

After M&T has been in operation for a while, the preliminary target based on standard performance will be easily attainable and should be reset. This can be done in a number of ways, including the following:

- Use the best fit of the improved data as a target. This yields a modest but generally attainable target.
- Define best historical performance as the target. This will produce the most demanding target, but with the required effort it will still be attainable.
- Base a target on agreed-upon actions that are designed to yield specific, quantifiable savings.

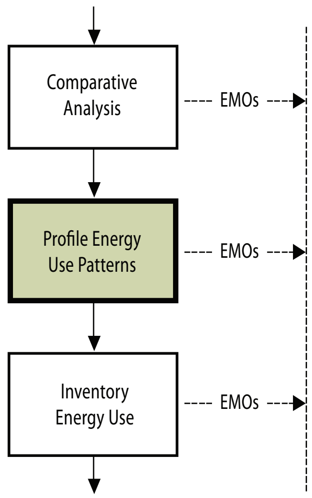
- Set a target for an arbitrary percentage improvement on current performance. Although arbitrary, this target will be attainable if chosen properly. If the target exceeds the best historical performance, it will likely be unattainable and therefore avoided. This method is not recommended.

Whichever method is used, it is essential for staff from each department to be involved in the process of setting the targets and to have input regarding what is or is not realistic. Otherwise, key staff members may not buy into the M&T approach, and targets will not be achieved.

## 5.5 Reference

Dollars to $ense Energy Monitoring workshop, Natural Resources Canada
oee.nrcan.gc.ca/industrial/training-awareness/em.cfm

# 6 PROFILE ENERGY USE PATTERNS




## 6.1 Introduction

Considerable information about your facility's operations can be revealed by its electrical demand profile. This time record of energy consumption shows electrical loads operating at any time and the aggregate demand represented by those loads. In addition, a demand profile can reveal loads that are operating when they don't need to be and identify systems that are inappropriately sized. Because the cost of electricity is determined in part by the maximum demand drawn, reducing that demand can significantly lower your energy costs.

Depending on the size of your facility and the resources at your disposal, it may be possible to install metering – even temporarily – at various locations in your facility to generate a profile of electrical demand. Alternatively, your electrical utility may be able to provide you with an electrical demand profile or help you to obtain it.

Although the demand profile is a measurement of electrical energy, it also provides information about the consumption of other forms of energy. The demand profile provides an operational fingerprint, or energy signature, of a facility, and it is a key part of any energy audit. Other methods of profiling or data logging are discussed in Section 6.6 and in Section C-4, "Instrumentation for Energy Auditing."

## 6.2 What Is a Demand Profile?

The demand profile for a facility, building, service entrance or any user of electricity is simply a record of the power demand (rate of energy use) over time. Its purpose is to provide detailed information about how the facility as a whole uses energy. As the electrical fingerprint of the facility, it is extremely useful for tracking energy use.

The simplest demand profile is a series of manual utility meter readings recorded monthly, daily, hourly or, if possible, more frequently. The particular time interval used will depend on what the information in the demand profile is to be used for. Table 6.1 shows a sample of a manually recorded hourly demand profile.

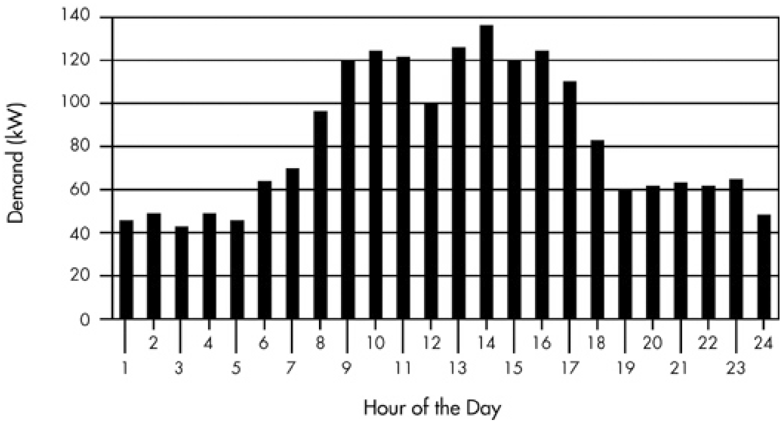
**Table 6.1 Manual (Tabular) Demand Profile**

| Hour | kW | Hour | kW | Hour | kW |
|---|---|---|---|---|---|
| 1:00 a.m. | 45 | 9:00 a.m. | 120 | 5:00 p.m. | 110 |
| 2:00 a.m. | 47 | 10:00 a.m. | 122 | 6:00 p.m. | 82 |
| 3:00 a.m. | 43 | 11:00 a.m. | 121 | 7:00 p.m. | 60 |
| 4:00 a.m. | 46 | 12:00 p.m. | 100 | 8:00 p.m. | 61 |
| 5:00 a.m. | 45 | 1:00 p.m. | 124 | 9:00 p.m. | 63 |
| 6:00 a.m. | 62 | 2:00 p.m. | 135 | 10:00 p.m. | 61 |
| 7:00 a.m. | 69 | 3:00 p.m. | 120 | 11:00 p.m. | 65 |
| 8:00 a.m. | 95 | 4:00 p.m. | 123 | 12:00 a.m. | 50 |

The information required for a monthly demand profile appears on most utility invoices. With such a profile, there are of course only 12 values available for a year.

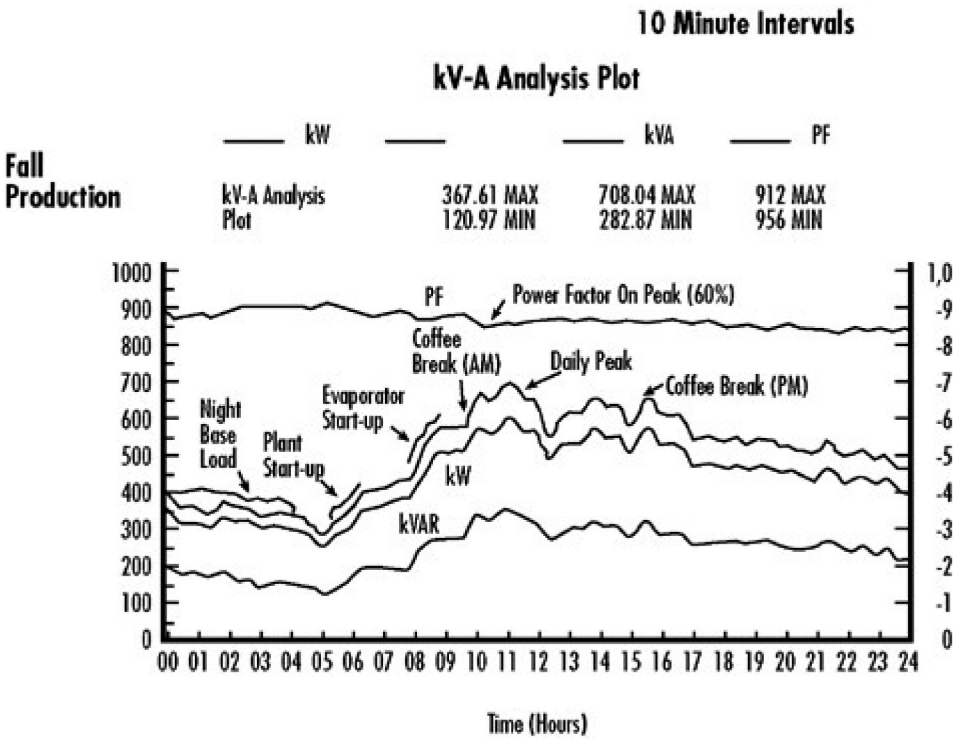
An alternative to a manual tabulation of demand readings, as shown in Table 6.1, would be a graph similar to that shown in Figure 6.1. This method of presentation helps compare relative demand levels throughout the day and quickly identifies the hours of peak power demand and startup and shutdown characteristics.

**Figure 6.1**




The most commonly used form of demand profile is similar to that shown in Figure 6.2. The profile covers a period of approximately 24 hours; slightly more than 24 hours is better than slightly fewer. The power demand appears on the vertical axis; the time, in hours, appears on the horizontal axis.

Figure 6.2




A recording power meter was used to generate the demand profile shown in Figure 6.2. Readings are generally recorded automatically, less than one minute apart. In some cases, readings may be adjusted by the recording instrument to match those that would be taken from the utility meter.

The profile shown in Figure 6.2 contains real power information measured in kilowatts (kW), kilovolt-amps (kVA) and power factor. More sophisticated recording power meters can record these values and others, including three-phase voltage, current and power quality parameters.

Comparing Figure 6.1 and 6.2 clearly shows the advantage of using a recording power meter. Although an hour-by-hour profile is a valuable starting point, a recording power meter provides significantly more detail.

A great deal of useful information can be derived from the demand profile, as Table 6.2 illustrates.

**Table 6.2 Events to Look For in a Demand Profile**

| Information | Description |
|---|---|
| Peak demand | The time, magnitude and duration of the peak demand period or periods may be determined. |
| Night load | The demand at night (or during unoccupied hours) is clearly identified. |
| Start-up | The effect of operation start-up(s) upon demand and peak demand may be determined. |
| Shutdown | The amount of load turned off at shutdown may be identified. This should equal the start-up increment. |
| Weather effects | The effect of weather conditions on demand for electricity can be identified from day to night (with changing temperature) and from season to season by comparing demand profiles in each season. |
| Loads that cycle | The duty cycle of many loads can usually be seen in the demand profile. This can be compared to what is expected. |
| Interactions | Interactions between systems may be evident: for example, increased demand for electric heat when ventilation dampers are opened. |
| Occupancy effects | Often the occupancy schedule for a facility is reflected in the demand profile; if not, it could be an indication of control problems. |
| Production effects | As in the case of occupancy, the effect of increased load on production equipment should be evident in the demand profile; again, lack of data may be an indication of problems. |
| Problem areas | A short-cycling compressor is usually easy to spot from the demand profile. |

Information from the demand profile is not limited to the items mentioned above; these are some of the most obvious examples. By profiling departments and/or other sections of the facility, you can gain detailed information about the facility's power demand habits.

## 6.3 Obtaining a Demand Profile

Facility demand profiles may be obtained by a number of methods, including

- periodic utility meter readings
- recording clip-on ammeter measurements
- basic and multi-channel recording power meters
- a facility energy management system
- a dedicated monitoring system

Although reading utility meter readings periodically is the cheapest and simplest method, the resulting data is limited. At the other end of the spectrum (a dedicated monitoring system), multi-channel recorders are expensive and complex to use, but they yield a wealth of information, from real power to power quality. Details on the instruments used to generate demand profiles are found in Section C-4, "Instrumentation for Energy Auditing."

Whatever technique is used, it is important to measure the demand profile at a time when the operation of the facility is typical and, if at all possible, when peak demand is equal to the peak demand as registered by the utility meter for the current billing period. This is because the overall objective in measuring the load profile is to identify which loads contribute to the billed peak demand.

### 6.3.1 | Periodic Utility Meter Readings

This manual method usually records data hourly, and it requires a meter that is accessible for readings. Its principal drawbacks are its limited time resolution (forcing the interpreter to estimate the load in between readings) and the demand that it places on staff (taking readings might be a suitable task for a student). The advantages of the method are its simplicity, no capital cost, and the fact that readings match the utility's readings exactly. Matching utility readings using other methods is less straightforward.

### 6.3.2 | Recording Ammeter

A recording ammeter is a single- or three-phase ammeter connected to a device that stores readings periodically. It may be installed on a facility's incoming service conductors to record current draw over time. The data acquired may then be combined with the system voltage and the power factor to yield an estimated demand reading. The recording device, which may be a computerized unit, is usually a strip chart recorder.

The most significant limitation of this method is that it does not measure real power (kW) or reactive power (kVA). Instead, it makes the assumption that the current is proportional to the power. This is true only when two conditions exist:

- The voltage at the service entrance is always constant; if it is not, the error introduced will depend directly on the voltage variation. This is a reasonable assumption given the normally expected voltage variation; and
- The power factor is constant at all demand levels. This assumption is questionable, and the only way to test it is to measure the power factor by means of the method described above at various demand levels – for example, at 25%, 50%, 75% and 100% of the peak demand. If there is a dramatic change in power factor, this method may well yield inaccurate results.

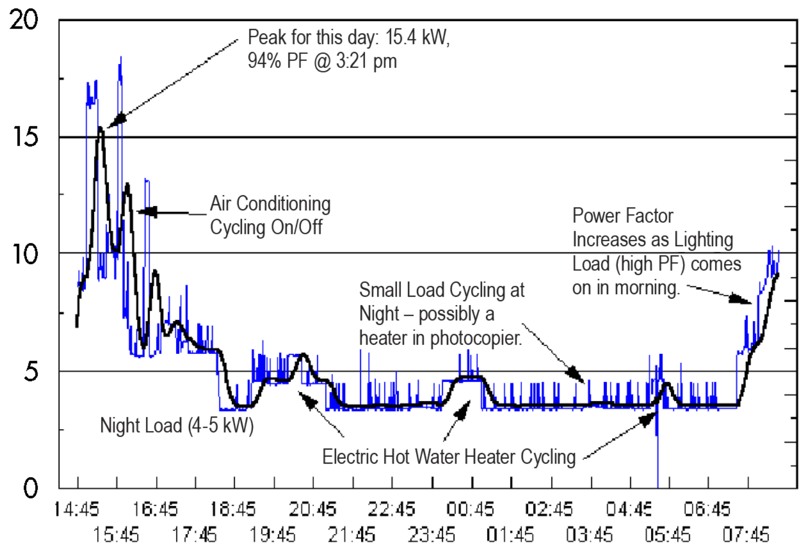
### 6.3.3 | Basic and Multi-Channel Recording Power Meters

These methods of measuring the demand profile are virtually the same except that the basic method would normally record only one value, such as kW or kVA, whereas the multi-channel method could record kW, kVA, phase current, voltage, overall power factor and possibly other values.

The recording power meter measures current and voltage simultaneously for up to three phases, and it electronically calculates kW, kVA and power factor. A recording device such as a magnetic tape, paper chart recorder or microprocessor-based data logger stores all information for later use.

When using demand profile results measured by a recording power meter or ammeter, it is important to remember that the power meter takes a large number of readings per minute. Such meters are capable of registering very fast changes in power demand, whereas utility meters are not (see Figure 6.3). The standard utility meter averages the demand over the previous 15-minute period. Some power meter models will calculate an average; others will not. Interpreting the demand profile (see Section 6.4) must take this into consideration.

**Figure 6.3 Power Metering Readings vs. 15-Minute Average Data**




### 6.3.4 | A Facility Energy Management System

The key advantage of this method is that the measurements are ongoing and routine. Data is continuously available, and analysis can be integrated into a daily energy management routine. Often, existing facility energy management systems are capable of performing these measurements but simply lack the necessary power (watt) sensors. Disadvantages may include a lack of memory to store values (which requires printing or downloading of data periodically), limited time resolution of measurements, low accuracy readings due to transducers, and minimal number of installations.

### 6.3.5 | A Dedicated Monitoring System

At a minimum, a dedicated monitoring system would measure the power consumed at the service entrance. Typically, such systems are implemented to provide sub-meter information for selected parts of the overall facility. Monitoring systems are generally designed for accurate measurements and effective data storage and presentations. Measurements of many other parameters may be correlated with demand to help analyse the demand profiles. Dedicated monitoring systems are generally at the core of larger, fully integrated monitoring and tracking systems.

## 6.4 Analysing the Demand Profile

The demand profile is the electrical fingerprint of a facility's electrical consumption patterns. Key information can be obtained by reading or interpreting the profile. This includes loads that operate continuously and that could be shut down, loads that contribute unnecessarily to the peak demand, and loads that are operating abnormally and require maintenance.

Many electrical loads leave behind very distinct fingerprints as they operate. By recognizing the patterns associated with each component, it is possible to identify the contribution of various loads to the overall demand profile.

Interpreting a demand profile is not just science (technical skill) – art (interpretative skill) is involved too. Good knowledge of the facility, its loads, operational patterns and the examples in this section should provide a solid basis for developing that interpretative skill.

**Step 1**
It is useful to begin with a list or inventory of electrical loads within a facility. Section 7 describes a method of compiling such a list.

**Step 2**
Study the demand profile and circle or make a note of all the significant occurrences, such as:

- abrupt changes in demand
- the top three peak demands
- repeated patterns
- flat sections
- dips during peak periods
- minimum demand level

This is only a partial list; every demand profile is different. Mark anything that appears to be significant.

**Step 3**
Mark along the time scale the time of day when significant operational events occur. Such events include:

- start-up and shutdown
- coffee breaks
- lunch hour
- shift changes
- other notable events (operation of a specific process)

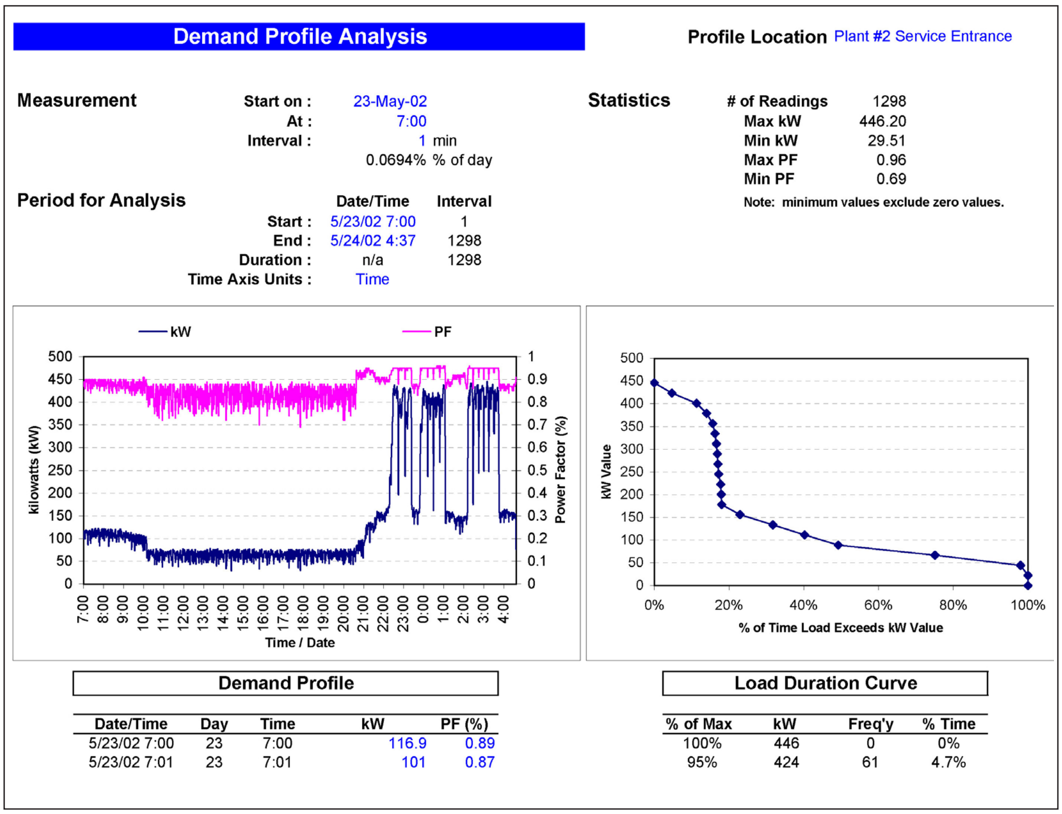
The purpose here is to spot some correlation between the features noted in Step 2 and work patterns in the facility.

**Step 4**

Study the examples in the following section. Note the patterns and the interpretations given and try to match the patterns and shapes of your operation with the examples. The overall result should be an annotated profile similar to that shown in Figure 6.3.

Spreadsheets are a convenient means of analysing profiles. The profile spreadsheet template (Profile.xls) in this guide provides a simple tool for graphing and analysing profile data. Figure 6.4 shows a sample demand profile analysis for an industrial facility.

**Figure 6.4 Demand Profile Analysis Spreadsheet (from Profile.xls)**




In addition to the familiar time-series representation of the demand profile, this spreadsheet template provides a load duration curve, which is essentially a histogram of load versus time. The load duration curve shows the amount of time that the load is above a certain value. This curve simplifies the assessment of demand control opportunities. In the example shown, the demand peaks at 446 kW, and the demand is between 424 and 446 kW for 4.6% of the time. This means that to achieve a demand savings of 22 kW (446 kW minus 424 kW), this plant would need to be in a demand-limiting or demand-controlling mode for about 5% of the time.

## 6.5 Opportunities for Savings in the Demand Profile

Often, opportunities for savings can be found in the demand profile. The following are typical examples of savings opportunities:

- A peak demand that is significantly higher than the remainder of the profile for a short amount of time affords an opportunity to reduce demand through scheduling.
- A high night load in a facility without night operations presents an opportunity for energy savings through better manual or automatic control or possibly time clocks to shut down equipment that is not required to operate all night.
- Loads that cycle on and off frequently during unoccupied periods – it may be possible to shut them down completely.
- High demands during breaks in a production operation or insignificant drops at break times suggest that equipment idling may be costly. Consider shutting equipment down during these periods.
- Make sure that systems are not starting up before they are needed and shutting down after the need has passed. Even half an hour per day can save a significant amount if the load is high.
- Peak demand periods at start-up times suggest an opportunity for staged start-up in order to avoid the peak.
- If the billed demand peak is not evident on a typical demand profile, this suggests that the load or loads that determine the demand may not be necessary (i.e. if they operate only once in a while). Consider scheduling or shedding these loads. Also check the billing history to see if the demand peak is consistent.
- A large load that cycles on and off frequently may result in a higher peak demand and lower utilization efficiency than a smaller machine running continuously. Consider using smaller staged units or machines. This strategy may also reduce maintenance because starting and stopping machines increases wear and tear.
- Short cycling loads provide a clue to identifying opportunities for maintenance savings and failure prevention.
- In some cases, non-essential loads may be temporarily disconnected during peak periods. This practice is commonly referred to as peak shedding or peak shaving.

### 6.5.1 | Savings Opportunities Through Power Factor Correction

Power factor should be considered when analysing electricity billings. A value for power factor may appear on your utility invoice; however, it is common to meter power factor when metering demand. Power factor values, when viewed alongside the demand profile, help to determine what actions have caused demand changes. Therefore, it is useful to consider savings opportunities related to power factor at this point.

The demand profile illustrated in Figure 6.2 shows power factor values throughout the day, including the time of peak or maximum demand. For customers billed on kVA demand, there is an opportunity to reduce the peak or maximum kVA demand by increasing power factor. As detailed in Section C-1, "Energy Fundamentals," power factor is the ratio of real power in kilowatts (kW) to the apparent power in kilovolt-amps (kVA). With the application of a capacitor or bank of capacitors, it is possible to reduce kVA demand while maintaining real power consumption (i.e. kW demand).

In practice, it is only the on-peak power factor that is relevant to demand costs.

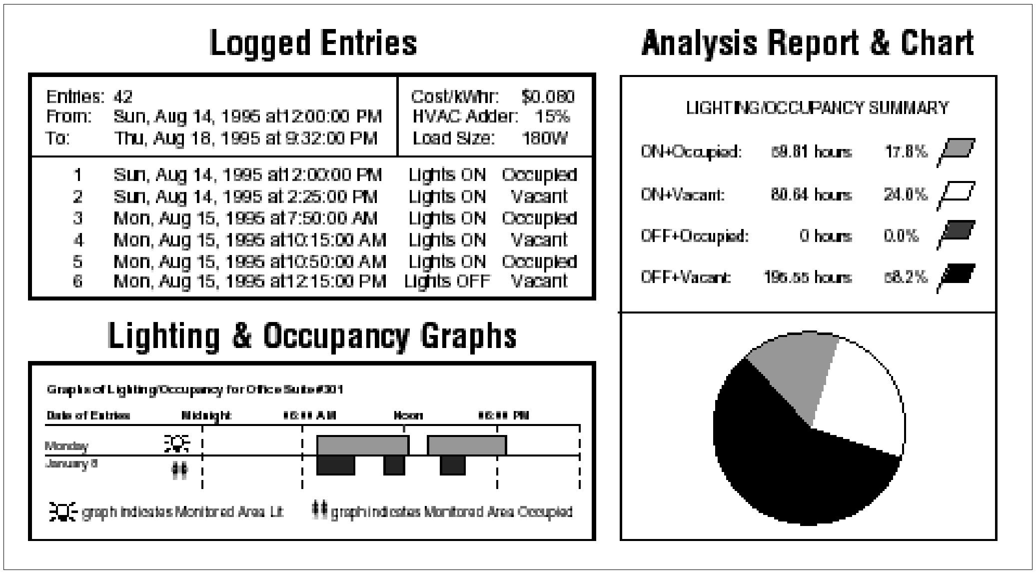
- Correct power factor at the service entrance: This can be achieved by adding a fixed capacitor bank, provided that the load and power factor are constant. Otherwise, a variable capacitor bank (i.e. one that adjusts to the load and power factor) will be required.
- Correct power factor in the distribution system: When large banks of loads are switched as a unit within the distribution system, installing capacitors at the point of switching may be an advantage. This has a secondary benefit in that it may also free up current-carrying capacity within the distribution system.
- Correct point-of-use power factor: When a large number of motors start and stop frequently or are only partially loaded, it may be operationally advantageous to install power factor correction capacitors at the point of use (i.e. the motor). In this way the correction capacitors are brought online with the motor and removed as the motor is stopped.
- Utilize synchronous motors to provide power factor correction: For very large systems, capacitors can become large and unwieldy. One alternative approach is to use a large over-excited synchronous motor, which can have the same effect on an electrical circuit as a capacitor.

## 6.6 Other Useful Profiles

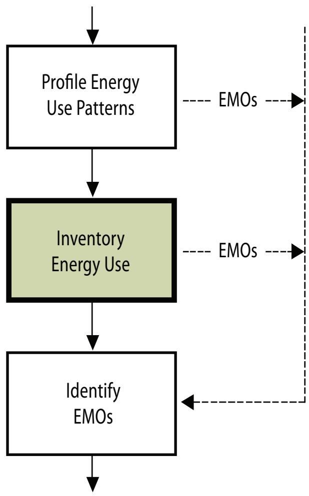
Although demand profiling reveals a wealth of information about electricity-consuming systems, there are many other parameters that can be profiled for short periods as part of an audit. Some typical applications are listed in Section C-4.12, "Compact Data Loggers," which describes the general purpose of dedicated data loggers. Using such data loggers usually generates EMOs.

An example of a dedicated data logger is a combination occupancy light-sensor logger. Figure 6.5 provides a sample of the output of this type of logger, showing when an area is occupied and when the lights are on. This device quickly indicates the benefit of installing motion-sensor lighting: lights remained on when the area was vacant for 24% of the time.

Figure 6.5 Sample Output from a Dedicated Data Logger (courtesy of The Watt Stopper Inc.)



# 7 INVENTORY ENERGY USE




## 7.1 Introduction

Two of the energy auditor's essential tools for fully assessing a facility are the demand profile (i.e. the characterization of the electrical loads in terms of time of use and size) and the load inventory. These two tools are complementary in that they describe in quantitative detail the systems that consume energy in a facility.

The energy auditor needs to know where energy is being consumed, how much is consumed by each system, and how all the systems add up as an aggregate load. It is helpful to know how the total energy load is distributed among various systems.

The load inventory is a systematic way of collecting and organizing this kind of information. It is a useful tool for undertaking "what if" assessments of proposed measures, i.e. estimating the impact of retrofits or other technological or operational change.

## 7.2 The Electrical Load Inventory

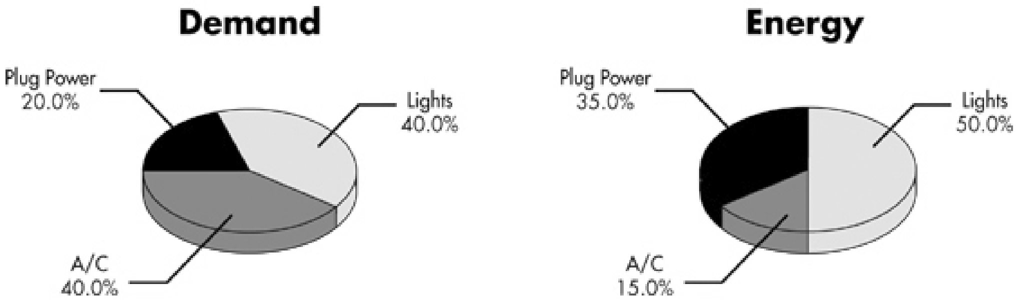
Making a list or inventory of all loads in a facility answers two important questions:

- **Where** is the electricity used?
- **How much** and **how fast** is electricity used in each category?

Often, the process of identifying categories of use allows waste to be easily identified, and this frequently leads to low-cost savings opportunities. Identifying high-consumption loads lets you consider the best savings opportunities first. Because the inventory also quantifies the demand (i.e. how fast electricity is used) associated with each load or group of loads, it is invaluable for further interpretation of the demand profile (see Section 6, "Profile Energy Use Patterns").

Figure 7.1 illustrates a possible presentation of the results of the load inventory.

**Figure 7.1 Load Inventory Results**



### 7.2.1 | Compiling a Load Inventory

This section outlines a method for compiling a load inventory. Forms and calculations of the load inventory are described in Section C-5, "Electrical Inventory Method." The method is illustrated with sample sheets from the load inventory spreadsheet template included in the "Technical Supplement."

In addition to the load inventory forms (paper or electronic), a clipboard, pencil and calculator are needed. Instrumentation is not a necessity; a simple hand-held power meter is probably the most valuable tool. This and other instruments are discussed in Section C-4, "Instrumentation for Energy Auditing."

To begin the load inventory, choose a **period of time** corresponding to the utility billing period (usually a month, although it could also be a day, week or year). Select a period that is typical for your operations. Determine the **actual demand in kW** and the **energy consumption in kWh** for the period selected. If the period is a month, take information from the utility bill. If the facility demand is measured in kVA, this will require a calculation based on the peak power factor to convert kVA to kW (see Section C-1, "Energy Fundamentals").

Identify each of the major categories of electricity use in the facility. You may have to tour the facility and list categories as you notice them. When identifying various categories of energy use, it is useful to consider both the type of electricity use and the activity in each area. Selecting categories with similar operational patterns is a good approach. Figure 7.2 shows categories of use and the billing information entered.

**Figure 7.2 Load Inventory Categories of Use in Spreadsheet (from Load Inventory.xls)**

**Load Inventory**

**for:** ABC Manufacturing Facility

| # | Description of Load Group | Peak Demand kW | % | Energy kWh | % |
|---|---|---|---|---|---|
| 1. | Motors | 28 | 60% | 47,247 | 74% |
| 2. | Lighting | 4 | 9% | 5,640 | 9% |
| 3. | Heating | 5 | 10% | 6,000 | 9% |
| 4. | Process | 9 | 19% | 4,000 | 6% |
| 5. | Other | 1 | 2% | 920 | 1% |
| | **Facility Totals** | **47** | **100%** | **63,807** | **100%** |
| | **Monthly Utility Bills** | **55** | **kW** | **12,000** | **kWh** |
| | **Difference from Bills** | **(8)** | **-15%** | **51,807** | **432%** |

Figure 7.2 also shows the peak demand and energy consumption of each area of use. These values are derived from load and time data for individual loads. The two most common load calculations are

- motor load method – this estimates motor-connected electrical loads from motor horsepower, loading and efficiency
- nameplate or measured connected kW load – this estimates load power consumption based on the nameplate rating of the load or from a power measurement with a power meter

Details of these and a more detailed method involving current and voltage are provided in Section C-5.

Figure 7.3 illustrates sample spreadsheets for use with the motor load method and the nameplate or measured connected kW load method.

**Figure 7.3 Load Inventory Spreadsheets ( Load Inventory.xls)**

**Load Inventory of Motors**
for ABC

View Summary

Subtotals for Motors 47 247 kWh 28 kW (Peak)

| Motor Description | Qty | HP | Motor Load | Eff'y | Unit kW | Total kW | Hours /Month | Total kWh | Diversity Factor | Peak kW Demand |
|---|---|---|---|---|---|---|---|---|---|---|
| Vent Fans System 1 | 1 | 75 | 100% | 90% | 62.2 | 62.2 | 760 | 47 247 | 0.45 | 28.0 |

**Load Inventory of Lighting**
for ABC Manufacturing Facility

View Summary

**Sub-Totals for Lighting 5 640 kWh 4 kW (Peak)**

| Load Description | Qty | Unit kW | Total kW | Hours /Month | Total kWh | Diversity Factor | Peak kW Demand |
|---|---|---|---|---|---|---|---|
| Office Areas Fluorescent Lighting (4') | 200 | 0.047 | 9.4 | 600 | 5 640 | 0.45 | 4.2 |

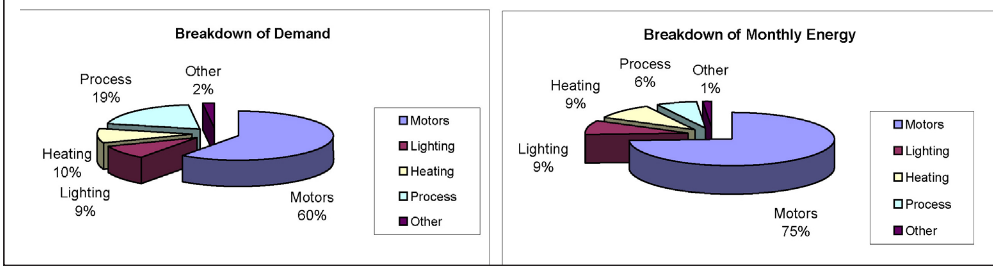
After all loads in all categories are inventoried, the total demand and energy can be reconciled with the utility billed data for the period selected. Pie charts can be created from the summary information. Figure 7.4 shows a partially completed inventory not fully reconciled with utility bills.

**Figure 7.4 Load Inventory Summary with Pie Charts (from Load Inventory.xls)**

**Load Inventory**

**for:** ABC Manufacturing Facility

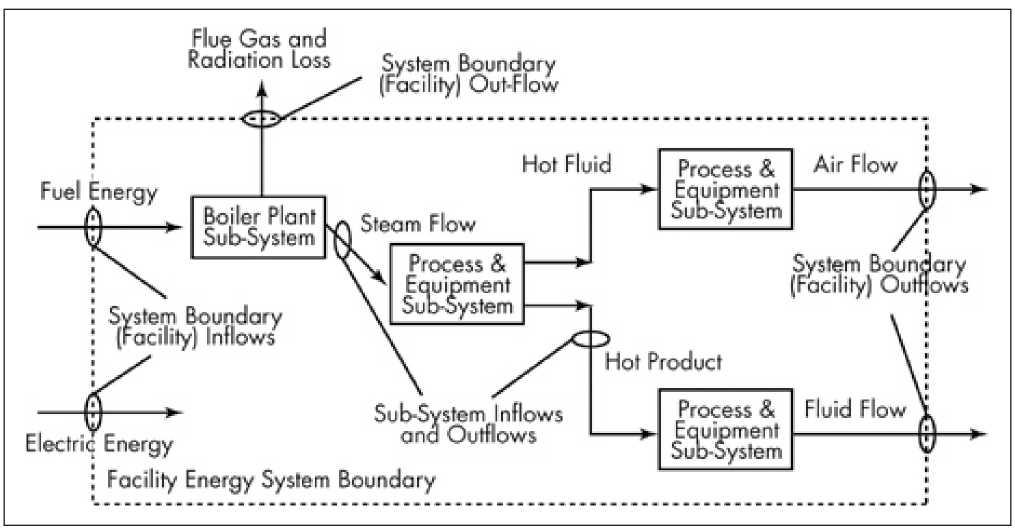
| | | Peak Demand | | Energy | |
|---|---|---|---|---|---|
| # | Description of Load Group | kW | % | kWh | % |
| 1. | Motors | 28 | 60% | 47,247 | 74% |
| 2. | Lighting | 4 | 9% | 5,640 | 9% |
| 3. | Heating | 5 | 10% | 6,000 | 9% |
| 4. | Process | 9 | 19% | 4,000 | 6% |
| 5. | Other | 1 | 2% | 920 | 1% |
| | **Facility Totals** | **47** | **100%** | **63,807** | **100%** |
| | **Monthly Utility Bills** | **55** | **kW** | **12,000** | **kWh** |
| | **Difference from Bills** | **(8)** | **-15%** | **51,807** | **432%** |




## 7.3 The Thermal Energy Use Inventory – Identification of Energy Flows

Identifying thermal energy flows associated with each energy use in a facility is made simple with an energy flow diagram. A useful diagram will show all energy flows into the facility, all outgoing flows from the facility to the environment, and all significant energy flows within the facility.

**Figure 7.5 Energy Flow Diagram**



The purpose of an energy flow diagram is not to describe a process in detail; it will generally not show specific devices and equipment that are found in its various subsystem "blocks." Illustrating energy flows is the principal objective at this stage.

The sum of the energy outflows should equal purchased energy inflows. When we have the complete picture of the major internal energy flows and those from and to the surroundings, it is often possible to see opportunities for energy reduction and recovery.

### 7.3.1 | Identifying the Type of Energy Flow

Table 7.1 below can be used as a checklist to help identify thermal energy outflows from a subsystem or a facility. Although this list does not contain every possible type of energy flow, it does cover a selection of the more common types – ones that often lead to savings opportunities.

**Table 7.1 Checklist of Thermal Energy Outflows**

| Energy Flow Type | Example | Equipment/Functions |
|---|---|---|
| Conduction | Wall, windows | Building structure |
| Airflow – sensible | General exhaust | Exhaust and make-up air systems, combustion air intake |
| Airflow – latent | Dryer exhaust | Laundry exhaust, pool ventilation, process drying, equipment exhaust |
| Hot or cold fluid | Warm water to drain | Domestic hot water, process hot water, process cooling water, water-cooled air compressors |
| Pipe heat loss | Steam pipeline | Steam pipes, hot water pipes, any hot pipe |
| Tank heat loss | Hot fluid tank | Storage and holding tanks |
| Refrigeration system output heat | Cold storage | Coolers, freezers, process cooling, air conditioning |
| Steam leaks and vents | Steam vent | Boiler plant, distribution system, steam appliance |

### 7.3.2 | Calculations for Estimating Energy Outflows

Section C-1 describes how to calculate thermal energy flows. The spreadsheet template "Thermal Inventory.xls" automates many of these methods. See Figure 7.6 for examples of calculations of energy in latent heat in moist airflows and steam flows.

Figure 7.6 Thermal Energy Calculations Spreadsheet Template (from [Thermal Inventory.xls])

**Air Flow - Latent Heat** — Menu

| Description | Air Flow litres/sec | $T_{high}$ ( C ) | $RH_{high}$ (%) | $T_{low}$ ( C ) | $RH_{low}$ (%) | $H_{high}$ g/kg | $H_{low}$ g/kg | Heat Flow kW | Monthly Hours | Monthly Energy kWh | GJ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dryer Exhaust | 2,000 | 40 | 90% | 20 | 50% | 43.8 | 7.3 | 219.8 | 732 | 160,920 | 579.3 |

**Conduction** — Menu

| Description | Area $m^2$ | Conductance $W/m^2C$ | $T_{high}$ C | $T_{low}$ C | Heat Flow kW | Monthly Hours | Monthly Energy kWh | GJ |
|---|---|---|---|---|---|---|---|---|
| Warehouse Roof | 100 | 0.900 | 20 | 5 | 1.35 | 732 | 988 | 3.6 |

**Steam Flow, Leak & Cost** — Menu

| Description | Steam Flow Type | Size Specifier | | Steam Pressure kPA gauge | Steam Flow kg/hr | Steam Enthalpy kJ/kg | Heat Flow kW | Monthly Hours | Monthly Energy kWh | GJ |
|---|---|---|---|---|---|---|---|---|---|---|
| Small Dryer in Plant B | Plume | Length (mmx100) | 20.0 | 520 | 105.6 | 2,758 | 81 | 732 | 59,245 | 213.3 |

## 7.3.3 | Calculations for Estimating Energy Inflows

Using an energy flow diagram, you can begin to quantify the inflows of energy in terms of rate (kW) and amount (GJ per day, month or year).

In many cases, the information necessary to perform these energy calculations is readily available for several pieces of equipment and processes.

### *Nameplate Ratings*

Equipment specifications provide thermal energy requirement data. Fuel-fired equipment is rated in terms of fuel input rates. Oil-fired boilers are often rated according to energy input rates such as Btu/hr. or MBtu/hr. Given equipment operating times, energy use can be estimated by means of the energy calculation methods presented in Section C-1, "Energy Fundamentals." Figure 7.7 shows a sample inventory of energy inputs from the fuel systems spreadsheet template.

Figure 7.7 Fuel-Consuming Systems Spreadsheet (from Fuel Systems.xls)

**Summary of Fuel Consuming Systems**

| Equipment | Fuel Type | Estimated Fuel Usage | Units | Input Energy Energy (GJ) |
|---|---|---|---|---|
| Main Boiler | N. Gas | 600000 | $m^3$ | 22,560,000 |
| DHW Heater | N. Gas | 50000 | $m^3$ | 1,880,000 |
| Heat Treat Furnace | N. Gas | 1000000 | $m^3$ | 37,600,000 |
| | | | | - |
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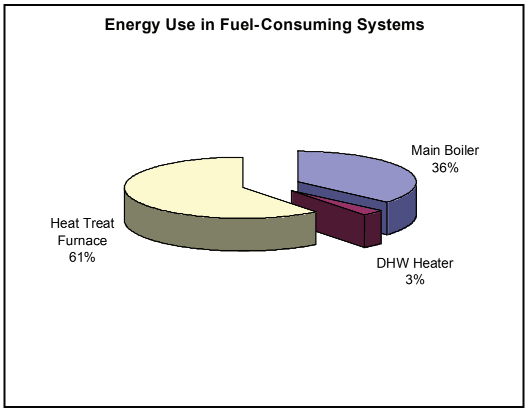
| | | | | - |
| | | | | - |
| Total | | 3 Combustion Systems | | 62,040,000 |




### *Steam Flow*

There may be steam flow metering available in your plant. Steam-consuming equipment will have a specified requirement for steam flow rate. Section C-1 details methods of estimating energy use from steam flow rates. Figure 7.8 shows a sample steam calculation spreadsheet for estimating the cost of energy from steam.

Figure 7.8 Steam Cost Calculation Spreadsheet (from Thermal Inventory.xls)

**Estimation of the Cost of Saturated Steam**

| | | |
|---|---|---|
| **Incremental Cost of Fuel** | $0.25 | **/unit** |
| **Energy Content** | 37.60 | **MJ/unit** |
| **Boiler Efficiency** | 76% | |
| **Saturated Steam Pressure (gauge)** | 700.0 | **kPa gauge** |
| **Steam Enthalpy (Vapour + Water)** | 2769 | **kJ/kg** |
| **Cost per 1000 kg** | $24.23 | **/1000 kg** |
| **Cost per 1000 lb** | $11.01 | **/1000 lb** |

Note: Steam enthalpies are calculated for saturated steam using an approximation with an accuracy of +/- 1%.

## Application to a Sample Energy System

Section 7.3 introduced the concept of the energy flow diagram as a way to develop a thermal energy-use inventory for a facility. Figure 7.9 illustrates a simple industrial food-processing system.

**Figure 7.9 Industrial Food-Processing System**

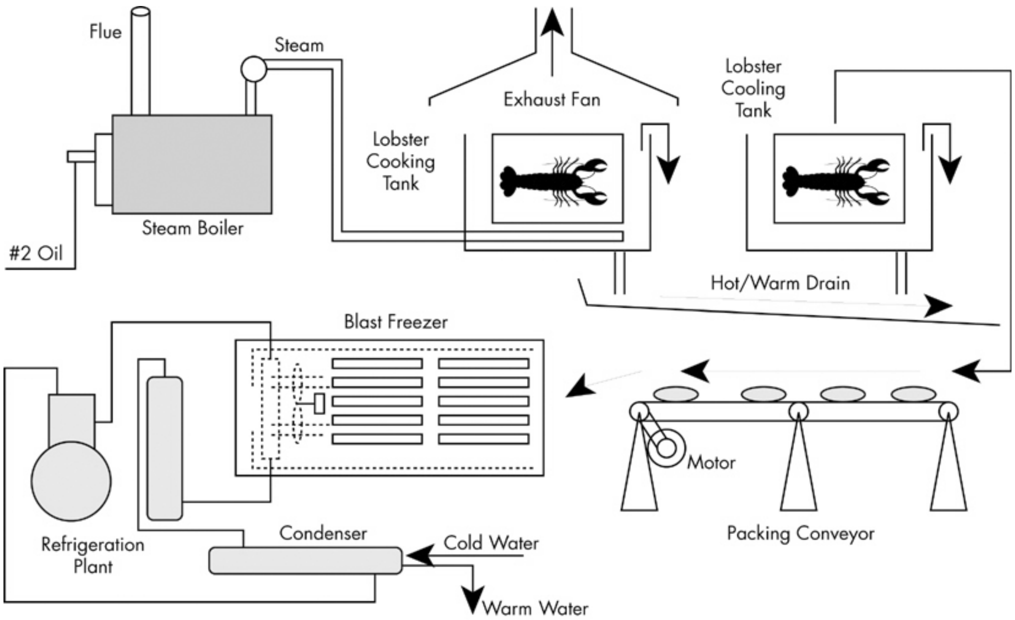



**Figure 7.10 Energy Flow Diagram**

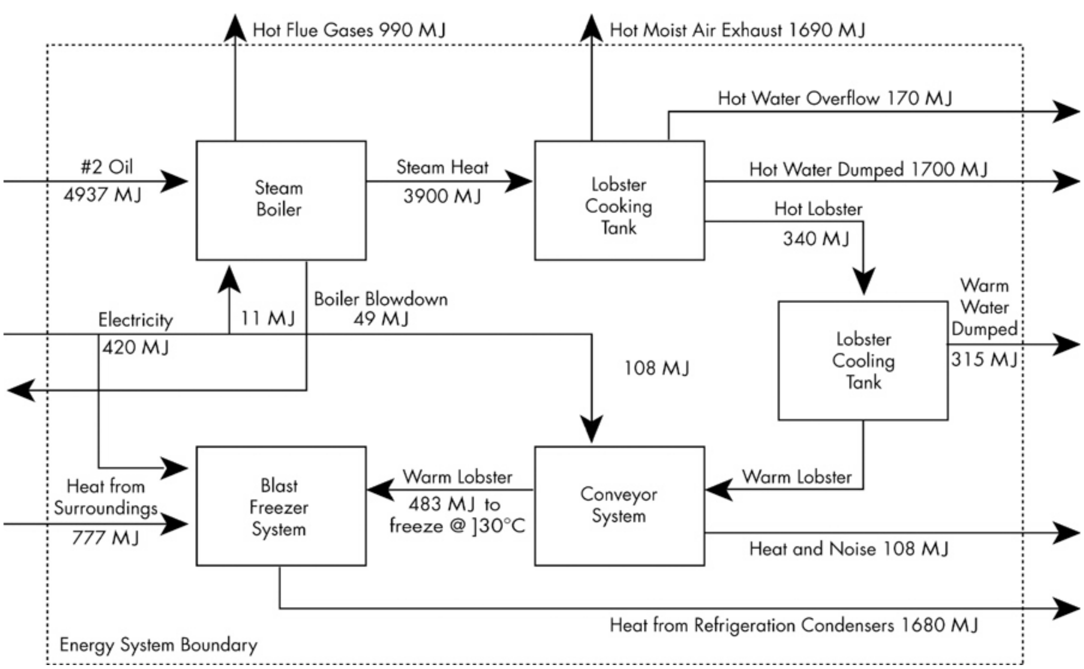


Figure 7.10 represents the simplified energy flow diagram that was used to build the energy use inventory shown in Table 7.2. All calculations are based on the methods outlined in this chapter.

All energy figures for this example are for one day's operation of a lobster processing plant – a 10-hour operating period. The heat of fusion (freezing and melting) for water is assumed to be 360 kJ/kg. The amount of lobster processed during this 10-hour period is assumed to be equivalent to 1000 kg of water in heat capacity. The reference water temperature is assumed to be 10°C.

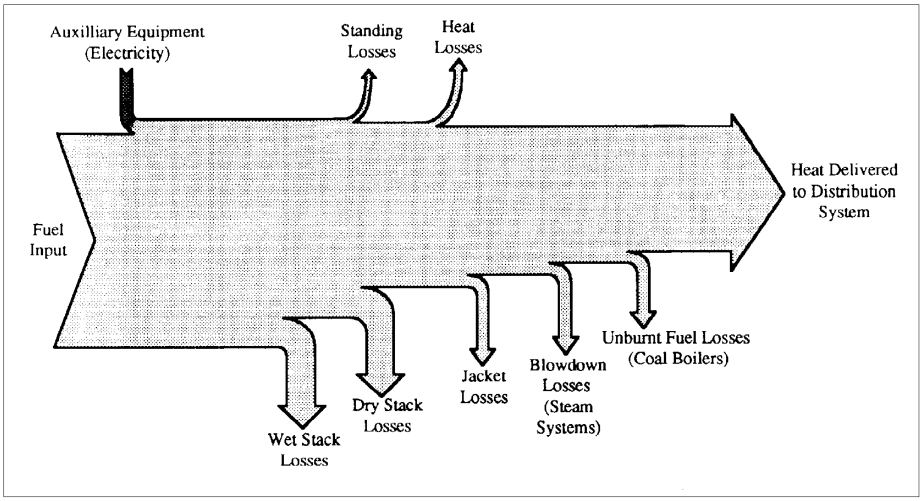
**Table 7.2 The Energy Use Inventory**

| Energy Flow | Basis for Energy Calculations | Energy (MJ) |
|---|---|---|
| No. 2 oil | 127 L per day | 4937 MJ |
| Electricity | 150 kWh per day | 539 MJ |
| Hot flue gases | 20% of energy into boiler | 990 MJ |
| Blowdown loss | 1% of fuel | 49 MJ |
| Steam heat | 79% of energy into boiler | 3900 MJ |
| Moist exhaust | Sensible heat (1000 L/s from 20°C to 30°C)<br>Latent heat (1000 L/s from 50% to 70% relative humidity | 430 MJ<br>1260 MJ<br>1690 MJ total |
| Hot water overflow | 450 L per day at 90°C | 170 MJ |
| Hot water dumped | 4500 L per day at 90°C | 1700 MJ |
| Hot lobster | Equivalent to 1000 kg of water raised from 10°C to 90°C | 340 MJ |
| Warm water dumped | 15 000 L at 15°C (lobster cooled to 15°C) | 315 MJ |
| Electricity to conveyor | 3 kW for 10 hours | 108 MJ |
| Heat and noise | All of conveyor energy | 108 MJ |
| Warm lobster to freezer | Lobster is cooled from 15°C to 0°C<br>Lobster is frozen at 0°C<br>Lobster is cooled to –30°C<br>(equivalent to 1000 kg of water) | 63 MJ<br>360 MJ<br>60 MJ<br><br>483 MJ total |
| Electricity to compressor | 11.6 kW for 10 hours<br>Freezer is 10 tons (convert to "tonnes") (35 kW) with a COP of 3.0 | 420 MJ |
| Condenser cooling water | 33 L/min from 10°C to 30°C | 1680 MJ |
| Heat from surroundings | Cooling water minus heat from lobster minus electricity to compressor | 777 MJ |

## 7.4 Energy Inventories and the Energy Balance

One of the implications of the energy balance principle underlying the audit is that we can quantify all energy inputs and balance them against all energy outputs. The energy flow diagram for the industrial food-processing plant is balanced – the energy inflow equals the energy outflows. A convenient graphical representation of this is the Sankey diagram, which is illustrated with reference to a boiler in Figure 7.11.

**Figure 7.11 Sankey Diagram of Energy Balance for a Boiler**




The Sankey diagram summarizes the energy balance for a given system, indicating (1) the magnitude of all energy inputs and outputs by the size of the arrows and (2) the approximate sequence in which outputs occur along the energy flow path. Other Sankey diagrams are shown in Section C-2, "Details of Energy-Consuming Systems."

### 7.4.1 | Building Envelope Energy Heat Loss

Another example of a thermal energy balance is the analysis of heat loss from the envelope of a building. This involves calculating heat loss through windows, doors, walls, roofs and ventilation and exhaust systems. The spreadsheet in Figure 7.12 illustrates a very simple heat loss calculation for a building, showing all energy outflows, with the contribution to space heat from internal heat gains such as electricity and human heat taken into account. The result is a breakdown of energy use into the major categories. A Sankey diagram for building envelope heat loss is shown in Section C-2.

Figure 7.12 Simple Building Heat Loss Analysis Spreadsheet (from Envelope.xls)

**Simple Building Heat Loss Calculator**

**Building Envelope**

| Walls | Length m | Height m | Slab W/m°C | U-Val W/m²°C | Window Qty 1. | 2. | 3. | 4. | 5. | Door Qty 1. | 2. | 3. | Schedule |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Main Walls | 180 | 6 | 0.1 | 0.6 | 30 | 8 | | | | 2 | 4 | | 24h 7d |
| 2. Gym Walls | 120 | 10 | 0.3 | 0.9 | | | | | | 3 | | 1 | Other |
| 3. | | | | | | | | | | | | | 24h 7d |
| 4. | | | | | | | | | | | | | 24h 7d |
| 5. | | | | | | | | | | | | | 24h 7d |

| Roofs | Length m | Width m | n/a | U-Val W/m²°C | 1. | 2. | 3. | 4. | 5. | Schedule |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Main Roof | 50 | 40 | n/a | 0.6 | | | 1 | | | 24h 7d |
| 2. Gym Roof | 30 | 30 | n/a | 1 | | | | | | 24h 7d |
| 3. | | | n/a | | | | | | | 24h 7d |

| Windows | Length m | Width m | Infilt. L/s per m | U-Val W/m²°C |
|---|---|---|---|---|
| 1. Large Th'pane | 1 | 1 | 2 | 3.3 |
| 2. Small Th'pane | 0.3 | 1 | 2 | 3.3 |
| 3. | | | | |
| 4. | | | | |
| 5. | | | | |

| Doors | Length m | Width m | Infiltration L/s per m | U-Val |
|---|---|---|---|---|
| 1. Steel Doors | 1 | 2.5 | 5 | 2.5 |
| 2. Glass Doors | 1 | 2.5 | 5 | 4.5 |
| 3. Overhead Doors | 3 | 3 | 10 | 2.5 |

| Slab Heat Loss | W/m°C |
|---|---|
| 1. None | |
| 2. Insulated | 0.1 |
| 3. Un-Insulated | 0.3 |

| Infiltration | L/s per m |
|---|---|
| Low | 2 |
| Medium | 10 |
| High | 20 |

**Ventilation**

| Area/System | Persons | L/s per person | System litre/sec | Average O/A % | Outside Air Flow | Unocc'd State | Schedule |
|---|---|---|---|---|---|---|---|
| 1. Class & Offices | 120 | 15 | | | 1800 | On | Setback |
| 2. Gym | | | 3500 | 100% | 3500 | On | Setback |
| 3. Kitchen | | | 500 | 100% | 500 | On | Setback |

**Schedules & Temperatures**

| Schedule Name ---> | Setback Occ'd | Setback Unocc'd | Other | 24h 7d |
|---|---|---|---|---|
| Temperatures | 20.0 °C | 15.0 °C | 17.0 °C | 20.0 °C |
| Sunday | | 24 | 24 | 24 |
| Monday | 9 | 15 | 24 | 24 |
| Tuesday | 9 | 15 | 24 | 24 |
| Wednesday | 9 | 15 | 24 | 24 |
| Thursday | 9 | 15 | 24 | 24 |
| Friday | 9 | 15 | 24 | 24 |
| Saturday | | 24 | 24 | 24 |
| Monthly Hours | 196 | 534 | 730 | 730 |
| Ave Temp | 16.3 °C | | 17.0 °C | 20.0 °C |
| Temp Diff x hours | 54109.4 °C | | 57968.4 °C | 75490.3 °C |

**Heating Plant Efficiency**

| | |
|---|---|
| Fuel Type | Natural Gas |
| Combustion Efficiency | 85% |
| Other Losses | 7% |
| Seasonal Plant Efficiency | 78% |

| Internal Heat Gains |
|---|
| 240,000 |
| kWh/year |
| 33% |

| Annual Energy Use Component | kWh/year Loss | kWh/year less IHG | GJ/year Fuel Input |
|---|---|---|---|
| Walls | 111,961 | 74,717 | 345 |
| Roofs | 158,530 | 105,794 | 488 |
| Windows | 29,329 | 19,573 | 90 |
| Door | 35,628 | 23,776 | 110 |
| Ventilation | 386,016 | 257,606 | 1,189 |
| **Total Building Energy** | **721,465** | **481,465** | **2,222** |

## 7.5 Finding EMOs in the Energy Inventory

The electrical load inventory and thermal energy use inventory are good starting points in the search for EMOs.

The process of evaluating the breakdown or distribution of energy use can often unearth potential savings opportunities. While considering each piece of equipment, group of loads or heat-consuming systems, take into account operating time, the justification for each load and the need for the equipment to be operating at any given time.

### 7.5.1 | Special Consideration for the Thermal Energy-Use Inventory

The results of the thermal energy-use inventory can help to identify savings opportunities.

#### Opportunities for Energy Flow Reduction

The magnitude of each outflow depends on several factors, such as temperatures, flow rates, humidity, time and the characteristics of materials. Finding savings opportunities involves considering which of these factors, if any, may be changed to reduce the amount of energy consumed.

Can flows be reduced? Can temperatures be changed? In most cases, there are valid reasons for present values being what they are. But taking a look at the type and magnitude of existing energy outflows often reveals some worthwhile savings opportunities.

So far we have not concerned ourselves with the technical details of the systems and equipment involved with the energy flows under consideration. Now, however, it is time to turn our attention to the hardware itself and consider the possibility of changing one or more aspects of how the system functions in order to reduce energy flow.

Is it possible, for example, to reduce the amount of energy consumed by a ventilation system that provides general ventilation for an office area of a building? Ventilation systems of this kind are responsible for increased consumption of winter heating energy because they introduce cool, fresh outside air that must be heated to replace warm, stale building air that is exhausted. The factors that influence the amount of energy consumed in this system are the rate at which outside air is brought in, the temperature difference between outside and inside air, and the duration of the ventilation.

Because building occupants have a legitimate need for fresh air, we ordinarily cannot reduce the amount of air brought in and exhausted. When considering ventilation and temperature, there are regulatory requirements that must be adhered to. For example, the Ontario Ministry of Labour's *Occupational Health and Safety Act* (available at www.e-laws.gov.on.ca/index.html) provides for standards governing workplace conditions. In addition, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is an international organization that publishes standards for workplace ventilation and temperature. Visit ASHRAE's Web site (www.ashrae.org) to obtain these standards.

Given the need to maintain the amount of air brought in by a ventilation system, how can the parameters of the system be manipulated to yield energy savings?

- **Time**: It may be possible to control operation of the ventilation system more effectively, reduce operating time, and match it to building occupancy more closely.
- **Flow**: Although the airflow rates during occupied periods cannot be adjusted, the rate of unneeded ventilation at night could be reduced by using dampers that seal properly when closed, or perhaps the system could be shut down completely at night.
- **Temperatures**: If the system must run for extended periods to clear stale air properly, it may be possible to reduce the temperature of the air during unoccupied periods, using some sort of temperature setback method.

These are simple examples, but they illustrate the value of addressing each of the factors that influence energy consumption. Actual reduction in energy flows is achieved through specific changes to equipment, devices and operational practices.

### Reducible or Recoverable Energy

An energy flow can be either reducible or recoverable, and energy savings will be realized accordingly:

- **Reducible**: A flow directly associated with a purchased energy form. In this case, reducing the flow will directly result in a reduction of purchased energy. Examples are (1) reducing heat flow through the walls of a building by adding insulation and (2) reducing warm air lost by trimming hours of ventilation.

- **Recoverable**: A flow of waste heat, the reduction of which will not directly reduce purchased energy. A good example of this is cooling water from water-cooled air compressors. This energy flow cannot be reduced – nor should it be, since it serves a useful purpose. However, there is real value in the heated water, and it could be used to replace the purchased energy being used in another system. This is called energy recovery or heat recovery.

It is important to determine precisely the type of flow in the facility. In some cases, it may be a mixture. The method of calculation of savings is different for reducible and recoverable energy flows.

### 7.5.2 | Special Consideration for the Electrical Load Inventory

Examine each load in the inventory by means of a quadrant analysis (see Section 8.2.5). Look first at the required energy being provided – light, air or water power, process energy or heat. Also consider the following factors.

***The Diversity Factor***

A high value indicates a load that is contributing heavily to the peak demand. Is this necessary? Could it be avoided?

***Operating Hours***

Loads that have valid extended operating hours are good candidates for efficiency improvement. Could lamps be upgraded? Are pumps and fans the most efficient? Could a higher-efficiency motor be used?

***Load Grouping***

Are there large groups of loads that have similar operating hours simply because they operate or are switched only as a group? A good example of this is lighting. Can lights be zoned or switched automatically by occupancy detectors, time clocks or photocells?

***The Night Load***

If you have a demand profile available, can you justify the night load? Do all loads that operate during night or unoccupied hours need to operate?

***Loads That Require Monitoring***

Are there loads or groups of loads that consume a significant portion of the overall energy and demand? Could these loads be monitored for excessive running time or power consumption? A good example of this would be a large refrigeration system in a supermarket or food-processing operation.

### 7.5.3 | Load Flexibility Assessment

Load flexibility can be defined as the degree to which the pattern of electrical use in a facility can be changed. One goal of assessing load flexibility is to shift energy consumption from one daily time period to another (less expensive) time of day.

A secondary goal might be to free up capacity of a fully loaded system by spreading the load out. The idea of flexible loads should be of interest to energy users who are considering alternative electric rates, such as time-of-use and real-time pricing.

After performing a detailed load inventory and analysis of your existing operation, you will have a better understanding of

- load groups by function (lighting, process, cooling, heating, etc.)
- dependencies of the loads or load groups on external factors (weather, production, occupancy, etc.)
- interdependencies between loads or load groups (e.g. which loads must be operated together or in a predetermined schedule)

Using this knowledge, you can examine your loads for any flexibility in their operation. Flexible loads usually fall into one of the following scenarios.

**Energy storage**: For practical purposes, this would be hot water or cold (ice) water storage. Insulated storage tanks can be used to stockpile electrically heated hot water during off-peak periods, so the heaters can be shut down in peak periods. Example of cooling storage: Some dairies operate refrigeration to produce and store "sweet water" (ice water) during production down time; the sweet water is then used during processing instead of a large refrigeration plant supply cooling on demand.

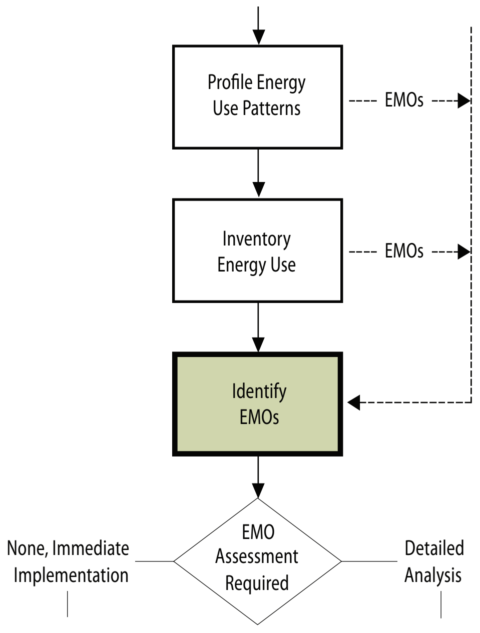
**Product storage**: In a plant that produces several different products or in which the production is in distinct stages that can be run independently, different products can be manufactured in a specific shift and stockpiled for the following shift. One example of this approach is a rock quarry that staggers different processes to smooth out loads on the electrical system.

**Task rescheduling**: In a plant where industrial processes are independent of each other, it may be possible to schedule some tasks or processes to a different shift, away from the more expensive electrical time of day.

## 7.6 Reference

*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001
Web site: iac.rutgers.edu/manual_industrial.php

# 8 IDENTIFY ENERGY MANAGEMENT OPPORTUNITIES




## 8.1 Introduction

The audit process flow chart shows several stages at which EMOs can be identified:

- At the **Condition Survey** stage, obvious needs for repair or operational changes that require no further assessment become apparent.
- When the facility **Demand Profile** is examined, other opportunities are identified that can reduce cost or consumption: for example, load-shifting opportunities that lower peak demand or loads that are on when the plant is down.
- The **Load Inventory** quantifies the distribution of energy consumption among plant systems and provides a basis for reconciling load with billings; variances in the reconciliation and insight into load distribution can lead to further EMOs.

EMOs arising from the Condition Survey and Demand Profile are addressed elsewhere in the guide. This section outlines how to identify further EMOs and how to assess their feasibility and cost-effectiveness logically and systematically.

## 8.2 A Three-Step Approach to Identifying EMOs

All energy-consuming equipment and systems were designed to meet a specific need or set of needs. This may be as simple as providing illumination or be far more complex, as in the case of an integrated processing plant. **Finding EMOs involves reducing the level of energy use while still meeting the original need or requirement**.

The process of identifying EMOs begins at the point of end use where the need or requirement is met and works methodically back toward the point of energy purchase.

### 8.2.1 | Step 1: Match Usage to Requirement

The first and most important step in realizing savings opportunities is to match what is actually used to what is needed. The key consideration here is the duration of use and the magnitude of use. Questions that might be asked include the following:

- What is being done?
- Why is it being done?
- What energy is being consumed?
- What energy should be consumed?
- Does the process equipment idle for significant periods of time?

### 8.2.2 | Step 2: Maximize System Efficiencies

Once the need and usage are matched properly, the next step is to ensure that the system components meeting the need are operating as efficiently as possible. In this step, the effects of operating conditions, maintenance and equipment/technology will be considered. Questions to guide this aspect of the investigation include the following:

- Could it be done the same way but more efficiently?
- Are the principles underlying the process being correctly addressed?
- Why is there a difference?

### 8.2.3 | Step 3: Optimize the Energy Supply

The first two steps will reduce the requirement for energy. At this point it makes sense to seek the optimum source or sources for the net energy requirement.

The final step in identifying savings opportunities is to consider the supply of energy to the system and to look for savings opportunities that you can achieve by optimizing the supply. Opportunities for optimization typically include the following.

***Heat Recovery***

Heat recovery systems utilize waste energy streams to displace inflowing energy. Such systems range from simple ducting of warm air to complex heat pump systems.

***Heat Pumps***

In addition to facilitating heat recovery, heat pumps are used to exploit low-grade energy sources, such as geothermal energy (ground heat) and air. These are commonly called ground-source and air-source heat pumps.

***Cogeneration***

Cogeneration is often referred to as combined heat and power (CHP) systems. When facilities or processes require hot water and/or steam and at the same time have a demand for electrical energy, there may be an opportunity to supply both/all of them from fuel-fired combustion equipment. These systems take advantage of what would otherwise be waste energy. With a typical efficiency of 15% to 30% in converting fuel to electricity, the waste heat from the exhaust stream can provide the required thermal inflow to the appropriate facilities or processes; this can boost the overall efficiency by 50% to 80% or more.

***Renewable Energy Systems***

Renewable energy, such as solar, wind or ground heat, can be used to supplement conventional energy sources. Although not always economical, certain applications of renewable energy may be cost-effective, including off-grid use of photovoltaic (solar-generated electricity) and wind energy as well as passive solar designs for new and existing buildings.

***Fuel Switching***

Fuel switching involves replacing one fuel with another, less expensive energy source. A good example would be converting hot water heating from electric to gas.

***Purchase Optimization***

Purchase optimization takes full advantage of the open marketing of natural gas and electricity. Operations that understand what their energy use patterns are and how these patterns can be manipulated will benefit most from purchase optimization.

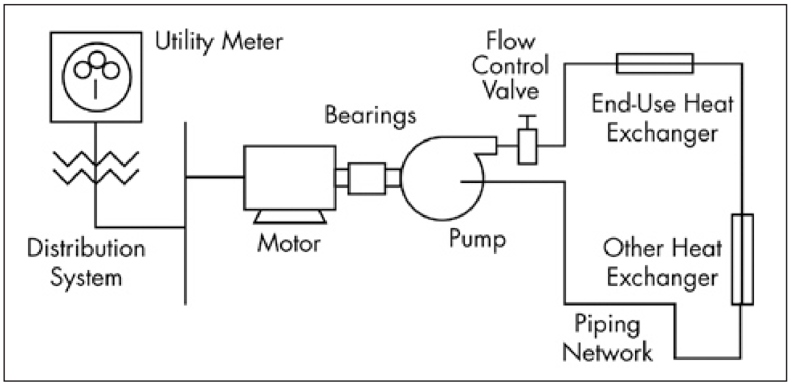
It is important to recognize that the appropriate time to consider purchase optimization is after each of the preceding steps. It would be counter-productive, for example, to negotiate a new electricity supply contract before properly managing the facility's demand profile. Any future changes to the demand profile could make the new supply agreement less economical. Likewise, sizing a cogeneration system on the basis of existing electrical and thermal loads without good usage practices in place would be less than optimal. In fact, future reductions in thermal or electrical loads could make the cogeneration system uneconomical.

### 8.2.4 | Actions at the Point of End Use Save More

Where is the best place to begin to look for EMOs? This is a simple question with a simple answer: **begin the search for opportunities where the energy is the most expensive – at the point of end use**.

**Example:** To illustrate this point, consider the case of a system designed to pump a fluid throughout a facility. In a commercial facility, this might be a chilled water pump for the air-conditioning system or for cooling process equipment. Figure 8.1 is a simplified picture of such a system, showing each component involved in the system's energy conversion. Energy passes through each system element, starting at the meter – the point of purchase – through to the heat exchanger in the terminal devices, where the cooling is required. Energy is constantly being converted and transferred.

**Figure 8.1 Energy Conversion Diagram**



Next, consider that the efficiency of each component is 100% or less. The meter would have an efficiency of very close to 100%, but other components are not as efficient. Efficiency is defined as the ratio of the output of a system or component to its corresponding input.

Each component with an efficiency of less than 100% wastes the difference between the energy input and output. The result of this waste is that the unit cost ($/kWh or $/MJ) of the energy increases between the input and output. The unit cost of the energy at the output can be calculated as follows:

$$\text{Energy Efficiency (\%)} = \frac{\text{Energy Output}}{\text{Energy Input}} \times 100$$

$$\text{Output Cost (\$/unit)} = \frac{\text{Input Cost (\$/unit)}}{\text{Energy Efficiency}}$$

Table 8.1 lists each of the components of the chilled water pumping system along with a description of the losses and an estimate of the typical energy efficiency of the component for a system of moderate size (10 to 100 hp).

**Table 8.1 Component and System Efficiencies**

| Component | Losses | Typical Efficiency |
|---|---|---|
| Utility meter | Negligible | 100% |
| Distribution system | Electrical resistance | 96% |
| Motor | Electrical resistance, friction, magnetic loss | 85% |
| Bearing | Friction | 98% |
| Pump | Fluid and mechanical friction | 60% |
| Valve | Minimal throttling | 70% |
| Piping network | Fluid friction | 60% |
| **Overall System Efficiency** | | **20%** |

From the overall efficiency it can be seen that only one fifth of the energy actually gets to the point where it is required. In other words, the system needed five times the actual end-use energy requirement, which in this case is in the form of water movement, to overcome all the losses in the system. The impact on the unit cost of energy is illustrated in Table 8.2.

Table 8.2 Unit Cost of Energy Through the System

| Component | Typical Efficiency | Unit Cost at Input ¢/kWh | Unit Cost at Output ¢/kWh |
|---|---|---|---|
| Utility meter | 100% | 5.00 | 5.00 |
| Distribution system | 96% | 5.00 | 5.21 |
| Motor | 85% | 5.21 | 6.13 |
| Bearing | 98% | 6.13 | 6.25 |
| Pump | 60% | 6.26 | 10.42 |
| Valve | 70% | 10.43 | 14.88 |
| Piping network | 60% | 14.90 | 24.81 |
| **Ratio of Overall Unit Cost** | | | **5:1** |

Clearly, the most expensive energy in the system is at the point of end use; this is where the greatest opportunity exists to impact the overall energy efficiency of the system and hence the cost of operation.

Saving small amounts of energy in the piping network in this simple chilled water pumping system will result in significant savings – about five times more – at the point of purchase.

### 8.2.5 | Cost Considerations

Energy consumption can be reduced in two general ways:

- changing the **operation** of the existing systems and equipment
- changing the system or equipment **technology**

Operational actions tend to cost less to implement; they are referred to as **low-cost** or **housekeeping measures**.

In contrast, measures that require investment in new technology will tend to cost more to implement. These actions are often referred to as **retrofit measures**.

The sequence of actions in this assessment is important. It does not make sense to install a new technology without clearly defining the requirement and properly sizing the equipment to meet that requirement. Similarly, the return on investment for a piece of energy-efficient equipment will depend on its operating times; any action that changes operating times must be considered first.

There is a range in cost when implementing energy-saving actions. A quadrant analysis considers two distinct action/cost categories:

- **Lower cost** – actions that could be funded from operational/expense budgets and tend to result from **operational actions**
- **Higher cost** – actions that may require capital funding and tend to involve the installation of equipment or new **technology**

The Waste-Loss Analysis combines these categories of actions into a table with four quadrants as numbered below. Examples given in the table are for a lighting system.

| Action/Cost | Lower Cost | | Higher Cost | |
|---|---|---|---|---|
| Match the Need | 1. | Turn off the lights | 2. | Install motion sensors |
| Maximize Efficiency | 3. | Lower wattage of lamps with lighter wall colours | 4. | Install new lamps/ballasts and fixtures |

Typically, actions that fall into the fourth quadrant have the highest cost; those in the first quadrant have the lowest. The relative cost of the second and third quadrants will vary depending on the specific actions and equipment.

A general form of the Waste-Loss Analysis table is presented below. In this case, actions have been generalized into broader categories that may exist in any energy-consuming system.

| Action/Cost | Lower Cost (often operational) | | Higher Cost (often technological) | |
|---|---|---|---|---|
| Match the Need | 1. | Manual control of time and quantity | 2. | Automatic control of time and quantity |
| Maximize Efficiency | 3. | Maintenance and operating conditions | 4. | New and more efficient devices and equipment |

## 8.3 Special Considerations for Process Systems

There is significant energy savings potential in actions that deal with operations and technology. Often, in the search for savings, much emphasis is placed on technological actions such as equipment retrofits and upgrades; however, many high-potential/low-cost operational opportunities are overlooked.

Industrial energy use can be broken down into plant and process use. **Plant** use includes the supporting equipment and systems that supply the **process** equipment.

Many other types of systems may be present to provide for the energy needs of the process systems:

- combustion systems
- steam and hot water boilers and distribution
- compressed air
- lighting
- refrigeration
- pumps and fans (fluid movement)

Applying the three-step critical assessment process requires us to determine how closely the process needs are being met. Then we can consider the energy use in the system designed to meet the requirement. To analyse the requirement, we must take a more in-depth look at the internal workings of the process.

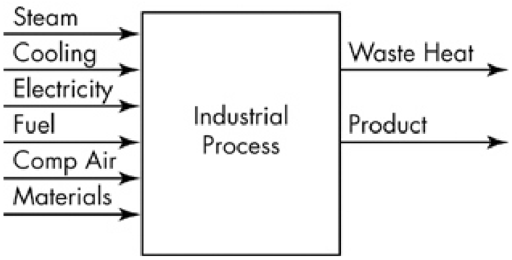
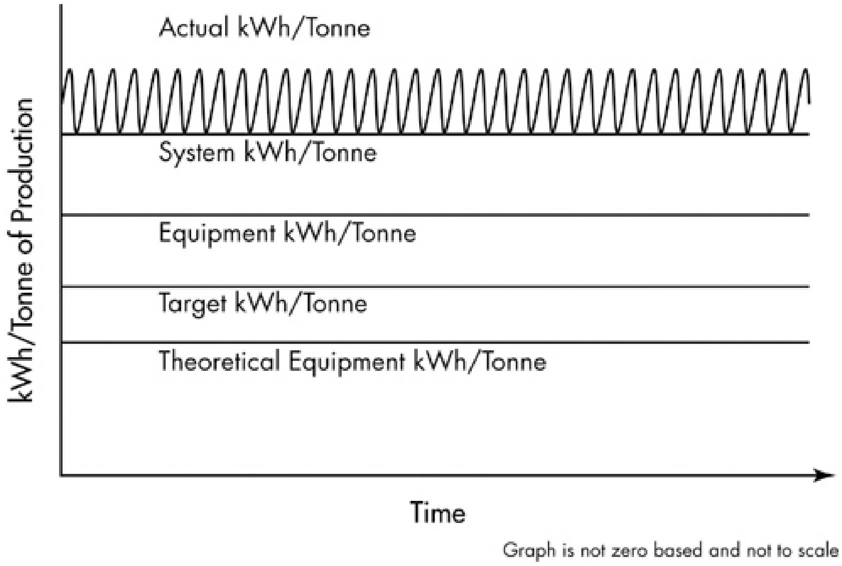



Figure 8.2 shows an example of the breakdown of process energy use in terms of the kilowatt-hours per tonne (kWh/tonne) ratio.

**Figure 8.2 Process Energy Use**



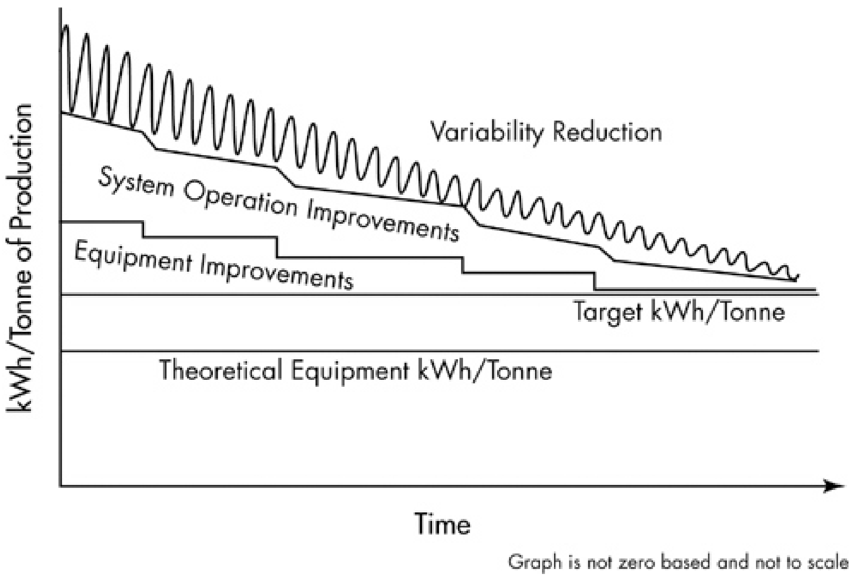

- **Equipment kWh/tonne** is defined as the energy required when the optimum amount of equipment is operating at design efficiency.
- **System kWh/tonne** is defined as the energy required when the operator and machine influences are included – this takes into account operational techniques and maintenance practices.
- **Actual kWh/tonne** is the energy use, taking into account any responses of the operators and supervisors to variations and external influences and the time lag in responding.

The differences between the various levels identified in Figure 8.2 represents potential for reduced energy use. Although it may not be possible to achieve a theoretical consumption level for a real process, a realistic target can be set. An energy audit or assessment on each process area would examine each of these levels and associated factors that influence consumption.

Every manufacturing or industrial process presents opportunities for energy management. However, for the unwary, energy management also has the potential to create operational problems. The best way to avoid these problems is to involve operating staff in an auditing or assessment process.

The audit or assessment outcome will often include a set of actions that are operational and technological. Operational actions typically address variability and system consumption levels; technological actions reduce equipment consumption levels. It is expected that over time, as actions are implemented, various consumption levels will drop and actual consumption will approach the target level for the process (see Figure 8.3).

**Figure 8.3 Consumption Levels**



## 8.4 Summary

TIP: **First match the need – then maximize efficiency of delivery.**

The method presented above is a means of looking at each of the energy-consuming systems in your facility and identifying savings opportunities. The steps in the method are as follows:

1. Verify/validate energy need/requirement.
2. Conduct waste-loss analysis.
3. Optimize energy supply.

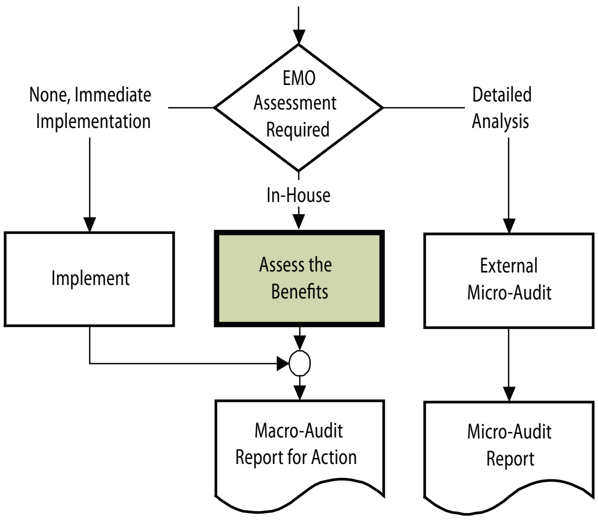
Electrical and thermal inventories can provide valuable insight into finding savings opportunities and determining their extent. In Section C-2, "Details of Energy-Consuming Systems," typical systems in facilities are examined in terms of where energy losses occur and what can be done to minimize them. A Sankey diagram (as described in Section B-7) is provided for each system, followed by an application of the three-step method described in this section.

## 8.5 References

*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001
Web site: iac.rutgers.edu/manual_industrial.php

*Energy Efficiency Planning and Management Guide*, Natural Resources Canada, 2002
Web site: oee.nrcan.gc.ca/publications/infosource/pub/cipec/efficiency/index.cfm?attr=24

# 9 ASSESS THE COSTS AND BENEFITS




## 9.1 Introduction

Having identified a "shopping basket" of EMOs, the auditor should also provide guidance on the feasibility of measures and recommendations for implementation. Assessing proposed measures primarily involves cost/benefit analysis.

Although detailed economic analysis may go beyond the parameters of the audit, the auditor should nevertheless know the following:

- what benefits should be taken into account
- what costs should be included in the analysis
- what economic indicators provide a realistic projection of the financial viability of a proposed measure over time

## 9.2 A Comprehensive Assessment

A comprehensive assessment of the benefits and cost associated with an energy savings opportunity extends well beyond the cost of the energy involved and in many cases may involve the following.

**Benefits**

- direct energy savings
- indirect energy savings
- comfort/productivity increases
- operating and maintenance cost reductions
- environmental impact reduction

**Costs**

- direct implementation costs
- direct energy costs
- indirect energy costs
- operating and maintenance (O&M) cost increases

These issues are explored in the following sections.

### 9.2.1 | Assessing Disadvantages Associated With Savings

Assessment of savings opportunities generally involves cost/benefit analysis. First, what are the savings (and other benefits) associated with the opportunity? Second, what will the EMO cost to implement? Depending on the type of economic analysis used, consideration may also be given to the cost of maintenance, with and without implementation of the EMO.

One factor often overlooked is the indirect costs of the proposed action. These can include such things as reduced illumination levels and increased heating costs when lighting is reduced, since energy for light contributes to a building's heat in the winter. An extreme indirect cost could be reduced personal productivity because of unexpected reductions in light levels or a safety problem created by an improperly located motion detector that switches lights off when a space is still occupied. It may become apparent that what seems to be the most attractive savings opportunity is in fact not so desirable when all impacts are considered.

Often these costs are declared as unforeseen. A thorough assessment should anticipate most of them and clearly identify the associated risks before any changes are implemented.

Another consideration often neglected is the technical and economic risk associated with the planned implementation. Savings are not always guaranteed: for example, it is unlikely that a motion detector installed to switch lighting in a heavy traffic area will pay back its cost. Replacing a poorly loaded motor with an energy-efficient one may result in lower overall efficiency because of its partial load characteristics. When the savings predicted depend on varying operating conditions or occupant habits, there is a risk that the savings expected might not be realized or be lower than predicted.

In such cases, the indirect costs are, in fact, uncertain savings. A conservative assessment would be based only on savings that are certain to be realized. If the uncertain savings do occur, this is a bonus.

In summary, consider the direct costs and the impact that the planned implementation will have on occupants, comfort, productivity, safety and equipment maintenance. Also consider any potential interactions between the new equipment and existing systems and the likelihood that the expected savings will be realized.

### 9.2.2 | Savings

Depending on the energy source, there are three types of savings to be realized directly from a savings opportunity:

- Energy savings – These would simply be equal to the energy saved (e.g. kWh) × the incremental energy rate (e.g. $/kWh – usually the last energy rate)
- Demand savings – If the step implemented has a measurable effect on the peak demand, the demand saving would be

  ***kW or kVA saved × the incremental demand rate ($/kW or kVA)***

- Block size savings (only certain rates) – If there is a peak demand reduction, there may also be a reduction in the first energy block size (assuming the rate is a multi-block type). Effectively, this moves some of the energy from the more expensive first block to the less expensive second block. The savings would be

  ***kW or kVA saved × 100 × (first block energy rate – second block energy rate)***

In addition to the direct electrical savings calculated for the measure itself, there may be other considerations:

- Thermal fuel savings – The thermal energy saved at the point of use must be "grossed up" by the efficiency of the heating before the incremental cost of fuel or thermal energy can be applied:

  ***Fuel energy saved = Point of use energy saved ÷ Heating plant efficiency***
  ***Fuel cost saved = Fuel energy saved × Incremental cost of fuel ÷ Energy content of fuel***

- Indirect electrical savings such as reduced air-conditioning (A/C) loads due to more efficient or switched lighting. A/C savings can be calculated as

  ***A/C kWh saved = Lighting kWh saved ÷ COP***

  where COP (coefficient of performance) for a typical central A/C unit would be 3. A/C kWh saved would, of course, apply only to the periods when the A/C is operating.
- Less re-lamping labour and lamp cost from switching to a longer-life lamp type (replacing incandescent lamps with compact fluorescent lamps offers a tenfold increase in lamp life).
- Increase in employee productivity from converting to a higher-quality, higher-efficiency fixture type.

### 9.2.3 | Costs

When evaluating the cost of implementing a measure, be sure to include all costs, including the following:

- Initial cost of implementing the retrofit (quotes by contractors).
- Decrease in lamp life resulting in increased re-lamping costs, e.g. switching from mercury vapour lamps, which have a life of 24 000 hours, to metal halide lamps, which last 20 000 hours.
- Decrease in lamp life due to increase in switching, e.g. a standard 40-W rapid-start fluorescent tube operated for 10 hours per start will last 28 000 hours. The same tube operated for only 3 hours per start will last 20 000 hours.
- Any increase in maintenance costs, such as higher-cost lamps and ballasts, higher cost of repairs or lower life of any replacement energy-efficient equipment.
- Increase in heating costs due to more efficient or switched lighting (assuming heat from lights ends up as useful space heat). This heating increase can be calculated as

$$\text{Heating Increase (kWh)} = \frac{\text{Lighting kWh Saved}}{\text{Heating System Efficiency}}$$

Again, the kWh used for lighting saved would apply only to periods when the heating system is operated. The heating system efficiency could typically range from 0.75 (oil) to 0.85 (gas or propane) to 1 (resistive electric) to 3 (i.e. the COP of a heat pump).

A comprehensive example of savings analysis is provided in Figure 9.1, taken from the "Assess the Benefit.xls" spreadsheet template. This example details two EMOs that are commonly found in compressed-air systems. The savings analysis takes into account the fact that the first EMO will affect the savings of the second. By improving the controls on the compressor, the savings for heat recovery will be reduced.

**Figure 9.1 Savings Analysis Spreadsheet (from Assess the Benefit.xls)**

## EMO Cost Savings Analysis

**#1 Compressor Control & Heat Recovery**

**Existing Conditions**

Presently there are three 50 HP packaged air compressors supplying air to the main plant and process areas. These compressors are operating under individual control with cascaded pressure settings. During the audit it was observed that two compressors often operate when one unit can meet the demand for air. The 3rd unit is backup. The heat from the air cooled compressors is currently exhausted from the compressor room year round.

**Proposed Conditions**

Install a sequencing controller to dispatch the 3 compressors, in sequence upon demand for air, indicated by a pressure sensor in the air main to the plant. It is expected that this will result in only one air compressor operating at full load, while the second compressor will only operate during peak air demand periods, estimated to be less that 10% of the time. Second, install a simple system of ductwork and dampers to direct the heat compressor cooling air into the plant during the heating season or exhaust outside during non-heating periods.

**Expected Energy & Cost Savings**

**Electricity**

Reduce the use of the second compressor at a measured load of 30 kW for 5000 hours per year

| | | | |
|---|---|---|---|
| Demand Savings | kW | | |
| Energy Savings | 150 000 kWh | ( 30 kW for 5000 hours/year ) | |
| Incremental Cost of Electrical Energy | | $0.07 /kWh | |
| Incremental Cost of Electrical Demand | | $8.20 /kW | |
| **Annual Electricity Cost Savings** | | **$10 500 /year** | |
| GHG Factor for Electricity .... in: | | Ontario | 0.276 eq kg $CO_2$ per kWh |
| **Greenhouse Gas Reduction** | | | **41 400 eq kg $CO_2$** |

**Natural Gas**

The remaining compressor heat will contribute at least 40 kW to space heat for 6 heating months per year

| | | |
|---|---|---|
| Reduced Heating Load | 176 000 kWh | (40 kW for 4400 hours/year) |
| Heating System Efficiency | 75% | |
| Reduction in Fuel Energy | 234 667 kWh | |
| Fuel Type (units) | Natural Gas $m^3$ | |
| Energy Content of Natural Gas | 10.6 kWh/$m^3$ | |
| Incremental Cost of Natural Gas | 0.25 /$m^3$ | |
| Saved | 22 081 $m^3$ | |
| **Annual Gas Cost Savings** | **$5 520 /year** | |
| GHG Factor for Natural Gas | 1.9 eq kg $CO_2$ per $m^3$ | |
| Greenhouse Gas Reduction | **41 953 eq kg $CO_2$** | |

| | |
|---|---|
| **Total Cost Savings** | **$16 020 /year** |
| **Total GHG Reduction** | **83 353 eq kg $CO_2$ per year** |

The following worked example shows that even a simple EMO such as controlling (i.e. turning off) lights must be analysed carefully. In this example, the energy saved is no longer available for building heating, and this will increase heating costs and offset some savings.

**Lighting Savings Example**

**Electricity Savings**

| | | |
|---|---|---|
| Lighting kWh saved (heating season) | = | 20 000 kWh/yr. |
| Incremental cost of electricity | = | $0.06/kWh |
| Electricity cost saving (20 000 × 0.06) | = | $1,200/yr. |

**Adjustment for Heating Increase**

| | | |
|---|---|---|
| Heating system efficiency (No. 2 oil) | = | 0.75 |
| No. 2 oil energy content | = | 10.5 kWh/litre |
| No. 2 oil cost | = | $0.25/litre |
| Heating kWh increase (20 000/0.75) | = | 26 667 kWh |
| No. 2 oil increase (26 667/10.5) | = | 2 540 litres |
| $ heating increase (2 540 × 0.25) | = | $635/yr. |
| **Net Savings (1200 – 635)** | **=** | **$565 (47% of non-adjusted)** |

## 9.3 Economic Analysis

### 9.3.1 | Simple Payback

For the most part, a simple payback evaluation in the form

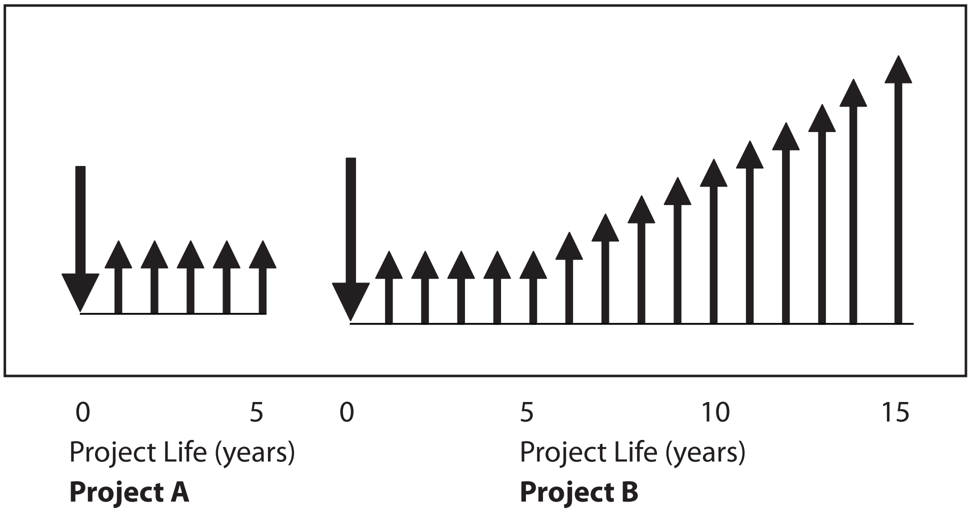
$$\mathit{SPP\ (years)} = \frac{\mathit{Capital\ Cost}}{\mathit{Annual\ Savings}}$$

is adequate as a “first cut” assessment of the feasibility of a retrofit measure. Simple payback would not normally be used as the basis for investment decisions, for two good reasons:

- It does not take into account the cost of money, which may be an important concern.
- It does not take into account anything that happens after the payback period. For example, a project could pay back its cost in one year but fail to continue to achieve the savings accrued in that first year; the payback period would be an attractive one year, but a more detailed analysis would show that it is not a good investment.

Figure 9.2 illustrates this point by comparing two cash flow scenarios for the same initial cost. Clearly, Project B is the more attractive investment because of its total return over time, even if the initial cost is recovered in the same period for Project A.

**Figure 9.2 Comparison of Cash Flows**




The cash flow diagram shown in Figure 9.2 is a simple but very useful tool for financial analysis. It shows, for example, that an investment may have a five-year payback, as in Project A, but if the life of the investment is 15 years in total, as in Project B, it may have a significant internal rate of return. This point is captured in Table 9.2.

The diagram is a graphical representation of

- the time line, typically in years
- costs incurred, including the initial capital investment, as well as subsequent costs related to the project (maintenance expenditures, for example) – shown as downward-pointing arrows
- positive cash flow, such as savings, shown as upward-pointing arrows

The same information can be presented more quantitatively in tabular form, as the following example illustrates. A new boiler is to be installed at a total cost of $100,000, payable in two instalments. Expected savings in total are $48,000 per year, with half of that amount accruing in the first year and the full amount accruing in all subsequent years.

**Table 9.1 Cash Flow Table for Purchase of New Boiler**

| Capital Expenditure: $100,000<br>Expected Savings: $48,000 | 90% on delivery/commissioning and 10% performance guarantee due at one year<br>Half in first year, full amount in all remaining years | | | | | |
|---|---|---|---|---|---|---|
| **(Values in $000)** | | | | | | |
| **Year** | **0** | **1** | **2** | **3** | **4** | **5** |
| Costs | (90.0) | (10.0) | .0 | .0 | .0 | .0 |
| Savings | .0 | 24.0 | 48.0 | 48.0 | 48.0 | 48.0 |
| Net Cash Flow | (90.0) | 14.0 | 48.0 | 48.0 | 48.0 | 48.0 |
| Net Project Value | (90.0) | (76.0) | (28.0) | 20.0 | 68.0 | 116.0 |

For this table, in addition to calculating the net cash flow each year (i.e. the savings less the costs for that year), we have calculated the cumulative net cash flow, or net project value.

A quick calculation – dividing $100,000 by $48,000 – shows that the simple payback period is between two and three years. More importantly, the analysis shows that the value of the investment continues to grow with each subsequent year of savings. The table can also accommodate other costs referred to in the cash flow diagram, so that a considerably more complex analysis can be made.

### 9.3.2 | Return on Investment (ROI)

Return on investment (ROI) is a broad indicator of the annual return expected from the initial capital investment, expressed as a percentage:

$$ROI = \frac{\text{Annual Net Cash Flow}}{\text{Capital Cost}} \times 100\ \%$$

The ROI must always be higher than the cost of money and, in comparison with other projects, a greater ROI indicates a better investment. Once again, however, ROI does not take into account the time value of money or a variable annual net cash flow.

Another way of looking at ROI over the life of a project is represented by the following equation:

$$ROI = \frac{\text{Total Energy Savings (For Life of Project)} - \text{Estimated Project Cost}}{\text{Estimated Project Cost}} \times \frac{100\ \%}{\text{Project Life}}$$

However, a life-cycle costing or complex payback calculation may be required, especially for larger investments. The complex payback would take into account the time value of money and possible changes in cost and savings amounts over the life of the measure.

A life-cycle costing analysis determines the net cost/savings of a particular measure, considering all costs and savings over the life of the measure. Simply put,

*Net Costs/Savings = Cost Savings – Cost of Capital + Net O&M Cost Reduction**

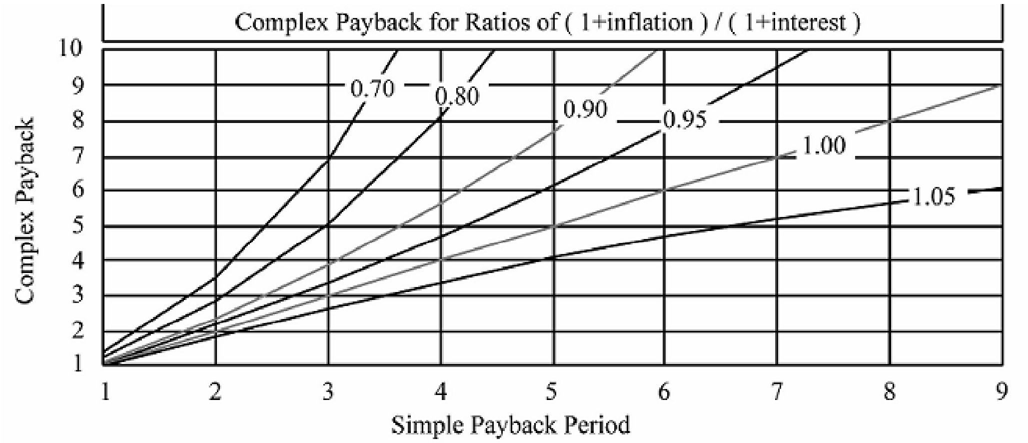
*(summed for the life of the particular measure taken)

More details on the calculation of life-cycle costing parameters – net present value (NPV) and internal rate of return (IRR) – are provided in Section 9.3.4.

### 9.3.3 | Simple Versus Complex Payback

The following graph provides a simple means of adjusting the simple payback period to take into account the cost of capital (the interest rate) and the escalation of energy prices (the inflation rate). The result is approximate to the result of a life-cycle cost analysis, sometimes called the complex payback period.

**Figure 9.3 Simple Versus Complex Payback**




**Simple Payback Versus IRR**

Simple payback may not be the best indicator of the real value of a project. Table 9.2 relates the simple payback of a savings project to the internal rate of return (IRR) that the net savings stream represents.

This chart answers the following question:

If I have a project with a simple payback of *y* years and a project life of *x* years, approximately what IRR does this represent?

Table 9.2 Internal Rate of Return Estimation Chart

| Simple Payback (years) | Project Life or Time Horizon (years) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **10** | **15** |
| 1 | 0% | 62% | 84% | 93% | 97% | 100% | 100% |
| 2 | | 0% | 23% | 35% | 41% | 49% | 50% |
| 3 | | | 0% | 13% | 20% | 31% | 33% |
| 4 | | | | 0% | 8% | 21% | 24% |
| 5 | | | | | 0% | 15% | 18% |
| 6 | | | | | | 11% | 15% |
| 7 | | | | | | 7% | 12% |
| 8 | | | | | | 4% | 9% |
| 9 | | | | | | 2% | 7% |
| 10 | | | | | | 0% | 6% |

For example, a heat recovery project that has a simple payback of three years and is expected to deliver savings for 15 years would have an IRR of approximately 33%.

### 9.3.4 | Net Present Value and Internal Rate of Return

The critical factor that is omitted from the simple financial indicators is the **time value of money** – the fact that interest applies to any invested funds. Obviously, $1,000 today is more valuable than $1,000 a year from now because of the interest that the first amount will accumulate over that year.

Therefore, in evaluating energy management investments, we need to consider the **Present Value (PV)** and the **Future Value (FV)** of money. The two are related very simply by the following:

$$FV = PV \times (1+i)^n \quad \text{or} \quad PV = \frac{FV}{(1+i)^n}$$

where

FV = future value of the cash flow

PV = present value of the cash flow

i = interest or discount rate

n = number of years into the future

In NPV and IRR appraisals, instead of calculating the net present value of a project, we need to calculate the discounted net present value to put future savings into present value terms based on the existing interest or discount rate.

Fortunately, in doing so, it is not necessary to calculate the power series in the PV/FV equations directly. Tables of discount factors are commonly available, and spreadsheet applications do the calculation for you.

If we recalculate the example in Table 9.1, now applying discounting to the cash flow, the discounted net cash flow, or the Net Present Value (NPV), of the project is determined as shown in Table 9.3. (Following usual accounting practice, values in parentheses are negative; the normal practice is to indicate costs as negative and benefits such as savings as positive in this kind of analysis.)

**Table 9.3 Net Present Value Calculation**

| Year | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Net cash flow ($000) | (90.0) | 14.0 | 48.0 | 48.0 | 48.0 | 48.0 |
| The discounted cash flow at 10% can be calculated as follows: | | | | | | |
| Year 0 | $1 \times (90.0) = (90.0)$ | | | | | |
| Year 1 | $0.909 \times 14.0 = 12.73$ | | | | | |
| Year 2 | $0.826 \times 48.0 = 39.65$ | | | | | |
| Year 3 | $0.751 \times 48.0 = 36.05$ | | | | | |
| Year 4 | $0.683 \times 48.0 = 32.78$ | | | | | |
| Year 5 | $0.620 \times 48.0 = 29.76$ | | | | | |
| NPV = the sum of all these values = 60.97 (compare with net project value = 116.0) | | | | | | |

The discount rate that is applied in this calculation represents not only the prevailing interest rate but also some factor to cover handling costs of money, often around 5%. In other words, as a matter of policy, an organization may choose to use a discount factor of, say, the national bank interest rate plus 5% (or some other appropriate factor to cover handling and perhaps risk).

If this NPV calculation were repeated for different discount rates, we would find that the higher the discount rate, the lower the NPV, which would eventually become negative. It follows that there is a discount rate for which the NPV = 0; this discount rate is defined as the Internal Rate of Return (IRR). Determining the IRR manually involves an iterative process in which the NPV is calculated for various discount factors, with NPV plotted against discount rate to generate a curve that crosses the x-axis (i.e. at NPV = 0), thereby giving the IRR.

For many organizations, the decision on whether to make a specific investment is based on the IRR compared with company expectations or policy – i.e. if the IRR is equal to or greater than the criterion value, the investment might be considered feasible.

Most spreadsheet programs include NPV and IRR calculations, allowing you to input a range of cash flow values along with the discount factor to be applied, to calculate the NPV and, for a given set of cash flows, to determine the IRR.

### 9.3.5 | Cash Flows

In these examples, there have been only two kinds of cash flow: the initial investment as one or more instalments and the savings arising from the investment. Of course, this oversimplifies the reality of energy management investments.

There are usually other cash flows related to a project. These include the following:

- **Capital costs** are the costs associated with the design, planning, installation and commissioning of the project; these are usually one-time costs unaffected by inflation or discount rate factors, although, as in the example, instalments paid over a period of time will have time costs.
- **Annual cash flows**, such as annual savings accruing from a project, occur each year over the life of the project; these include taxes, insurance, equipment leases, energy costs, servicing, maintenance, operating labour and so on. Increases in any of these costs represent negative cash flows (the downward arrows in Figure 9.2), whereas decreases in the costs represent positive cash flows (upward arrows).

Factors that should be considered in calculating annual cash flows are as follows:

- **Taxes**, using the marginal tax rate applied to positive (i.e. increasing taxes) or negative (i.e. decreasing taxes) cash flows.
- **Asset depreciation**, the depreciation of plant assets over their life. Depreciation is a "paper expense allocation" rather than a real cash flow, and therefore it is not included directly in the life-cycle cost. However, depreciation is "real expense" in terms of tax calculations and therefore does have an impact on the tax calculation noted above. For example, if a $100,000 asset is depreciated at 20% and the marginal tax rate is 40%, the depreciation will be $20,000 and the tax cash flow will be $8,000 – it is this latter amount that will show up in the costing calculation.
- **Intermittent cash flows** occur sporadically rather than annually during the life of the project; relining a boiler once every five years would be an example.

**Example: Simple Payback Calculation for a Lighting Retrofit**

## Given

| | | |
|---|---|---|
| Existing fixtures are 4-tube, 4-foot standard fluorescent fixtures, total load per fixture | = | 192 watts |
| Operating hours | = | 3000 hrs./year |
| Existing lamp cost | = | $2 ea. |
| Existing ballast cost | = | $10 ea. |
| Electricity rates: Demand | = | $7/kW/month |
| Energy | = | $0.08/kWh |

Proposed retrofit involves replacing 4 lamps, 2 ballasts with 2 T-8 lamps and 1 electronic ballast and installing reflectors.

## Retrofit Cost (Per Fixture)

| | | |
|---|---|---|
| T-8 lamps (2 @ $5) | = | $10 |
| Electronic ballast | = | $35 |
| Reflector kit | = | $20 |
| Labour (half-hour @ $30/hr.) | = | $15 |
| **Total** | **=** | **$80** |

## Existing Operating Cost

| | | |
|---|---|---|
| **kWh** 192 W × 1/1000 × 3000 hrs./yr. | = | 576 kWh |
| **kWh $** 576 kWh × $0.08/kWh | = | $46.08 |
| **Demand $** 192 × 1/1000 × 12 mos. × $7 | = | $16.13 |
| **Relamping $** 3 000 hrs./yr./20 000 hrs. × $2/lamp × 4 lamps | = | $1.20 |
| **Reballasting** 3 000 hrs./50 000 hrs. × $10/ballast × 2 ballasts | = | $1.20 |
| **Total Existing Operating Cost** | | **$64.61/yr.** |

## Proposed Operating Cost

| | | |
|---|---|---|
| **kWh** 58 W × 1/1000 × 3000 hrs./yr. | = | 174 kWh |
| **kWh $** 174 kWh × $0.08/kWh | = | $13.92 |
| **Demand $** 58 × 1/1000 × 12 mos. × $7 | = | $4.87 |
| **Re-lamping** 3 000 hrs./yr./20 000 hrs. × $5 × 2 lamps | = | $1.50 |
| **Reballasting** 3 000 hrs./100 000 hrs. × $35 | = | $1.05 |
| **Total Proposed Operating Cost** | | **$21.34/yr.** |
| **SAVINGS** = $64.61 – $21.34 | = | **$43.27/yr.** |
| **PAYBACK** = $80.00/$43.27/yr. | = | **1.85 yrs.** |

Figure 9.4 illustrates a complete life-cycle cost analysis of the savings from an EMO. In the example, three variations on the analysis are used to assess the benefit for an optimistic, pessimistic and expected (base) financial case.

**Figure 9.4 EMO Life-Cycle Cost Analysis Spreadsheet (from Assess the Benefit.xls)**

EMO Life-Cycle Cash Flow Analysis — Base Financial Case

EMO Life-Cycle Cash Flow Analysis — Pessimistic Case

EMO Life-Cycle Cash Flow Analysis — Optimistic Case

| Costs for Period | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $50,000 | | | | | | | | | | |
| Maintenance | $200 | $204 | $208 | $212 | $216 | $221 | $225 | $230 | $234 | $239 | $244 |
| Asset depreciation | | | | | | | | | | | |
| Lease costs | | | | | | | | | | | |
| Taxes | | | | | | | | | | | |
| Insurance | | | | | | | | | | | |
| Labour | | | | | | | | | | | |
| Other | | | | | | | | | | | |
| **Sub-total Costs** | **$50,200** | **$204** | **$208** | **$212** | **$216** | **$221** | **$225** | **$230** | **$234** | **$239** | **$244** |
| **Savings for Period** | | | | | | | | | | | |
| Electricity | $10,500 | $10,710 | $10,924 | $11,143 | $11,366 | $11,593 | $11,825 | $12,061 | $12,302 | $12,548 | $12,799 |
| Gas or Fuel | $5,535 | $5,646 | $5,759 | $5,874 | $5,991 | $6,111 | $6,233 | $6,358 | $6,485 | $6,615 | $6,747 |
| Water | | | | | | | | | | | |
| Maintenance | | | | | | | | | | | |
| Taxes | | | | | | | | | | | |
| Insurance | | | | | | | | | | | |
| Labour | | | | | | | | | | | |
| GHG Factors | | | | | | | | | | | |
| Sub-total Savings | $16,035 | $16,356 | $16,683 | $17,016 | $17,357 | $17,704 | $18,058 | $18,419 | $18,788 | $19,163 | $19,547 |
| Net Cash Flow | ($34,165) | $16,152 | $16,475 | $16,804 | $17,140 | $17,483 | $17,833 | $18,189 | $18,553 | $18,924 | $19,303 |
| **Net Project Value** | **($34,165)** | **($18,013)** | **($1,539)** | **$15,266** | **$32,406** | **$49,889** | **$67,722** | **$85,911** | **$104,465** | **$123,389** | **$142,692** |
| **Discount Rate** | 15.00% | | | | | | | | | | |
| **Discounted Cash Flow** | ($34,165) | $14,045 | $12,457 | $11,049 | $9,800 | $8,692 | $7,710 | $6,838 | $6,065 | $5,379 | $4,771 |

**Net Present Value (NPV) : $52,642** **Internal Rate of Return (IRR) : 48%**

Notes:
Electricity and natural gas savings and maintenance costs are adjusted for inflation at a rate of 2% per year.

## 9.4 Environmental Impact

Measures to improve energy efficiency will reduce greenhouse gas (GHG) emissions in two ways:

- Energy efficiency measures for on-site combustion systems such as boilers, furnaces or ovens will reduce GHG emissions in direct proportion to the fuel savings. These are called **direct** impacts.
- Reduced electrical consumption will lead to GHG emissions reductions at the electric power generating station. These are called **indirect** impacts.

Although the following examples may appear to be of rather limited application, the method used to calculate emissions reductions can be applied to any energy management project that results in fuel or electricity consumption reductions.

Figure 9.5, from the "Assess the Benefit.xls" spreadsheet, shows the factors required for calculating indirect and direct GHG emissions reductions.

These factors have been used to estimate GHG emissions reductions in the comprehensive example in Figure 9.1. Reductions in emissions due to electricity and natural gas savings are calculated.

**Figure 9.5 GHG Factors Spreadsheet (from Assess the Benefit.xls)**

**Greenhouse Gas Factors** Menu

**Emission Factors for "Indirect Emissions" (Electricity)**

| | kg $CO_2$ eq/kWh | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Province/Territory** | **1990** | **2000** | **2002** | **2003** | **2004** | **2005** | **2006** | **2007** | **2008**(1) |
| Alberta | 0.98 | 0.93 | 0.89 | 0.96 | 0.89 | 0.87 | 0.88 | 0.86 | 0.88 |
| British Columbia | 0.02 | 0.03 | 0..01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 |
| Manitoba | 0.03 | 0.03 | 0.02 | 0.04 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| New Brunswick | 0.37 | 0.46 | 0.51 | 0.45 | 0.48 | 0.46 | 0.39 | 0.42 | 0.46 |
| Newfoundland and Labrador | 0.04 | 0.02 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 | 0.03 | 0.02 |
| NWT / Nunavut, Yukon | 0.27 | 0.15 | 0.11 | 0.11 | 0.11 | 0.08 | 0.08 | 0.07 | 0.06 |
| Nova Scotia | 0.75 | 0.76 | 0.59 | 0.67 | 0.79 | 0.75 | 0.76 | 0.74 | 0.79 |
| Ontario | 0.21 | 0.28 | 0.26 | 0.27 | 0.2 | 0.21 | 0.18 | 0.2 | 0.17 |
| Prince Edward Island | 1.26 | 1.15 | 0.75 | 0.68 | 0.38 | 0.26 | 0.2 | N/A | N/A |
| Quebec | 0.012 | 0.002 | 0.002 | 0.01 | 0.009 | 0.003 | 0.004 | 12 | 0.002 |
| Saskatchewan | 0.78 | 0.85 | 0.87 | 0.84 | 0.88 | 0.79 | 0.76 | 0.77 | 0.71 |

**Notes:** N/A: Not Available
(1) Data for 2008 is preliminary in National Inventory Report 1990-2008
**Source:** Environment Canada's National Inventory Report 1990-2008 - Greenhouse Gas Sources and Sinks in Canada;
Annex 13: Electricity Intensity Tables

**Emission Factors for Selected Thermal Fuels**

| Fuel Type | Factor eq kg $CO_2$ per unit (1) | Unit of Measure | MJ per Unit (2) |
|---|---|---|---|
| Natural Gas | 1.9 | $m^3$ | 38.26 |
| #2 Oil | 2.69 | litres | 38.55 |
| #6 Oil | 3.12 | litres | 42.5 |
| Propane | 1.51 | litres | 25.31 |

**Notes:** Fuel type #2 Oil factors are the average of Light Fuel and Diesel
**Sources:** (1) Environment Canada's National Inventory Report 1990-2008 - Greenhouse Gas Sources and Sinks in Canada;
Annex 8: Emission factors
(2) Statistics Canada - Catalogue no. 57-003, Text table 1 - Energy Conversion Factors

## 9.5 Summary

The benefits that may be derived from energy management projects are clearly comprehensive. So, too, must be the approach to assessment, whether it involves identifying opportunities or, as outlined in this section, quantifying the benefits.

## 9.6 References

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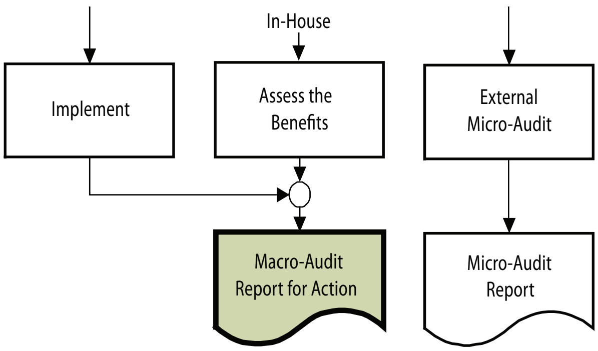
# 10 REPORT FOR ACTION




## 10.1 Introduction

Regardless of how thoroughly and carefully you conduct the energy audit or how beneficial the proposed EMOs are, nothing will be achieved unless action is taken to achieve them. The step between the audit and action is the audit report.

Too often, audit reports gather dust on the shelf. The goals of the audit report should be to provide a clear account of the facts upon which your recommendations are made and to interest readers in acting on those recommendations.

A "sales job" may need to be done on the audit's findings, and the audit report is your vehicle for making the sale.

Some principles of good technical writing are outlined below. A good audit report uses language that is concise, accurate and appropriate for the target readership. This section offers suggestions on how to ensure that your audit report leads to action.

## 10.2 Some General Principles for Good Audit Report Writing

### 10.2.1 | Know Your Reader

There may be several people in your organization who will read your report, including the CEO or plant manager, the supervisor of engineering or maintenance, and the heating plant shift supervisor. Their information needs may be quite different, so be sure to consider all needs when writing. Include an **executive summary** that gives the highlights for senior decision-makers and a **technical section** that provides details for those who will be involved in implementing your recommendations.

### 10.2.2 | Use Simple, Direct Language

Some of your readers may be professional engineers or advanced degree-holders; others may have hands-on experience as qualified trades people. The language you use must be clear, concise and understandable by all readers:

- Use the active voice rather than the passive: "We found that the insulation on the steam mains was badly degraded . . ." is better than "It was found that the insulation . . . "
- Avoid technical jargon. We have used the term "energy management opportunity (EMO)" in this guide; if you use this term in your report, make sure to define it the first time you use it. Where possible, use commonly understood terms rather than technical ones and spell out terms that you might normally express as abbreviations (e.g. "variable frequency drive" instead of "VFD" at first mention).

- Ensure that your report is grammatically correct and that the language flows easily. You may find it helpful to have someone whom you regard as a good communicator to critique your report before it is distributed.

### 10.2.3 | Present Information Graphically

The tone of any technical report tends to be dry. Use graphics such as photos and pie charts to complement or replace data tables, diagrams and schematics – to give your report and its recommendations visual appeal. Widely available software applications can generate graphs and charts that can be easily incorporated into your report.

### 10.2.4 | Make Your Recommendations Clear

The core of your report is your recommendations section. Leave no room for questions in your readers' minds about exactly what you are recommending: be specific, clear and sufficiently detailed. For example, the recommendation "Decommission one 75-hp compressor" doesn't tell the whole story if what you really mean is the following: "Reduce the compressed air load through a leak detection and repair program; upgrade compressor controls; deliver base load with existing 100-hp compressor and peak load with existing 50-hp unit; decommission 75-hp compressor."

### 10.2.5 Explain Your Assumptions

Since you will have to make assumptions in your calculations, be sure to explain them clearly. For example, if a manufacturing unit normally operates on the basis of one shift per day, five days a week and 50 weeks per year, state this information to explain why you are using 2000 hours per year as the time factor in your energy consumption calculations. If it turns out that the plant is going to change to two-shift operation, it will be easier for the reader to adjust your calculations.

### 10.2.6 | Be Accurate and Consistent

Obviously, you want your calculations to be accurate; errors will destroy the report's credibility. In addition,

- be consistent in the style and terminology you use
- be consistent when expressing units of measure (for example, avoid using $m^3$ of gas in one place and therms or Btus in another)
- proofread and spell-check your report and have someone help with subsequent proofreading

### 10.2.7 | Present Your Calculations Clearly

Some of your readers may have a technical background, and they may want to check the accuracy of your assumptions and calculations. Therefore, you should present your calculation methodology clearly, along with at least one sample of each kind of calculation.

## 10.3 A Template for the Audit Report

### 10.3.1 | Executive Summary

Some readers, especially senior decision-makers, will want to know what the report's key recommendations and bottom-line implications are without having to read the whole report. The executive summary should include the following:

**TIP:** To make the Executive Summary stand out from the rest of the report, you may want to print it on coloured paper.

- **summary information on key audit findings** – annual consumption and/or energy budget, key performance indicators, etc.
- **recommended EMOs**, with a brief explanation of each – it may be useful to categorize these as operations and maintenance (O&M) improvements, process improvements and building system improvements
- **implementation costs, savings and payback periods** (or other financial criteria used in your organization, such as the Internal Rate of Return associated with each EMO)
- any special information related to the implementation of EMOs

### 10.3.2 | Technical Section

The  technical section of the report contains details on your audit findings. The following should be included as subsections.

***Audit Mandate, Scope and Methodology***

The audit mandate, scope and methodology should include

- a statement of the mandate, i.e. the goals and objectives of the audit
- a description of the audit scope in terms of the facilities and processes covered
- the methods used for information gathering and analysis
- the key sources of information (people), etc.

***Facility Description and Observations***

The description and observations of the facility should include

- a general description of the facility or the parts of it covered in the audit (size, purpose, configuration, etc.)
- observations on the general condition of the facility (from the Condition Survey)
- detailed cost and consumption information for electricity and fuels
- summary demand information
- summary load inventory data

***Assumptions and Calculations***

The report should give samples of all calculations made so that assumptions, such as operating hours and key tariff features, are clear.

***Audit Recommendations***

The recommendations should include detailed descriptions of the EMOs, their cost, their impact on energy consumption and savings, and a payback analysis. The recommendations may also include potential EMOs that have been considered but found not to be cost-effective.

***Appendix***

The appendix to the report includes background that is essential for understanding the calculations and recommendations. It can include

- data tables
- reference graphs used in calculations, such as motor efficiency curves
- electricity and fuel tariffs

# C

# TECHNICAL SUPPLEMENT


# 1 ENERGY FUNDAMENTALS

## 1.1 Introduction

The ultimate purpose of an energy audit is to identify opportunities to reduce energy consumption and/or energy costs incurred in the operation of a facility. Needless to say, the auditor must be conversant with the principles of energy and its use in its diverse forms by the wide variety of energy-consuming systems in an industrial facility.

This section reviews the basic principles of electrical and thermal energy and is intended to provide a working knowledge – or perhaps a refresher – of the principles required to understand the information gathered in an audit.

The energy consumed in industrial, commercial and institutional facilities takes many forms. Typically, a facility will purchase an energy source such as fuel oil to generate heat for a variety of purposes. In most cases, electricity will be purchased for use in lighting, motors, directly for a process and, in some cases, as a source of heat. The term "thermal energy" refers to all energy forms involving heat, typically derived from gas, oil, propane or sometimes electricity. The processes by which thermal and electrical energy are purchased and consumed differ somewhat. A basic model for each is outlined in the sections that follow, along with a simple process for analysing energy use and identifying savings opportunities.

## 1.2 Energy and Its Various Forms

Energy is very simply defined as the ability to do work. Although "work" has a special technical definition, it can be thought of as the ability to do something useful. This might be to move a car along the road, light a light bulb, drive a pump, heat an oven, or cool a room with an air conditioner.

Energy can take many different forms and do many different types of work. One very important law of nature, which guides the process of energy management, is that energy cannot be created or destroyed, only converted from one form to another. The forms of energy discussed in this guide include chemical energy, thermal energy, mechanical energy and electrical energy.

### 1.2.1 | Chemical Energy

Chemical energy is the energy that helps to "glue" atoms together in clusters called molecules, or chemical compounds. Of special interest to us are substances such as natural gas, propane and oil that are capable of releasing some of that energy. When we burn these fuels, we unglue some of the atoms from each other, liberating the chemically bound energy that held them together. In the process, the chemical energy is changed to high-temperature heat energy, a form well suited to doing many different kinds of work. This process takes place every time we flick a butane lighter.

### 1.2.2 | Thermal Energy

Thermal energy is created by the microscopic movement of atoms and molecules in everything around us. Thermal energy is often commonly referred to as heat. In fact, there are two types of thermal energy.

> **"Sensible" energy**, or sensible heat, is energy that jostles molecules and atoms in substances such as water. The more movement, the hotter the substance becomes. Sensible energy gets its name from the fact that we can sense it by touching the substance directly or indirectly with a thermometer.

When we add heat to water in a kettle, we increase its temperature.

> **"Latent" energy**, or latent heat, is the energy that is needed to make a substance such as water (a liquid) change to a different form of the same substance such as water vapour (a gas). The change of form happens when enough sensible heat is added and the molecules move too fast to be connected together and eventually separate. It gets its name from the fact that it lies hidden, or latent, until the conditions are suitable for it to emerge.

If enough heat is added to liquid water at 100°C, it eventually boils and becomes a vapour (gas). If enough heat is removed from liquid water at 0°C, it eventually turns into a solid (ice). Heat will naturally flow from higher to lower temperatures.

Thermal energy may move in many different ways, between many different substances, and change back and forth between its sensible and latent forms. Much of the information in this guide focuses on understanding and managing the movement and transformations of every form of energy.

### 1.2.3 | Mechanical Energy

Mechanical energy is the energy of physical movement, such as moving air or water, a ball being thrown or a person sanding a piece of wood. As with many forms of energy, mechanical energy eventually ends up being released or lost as thermal energy. For example, sandpaper applied to wood converts mechanical energy to heat.

### 1.2.4 | Electrical Energy

Electrical energy involves the movement of electric current through wires. Electrical energy is very useful because it can perform many functions. Ultimately, most electrical energy or electricity also ends up as thermal energy in the form of sensible heat. Some devices, such as electric heaters, convert the energy directly; other devices, such as motors, convert electricity to mechanical energy that eventually becomes heat. The trick to optimizing electricity use is to maximize the amount of work done by electricity before it is lost as heat. Typically, this also involves optimizing the use of mechanical energy.

## 1.3 Electricity: From Purchase to End-Use

Electricity provides a method of moving energy from one point to another. Some energy will be lost in the process since the method used for transmitting it is not perfect. Ultimately, the electrical energy will arrive at a point of use where it will perform a useful action. To understand how to reduce the amount of electricity that is purchased, it is useful to trace the flow of energy from the point of purchase to the point of use.

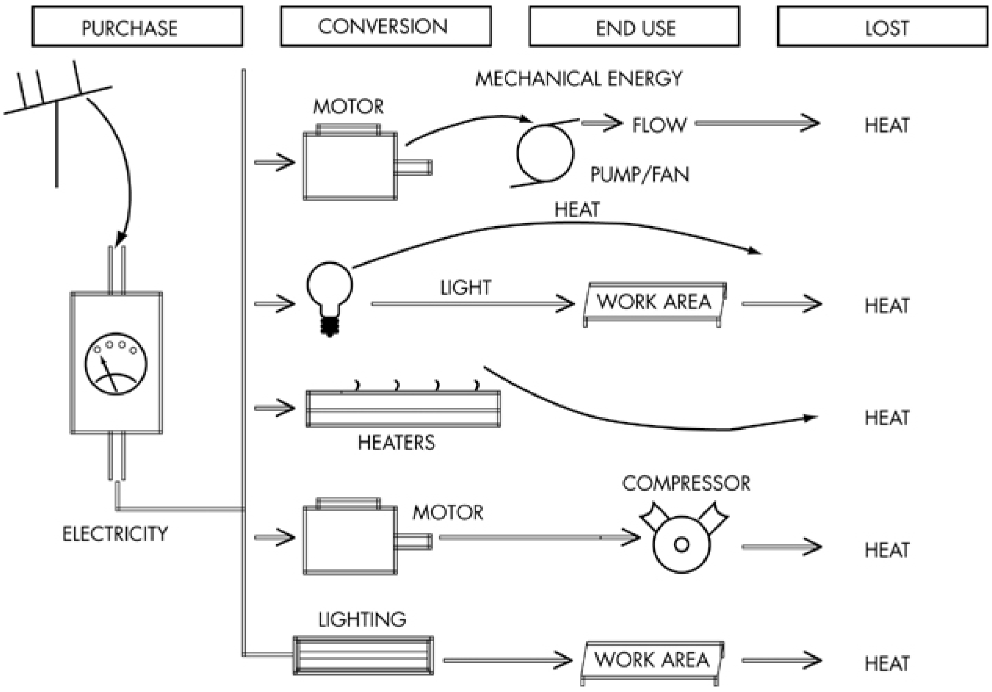
Once past the utility meter, electricity is directed by a facility's distribution system to a point of conversion, where it will be converted to another form of energy, such as light, mechanical energy in a motor, heat or possibly sound. In some cases the electricity will be used directly, as for an electric welder, where the flow of electric current heats and melts metal.

Figure 1.1 shows the path of electricity from the utility meter to various points of use in a facility. A refrigeration system converts the energy twice – from electrical to mechanical and then to heat – involving a motor and a compressor. Ultimately, all the electrical energy we purchase ends up as heat and is absorbed into the surroundings or vented to the outside.

To minimize the amount of electricity purchased, we must

- ensure that the end-use serves a useful purpose
- minimize the amount of energy required at the point of use
- minimize the losses incurred between the meter and the point of use

**Figure 1.1**



## 1.4 Thermal Energy: Purchase to End-Use

The flow of thermal energy from the point of purchase to the point of end-use may be traced in a manner similar to electricity. In an industrial context, a boiler may convert purchased natural gas to steam, which is then used directly in a process and also converted to heat hot water and to heat the building. In a commercial facility, natural gas heats hot water in a boiler for space heat and in a hot water heater for domestic hot water.

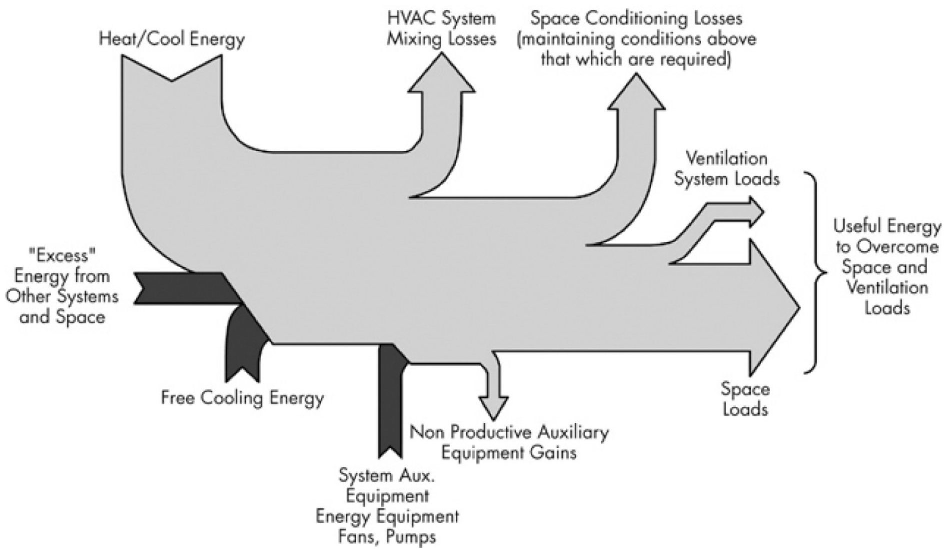
In both instances, significant energy is lost from the boiler (heater) at the point of conversion from fuel to thermal energy. Figure 1.2 provides a simple representation of the numerous losses that the heating and cooling energy required by a heating, ventilating and air-conditioning (HVAC) system sustains beyond the boiler.

**Throughout this guide, the identification of electricity usage will start at the meter and work toward the end-use, while the identification and assessment of electricity savings opportunities always start at the point of end-use and work back toward the meter.**

Again, in an approach similar to that for electricity, reducing the amount of thermal fuel purchased requires us to

- ensure that the end-use serves a useful purpose (e.g. avoid unnecessary air leakage from doors and windows)
- minimize the amount of energy required at the point of use (e.g. utilize temperature setbacks during unoccupied hours)
- minimize the losses incurred between the meter and the point of use (e.g. ensure the HVAC system is efficient)
- minimize the losses as outlined in Figure 1.2
- examine the mechanical system design for meeting the requirements now that they have been rationalized (e.g. is the original system oversized?)

**Figure 1.2 Thermal Energy Losses in a Boiler Plant**



## 1.5 Units of Energy

The basic unit of energy in the SI (metric) system is the joule (J). Energy in the form of electricity is expressed in watt-hours. In the imperial system, the basic unit of energy is the British thermal unit (Btu). The prefix "kilo" indicates 1000 units. Common equivalencies between units are as follows:

| Energy Equivalents | |
|---|---|
| 1000 joules (J) | 1 kilojoule (kJ) |
| 1 Btu | 1055.66 J or 1.056 kJ |
| 1 kilowatt-hour (kWh) | 3 600 000 J or 3.6 MJ |
| 1 kilowatt-hour (kWh) | 3413 Btu |

### 1.5.1 | Power

It is often useful to express the rate of energy flow over time, i.e. how fast energy is being used or transferred. In electrical and mechanical terms, this is the same as referring to power or how fast work is being done. Thermal power is measured in joules per second (J/s). One joule per second is equivalent to one watt. In the imperial system, thermal power is commonly measured in Btu per hour (Btu/hr). Mechanical power is usually measured in kilowatts (kW) in the SI (metric) system and in horsepower (hp) in the imperial system. Following are some useful power unit equivalencies:

| Power (Energy Rate) Equivalents | |
|---|---|
| 1 kilowatt (kW) | 1 kilojoule/second (kJ/s) |
| 1 kilowatt (kW) | 3413 Btu/hour (Btu/hr.) |
| 1 horsepower (hp) | 746 watts (0.746 kW) |
| 1 ton of refrigeration | 12 000 Btu/hr. |

The capacity of a boiler is often rated in a unit of heat-energy production termed a "boiler horsepower," which is equal to 9809.6 watts. This should not be confused with the unit of mechanical power, also called "horsepower."

## 1.6 Electricity Basics

In this section we define the terms used in this guide.

The electrical power or demand used in a circuit depends on two fundamental quantities, voltage and current:

1) Voltage is the magnitude of the push trying to send electrical charge through a wire (similar to pressure in a water distribution system or someone pushing a child on a swing). Voltage is measured in volts.

2) Current is the magnitude of the flow of charge through a wire caused by the push of the voltage (similar to the rate of flow of water through a pipe or the speed of the child being pushed on a swing). Current is measured in amperes (amps).
3) Power is voltage and current acting together to do useful work. Power is measured in watts. The relationship is represented in the following formula:

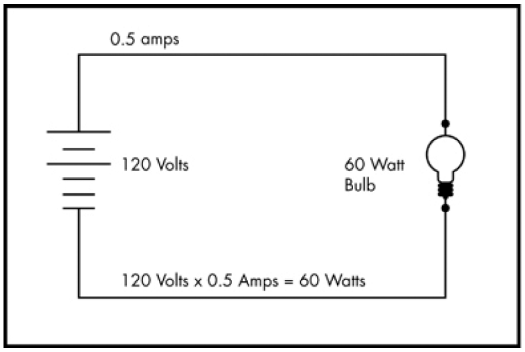
   *Power = Voltage × Current*

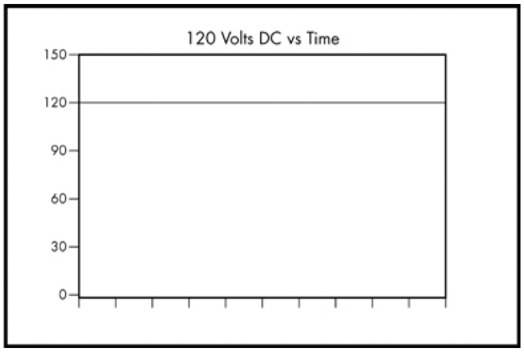
   The units of power are watts:

   *Watts = Volts × Amps*
4) Demand is the rate of use of electrical energy. The term "demand" is essentially the same as electrical power, although demand generally refers to the average power measured over a given time interval.

### 1.6.1 | Alternating Current and Power Factor

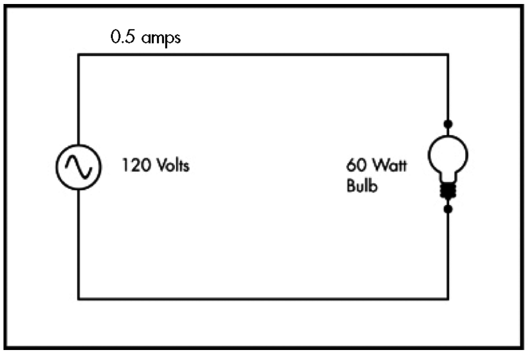
Direct current (DC) is an electric current that always flows in the same direction, as in a car's electrical system:

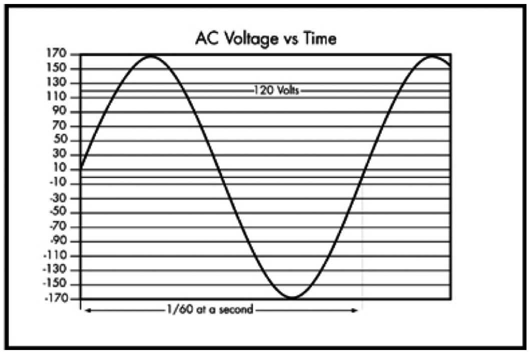



In DC circuits, power is always equal to volts multiplied by amps, because the voltage (push) and current (flow) always work together.

Alternating current (AC), as its name implies, changes direction, reversing its flow on a regular basis (switching from push to pull). AC is used by utilities to transmit and distribute electricity because it is safer and easier to control. The typical household voltage goes through a complete cycle 60 times per second, known as 60 Hertz (Hz). When it does this, it swings from +170 volts to –170 volts. This results in an average voltage of 120 volts:



In AC circuits, the current and voltage do not always work together. How well they work together is represented by the power factor (PF), a number from 0 to 1 or from 0% to 100%. Using the analogy of a person pushing a child on a swing, if the push occurs at the very top of the swing cycle, maximum benefit of the push (100% PF) is obtained. If the push is started at a point lower than the top of the cycle, some of the push is lost, and the power factor is less than 100%.

### 1.6.2 | Things That Affect Power Factor

Electric heaters and incandescent lamps are called "resistive loads." These loads do not reduce power factor. They allow the voltage and current to work together (100% PF).

Motors, transformers and loads with coils are called "inductive loads." These cause the current to slow down. The power factor can range from 0% to 100%.

The effect of inductive loads is counteracted by that of capacitive loads by means of devices called capacitors, which consist of wires or metal plates separated by an insulating material to slow down the voltage. The power factor can range from 100% to 0%.

Since capacitive and inductive loads counter each other, this leads us to a technique called power factor correction, which involves adding capacitors to a circuit to move its power factor closer to 100%.

Over-excited synchronous motors, which are typically found in large systems, behave electrically like capacitors and thus can also be used to correct power factor.

### 1.6.3 | The Basic Arithmetic for Power Factor

The relationships between power, current, voltage and power factor in AC circuits can be summed up by these equations:

$$\textit{Kilowatts (kW)} = \frac{\textit{Volts} \times \textit{Amps} \times \textit{Power Factor}}{1000}$$

If we ignore the effect of power factor and simply multiply the voltage by the current in an AC circuit, the result is called voltamps, or, in multiples of 1000, kilovoltamps:

$$\textit{Kilovoltamps (kVA)} = \frac{\textit{Volts} \times \textit{Amps}}{1000}$$

We can therefore conclude that the kilowatts and the kilovoltamps are related by the power factor:

$$\textit{kW} = \textit{kVA} \times \textit{Power Factor}$$

And finally, if we know both the kilowatts and the kilovoltamps, we can calculate the power factor:

$$\textit{Power Factor} = \frac{\textit{kW}}{\textit{kVA}}$$

**It is important to note that kVA will either equal kW (in the case of a purely resistive load) or be greater than kW (in the presence of inductive loads, i.e. motors and transformers). When metered in kVA (rather than kW), the difference will cost you money. Therefore, controlling the power factor will bring the kVA closer to the kW and save you money.**

Note the use of the prefix “kilo,” meaning “thousands of.” It is the most common multiple used to express power quantities. (At the utility level, it is also common to use “mega,” meaning “millions of.”)

### 1.6.4 | Electrical Energy

In the previous section, we discussed electric power. When power is consumed for any period of time, energy is used. Energy consumption is the total amount of electricity consumed over time and is measured in **kilowatt-hours (kWh)**.

*Energy = average demand × time*

Kilowatt-hours are the units of energy:

*Kilowatt-hours = kilowatts × hours*

### 1.6.5 | Demand and Energy: How Fast and How Much?

The term “demand” generally refers to the average value of power measured over a given time interval (typically, a given load will register 99% of its instantaneous measurement after 30 minutes). The maximum (or peak) demand is the maximum demand (in kW) measured by the utility meter during a billing period.

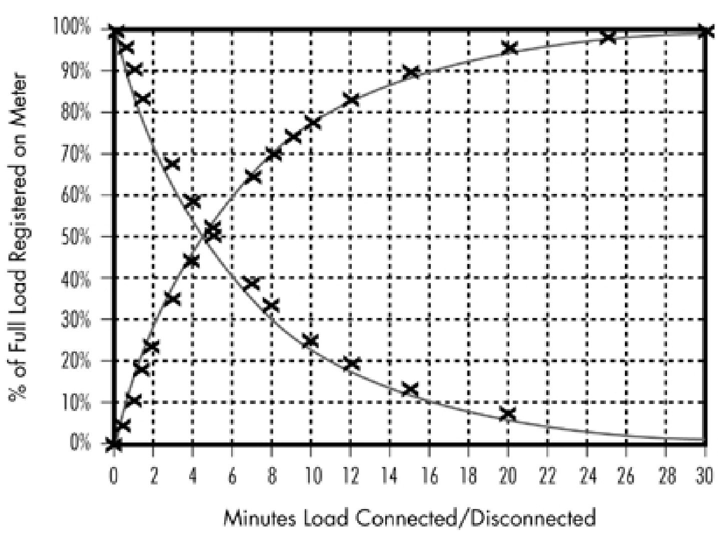
Energy (kWh) is the product of power over time and the sum of all the instantaneous power measurements during a period (i.e. how much electricity was used).

These two quantities – maximum demand and energy – are measured by your electric meter and are used to determine the amount of your monthly electric bill.

#### 1.6.5.1 Average Versus Instantaneous Demand

When a load is applied to a utility demand meter, the demand pointer does not indicate the magnitude of the load immediately. The demand pointer slowly rises until it is at 99% of the applied load, typically after 30 minutes, as illustrated by the graph in Figure 1.3.

**Figure 1.3**



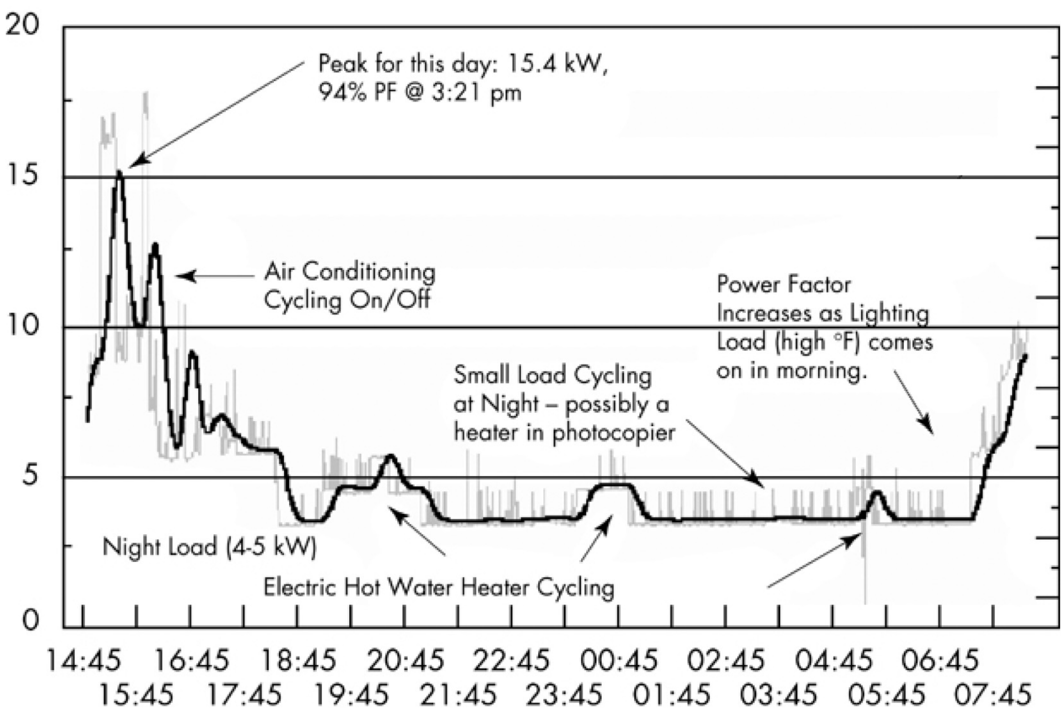
This results in a smoothing of the meter response to applied loads over time as well as a time lag between when a load switches on and when it fully registers on the meter, as shown in Figure 1.4.

The thick line represents the response of the demand meter, and the thin line represents the actual applied load over time. The implications of this response lag are as follows:

- High, short duration loads (e.g. large motor start-up currents) will not register fully on the meter.
- Conversely, when a large load is shut off after operating for at least 30 minutes, the metered demand does not drop off right away.

Keep these points in mind when considering opportunities for demand reduction.

**Figure 1.4**




### 1.6.5.2 Time-of-Use Metering

New technologies in electricity metering give electric utilities an opportunity to measure and record energy consumption as a function of time. This enables the utility to measure not only how much energy was consumed but also when the energy was consumed during the billing period. A time-of-use (TOU) meter measures and records electrical usage during pre-specified periods of the day, accumulating daily periods over a billing period (e.g. one month). These meters also calculate average power consumption (average demand) as a function of time. Time-of-use rates are a direct result of this technology.

Electric utilities calculate maximum demand by one or more of the following methods of calculating average demand with a time-of-use meter:

- 15-minute average demand
- 60-minute sliding window and rolling averages

The 15-minute average demand is calculated by multiplying the average energy consumed in each 15-minute interval by 4 (4 × 15-minute intervals per hour).

One facility, for example, consumed 1000 kWh over a two-hour period:

| | 15-minute interval (no.) | Energy consumed during the 15-minute interval (kWh) | Average Demand (15-minute interval kWh × 4 = average kW) |
|---|---|---|---|
| 2 Hours | 1 | 60 | 60 × 4 = 240 |
| | 2 | 140 | 140 × 4 = 560 |
| | 3 | 200 | 200 × 4 = 800 |
| | 4 | 300 | 300 × 4 = 1200 |
| | 5 | 160 | 160 × 4 = 640 |
| | 6 | 100 | 100 × 4 = 400 |
| | 7 | 80 | 80 × 4 = 320 |
| | 8 | 20 | 20 × 4 = 80 |

The maximum 15-minute average demand was 1200 kW and occurred during the fourth interval.

Most utilities superimpose a sliding window on the 15-minute averages. Typically, this is a 60-minute sliding window. Each 15-minute average demand is then averaged with the previous three values to obtain a rolling average. If we reuse the example above, the maximum recorded demand values change to the following:

| 15-minute interval (no.) | 15-minute Average Demand (kW) | 60-minute Rolled Average (kW) |
|---|---|---|
| 1 | 240 | – |
| 2 | 560 | – |
| 3 | 800 | – |
| 4 | 1200 | (240 + 560 + 800 + 1200)/4 = 700 |
| 5 | 640 | (560 + 800 + 1200 + 640)/4 = 800 |
| 6 | 400 | (800 + 1200 + 640 + 400)/4 = 760 |
| 7 | 320 | (1200 + 640 + 400 + 320)/4 = 640 |
| 8 | 80 | (640 + 400 + 320 + 80)/4 = 360 |

To the customer's benefit, the maximum demand has been reduced to 800 kW. It appears to have occurred during the fifth interval. For the 60-minute rolled average to be equal to the maximum 15-minute demand, the maximum 15-minute demand must be maintained for four consecutive intervals (one hour). Unfortunately, the opposite holds true as well: if a facility shifts electrical demand into off-peak hours, you may need to start the demand reduction at a point up to 75 minutes before the start of the on-peak period.

The previous examples used 15 minutes for the interval averaging and 60 minutes for the rolling average. Since different averaging periods may be used by your utility, always confirm these details with your utility representative.

The application of time-of-use metering can have both positive and negative effects on existing demand management strategies. Prudence is required when conducting a comparative analysis of conventional and TOU rates. The relevant information lies in a facility's electrical demand profile, load inventory and load flexibility.

#### 1.6.5.3 Interval Metering

Interval meters, like time-of-use meters, measure energy consumption vs. time, but instead of accumulating in TOU periods, each value is stored separately. This gives a more accurate picture of a facility's energy-use patterns. Utilities use interval metering for real-time pricing rate structures.

## 1.7 Thermal Basics

Thermal energy is stored and transferred in a variety of ways in industrial and commercial facilities. This section provides an introduction to the basic concepts.

### 1.7.1 | Temperature and Pressure

Temperature and pressure are measures of the physical condition or state of a substance. Typically, they are closely related to the energy contained in the substance. As a result, measurements of temperature and pressure provide a means of determining energy content.

#### 1.7.1.1 Temperature

The temperature of a substance is a measure of the amount of energy involved in the movement of the molecules and atoms. Temperature is a measure of the sensible heat of a substance. On the Celsius scale, the freezing point of water is 0°C and the boiling point of water is 100°C. The Fahrenheit scale is defined in a similar fashion, but with a different pair of reference points (32°F and 212°F, respectively). The relationship between the Celsius and Fahrenheit scales is as follows:

*Degrees C = (degrees F – 32) × 5/9*

Temperature may be measured in many different ways. A mercury or alcohol thermometer (in which a fluid expands as it warms) is the most common. Other devices, such as a thermocouple, produce an electrical voltage that is proportional to the temperature or change their electric resistance with temperature. Others rely on the expansion of fluids or the expansion of solid materials in an observable manner.

#### 1.7.1.2 Pressure

Pressure is the push exerted by a substance upon its surroundings. Air molecules move because of their energy. We can increase the amount of molecular movement by adding sensible energy or heat to a gas. When we heat a gas in a confined space, we increase its pressure. For example, heating the air inside a balloon will cause the balloon to stretch as the pressure increases.

The principle of pressure is useful because it provides a method of storing thermal energy in a substance by confining the substance and then adding energy. High-pressure steam allows us to store much more energy than steam at low pressures. Pressure can be stated as pressure relative to the prevailing atmospheric pressure. This is the gauge pressure that would be indicated on a pressure gauge. Pressure can also be stated as absolute pressure, i.e. the gauge pressure plus the prevailing atmospheric pressure.

***Absolute pressure = Gauge pressure + Prevailing atmospheric pressure***

Units of measure of pressure:

***SI (metric): kilopascals (kPa)***

***Imperial: pounds per square inch (psi)***

### 1.7.2 | Heat Capacity

In many everyday situations, we move thermal energy from one place to another by simply heating a substance and then moving it. A good example is a hot water heating system in a home or office building. Heat is moved from the boiler to the room radiator by heating water in the boiler and then pumping it to the radiator, where it heats the room. Water is frequently used because it has a good capacity to hold heat.

The heat capacity of a substance can be calculated by adding a known amount of sensible thermal energy to a known mass of substance and then measuring its rise in temperature. The heat capacity of a substance is specified as the amount of heat required to raise 1 kilogram of the substance by 1°C.

The units of measure are kilojoules per kilogram per degree Celsius. Heat capacity per unit of mass is referred to as “specific heat capacity” or simply “specific heat.” Specific heats for common substances are listed below.

| Substance | Specific Heat Capacity |
|---|---|
| Water | 4.2 kJ/(kg/°C) |
| Ice | 2.04 kJ/(kg/°C) |
| Aluminum | 0.912 kJ/(kg/°C) |
| Brick | 0.8 kJ/(kg/°C) |

Usually, the heat capacity of a substance is known, but not the amount of heat it contains or how much heat is required to raise its temperature by a certain amount. The following formula can be used to calculate these figures (units are shown in parentheses):

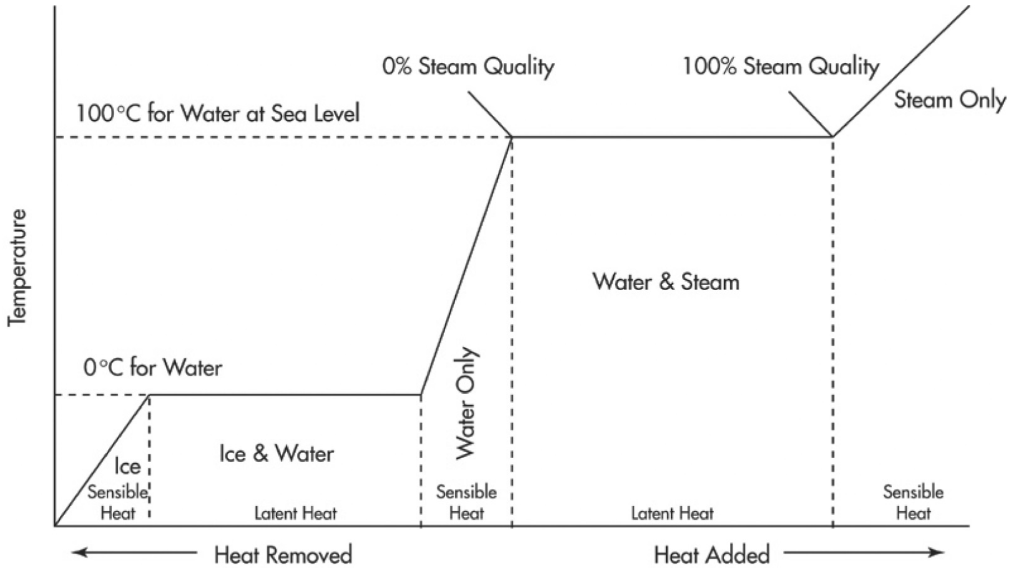
*Heat (kJ) = Mass (kg) × Heat Capacity (kJ/kg/°C) × Temperature Change (°C)*

**or**

$Q = M \times C \times (T_2 - T_1)$

This is a useful formula for energy management. Thermal energy is often transferred via the flow of water, air or other fluid. This formula, or one based on it, can be used to calculate the energy flow associated with this mass flow.

**Figure 1.5**




### 1.7.3 | Sensible and Latent Heat: A Closer Look

It is impossible to add unlimited sensible heat to a substance. If enough heat is added to any given substance, a point is reached when the form of the substance changes. In other words, at a certain temperature, the movement of the molecules that make up the substance becomes so great that the form of the substance changes. This is what happens when ice is heated: eventually it melts and becomes water. At 100°C, water becomes water vapour. Figure 1.6 illustrates this: as heat is added, the temperature of the ice increases according to its capacity to hold heat. At 0°C, the temperature stops rising, but heat is still being added. Eventually, all the ice turns to water and the temperature starts to rise again. The heat added to melt the ice is called the latent heat of melting or fusion, as this is the amount of heat that must be added to a substance to convert it to a liquid.

As more heat is added, the temperature of the water rises. As a result, the sensible heat in the water increases. Eventually, the water cannot hold any more sensible heat, and the temperature once again reaches a plateau. Now water is being converted to water vapour. Heat is added and absorbed until all the water becomes a vapour. The total amount of heat absorbed and hidden in the vapour on this plateau is called the latent heat of vaporization. Finally, when enough heat is added and all the water is converted to vapour, the water vapour begins to absorb sensible heat, and its temperature starts to rise again.

The ability of the ice (solid), water (liquid) or vapour (gas) to absorb heat is called its heat capacity. This determines the slope of the temperature line for the temperature change portions of the chart. The more heat the substance can absorb, the less pronounced the slope. The less heat it can absorb, the faster its temperature rises and the greater the slope.

The amount of heat that lies latent or hidden in the liquid or vapour is indicated by the length of the plateau sections. The longer the plateau, the more heat is absorbed, resulting in a greater amount of latent heat. From this we can observe that latent heat stored in water vapour is much greater than that in liquid water. Because it holds a lot of energy, steam is useful for thermal energy systems. The latent heat of vaporization is 2256.9 kJ/kg at 100°C and 101.325 kPa absolute pressure.

#### 1.7.3.1 Evaporation

Evaporation is the process through which a substance in its liquid form changes to a vapour or gas. This is achieved by adding heat as described above.

#### 1.7.3.2 Condensation

Condensation is the process through which a substance in its gaseous state changes state into a liquid form. This is achieved by cooling the substance. When the change of state occurs, the latent or hidden heat is released.

#### 1.7.3.3 Steam

The term "steam" often refers to a mixture of water and vapour. Strictly speaking, "dry" steam is water vapour only; "wet" steam is a mixture of vapour and fine liquid droplets. At the beginning of the vaporization plateau, there is 0% vapour and 100% water. At the end of the plateau, there is 100% vapour and 0% water. In the middle, there is 50% vapour and 50% water. The water in the middle may be in the form of very small droplets, just like fog. Sometimes people will refer to the quality of steam from 0% to 100%. This refers to the amount of vapour in the steam.

Steam's many properties have been extensively studied and tabulated. Steam tables provide values for the energy content of steam under various conditions. The latent heat of vaporization is 2256.9 kJ/kg at 100°C and 101.325 kPa absolute pressure. These values are used to estimate energy losses due to steam leaks.

Typical units related to steam measurement are as follows:

| | |
|---|---|
| *Conditions* | *temperature (°C) and pressure (kPa)* |
| *Mass* | *kilograms (kg)* |
| *Mass flow* | *kilograms per hour (kg/h)* |
| *Energy content* | *kilojoules per kilogram (kJ/kg)* |

#### 1.7.3.4 Moist Air and Humidity

Another very common form of latent heat in facility systems is latent heat contained in moist air. When it rains or it is very foggy, there is moisture in the air. In fact, when it rains, the moisture in the air has just changed from a vapour to a liquid. The dew on the grass in the morning has formed because of the same process – condensation.

The fact that air is moist has two important implications for the heating and cooling of air:

- Air that is moist has a greater heat capacity; thus, if we are going to heat it, we will need more heat.
- If we lower the temperature of the air, a temperature may be reached at which the water vapour turns to liquid, releasing its latent energy and making it more difficult to cool the air. Condensation makes it harder for an air conditioner to cool air, for instance. Similarly, heating moist air requires more energy than heating dry air.

The amount of moisture or water vapour contained in air is measured by what we call relative humidity (RH), a percentage from 0% to 100%. We use the term "relative" because it refers to how much vapour is present compared with the maximum amount that the air would hold at a given temperature. Relative humidity is always associated with a temperature as measured by a dry sensing element. For example, it is customary to state that the relative humidity is 65% at 20°C dry bulb.

A **psychrometer** is used to measure the relative humidity by comparing the temperatures sensed by a dry bulb and one completely enclosed by a saturated wick. At 100% RH, both bulbs should read the same temperature.

The properties of moist air have been studied and tabulated on a psychrometric chart.

Measures and units of humidity are as follows:

| | |
|---|---|
| *Humidity factor* | *grams of water per kilogram of dry air (g/kg)* |
| *Relative humidity* | *percentage (%) at temperature (°C)* |

### 1.7.4 | The Importance and Usefulness of Thermal Energy

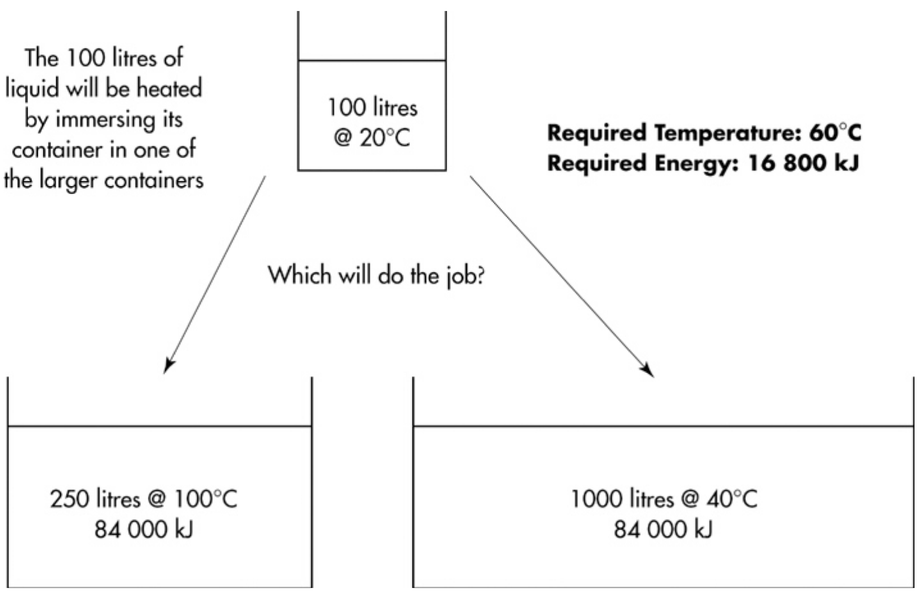
Given our original definition of energy as the ability to do work, we can say that thermal energy is useful if it can do some thermal work for us. Some simple forms of useful thermal work are the following:

- heating a tank of cold liquid with an electric heater
- heating a vat of chemicals with steam to sustain a chemical reaction
- heating a building in winter with a hot radiator
- evaporating water from milk with a steam coil

All these processes have one thing in common: heat is being added through the use of a device or fluid that is "hotter" or at a higher temperature than the original substance. So, in very simple terms, we could associate the ability to do useful work with an increased temperature.

Consider the question posed by Figure 1.6. We want to heat 100 litres of water from 20°C to 60°C by immersing the 100-litre container in one of the other containers. Which has the greater ability to do this work for us?

**Figure 1.6**




If the heat capacity of the water is 4.2 kJ/kg, we will need 16 800 kJ of heat. Both containers of water contain the same amount of thermal energy – 84 000 kJ when compared with water at 20°C. Which container should be used?

Can both do the amount of useful work necessary? The answer is no because the larger volume of water will never be able to raise anything above its own temperature of 40°C. The heating source must be hotter than the 60°C we want to achieve. Thus, we must conclude that we need the 250 litres of water at 100°C.

What may be learned from this situation is that the capacity to do work is not related only to the quantity of energy contained in a substance but also to the temperature of that substance. Another way to think about this is that heat and thermal energy will flow only from higher to lower temperatures. Much of thermal energy management is concerned with manipulating temperatures to get the maximum amount of useful work from the thermal energy or heat that we have purchased.

However, this doesn't work in the case of latent energy, where the ability to do some useful work is stored and the temperature may not indicate how much. In fact, this occurs in other situations too. Temperature is not the only measure of the ability to do useful work, but it is a good one for many of our thermal systems. In the case of latent systems, we must remember that if we can convert the latent energy to sensible energy at an elevated temperature, then we can do some useful thermal work.

The important thing to remember about latent energy is that it is the stored or hidden ability to do useful work.

The usefulness of sensible energy is indicated by the temperature of the substance possessing the energy compared with the surrounding temperatures.

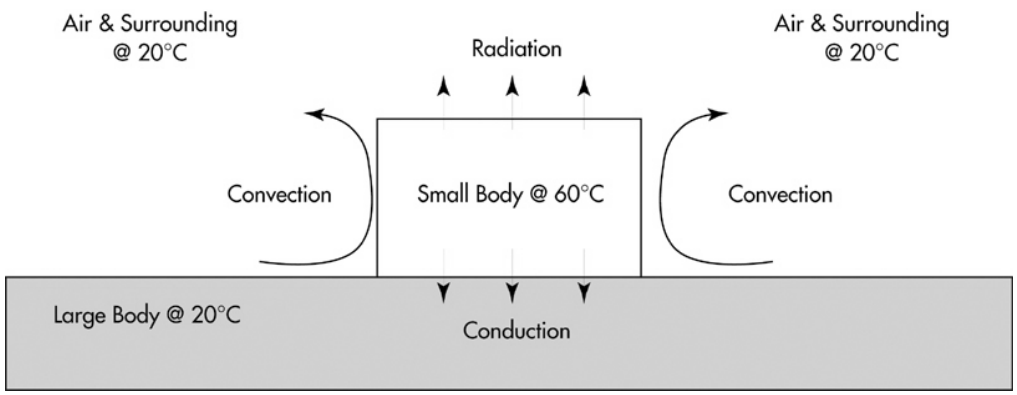
## 1.8 Heat Transfer: How Heat Moves

The transfer of thermal energy or heat is driven by a temperature difference. The rate at which heat moves from a high-temperature body to a body at a lower temperature is determined by the difference in temperatures and the materials through which the heat transfer takes place.

There are only three fundamental processes by which heat transfer takes place. These are conduction, convection and radiation. All heat transfer occurs by at least one of these processes or, more typically, by a combination of these processes. All heat transfer processes are driven by temperature differences and are dependent on the materials or substances used.

Figure 1.7 shows each of these heat transfer processes at work on a block at 60°C, sitting on a cool surface at a temperature of 20°C, surrounded by air at 20°C, and in a room with walls at 20°C.

Figure 1.7




### 1.8.1 | Conduction

The conduction of heat takes place when two bodies are in contact with one another. If one body is at a higher temperature than the other, the motion of the molecules in the hotter body will agitate the molecules at the point of contact in the cooler body and increase its temperature.

In the example shown in Figure 1.7, heat will flow by conduction to the material the block is sitting on until the block and the cool surface reach the same temperature. This means that the block will cool and the surface will warm.

The amount of heat transferred by conduction depends on the temperature difference, the properties of the materials involved, the thickness of the material, the surface contact area and the duration of the transfer.

Good heat conductors are typically dense substances. The molecules are close together, allowing the molecular agitation process to permeate the substance easily. Gases, on the contrary, are poor conductors of heat because their molecules are further apart. Poor conductors of heat are called insulators.

The measure of the ability of a substance to insulate is its thermal resistance. This is commonly referred to as the R-value (RSI in SI). The R-value is generally the inverse of the conductance, or ability to conduct.

Typical units of measure for conductive heat transfer are as follows:

Heat transfer rate

*SI (metric)* *watts (W) or kilowatts (kW)*

*Imperial* *Btu per hour (Btu/hr.)*

Heat transfer rate per unit area (for a given thickness)

*SI (metric)* *watts per square metre ($W/m^2$)*

*Imperial* *Btu per hour per square foot (Btu/hr./sq.ft.)*

### 1.8.2 | Convection

The transfer of heat by convection involves the movement of a fluid such as a gas or liquid. There are two types of convection: natural and forced.

In the case of natural convection, the fluid in contact with or adjacent to a high-temperature body is heated by conduction. As it is heated, it expands, becomes less dense and consequently rises. This begins a fluid motion process in which a circulating current of fluid moves past the heated body, continuously transferring heat away from it. Figure 1.7 illustrates how natural convection takes place on the sides and top of the body.

Natural convection helps to cool your coffee in a mug and bake a cake in an oven.

In the case of forced convection, the movement of the fluid is forced by a fan, pump or other external means. A hot air heating system is a good example of forced convection.

Convection depends on the conductive heat transfer between the hot body and the fluid involved. With a low conductivity fluid such as air, a rough surface can trap air, reducing the conductive heat transfer and consequently reducing the convective currents. Fibreglass wall insulation employs this principle. The fine glass mesh is designed to minimize convection currents in a wall and hence reduce convective heat transfer. Materials with many fine fibres impede convection, while smooth surfaces promote convection.

Forced convection can potentially transfer a much larger amount of heat or heat at a greater rate.

Units of measure for rate of convective heat transfer are as follows:

*SI (metric)* *watts (W) or kilowatts (kW)*

*Imperial* *Btu per hour (Btu/hr.)*

### 1.8.3 | Thermal Radiation

Thermal radiation is a process by which energy is transferred by electromagnetic waves similar to light waves. These waves may be both visible (light) and invisible. A very common example of thermal radiation is a heating element on a stove. When the stove element is first switched on, the radiation is invisible, but you can feel its warmth. As the element heats, it will glow orange, and some of the radiation is now visible. The hotter the element, the brighter it glows and the more radiant energy it emits.

The key processes in the interaction of a substance with thermal radiation are as follows:

- **Absorption** – the process by which radiation enters a body and becomes heat
- **Transmission** – the process by which radiation passes through a body
- **Reflection** – the process by which radiation is neither absorbed nor transmitted through the body; instead, it bounces off

Objects receive thermal radiation when they are struck by electromagnetic waves, which agitates the molecules and atoms. More agitation means more energy and a higher temperature. Energy is transferred to one body from another without contact or a transporting medium such as air or water. In fact, thermal radiation heat transfer is the only form of heat transfer possible in a vacuum.

All bodies emit a certain amount of radiation. The amount depends upon the body's temperature and the nature of the surface. Some bodies, commonly called low-emissivity materials (low-E), emit only a small amount of radiant energy for their temperature. Low-E windows are used to control the heat radiation in and out of buildings. Windows can be designed to reflect, absorb and transmit different parts of the sun's radiant energy.

The condition of a body's surface will determine the amount of thermal radiation that is absorbed, reflected or re-emitted. Surfaces that are black and rough, such as black iron, will absorb and re-emit almost all the energy that strikes them. Polished and smooth surfaces will tend to reflect rather than absorb a large part of the incoming radiant energy.

Typical units of measure for rate of radiative heat transfer are as follows:

| | |
|---|---|
| *SI (metric)* | *watts per square metre (W/m$^2$)* |
| *Imperial* | *Btu per hour per square foot (Btu/hr./sq.ft.)* |

## 1.9 Heat Loss Calculations

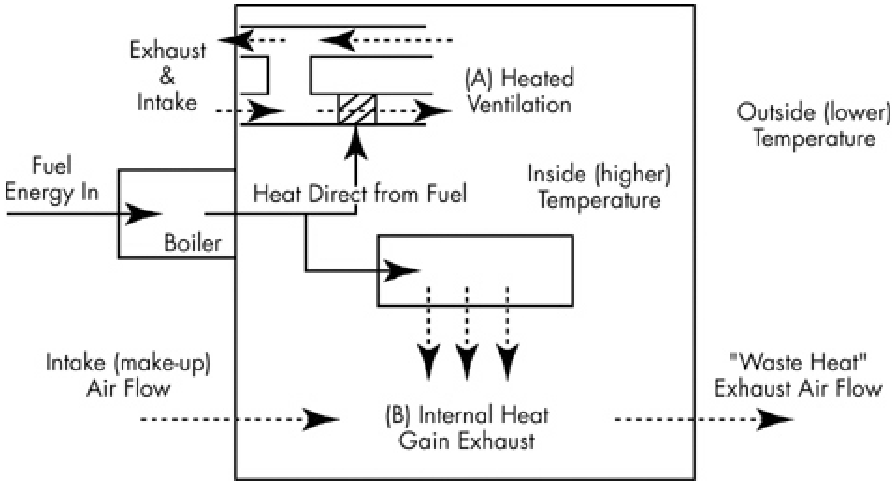
The following sections provide simple methods for estimating the amount of energy involved with each energy flow. The methods are general and may be used to estimate the energy involved in any process of heat transfer – inside, outside, or from the inside to the outside of a facility.

### 1.9.1 | Know the Heat Source

Consider the case of warm air flowing from a building in the winter and its corresponding make-up air intake that may or may not be heated. Two situations could exist, as illustrated in Figure 1.8 and described in the following:

- Ventilation air is drawn in and heated. The exhaust flow is necessary to balance the air pressures and exchange air.
- Cold air is drawn in to carry away excess heat in the building resulting from lights, motors and other internal heat gains. It is sometimes called waste heat. The intake air is not heated directly, or it may be only partially heated.

Figure 1.8

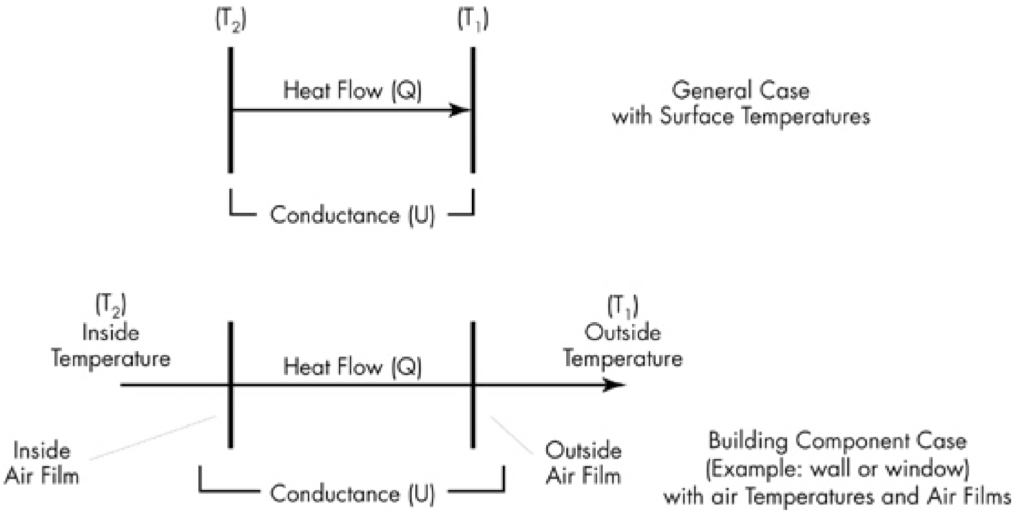



As you identify outflows, determine the source of the heat in the outflow, as this will be important when identifying and estimating savings opportunities.

### 1.9.2 | Conduction

Heat transfer by conduction occurs through the walls, roof and windows of buildings. As illustrated below, heat is transferred or conducted from the warmer side of the material to the cooler side.

Figure 1.9




Note: $T_2 > T_1$ in the above configurations

The nature of the material or materials between the two extremes of temperature determines the conductance. It is common to refer to the insulating value, or R-value, of the material rather than its conductance. In the SI (metric) system, this is called the RSI-value. (Thermal resistance and thermal conductance are related; one is the reciprocal of the other.) Section 1.9.2.1 provides details of the estimation of insulation and conductance values for various materials and structures such as walls, roofs and windows. This estimation method can be used with any flat surface if the two temperatures accurately represent the surface temperature of the material through which the heat is being conducted.

### 1.9.2.1 Determining Conductance

Thermal conductivity is a measure of the ability of a material to conduct heat across a material in the presence of a temperature difference between the two sides of the material. It is customarily expressed as heat flow per unit of material thickness per degree of temperature difference. Units are W/m °C (SI) and Btu/ [ft./hr./°F] (imperial). More commonly, for a given thickness of material, the conductance of the material is specified in heat flow per unit surface area per degree of temperature difference. Units of conductance are W/m$^2$ °C (SI) and Btu/ [sq.ft./hr./°F] (imperial).

| Parameter | Symbol | Unit | Sample | Method of Determination |
|---|---|---|---|---|
| Conductance | U | W/m$^2$/ °C | 0.9 W/m$^2$/°C | See below |
| Surface Area | A | m$^2$ | 100 m$^2$ | Measurement |
| Higher Temperature | $T_2$ | °C | 20°C | Measurement, estimation |
| Lower Temperature | $T_1$ | °C | 5°C | Measurement, estimation |
| Time | T | Hour | n/a | Estimation, calculation |
| Heat Flow | Q | kW | 1.35 kW | See formula below |

The resistance to heat flow per unit of thickness, or per unit area for a specific thickness, is commonly referred to as the “RSI-value” in SI units and the “R-value” in imperial units. The “R” and “RSI” values are the inverse of the conductivity and the conductance respectively. SI units are m °C/W and m$^2$ °C/W respectively. Imperial units are [ft.hr.°F]/Btu and [ft.hr.°F]/Btu respectively. The conductance, conductivity and resistance values for various materials and layers of common materials may be obtained from manufacturers’ literature, which is often available on the Internet. The conductance of an assembly of materials (layers) is often referred to as the transmittance.

### 1.9.2.2 Temperatures

In some circumstances, it is possible to substitute air temperatures for the surface temperatures $T_2$ and $T_1$. This is commonly done in the case of building components such as walls, roofs and windows, where the insulating effect of the air layer adjacent to the inside and outside surfaces is taken into account.

**Equation for rate of heat transfer**

*$Q = U\ A \times (T_2 - T_1)$ in units of watts (W)*

**Total heat transferred**

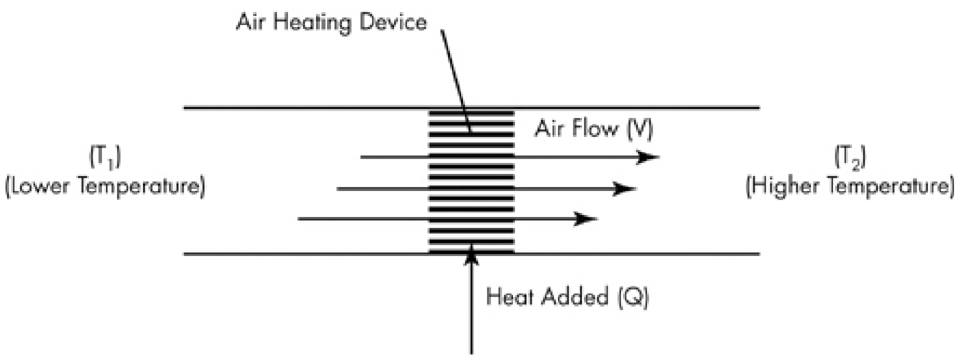
*$Heat = Q \times t/1000$ in units of kilowatt-hours (kWh)*

*$Heat = Q \times t \times 3600$ in units of joules (J)*

**Assumption and Cautions**

- Significant temperature variations over time will reduce accuracy.
- The temperature does not vary across the surface area involved.
- Temperatures used must be surface temperatures if conductance measurements do not include allowance for air films.

### 1.9.3 | Airflow – Sensible Heat




Example Illustrated: heating of cold air required to balance a flow of exhaust air

This type of forced convective energy flow is common in the heated or cooled air streams that provide ventilation and exhaust in industrial buildings. This estimation method considers only the sensible heat in the air and the moisture contained in the air; it does not take into account possible changes in moisture content of the air due to condensation or evaporation. Various facility energy flows are represented:

- Heat loss when warm air flows to a cooler environment. An example would be warm exhaust air in winter.
- Heat required to raise the temperature of cold air entering a warm environment. An example would be cold air intake in the winter.
- The heat gained (and hence requirement for cooling) when warm air is drawn into a cool environment. An example would be warm air intake into an air-conditioned building in the summer.

| Parameter | Symbol | Unit | Sample | Method of Determination |
|---|---|---|---|---|
| Airflow Rate | V | L/s | 1800 L/s | Measurement, estimation |
| Inside/Outside Temperature | $T_2$ | °C | 20°C | Measurement, estimation (see note below)* |
| Outside/Inside Temperature | $T_1$ | °C | 5°C | Measurement, estimation (see note below)* |
| Time | t | Hour | n/a | Estimation, calculation |
| Heat Flow | Q | kW | 33.3 kW | Formula below |

* Note 1: Average value can be calculated for annual periods from degree-days.

**Equation for rate of heat transfer**

$Q = V \times (T_2 - T_1) \times 1.232$ *in units of watts (W)*

**Total heat transferred**

$Heat = Q \times t/1000$ *in units of kilowatt-hours (kWh)*

$Heat = Q \times t \times 3600$ *in units of joules (J)*

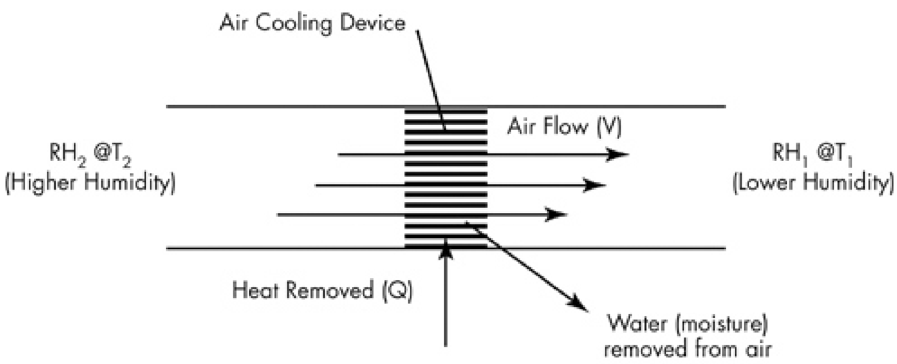
**Assumptions and Cautions**

- The relative humidity of the air involved is 50% at a temperature of 21°C. The constant 1.232 takes these conditions into account.
- This method should not be used for very high-temperature and high-humidity airflows. It is primarily intended for building heating and cooling calculations.
- For any given airflow into a building, there is a balancing outflow by means of a fan system, vents or exfiltration through the structure. The reverse is also true. When conducting an energy outflow inventory, account only for the energy needed to heat the incoming stream or lost in the outgoing stream. Including both would be double accounting.

### 1.9.4 | Airflow – Latent Heat

This type of energy flow is found in heated or cooled moist air streams such as commercial and industrial building ventilation and exhaust systems.

**Figure 1.10**




Example Illustrated: cooling of humid air required to balance a flow of exhaust air

This energy flow accounts for condensation or evaporation that may take place as a result of temperature and humidity changes associated with the airflow. It does not take into account the sensible heat involved in the airflow. Depending on the humidity difference, two types of facility energy flows are represented by the following situations:

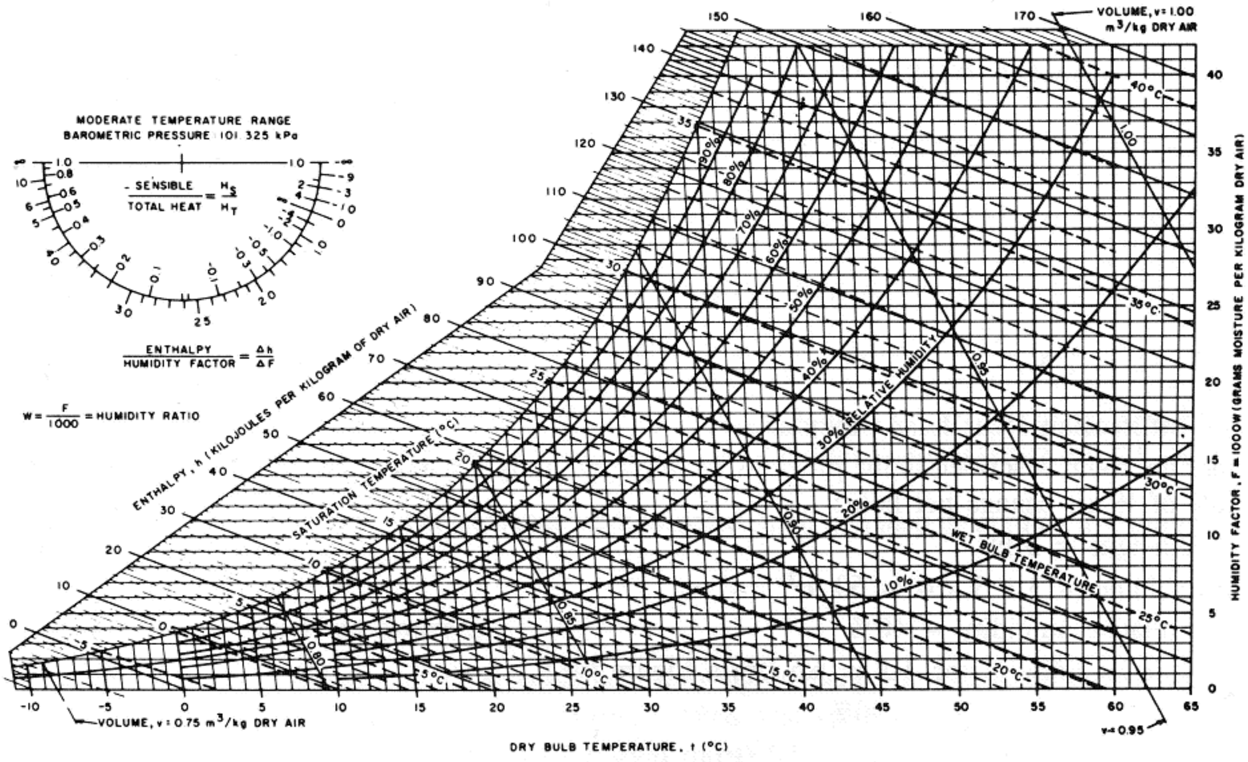
- Heat gain (need for cooling) when water condenses (or is removed) from humid air. This may be associated with the cooling of outside air supply stream by an air conditioning system during the summer.
- Heat required to humidify (add moisture to) dry air by evaporation. An example would be the humidification of outside ventilation air intake during the winter.

### 1.9.4.1 Determining the Humidity Factor

At any given humidity and temperature, the air will hold a certain amount of moisture. This is customarily expressed as the number of grams of water per kilogram of dry air (air with 0% relative humidity). Figure 1.11 provides a sample of a chart known as a Psychrometric[1] Chart, which is commonly used for determining the humidity factor, given the dry bulb temperature ($T_1$ or $T_2$) and the humidity ($RH_1$ or $RH_2$). Full-sized versions of this chart may be found in any edition of the *ASHRAE Fundamentals Handbook*. The "Thermal Inventory.xls" spreadsheet that accompanies this guide includes an electronic version of this chart (see Part C, "Technical Supplement," Section 6.10).

[1] Psychrometry: determination of the thermodynamic properties of moist or humid air.

Figure 1.11 Sample Psychrometric Chart (courtesy ASHRAE)




Psychrometric Chart

| Parameter | Symbol | Unit | Sample | Method of Determination |
|---|---|---|---|---|
| Air Flow Rate | V | L/s | 1 831 L/s | Measurement, estimation |
| Temperature (Dry Bulb) | $T_1$ | °C | 24°C | Measurement, estimation |
| Lower Relative Humidity | $RH_1$ | % | 50% | Measurement, estimation<br>See Section 1.7.3.4. |
| Temperature (Dry Bulb) | $T_2$ | °C | 31°C | Measurement, estimation |
| Higher Relative Humidity | $RH_2$ | % | 50% | Measurement, estimation<br>See Section 1.7.3.4 |
| Humidity Factor (High) | $H_2$ | g/kg | 14.5 g/kg | Humidity measurement and psychrometric chart |
| Humidity Factor (Low) | $H_1$ | g/kg | 9 g/kg | Humidity measurement and psychrometric chart |
| Time | t | hour | n/a | Estimation, calculation |
| Heat Flow | Q | kW | 30.3 kW | Formula below |

**Equation for rate of heat transfer**

$Q = V \times (H_2 - H_1) \times 3.012$ *in units of watts (W)*

**Total heat transferred**

$Heat = Q \times t/1000$ *in units of kilowatt-hours (kWh)*

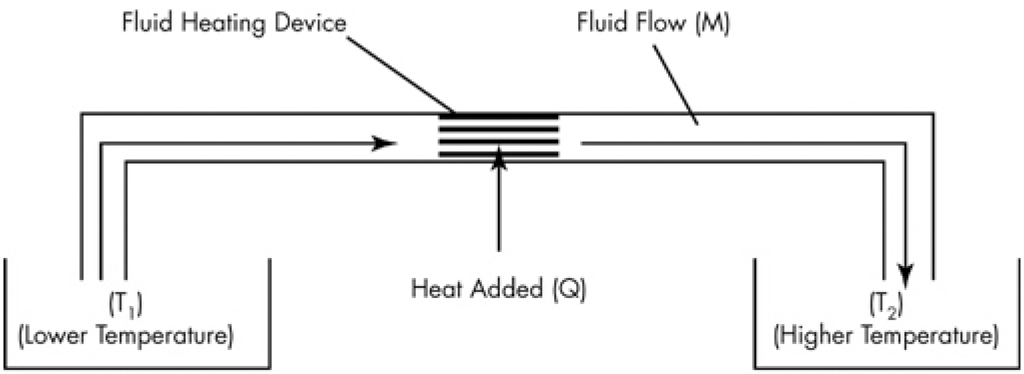
$Heat = Q \times t \times 3600$ *in units of joules (J)*

**Assumption and Cautions**

- This estimation method is intended primarily for building heating and cooling purposes. It should not be used for situations involving extremely high temperatures and humidity. Typical conditions are assumed in determining the factor 3.012.
- For any given air flow into a building, there is a balancing outflow by means of a fan system, vents, or exfiltration through the structure. The reverse is also true. In an *energy outflow inventory*, account only for the energy needed to heat the incoming stream or lost in the outgoing stream, as accounting for both would constitute double accounting.

### 1.9.5 | Hot or Cold Fluid

Fluid flows at various temperatures are common in industrial situations. Water is commonly used to move heat. Liquid product often requires heating and cooling as a routine part of the manufacturing process.




Example Illustrated: water being heated for use in a process

This method of estimating can be used for a number of purposes including the following:

- to determine heat lost in an outflow of hot fluid
- to determine the heat required to heat a stream of cold fluid
- to determine the amount of cooling required to reduce a fluid temperature

| Parameter | Symbol | Unit | Sample | Method of Determination |
|---|---|---|---|---|
| Mass Flow Rate | M | kg/s | 0.35 kg/s | Measurement, estimation |
| Higher Temperature | $T_2$ | °C | 40°C | Measurement, estimation |
| Lower Temperature | $T_1$ | °C | 10°C | Measurement, estimation |
| Heat Capacity (Specific Heat) of Fluid | C | kJ/ kg/°C | 4.2 kJ/kg/°C | Use the table in Section 1.7.2 above. |
| Time | t | hour | n/a | Estimation, calculation |
| Heat Flow | Q | kW | 44.1 kW | Formula below |

*Where* $Q = M \times C \times (T_2 - T_1)$

#### 1.9.5.1 Higher and Lower Temperature

When using this method to estimate energy outflows, the lower temperature is typically assumed to be the temperature of the fluid which entered the facility. For water, this might be the intake water temperature.

In heating circumstances, the lower and higher temperatures are simply taken as the "from" and "to" temperatures respectively. For cooling, the values are reversed.

### 1.9.5.2 Mass Flow Rate

The mass flow rate is related to the fluid volume flow rate by the density. Standard units of density are kilograms per cubic metre (kg/m³) in SI and pounds per cubic foot (lb./cu. ft.) in imperial measurement. Flow rates are often given in litres per second (L/s) or gallons per minute (gpm). It is therefore necessary to know the density of a substance in kg/L or lb./gal. respectively. Water is 1.0 kg/L. The mass flow rate would be

*Mass Flow Rate = Volume Flow (L/s) × Density (kg/L)*

**Equation for rate of heat transfer**

$Q = M \times (T_2 - T_1) \times C \times 1000$ *in units of watts (W)*

**Total heat transferred**

$Heat = Q \times t/1000$ *in units of kilowatt-hours (kWh)*

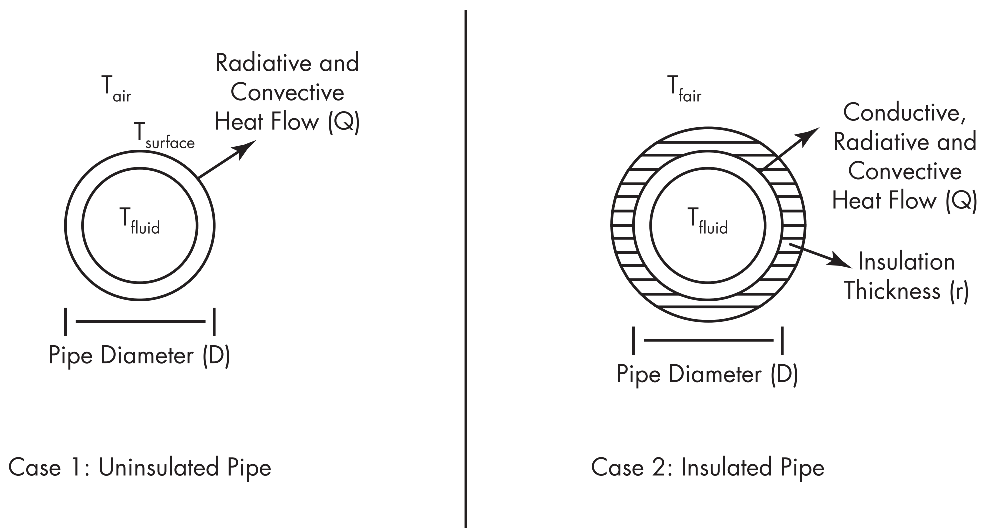
$Heat = Q \times t \times 3600$ *in units of joules (J)*

Reference: Any basic physics textbook.

### 1.9.6 | Pipe Heat Loss

Pipes carrying fluid will incur a heat loss or heat gain depending upon the relative temperatures inside and outside the pipe. Heat loss from a pipe (which is round) must be treated differently than that from a flat surface. The heat loss estimation method presented below is simplified.

**Figure 1.12 Pipe Heat Loss**




The heat transfer mechanism is a combination of conductive, convective and radiative heat transfer.

| Parameter | Symbol | Unit | Sample | Method of Determination |
|---|---|---|---|---|
| Fluid (interior) Temperature or Surface Temp. | $T_f$ $T_s$ | °C | 150°C Bare Surface | Measurement, estimation; use pipe temperature for bare or uninsulated pipes |
| Pipe Diameter | D | n. (Nominal Pipe Size) | 3 in. (Nominal Pipe Size) | Measurement |
| Pipe Length | L | m | 20 m | Measurement |
| Heat Loss Factor | F | W/m | 575 W/m | See note below |
| Insulation Thickness | r | mm | nil | If present, the thickness is in millimetres |
| Time | t | hours | n/a | Estimation, calculation |
| Heat Flow | Q | kW | 11.5 kW | See formula following |

**Heat loss factor**

Values for the heat loss factor, based on the fluid temperature (or pipe temperature for uninsulated pipes) and pipe diameter, are available in thermal insulation handbooks.

**Equation for rate of heat transfer (loss)**

$Q = F \times L$ *in units of watts (W)*

**Total heat transferred**

$Heat = Q \times t/1000$ *in units of kilowatt-hours (kWh)*

$Heat = Q \times t \times 3600$ *in units of joules (J)*

**Caution**

If the pipe is outside the building, the resultant heat loss is a facility outflow.

If the pipe is inside the building, the resultant heat can add to general building heating (or overheating in some cases). In this case, heat loss from the pipe is not a facility outflow.

However, facility outflow occurs when heat added from a pipe inside the building does one of the following:

- leaves the facility as exhausted air
- is lost by conduction through the building structure

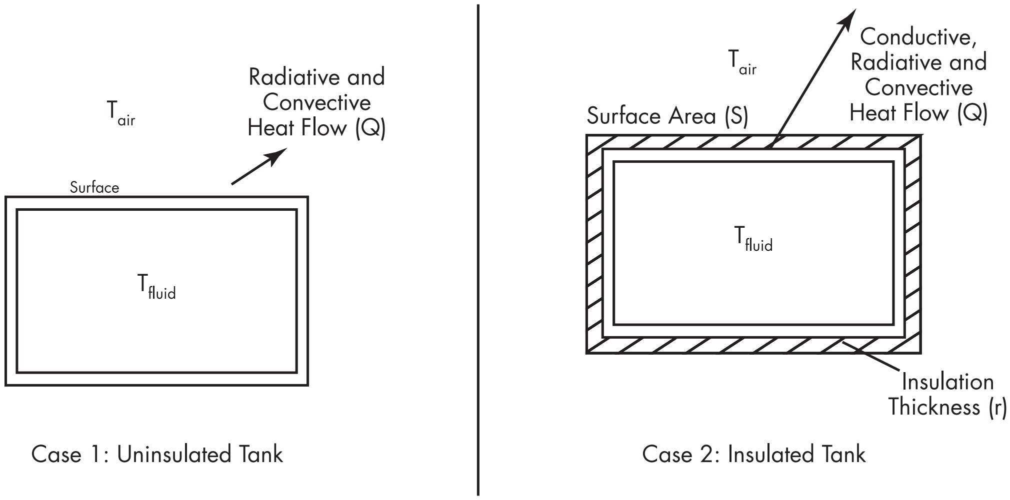
Be careful not to count such energy flows twice.

Note: Software is available online to calculate thermal performance of both insulated and uninsulated piping at www.pipeinsulation.org.

## 1.9.7 | Tank Heat Loss

Tanks holding fluid will incur a heat loss or heat gain depending upon the relative temperatures inside and outside the tank. The heat loss estimation method presented below is simplified.

**Figure 1.13 Tank Heat Loss**




The heat transfer mechanism is a combination of conductive, convective and radiative heat transfer.

| Parameter | Symbol | Unit | Sample | Method of Determination |
|---|---|---|---|---|
| Fluid (interior) Temperature or Surface Temp. | $T_f$ $T_s$ | °C | 90°C Bare Surface | Measurement, estimation; use tank temperature for bare or uninsulated tanks |
| Surface Area | S | m² | 20 m² | Measurement |
| Heat Loss Factor | F | W/m² | 950 W/m² | See note below |
| Insulation Thickness | r | mm | nil | If present, the thickness is radial |
| Time | t | hours | n/a | Estimation, calculation |
| Heat Flow | Q | kW | 19 kW | See formula following |

### Heat loss factor

Values for the heat loss factor, based on the fluid temperature (or tank temperature for uninsulated tanks), are available in thermal insulation handbooks.

**Equation for rate of heat transfer**

*$Q = F \times S$* *in units of watts (W)*

**Total heat transferred**

*$Heat = Q \times t/1000$* *in units of kilowatt-hours (kWh)*

*$Heat = Q \times t \times 3600$* *in units of joules (J)*

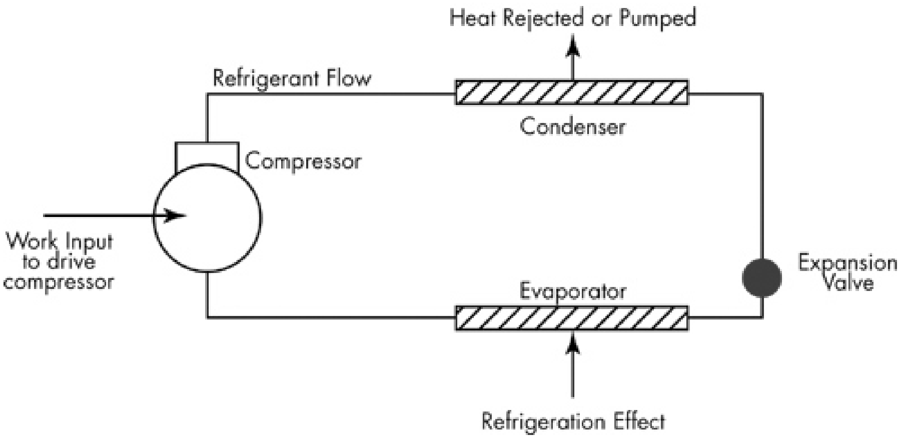
**Assumption and Caution**

- The tank temperature is considered to be uniform, regardless of position in the tank. This also assumes that the surface temperature of the tank is also uniform.
- If the tank is outside a building, then the heat lost will definitely be a facility outflow. But in the case of a tank inside a building, the heat may contribute to general building heating (or overheating, in some cases). In this case, the heat lost from the tank is not, itself, a facility outflow. The facility outflow occurs when the heat that the tank has added to the interior space leaves the facility as exhausted air or is lost by conduction through the building structure. One must be careful not to count such energy flows twice.

### 1.9.8 | Refrigeration

Refrigeration systems are designed and operated to move heat. It is often useful in an energy outflow inventory, or during assessment of the opportunities for heat recovery, to be able to estimate the quantity of heat rejected by a refrigeration system per unit of time.

**Figure 1.14**




The heat rejected by a refrigeration system is primarily the heat rejected at the condenser. The magnitude of this rejected heat is the sum of the electrical energy being supplied to the compressor and the heat being pumped from the evaporator. If this is a water-cooled condenser, the method described previously for a flow of heated fluid could be used. Likewise, for air-cooled condensers, the airflow method for sensible heat may be used. If the unit has an evaporative cooling tower, it may be necessary to take into account the latent heat in the air that removes heat from the condenser.

Alternatively, a rough approximation could be made based upon the system's ability to move heat, commonly referred to as the coefficient of performance (COP). For a refrigeration system designed to provide cooling or a refrigeration effect, the refrigerating COP is defined mathematically as

$COP_R$ = *Refrigeration Effect/Work Input*

When a the purpose of a refrigeration system is to heat, as with heat pumps, the heating COP is of interest. It is

$COP_H$ = *(Refrigeration Effect + Work Input)/Work Input*

From these equations, it is clear that, given the COP and the Work Input (which is commonly the electric power to the compressor), one can calculate the energy moved.

**Equation for rate of heat transfer**

*Q = COP × Power to Compressor* *in units of kilowatts (kW)*

**Total heat transferred in time t, measured in hours**

*Heat = Q × t* *in units of kilowatt-hours (kWh)*

*Heat = Q × t × 3 600 000* *in units of joules (J)*

**Sample Calculation**

A refrigeration system that has an estimated average $COP_R$ of 3.2 is found to be drawing 21 kW of electrical power. The rate of heat transfer is

$Q = 3.2 \times 21\ kW = 67.2\ kW$

Accurately determining the COP is a complex task. Furthermore, the COP of a system can vary widely with operating conditions, equipment design and type of refrigerant. Operating conditions can vary daily with temperatures. Refrigeration equipment manufacturers and service companies can provide performance information for systems at various operating conditions.

**Assumptions and Cautions**

- As this method is at best only a rough approximation, use results with caution.

### 1.9.9 | Steam Leaks and Vents

Steam is the most common medium for transporting large amounts of thermal energy in commercial and industrial facilities. Steam is generated in the boiler plant from fuel at various pressures depending on the type of equipment, systems, and processes requiring heat. The steam is then distributed by pipe to various uses, but some energy is lost in the distribution piping. These losses may be estimated by the pipe-heat loss method detailed earlier.

Another common loss of steam energy is leaks or venting to atmosphere. The discharge of steam may have a purpose if the steam is contaminated, but it still represents an energy flow and a potential opportunity for heat recovery. The energy lost in a leak or venting of steam can be estimated from the diameter of the leak.

### 1.9.9.1 Enthalpy of Steam

The *enthalpy* of the steam is the total heat contained in the water and the vapour. It is assumed in this method that the steam is saturated. This means that it has not been heated beyond the point of turning all the water to a vapour: i.e. it is not superheated. A sample table of saturated steam properties is given below.

**Figure 1.16 Sample Table of Saturated Steam Properties**

| Conditions | | | Specific Enthalpy | | | Steam |
|---|---|---|---|---|---|---|
| Gauge Pressure bar | Absolute Pressure bar | Temperature °C | Water ($h_f$) kJ/kg | Evaporation ($h_{fg}$) kJ/kg | Steam ($h_g$) kJ/kg | Specific Volume ($V_g$) $m^3/kg$ |
| 0.00 | 1.013 | 100.00 | 419.04 | 2,257.0 | 2,676.0 | 1.673 |
| 0.05 | 1.063 | 101.40 | 424.90 | 2,253.3 | 2,678.2 | 1.601 |
| 0.10 | 1.113 | 102.66 | 430.20 | 2,250.2 | 2,680.4 | 1.533 |
| 0.15 | 1.163 | 103.87 | 435.60 | 2,246.7 | 2,682.3 | 1.471 |
| 0.20 | 1.213 | 105.10 | 440.80 | 2,243.4 | 2,684.2 | 1.414 |
| 0.25 | 1.263 | 106.26 | 445.70 | 2,240.3 | 2,686.0 | 1.361 |
| 0.30 | 1.313 | 107.39 | 450.40 | 2,237.2 | 2,687.6 | 1.312 |
| 0.35 | 1.363 | 108.50 | 455.20 | 2,234.1 | 2,689.3 | 1.268 |
| 0.40 | 1.413 | 109.55 | 459.70 | 2,231.3 | 2,691.0 | 1.225 |
| 0.45 | 1.463 | 110.58 | 464.10 | 2,228.4 | 2,692.5 | 1.186 |
| 0.50 | 1.513 | 111.61 | 468.30 | 2,225.6 | 2,693.9 | 1.149 |
| 0.55 | 1.563 | 112.60 | 472.40 | 2,223.1 | 2,695.5 | 1.115 |
| 0.60 | 1.613 | 113.56 | 476.40 | 2,220.4 | 2,696.8 | 1.083 |
| 0.65 | 1.663 | 114.51 | 480.20 | 2,217.9 | 2,698.1 | 1.051 |
| 0.70 | 1.713 | 115.40 | 484.10 | 2,215.4 | 2,699.5 | 1.024 |
| 0.75 | 1.763 | 116.28 | 487.90 | 2,213.0 | 2,700.9 | 0.997 |
| 0.80 | 1.813 | 117.14 | 491.60 | 2,210.5 | 2,702.1 | 0.971 |
| 0.85 | 1.863 | 117.96 | 495.10 | 2,208.3 | 2,703.4 | 0.946 |
| 0.90 | 1.913 | 118.80 | 498.90 | 2,205.6 | 2,704.5 | 0.923 |
| 0.95 | 1.963 | 119.63 | 502.20 | 2,203.5 | 2,705.7 | 0.901 |
| 1.00 | 2.013 | 120.42 | 505.60 | 2,201.1 | 2,706.7 | 0.881 |
| 1.05 | 2.063 | 121.21 | 508.90 | 2,199.1 | 2,708.0 | 0.860 |
| 1.10 | 2.113 | 121.96 | 512.20 | 2,197.0 | 2,709.2 | 0.841 |
| 1.15 | 2.163 | 122.73 | 515.40 | 2,195.0 | 2,710.4 | 0.823 |
| 1.20 | 2.213 | 123.46 | 518.70 | 2,192.8 | 2,711.5 | 0.806 |
| 1.25 | 2.263 | 124.18 | 521.60 | 2,190.7 | 2,712.3 | 0.788 |
| 1.30 | 2.313 | 124.90 | 524.60 | 2,188.7 | 2,713.3 | 0.773 |
| 1.35 | 2.363 | 125.59 | 527.60 | 2,186.7 | 2,714.3 | 0.757 |
| 1.40 | 2.413 | 126.28 | 530.50 | 2,184.8 | 2,715.3 | 0.743 |
| 1.45 | 2.463 | 126.96 | 533.30 | 2,182.9 | 2,716.2 | 0.728 |
| 1.50 | 2.513 | 127.62 | 536.10 | 2,181.0 | 2,717.1 | 0.714 |

**Equation for rate of heat transfer**

Convert the flow in lb./hr. to flow in kg/h by dividing the number of lb./hr. by 2.205.

$Q = M \times h / 3600$ *in units of kilowatts (kW)*

**Total heat transferred in time *t* measured in hours**

$Heat = Q \times t$ *in units of kilowatt-hours (kWh)*

$Heat = Q \times t \times 3.6$ *in units of megajoules (MJ)*

**Assumptions and Cautions**

- This method is only a rough approximation.
- This method does not take into account the enthalpy of the water used to generate the steam.

## 1.9.10 | General Cautions

The methods detailed in this chapter are simple estimation methods and should be used only for a first approximation of energy use in a given situation. They can help identify potential energy saving opportunities, but proper engineering calculations should be done to verify and refine the initial estimates before actually changing the systems involved.

All of the methods above assume static or non-changing conditions over the time period specified. For estimations that may involve monthly or yearly time periods over which conditions change periodically (i.e. daily, nightly, weekly, or seasonally), it will be necessary to repeat the estimation for a number of shorter time periods over which conditions are assumed to be constant. For example, it may be necessary to estimate exhaust energy use for day and night periods for each month, taking into account night setback of temperatures, and seasonal changes in outdoor temperatures.

## 1.10 Reference

*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001
Web site: iac.rutgers.edu/manual_industrial.php

# 2 DETAILS OF ENERGY-CONSUMING SYSTEMS

## 2.1 Boiler Plant Systems

Boilers are used to generate steam and hot water for space heating and process requirements. In many facilities the boiler plant is the single largest consumer of fuel energy. All boilers utilize a burner to deliver a mixture of fuel – the major energy input – and air for the combustion process that produces heat, which is subsequently transferred to the output medium, either steam or hot water – the major energy output. There may also be a minor electrical energy input to operate auxiliary equipment such as a blower. Of particular importance to the energy audit are the various energy losses occurring in the system, as indicated in the Sankey diagram below.

While boilers are typically rated for a particular maximum or design thermal output, a boiler commonly operates for most of its life at some fraction of that output, or at partial load. The efficiency of a boiler varies significantly with load. Consequently, it is important to evaluate boiler plant performance and efficiency over the range of actual or partial loads that the boiler experiences.

Maintaining the optimum ratio of fuel to air is critical to efficient operation of these systems. A lack of air leads to incomplete combustion, resulting in losses of combustibles in the flue gases. Excess air needlessly increases the dry flue gas losses, as does the temperature of the flue gas. The temperature of the flue gas depends on the effectiveness of heat transfer in the boiler, and is a good indicator of the condition of internal heat transfer surfaces. The portable combustion analyser is a useful tool for gauging the combustion efficiency of boiler plant systems.

The various losses shown in the Sankey diagram in Figure 2.1 are itemized and defined in Table 2.1.

Identifying energy savings opportunities in boiler plant systems involves critically assessing the existing energy use. Table 2.2 provides examples of energy management opportunities (EMOs) for boiler plant systems according to the three-step method detailed in Section B-8, “Identify Energy Management Opportunities.”

**Figure 2.1 Sankey Diagram of Boiler Plant Energy Flows**

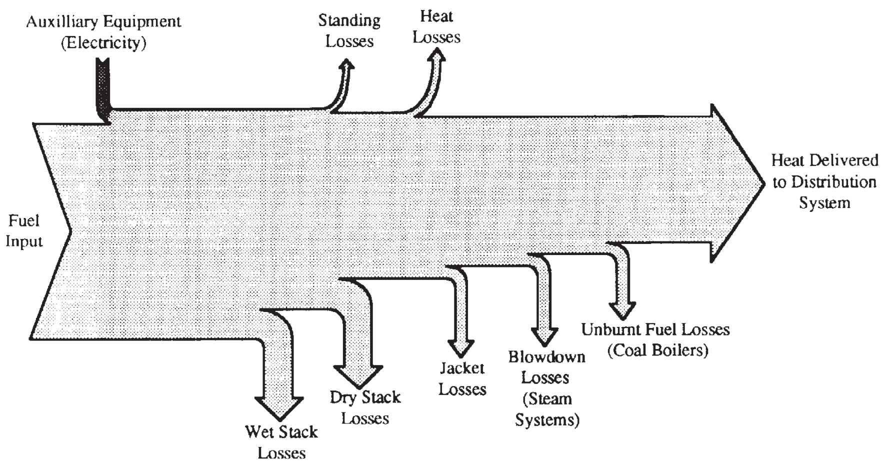



**Table 2.1 Energy Flows in a Boiler Plant System**

| Energy Flow | Description | Key Factors for Evaluation of Flow | Portable Instrumentation Used for Evaluation |
|---|---|---|---|
| Wet Stack Losses (more significant in solid fuels) | Moisture contained in fuel and formed during combustion and exhausted through flue | Flue gas analysis ($CO_2$, $O_2$, CO, etc.) and flue gas temperature | Combustion analyser |
| Dry Stack Losses | Sensible heat in flue gas | | |
| Jacket Losses | Radiation losses from surface of boiler | Surface temperature, area; ABMA standard boiler radiation loss chart | Non-contact thermometer or infrared temperature measurement device |
| Blowdown Losses (steam systems) | Water discharged from steam boiler to remove solids and excess chemicals from boiler water | Timing (scheduling), temperature, volume | |
| Unburnt Fuel Losses (predominantly solid fuel systems – coal, biomass) | Combustibles in solid waste (ash) and possibly flue gases | Dry refuse quantity, heat content | Advanced combustion analyser capable of detecting combustibles in flue gas |
| Standing Losses (also called off-cycle losses) | Heat lost during boiler off cycle | Duty cycle of boiler | Stopwatch or timer<br>Non-contact thermometer or infrared temperature measurement device |
| Other (unknown) | All other insignificant losses | Typically 0.5% of heat in fuel consumed | |
| Heat Delivered to Distribution System | Either hot water or steam delivered | Flow and temperature (pressure for steam) | If available, data from plant steam or hot water heat meters can be used; otherwise this is not measured in a macro-audit |

Table 2.2 Energy Management Opportunities in Boiler Plant Systems

| Step | Actions |
|---|---|
| Determine the Need | ❑ Document the load on the boiler – ideally an hourly profile.<br>❑ For hot water boilers:<br>❑ temperature and flow requirements<br>❑ For steam boilers:<br>❑ flow, pressure and steam quality requirements<br>❑ This may require an examination of the loads downstream of the distribution system.<br>❑ The load on the boiler will change as a result of other energy management actions at the point of end-use and in the distribution system – this step may need to be revised periodically. |
| Match the Need | ❑ Ensure that boiler temperature and operating pressure are not significantly greater than the highest requirement. Operate at the minimum possible temperature and/or pressure.<br>❑ In a multi-boiler plant, sequence boilers on-line to follow the demand for steam or hot water.<br>❑ Minimize the requirement for boilers on hot standby.<br>❑ Monitor overall boiler plant performance (fuel to steam / hot water).<br>❑ Minimize load swings and schedule demand (ideally at point of end-use) where possible.<br>❑ Adjust boiler blowdown schedules and frequency to load and water chemistry requirements. |
| Maximize Efficiency | ❑ Check combustion and boiler efficiency regularly.<br>❑ Check and adjust excess air levels on a regular basis.<br>❑ Check and adjust water treatment procedures on a regular basis.<br>❑ Keep burner assemblies and controls adjusted and calibrated.<br>❑ Maintain seals, air ducts, breeching and access doors to ensure airtightness.<br>❑ Ensure that boiler and piping insulation is up to standard. |
| Optimize Supply | ❑ Relocate combustion air intake or de-stratify boiler room air to take advantage of waste heat to preheat combustion air.<br>❑ Install a non-condensing economizer to capture heat in flue gases.<br>❑ Install a flue gas condenser to capture additional heat in flue gases.<br>❑ Reclaim heat from boiler blowdown. |

### Boiler Plant Systems References

*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001
Web site: iac.rutgers.edu/manual_industrial.php

*Boilers and Heaters*: *Improving Energy Efficiency*, Natural Resources Canada, 2001
oee.nrcan.gc.ca/Publications/infosource/Pub/cipec/BoilersHeaters_foreword.cfm

Boiler Efficiency Calculator, Natural Resources Canada, 2006
oee.nrcan.gc.ca/industrial/technical-info/tools/boilers/index.cfm

## 2.2 Building Envelope

Building envelope energy flows include all three types of heat transfer:

- Conduction (through or between adjacent solid materials)
- Convection (air circulation)
- Radiation (electromagnetic waves; e.g. sunlight)

All heat movement and losses through the building envelope can be quantified in terms of these three types. There are many complex software applications that can simulate in great detail the energy flows. However, for most audits the calculations can be done with reasonable accuracy on a spreadsheet using some basic formulas, assumptions and rules of thumb.

This section deals only with energy flows and losses from the conditioned space. Production (boiler, A/C) and distribution (HVAC) losses are dealt with in other sections. In addition to the energy flows from the heating or cooling source to the building envelope, it is important to recognize and understand the interactions between systems and how changing one system can affect another. For example, a reduction in the energy used by the lighting system could result in an increase in the winter space-heating requirements but a decrease in summer cooling. When considering temperature setback EMOs, take into consideration the *thermal mass* and *thermal response* of the building. If possible, use these characteristics to advantage when setting schedules.

Energy conservation strategies for the building envelope can be narrowed down to reducing losses of the three heat transfer types: conduction (add insulation); convection (minimize air infiltration); and radiation (replace or improve windows).

The recording thermometer can be a useful tool for tracking the temperature swings in a space. Many modern control systems have the capability of logging monitored points (temperature, airflow, humidity, run-time, etc.). If available, a thermal imaging device can indicate heat losses when used during cold weather.

The various losses shown in the Sankey diagram in Figure 2.2 are itemized and defined in Table 2.3.

Identifying energy savings opportunities in hot water systems involves critically assessing the existing energy use. Table 2.4 provides examples of energy management opportunities for the building envelope according to the three-step method detailed in Section B-8, "Identify Energy Management Opportunities."

**Figure 2.2 Sankey Diagram of Building Envelope Energy Flows**

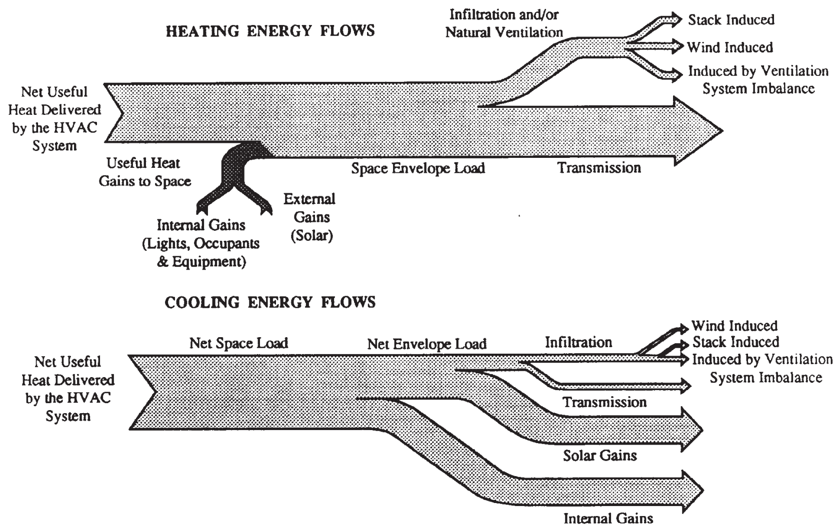



**Table 2.3 Energy Flows in Building Envelope**

| Energy Flow | Description | Key Factors for Evaluation of Flow | Portable Instrumentation Used for Evaluation |
|---|---|---|---|
| Internal Gains | Heat from occupants, lights and equipment | Occupancy, equipment and lighting inventory | |
| External Gains | Solar radiation entering through windows | Local sunlight hours, building orientation, window glazing type ("low-E") | |
| Infiltration/Ventilation | Air movement losses | Unbalanced HVAC airflows, local wind speed, building orientation | Airflow meter, pressure gauge |
| Transmission | Heat lost through walls, roof, etc. | Temperature, surface area, insulation levels | Thermometer or infrared temperature measurement device |

Table 2.4 Energy Management Opportunities in Building Envelope

| Step | Actions |
|---|---|
| Determine the Need | ❑ Document the load on the heating/cooling system; separate fuel energy used for space heating/cooling.<br>❑ Determine design and actual end-use requirements, temperature, fresh air, etc.<br>❑ The load on the system will change as a result of other energy management actions at the point of end-use – this step may need to be revised periodically. |
| Match the Need | ❑ Ensure space temperature is not significantly greater than the highest requirement. Operate at the minimum possible temperature.<br>❑ Reduce flows/temperatures to match end-use requirements.<br>❑ Reduce temperature stratification in high-ceiling areas.<br>❑ Ensure cooling and heating systems are not "competing." |
| Maximize Efficiency | ❑ Minimize air leaks at windows, doors and vents.<br>❑ Ensure windows and doors are closed during heating.<br>❑ Ensure building insulation is up to standard.<br>❑ Consider high-performance windows to reduce summer heat gains and winter heat losses. |
| Optimize Supply | ❑ Maximize solar gains when heating and minimize when cooling.<br>❑ Make innovative use of passive or active solar heating technology for space and/or water heating, especially when combined with improved insulation, window design and heat recovery from vented air.<br>❑ Consider a solar wall – a metal collector designed to provide preheated ventilation (make-up air) for buildings with large south-facing walls. |

## Building Envelope Reference

*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001.
Web site: iac.rutgers.edu/manual_industrial.php

## 2.3 Compressed Air Systems

Compressed air has been termed the third utility, often with operating costs close to those incurred for electricity and thermal energy. The compressor used to generate and treat compressed air accounts for a large but necessary portion of the electrical load in most industrial facilities.

Leaks of compressed air are the most common and major cause of excessive cost, typically accounting for about 70% of the total wastage. Sometimes, the cost of inefficiently produced and distributed air may reach $1.00/kWh! Energy losses in a poorly maintained air system arise from the requirement for additional energy to overcome equipment inefficiencies, since the air may not be delivered at the correct pressure.

Long-term cost of compressed air generation is typically 75% electricity, 15% capital and 10% maintenance. Simple, cost-effective measures can save 30% of electric power costs. Consequently, the effort to make a compressed air system energy efficient can pay off handsomely.

All plants should consider a compressed air system audit, including examination of compressed air generation, treatment, control, distribution, end-use and management.

The various losses shown in the energy flow diagram in Figure 2.3 are itemized and defined in Table 2.5.

Identifying energy savings opportunities in compressed air systems involves critically assessing the existing energy use. Table 2.6 provides examples of energy management opportunities for compressed air systems according to the three-step method detailed in Section B-8, "Identify Energy Management Opportunities."

**Figure 2.3 Energy Flow Diagram of Compressed Air System Energy Flows**

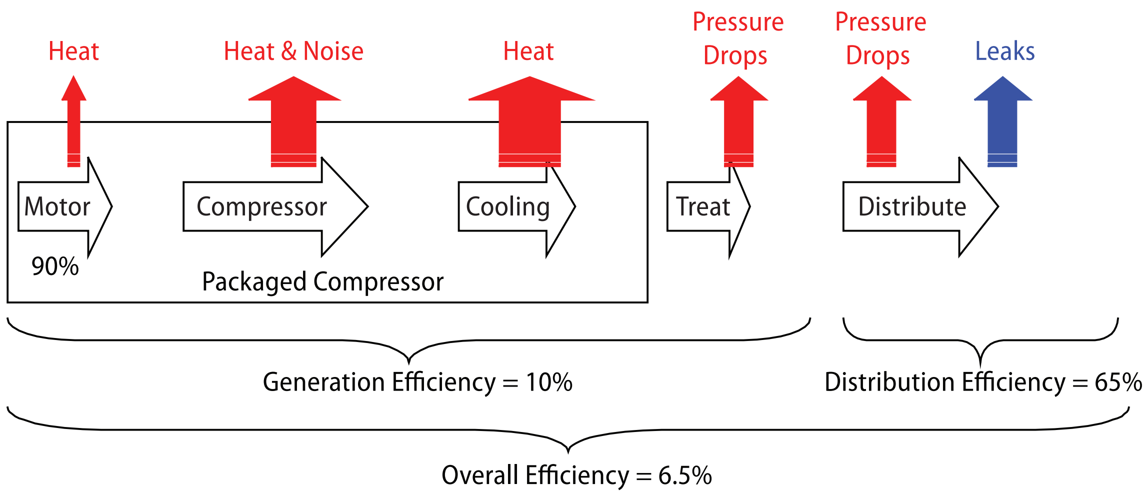


Table 2.5 Energy Flows in a Compressed Air System

| Energy Flow | Description | Key Factors for Evaluation of Flow | Portable Instrumentation Used for Evaluation |
|---|---|---|---|
| Motor losses | Heat created at the motor in conversion from electric to mechanical power | Motor efficiency rating and operating conditions, i.e. applied voltage, loading and temperature | Motor efficiency rating, temperature measurement of motor, tachometer to check motor loading from speed |
| Compressor losses | The thermodynamic inefficiency of the particular compressor | Compressor type, specs and operating conditions | |
| Heat rejected from air cooler | The heat generated during compression is rejected to deliver air at the required temperature | Air (water) flow and temperatures | Can be estimated from energy input to the systems and manufacturer's specs<br>Temperature and flow measurement |
| Losses in treatment including oil separation, filtration and drying | Loss due to pressure drop in each element and air leaks, vents and purged from various components | Equipment specs and visual observation of condition operation<br>Pressure readings | Pressure gauges in system |
| Distribution system pressure drops | Loss to pressure drops at elbows, fittings, T connections and pipe friction | Pressure readings | Pressure gauges in system and/or gauges connected via quick connects |
| Distribution systems leaks | Air lost throughout the systems from compressor to point of end-use | Flow rate and pressure of air | Ultrasonic leak detector |
| End-use pressure drops for low-pressure user | Losses introduced by pressure-reducing valves (regulators) at end-use points | Pressure differences and volume of air (flow) | Typical inlet/outlet pressure gauges will be installed in system |
| Compressed air end-use | Useful work done by the air | Pressure and flow of each use | Compressed airflow meter and pressure gauges |

**Table 2.6 Energy Management Opportunities in Compressed Air Systems**

| Step | Actions |
|---|---|
| Determine the Need | ❑ Is compressed air needed at all? Can another energy form be used? (especially air motors and cooling)<br>❑ Inventory the need for compressed air in terms of:<br>❑ flow requirement (SCFM)<br>❑ pressure requirement<br>❑ quality (temperature, moisture content, oil content, etc.)<br>❑ point(s) in the distribution system<br>❑ Document when compressed air is required.<br>❑ Is the real demand for compressed air growing? – or simply the leaks? |
| Match the Need | ❑ Implement a plant-wide awareness program for compressed air management.<br>❑ Eliminate leaks:<br>❑ Use ultrasonic leak detector to track down leaks and FIX.<br>❑ Isolate with valves appliances and equipment when not in use.<br>❑ Manage end-use:<br>❑ Eliminate unnecessary uses (floor sweeping).<br>❑ Consider intensifying nozzles instead of simple cutoff pipe nozzles.<br>❑ Minimize main supply pressure.<br>❑ Avoid pressure reduction at point of end-use, segregate large low-pressure uses and provide separate low-pressure supply – consider high-pressure blowers.<br>❑ Use treatment appropriate to quality requirement – segregate low-volume, high-quality users and provide separate supply.<br>❑ Ensure that controls for treatment (drying) are not set lower than required.<br>❑ Ensure that compressor capacity on-line follows the demand for air:<br>❑ Base-load compressors with poor capacity control (throttling) – check motor load when air delivery from compressor is low.<br>❑ Sequence compressors to ensure that unit with best capacity control follows the load.<br>❑ Ensure that idling compressors shut down promptly.<br>❑ Optimize the compressor plant with properly sized receivers, demand control devices and comprehensive system control. |

| Step | Actions |
|---|---|
| Maximize Efficiency | ❑ Ensure that inlet air temperature is as cool and dry as possible – use outside air during cold seasons.<br>❑ Ensure that inlet filters are clean with minimal pressure drop.<br>❑ Ensure that filtration and treatment equipment impose minimal pressure drop.<br>❑ Ensure that line sizing is appropriate to flows to minimize pressure drop.<br>❑ Ensure good piping practices to avoid excessive pressure drops at T connections, elbows, unions and other fittings.<br>❑ Ensure appropriate compressor room temperature.<br>❑ Consider compressor replacement with a more appropriate, newer and/or more efficient unit.<br>❑ Consider an energy-efficient motor replacement – not practical in many packaged units. |
| Optimize Supply | ❑ Install the simplest form of heat recovery possible to reclaim heat rejected from the compressors – either water- or air-cooled.<br>❑ Consider engine drive compressors with heat recovery. |

**Compressed Air References**


*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001
Web site: iac.rutgers.edu/manual_industrial.php

*The Compressed Air Challenge*, on-line at compressedairchallenge.org

*Team Up for Energy Savings – Compressed Air* (fact sheet), Natural Resources Canada, 2005
oee.nrcan.gc.ca/publications/industrial/cipec/compressed-air.cfm

## 2.4 Domestic and Process Hot Water Systems

By definition, domestic water is potable, while process water may or may not be potable. In central systems, the production and distribution systems of both may be identical. Domestic hot water (DHW) can be local (small electric boiler or on-demand heating coil) near the end-use point or central (large boiler/storage tank and pumped distribution system). Process hot water is almost always central.

The energy source for central HW systems can be the same as for regular boilers – gas, oil, electric (resistive heating), biomass, etc. Other possible sources are solar, recovered waste heat and heat pumps. In some cases the DHW is heated via a coil in the main boiler or through a steam coil in a storage tank. The HW energy audit should be based on a clear understanding of how the water is heated and distributed and should quantify all the losses quantified to the extent possible. Production (boiler) losses are described in the "Boiler Plant" section. This section deals with storage, distribution and other losses.

Optimizing the energy usage in a hot water system generally involves reducing the end-use and reducing the losses. End-use reduction or reuse has the added benefit of saving on purchased or pumped (if on a well) water. For the same reasons, end-use reduction in cold water use should also be pursued when possible. Fresh water will only get more expensive as demand increases on municipal water sources.

The non-contact (infrared) thermometer is a useful tool for tracking down insulation gaps in HW pipes and tanks. Sub-metering (flow, volume) of major water distribution branches can also help in breaking down water usage.

The various losses shown in the Sankey diagram in Figure 2.4 are itemized and defined in Table 2.7.

Identifying energy savings opportunities in hot water systems involves critically assessing the existing energy use. Table 2.8 provides examples of energy management opportunities for DHW systems according to the three-step method detailed in Section B-8, "Identify Energy Management Opportunities."

Figure 2.4 Sankey Diagram of DHW Energy Flows

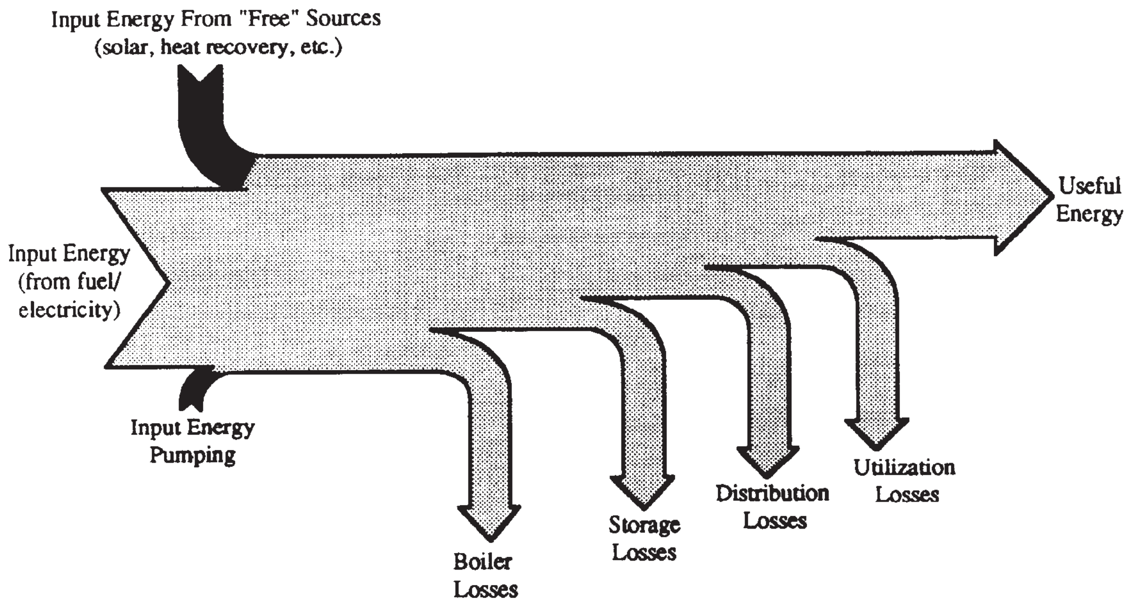



Table 2.7 Energy Flows in DHW Systems

| Energy Flow | Description | Key Factors for Evaluation of Flow | Portable Instrumentation Used for Evaluation |
|---|---|---|---|
| "Free" Input Energy | Auxiliary heat into HW supplied from solar, heat recovery, etc. | Temperature, volume | Non-contact thermometer or infrared temperature measurement device or temperature measurement device |
| Input Energy – Pumping | Heat added to water by mechanical action (friction) of circulator pump | | |
| Boiler Losses | Stack and other losses | See: Boiler Systems | |
| Storage Losses | Heat lost from poorly or uninsulated tank, fittings, etc. | Temperature, surface area, insulation levels | Thermometer or infrared temperature measurement device |
| Distribution Losses | Heat lost from poorly insulated or uninsulated pipes; continuous recirculation losses | Temperature, surface area, insulation levels; recirc. pump schedule; occupancy | Thermometer or infrared temperature measurement device |
| Utilization Losses | Heat lost due to excessive HW usage and temperature set too high | End-use requirements | Thermometer |
| Indirect Use | Heat delivered through heat exchanger | | |

Table 2.8 Energy Management Opportunities in DHW Systems

| Step | Actions |
|---|---|
| Determine the Need | ❑ Document the load on the HW system – ideally an hourly profile.<br>❑ Determine design and actual end-use requirements, considering both flow and temperature and time to full temperature requirement.<br>❑ The load on the system will change as a result of other energy management actions at the end-use – this step may need to be revised periodically. |
| Match the Need | ❑ Promote good housekeeping practices in all employees, maintain awareness and transform the newly acquired knowledge into habit.<br>❑ Ensure that the DHW temperature is not significantly greater than the highest requirement. Operate at the minimum possible temperature.<br>❑ Reduce flows to match end-use requirements.<br>❑ Minimize recirculation as appropriate for temperature requirements.<br>❑ Regularly check DHW piping systems for leaks.<br>❑ Install flow regulators for sanitary uses: delayed closing/timed flow taps on wash hand basins in the restrooms and reduced-flow showerheads.<br>❑ Reuse all rinse water from cleaning operations wherever possible, with due regard for product quality implications – e.g. cleaning-in-place (CIP) last rinse.<br>❑ Install water meters in different process areas to monitor consumption on an ongoing basis. |
| Maximize Efficiency | ❑ Check and adjust water treatment procedures on a regular basis.<br>❑ Disconnect and seal, or valve off, any unused DHW branches.<br>❑ Ensure that piping and fixture insulation is up to standard. |
| Optimize Supply | ❑ Use solar and/or recovered heat to supplement DHW requirements.<br>❑ Use "on-demand" in-line DHW heaters where requirements are low.<br>❑ Can a once-through system be converted to a circulating system?<br>❑ Revise the water distribution system to incorporate multiple reuse (recirculation) of process water wherever possible, employing suitable heat recovery regimes, and implement the measures. |

## Domestic and Process Hot Water References

*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001
Web site: iac.rutgers.edu/manual_industrial.php

Boiler Efficiency Calculator, Natural Resources Canada, 2006
oee.nrcan.gc.ca/industrial/technical-info/tools/boilers/index.cfm

## 2.5 Fan and Pump Systems

Fan and pump systems share many similar characteristics and as a consequence may be analysed in similar ways from an energy perspective. Each is typically driven by a motor, either directly or through a belt or gearbox. Both systems will frequently utilize centrifugal devices to create motion in the fluid or air, and as a result both systems are governed by a set of rules, known as affinity laws. The affinity laws describe the relationship between speed, flow, pressure and power required:

$$\frac{Q_2}{Q_1} = \frac{N_2}{N_1} \qquad \frac{P_2}{P_1} = \left(\frac{N_2}{N_1}\right)^2 \qquad \frac{kW_2}{kW_1} = \left(\frac{N_2}{N_1}\right)^3$$

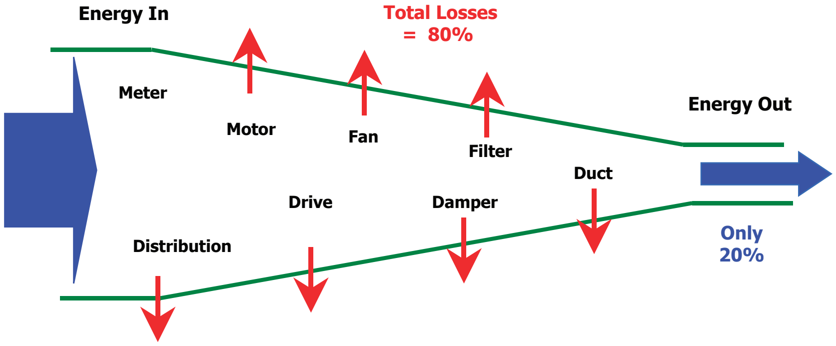
*N = speed, Q = flow, P = pressure, kW = kilowatt*

The power required for movement of air or fluid in the system downstream of the fan or pump is governed by the pressure drop presented by the system to the flow. Both systems share significant losses in friction downstream and consequently share similar opportunities for flow balancing, static and dynamic head (pressure) reduction, and speed control rather than throttling for flow control.

Identifying energy savings opportunities in fan and pump systems involves critically assessing the existing energy use. Table 2.10 provides examples of EMOs for fan and pump systems according to the three-step method detailed in Section B-8, "Identify Energy Management Opportunities."

The various losses shown in the Sankey diagram in Figure 2.5 are itemized and defined in Table 2.9. A similar diagram for a pumping system is provided in Section B-8, "Identify Energy Management Opportunities."

**Figure 2.5 Sankey Diagram of Fan System Energy Flows**




| Component | Typical Efficiency |
|---|---|
| Meter | 100% |
| Distribution | 96% |
| Motor | 85% |
| Drive | 98% |
| Fan | 60% |
| Damper | 70% |
| Filter | 75% |
| Ductwork | 80% |
| **Overall** | **20%** |

**Table 2.9 Energy Flows in a Fan (Pump) System**

| Energy Flow | Description | Key Factors for Evaluation of Flow | Portable Instrumentation Used for Evaluation |
|---|---|---|---|
| Electric Distribution Systems Losses | Heat from resistance of the wires | Voltage drop in wiring | Handheld power meter or clip-on ammeter |
| Motor Losses | Heat created at the motor in conversion from electric to mechanical power | Motor efficiency rating and operating conditions, i.e. applied voltage, loading and temperature | Motor efficiency rating, temperature measurement of motor, tachometer to check motor loading from speed |
| Drive Losses | Heat created due to friction in the bearings pulleys and belts and bearings | Belt tension, bearing and belt temperature | Infrared temperature measurement |
| Fan (Pump) Losses | Heat created due to friction and fluid viscous losses with the fan (pump) | Fan (pump) efficiency rating at operating point defined by flow rate and pressure as specified by the fan (pump) curve | Flow and pressure measurement |
| Damper (Valve) Losses | Heat and pressure drop created by friction damper (valve) | Damper (valve) setting and pressure drop inlet to outlet | Differential pressure measurement |
| Filter (Strainer) Losses | Heat and pressure drop created by friction to airflow in filter (strainer) | Pressure drop across filters (strainers) | Differential pressure measurement |
| Ductwork (Pipework) Losses | Heat and pressure drop created by friction within ductwork (pipework) to air (water) flow | Pressure drop per unit length or overall | Differential pressure measurement |
| Air (Water) Power Delivered | The amount of air (water) power delivered at the terminal point such as the diffuser or outlet (end-use heat exchanger) | Pressure difference and flow achieved at the point of end-use | Flow and pressure measurement |

Table 2.10 Energy Management Opportunities in Fan/Pump Systems

| Step | Actions |
| --- | --- |
| Determine the Need | ❑ Determine the requirement for air/water flow, possibly in terms of a profile over time.<br>❑ Determine the range of pressures that the fan/pump will need to overcome.<br>❑ Determine if the need for flow is fixed or variable.<br>❑ Determine the duration of the need for flow (hours per day). |
| Match the Need | ❑ Provide and use manual control of fans/pumps.<br>❑ Control operating times of fans/pumps by automatic control.<br>❑ Conduct an air/water balance with qualified contractors.<br>❑ Eliminate or reduce throttling as a means of flow control.<br>❑ For fan systems with a fixed flow requirement, reduce flow rates to the requirement by:<br>  ❑ reducing fan speeds by sheave changes<br>  ❑ shutting down extra (backup) fans<br>❑ For pump systems with a fixed flow requirement, reduce flow rates to the requirement by:<br>  ❑ changing or trimming pump impellers<br>  ❑ shutting down extra (backup) fans<br>❑ For fan or pump systems with a variable flow requirement, vary flow by:<br>  ❑ using a two-speed motor<br>  ❑ using a variable speed drive<br>❑ Eliminate leaks in the ductwork and pipework. |
| Maximize Efficiency | ❑ Provide proper maintenance for fans and pumps:<br>  ❑ Lubrication<br>  ❑ Belts and pulleys<br>  ❑ Pump and fan overhaul and cleaning<br>❑ Reduce pressure drops or pipework/ductwork resistance by:<br>  ❑ cleaning interior of pipes/ducts<br>  ❑ maintaining filters/strainers<br>  ❑ using efficient ductwork/pipework practices<br>❑ Select and install a more efficient pump or fan:<br>  ❑ More appropriate design for the application<br>  ❑ New equipment/technology<br>❑ Install a more efficient motor. |
| Optimize Supply | ❑ Consider the use of small steam turbines, typically in place of pressure reducing valves, to drive large fans and pumps (i.e. boiler feedwater pump, boiler forced draft or induced fan).<br>❑ Consider the use of an alternative such as diesel engines with heat recovery to electric motors as prime movers. |

## Fan and Pump Systems References

*Energy-Efficient Motor Systems Assessment Guide*, Natural Resources Canada, 2004
oee.nrcan.gc.ca/cipec/ieep/newscentre/motor_system/index.cfm

CanMOST: The Canadian Motor Selection Tool, Natural Resources Canada, 2004
oee.nrcan.gc.ca/industrial/equipment/software/intro.cfm

*Industrial Energy Efficient Equipment: Variable Frequency Drives,* Natural Resources Canada
oee.nrcan.gc.ca/industrial/equipment/vfd/vfd.cfm

Industrial Energy Efficient Equipment, Natural Resources Canada
oee.nrcan.gc.ca/industrial/equipment/products/index.cfm

## 2.6 Heating, Ventilating and Air-Conditioning Systems

HVAC systems are designed to provide a comfortable, safe and productive environment for occupants in the form of adequate ventilation and comfortable temperature and humidity levels. In this section the scope of HVAC will be limited to the control and delivery subsystems. The heating, cooling and humidification equipment, which provides the energy source for HVAC, is covered elsewhere in this guide.

Before implementing EMOs on HVAC systems, it is important to have some knowledge of the factors that affect environmental comfort. These include air temperature, mean radiant temperature, humidity, air quality, air velocity, activity level and clothing thermal resistance. HVAC changes can affect these factors and cause adverse reactions in the occupants. It follows that knowledge of the effects can prevent problems occurring.

HVAC systems can be quite complex, with a wide range of operating modes depending on the outdoor ambient conditions, occupancy schedules, and seasonal and other factors. Therefore it is essential to have a good understanding of how a system is designed to operate as well as how it is actually operating. You can often achieve substantial savings simply by restoring a system to its design condition. Historical operational information from logbooks or interviews with operators can be quite useful in evaluating a system over a full range of operating conditions.

Typically, the greatest savings in HVAC systems can be attained by matching the conditioning of the space to occupancy (schedules and levels). This is generally accomplished by system scheduling and control, preferably by means of closed-loop (feedback from the space and outside air) control strategies. Recording power and temperature meters are useful tools in gauging the efficiency of HVAC systems. Many modern control systems have the capability to log monitored points (temperature, airflow, humidity, run-time, etc.).

The various losses shown in the Sankey diagram in Figure 2.6 are itemized and defined in Table 2.11.

Identifying energy savings opportunities in HVAC systems involves critically assessing the existing energy use. Table 2.12 provides examples of EMOs for HVAC systems according to the three-step method detailed in Section B-8, "Identify Energy Management Opportunities."

**Figure 2.6 Sankey Diagram of HVAC Energy Flows**

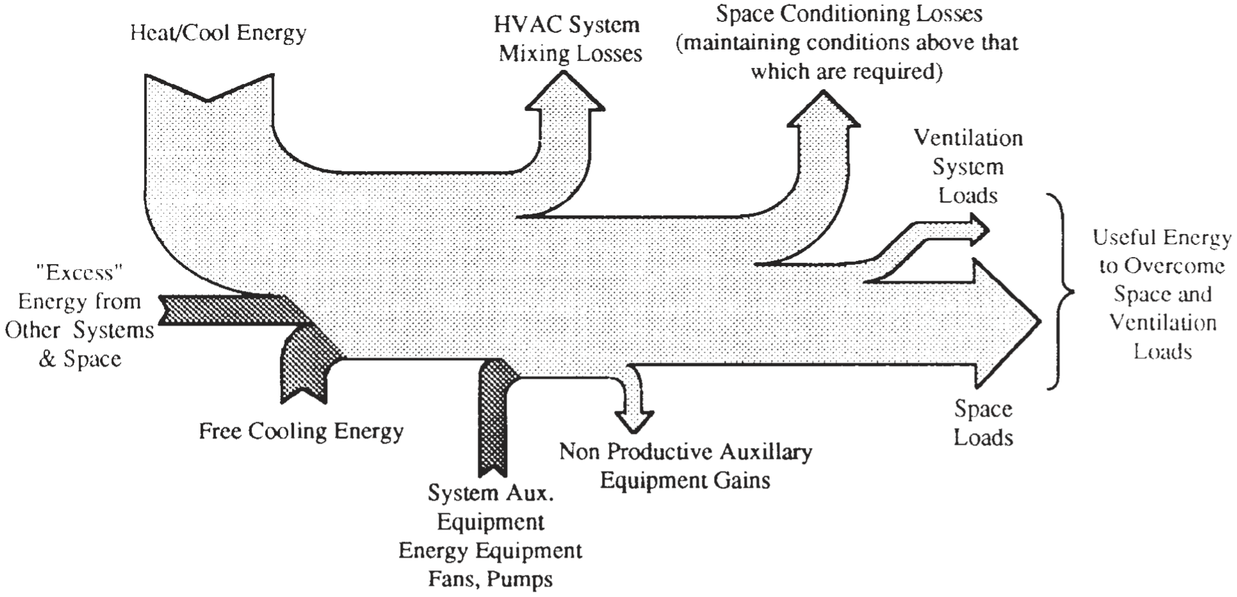



**Table 2.11 Energy Flows in an HVAC System**

| Energy Flow | Description | Key Factors for Evaluation of Flow | Portable Instrumentation Used for Evaluation |
|---|---|---|---|
| HVAC System Mixing Losses | Mixing of hot and cold fluid streams | Temperature and flow of streams; design requirements for mixing | Temperature and flow measurement devices |
| Space-Conditioning Losses | Maintaining conditions above required levels | Use of space, inadequate or uneven distribution system | Recording thermometer/ psychrometer |
| Ventilation System Loads | Losses due to necessary fresh air requirements | Outside air inflow, mixed air settings | |
| Space Loads | Occupant requirements, internal heat gains | Occupied density, lights and equipment | Temperature and humidity measurement |
| Auxiliary Equipment Gains/Losses | Heat introduced by fans/ pumps into system | Motor size | Recording power meter |
| Excess Energy from Other Systems | Crossover heating or cooling from another system | | |
| Free Cooling | Outside air when temperature/humidity is within range to be used as cooling | | |

**Table 2.12 Energy Management Opportunities in HVAC Systems**

| Step | Actions |
|---|---|
| Determine the Need | ❑ Document the load on the system – meter cooling or heating input.<br>❑ Evaluate the space requirements – schedules, occupancy, temperatures, and humidity, exhaust and ventilation.<br>❑ Consider carefully any effect an EMO might have on the environmental quality of the conditioned space.<br>❑ The load on the system will change as a result of other energy management actions at the end-use – this step may need to be revised periodically. |
| Match the Need | ❑ Ensure that supply temperature and humidity are not significantly greater than required. Operate at the minimum possible temperature, humidity, fresh air % and/or airflow. Consider ventilation on demand.<br>❑ Monitor overall HVAC performance (energy input to conditioned space).<br>❑ Minimize load swings and stagger demand and startups (ideally at point of end-use) where possible.<br>❑ Make use of free cooling where possible.<br>❑ Schedule systems and/or temperatures to match occupancy and O/A conditions.<br>❑ Ensure that controls are operating properly and calibrated regularly.<br>❑ Consider control upgrades to direct digital offering more flexible control of systems to loads, provided that underlying systems are capable of the appropriate modulation.<br>❑ Use variable speed drives where operating hours, conditions and economics dictate.<br>❑ Install local air treatment units (e.g. electronic air cleaners, activated charcoal odour-absorbing filter, high-efficiency filters) to reduce the need for general exhaust. |
| Maximize Efficiency | ❑ Regularly check mechanical maintenance items (fans, bearings, alignment, etc.).<br>❑ Ensure that air filters and ducts are clean.<br>❑ Use EE motors where operating hours, conditions and economics dictate.<br>❑ Insulate distribution system – pipes, ductwork.<br>❑ Maintain seals, air ducts, breeching and access doors to ensure airtightness.<br>❑ Ensure that duct and pipe insulation is up to standard. |
| Optimize Supply | ❑ Reclaim exhausted heat and cooling.<br>❑ Utilize thermal storage in cooling systems to optimize purchase of electricity.<br>❑ Consider a solar wall – a metal collector designed to provide preheated ventilation (make-up air) for buildings with large south-facing walls. |

## HVAC References

*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001
Web site: iac.rutgers.edu/manual_industrial.php

*Energy-Efficient Motor Systems Assessment Guide*, Natural Resources Canada, 2004
oee.nrcan.gc.ca/cipec/ieep/newscentre/motor_system/index.cfm

CanMOST: The Canadian Motor Selection Tool, Natural Resources Canada, 2004
oee.nrcan.gc.ca/industrial/equipment/software/intro.cfm

*Team Up for Energy Savings – Heating and Cooling (HVAC)* (fact sheet), Natural Resources Canada, 2005
oee.nrcan.gc.ca/publications/industrial/cipec/heating-cooling.cfm

*Industrial Energy Efficient Equipment*, Natural Resources Canada
oee.nrcan.gc.ca/industrial/equipment/products/index.cfm

## 2.7 Lighting Systems

Lighting constitutes a large but necessary portion of the electrical load in most facilities. Compared to other forms of energy conversion, there are many additional factors to consider beyond conversion efficiency and loss reduction. Lighting quality and visual comfort levels for the occupants must be given high priority in any recommendations, since a drop in worker productivity due to lighting changes can far outweigh energy savings.

The lighting source (lamp, reflector, lens) is only part of the complete system. The entire enclosed space should be considered part of the system, since many factors such as wall colour, reflectivity, window situation and interior partitions can have just as great an effect on the amount of light that is delivered to the task point. The end-use of a lighting system can be measured as the light level at the task point (useful illumination). A detailed energy audit should consider the various energy losses occurring in lighting systems, as indicated in the Sankey diagram below.

In addition to task light levels, some less quantifiable factors should be considered. These include light source colour (Colour Rendering Index, or CRI), glare (fixture and window), surface reflection and the age of the occupants.

The various losses shown in the Sankey diagram in Figure 2.7 are itemized and defined in Table 2.13.

Identifying energy savings opportunities in lighting systems involves critically assessing the existing energy use. Table 2.14 provides examples of EMOs for lighting systems according to the three-step method detailed in Section B-8, "Identify Energy Management Opportunities."

**Figure 2.7 Sankey Diagram of Lighting System Energy Flows**

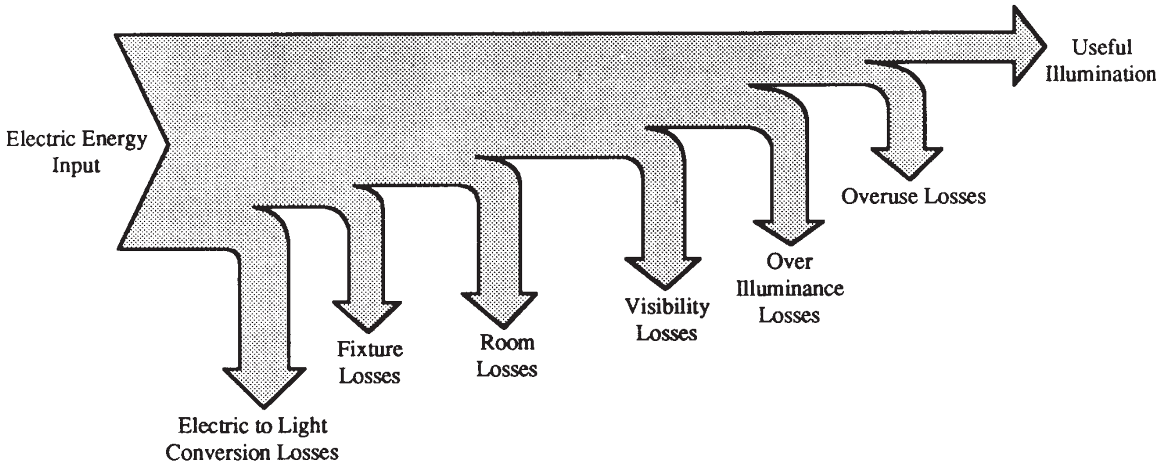


**Table 2.13 Energy Flows in a Lighting System**

| Energy Flow | Description | Key Factors for Evaluation of Flow | Portable Instrumentation Used for Evaluation |
|---|---|---|---|
| Electric-to-Light-Conversion Losses | Light output (lumens) of light source per unit of input power (watts) | Power input to fixture, mfr. specs on lamps, accurate fixture count | Handheld power meter or clip-on ammeter to spotcheck lighting circuit loads |
| Fixture Losses | Light trapped within fixture | Fixture design, cleanliness, dust levels | |
| Room Losses | Light lost before it reaches task due to physical room characteristics | Wall and ceiling surface colours, window placement | Light meter to determine reflectance ratio of reflected illumination to incident illumination (Lux) |
| Visibility Losses | Excess light supplied to overcome lighting quality problems | Glare, reflections | |
| Over-Illuminance Losses | Excess light supplied to overcome poor lighting distribution or consistency | Uneven distribution of light, multiple task light level requirements | Digital light meter |
| Overuse Losses | Lighting left switched on when not required | Occupancy vs. lighting schedules | Recording power meter or recording motion sensor and light sensor |
| Useful Illumination | Light level at the task point (or general room level) | Lux or foot-candles sampled over the area. Also lighting UPD (unit power density – $W/m^2$) | Light (Lux) meter (preferably digital) |

**Table 2.14 Energy Management Opportunities in Lighting Systems**

| Step | Actions |
| --- | --- |
| Determine the Need | ❑ Illumination level required<br>❑ Colour requirements (temperature and CRI)<br>❑ Quality requirements (low glare, indirect, decorative, etc.)<br>❑ Area of requirement – area lighting versus task lighting<br>❑ Duration of the need for lighting (hours per day) |
| Match the Need | ❑ Provide and use manual switches.<br>❑ Provide more levels of switching.<br>❑ Use employee awareness to encourage use of lighting controls.<br>❑ Use motion sensors or timer switches to control lights.<br>❑ Use photocells on window fixtures.<br>❑ Use time clocks or photocells on outdoors lights.<br>❑ Use task lighting and turn off overhead lights.<br>❑ Perform a lighting analysis to determine the applicability of:<br>    ❑ using reduced wattage lamps in existing fixtures<br>    ❑ removing unnecessary fixtures and/or lamps |
| Maximize Efficiency | ❑ Perform a lighting analysis to determine the applicability of:<br>    ❑ removing lamps or fixtures to reduce levels to match requirements<br>    ❑ more appropriate systems design and maintenance – reduced number of fixtures and group versus spot re-lamping<br>    ❑ using reduced wattage lamps and partially de-lamped or modified fixtures – possibly incorporating reflectors<br>    ❑ replacing entire lighting system with one incorporating a more efficient light source – e.g. switching from incandescent to fluorescent or from T12 to T8 fluorescent<br>❑ Use LED lamps in EXIT lights. |
| Optimize Supply | ❑ Install skylights in warehouses.<br>❑ Install skylights in new construction.<br>❑ Design natural lighting schemes into new construction. |

### Lighting Systems Reference

*Team Up for Energy Savings – Lighting* (fact sheet), Natural Resources Canada, 2005
oee.nrcan.gc.ca/publications/industrial/cipec/light.cfm

## 2.8 Process Furnaces, Dryers and Kilns

Process furnaces, dryers and kilns are used in such diverse applications as melting metal, drying wood, evaporating water, and manufacturing lime, bricks and ceramics. Some facilities are constructed and operated solely for the purpose of a single heating manufacturing process. Consequently, the furnace could be the single largest consumer of fuel energy. All non-electric furnaces utilize a burner to deliver a mixture of fuel and air for the combustion process that produces heat, which is subsequently transferred to the product either directly (within the combustion chamber) or indirectly (through a heat exchanger). There may also be electrical energy input to operate auxiliary equipment such as blowers and draft fans.

As with boilers, it is important to evaluate furnace performance and efficiency over the range of actual or partial loads. Unlike boilers, there is usually no large heating distribution system with its accompanying losses (i.e. the end-use of the heat is within the furnace).

Maintaining the optimum ratio of fuel to air is critical to efficient operation of fuel-burning furnaces. A lack of air leads to incomplete combustion, resulting in losses of combustibles in the flue gases (smoky flame). Excess air needlessly increases the dry flue gas losses, as indicated by higher flue gas temperatures. In addition, the excess air entering the furnace must be heated, increasing energy losses. The temperature of the flue gas also depends on the effectiveness of heat transfer to the product being processed and is a good indicator of the condition of internal heat transfer surfaces. In some cases a large amount of excess air is required to maintain product quality. In that case heat recovery should be considered. The portable combustion analyser is a useful tool for gauging the combustion efficiency of process furnaces, dryers and kilns.

The various losses shown in the Sankey diagram in Figure 2.8 are itemized and defined in Table 2.15.

Identifying energy savings opportunities in process heating systems involves critically assessing the existing energy use. Table 2.16 provides examples of EMOs for process furnaces, dryers and kilns according to the three-step method detailed in Section B-8, “Identify Energy Management Opportunities.”

Figure 2.8 Sankey Diagram of Process Heating Energy Flows

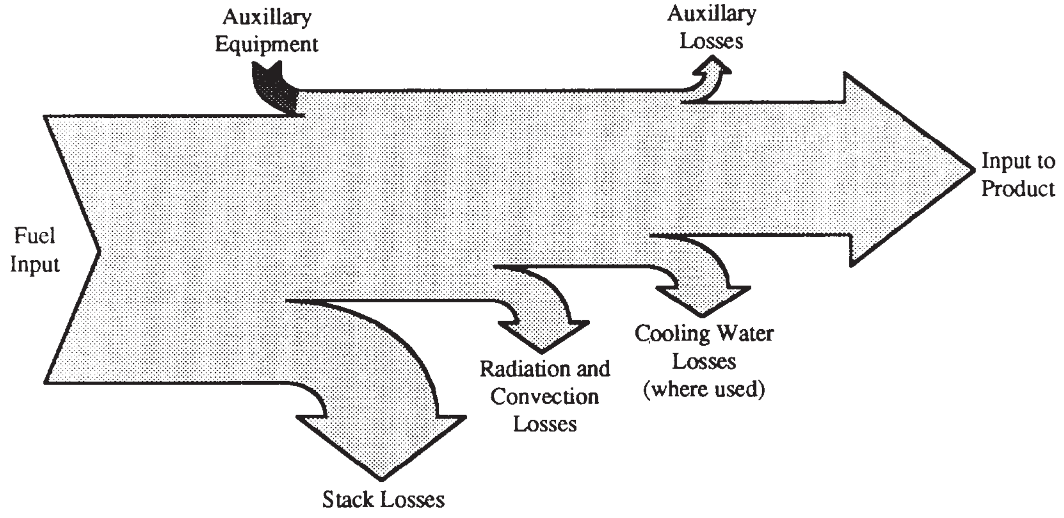



Table 2.15 Energy Flows in a Process Heating System

| Energy Flow | Description | Key Factors for Evaluation of Flow | Portable Instrumentation Used for Evaluation |
|---|---|---|---|
| Wet Stack Losses (more significant in solid fuels) | Moisture contained in fuel and formed during combustion and exhausted through flue | Flue gas analysis ($CO_2$, $O_2$, CO, etc.) and flue gas temperature | Combustion analyser |
| Dry Stack Losses | Sensible heat in flue gas | | |
| Radiation and Convection Losses | Losses from outside surfaces of the combustion chamber and heat exchanger(s) | Surface temperature, area | Non-contact thermometer or infrared temperature measurement device |
| Cooling Water Losses (where used) | Water used to moderate heating process or to cool product after processing | Timing (scheduling), entering and leaving temperature, volume of cooling water | Temperature measurement |
| Auxiliary Equipment Input/Losses | Fans, pumps, etc. and their associated losses (usually electrical) | Equipment specs and operating hours | Recording power meter |
| Heat Delivered to Product | Heat that product absorbs throughout the process cycle | | If available, data from plant instrumentation can be used; otherwise this is not measured in a macro-audit |

Table 2.16 Energy Management Opportunities in Process Furnaces, Dryers and Kilns

| Step | Actions |
|---|---|
| Determine the Need | ❑ Document the load on the furnace, dryer or kiln – perform an energy balance on the heat loss from the unit itself.<br>❑ Evaluate the process requirements in terms of product loading and thermodynamic requirements.<br>❑ Consider carefully any effect an EMO might have on the quality of the end product. |
| Match the Need | ❑ Ensure that process temperature is not significantly greater than the highest requirement. Operate at the minimum possible temperature and/or airflow.<br>❑ In a staged system, sequence burners on-line to follow the demand for heat.<br>❑ Minimize the requirement for furnaces on hot standby.<br>❑ Monitor overall process heating performance (fuel to product).<br>❑ Minimize load swings and schedule production to optimize use of furnace, dryer or kiln capacity when possible.<br>❑ Review operator procedures for minimal energy use practices. |
| Maximize Efficiency | ❑ Regularly check combustion efficiency.<br>❑ Check and adjust excess air levels on a regular basis.<br>❑ Keep burner assemblies and controls adjusted and calibrated.<br>❑ Maintain seals, air ducts, breeching and access doors to ensure airtightness.<br>❑ Relocate air intakes to ensure driest possible air is used in kilns.<br>❑ Ensure that surface insulation is up to standard.<br>❑ Install electronic controls for combustion and temperature control. |
| Optimize Supply | ❑ Relocate combustion air intake or de-stratify plant air to take advantage of waste heat to preheat combustion air.<br>❑ Install a non-condensing economizer to capture heat in flue gases.<br>❑ Install a flue gas condenser to capture additional heat in flue gases.<br>❑ Reclaim heat from product cooling. |

### Process Heating References

*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001
Web site: iac.rutgers.edu/manual_industrial.php

*Boilers and Heaters*: *Improving Energy Efficiency*, Natural Resources Canada, 2001
oee.nrcan.gc.ca/Publications/infosource/Pub/cipec/BoilersHeaters_foreword.cfm

Boiler Efficiency Calculator, Natural Resources Canada, 2006
oee.nrcan.gc.ca/industrial/technical-info/tools/boilers/index.cfm

*Team Up for Energy Savings – Waste-Heat Recovery* (fact sheet), Natural Resources Canada, 2005
oee.nrcan.gc.ca/publications/industrial/cipec/waste-heat.cfm

## 2.9 Refrigeration Systems

Refrigeration systems are used in many different environments – residential, commercial and industrial. All these systems are designed for one basic purpose: to move heat from a lower temperature (heat source) to a higher temperature (heat sink) medium, using a transfer fluid (refrigerant). Since this is the reverse of the natural direction of heat flow, energy input is required, usually in the form of electricity. Depending on the amount of heat to be moved, the cost of refrigeration can be significant. Of particular importance to the energy audit are the various energy losses occurring in the system, as indicated in the Sankey diagram below.

Refrigeration systems are relatively complex, and their efficiency is affected by the operating conditions. While a system is typically rated for a particular maximum or design cooling load, it usually operates for most of its life at some fraction of that output, or at partial load. The efficiency of a cooling system can vary significantly with load, depending on the capacity control method employed. Consequently, it is important to evaluate system performance and efficiency over the range of actual loads.

The energy required to run a cooling system is proportional to the temperature difference between the heat source and heat sink. Therefore reducing the temperature difference between the cooled medium (e.g. refrigerated storage) and the condensing (e.g. cooling tower) temperature has a substantial effect on the energy input to the system. Various measuring devices such as a wattmeter, thermometer, psychrometer or pressure gauge can be useful in evaluating the cooling efficiency of refrigeration systems.

The various losses shown in the Sankey diagram in Figure 2.9 are itemized and defined in Table 2.17.

Identifying energy savings opportunities in refrigeration systems involves critically assessing the existing energy use. Table 2.18 provides examples of EMOs for refrigeration systems according to the three-step method detailed in Section B-8, "Identify Energy Management Opportunities."

**Figure 2.9 Sankey Diagram of Refrigeration System Energy Flows**

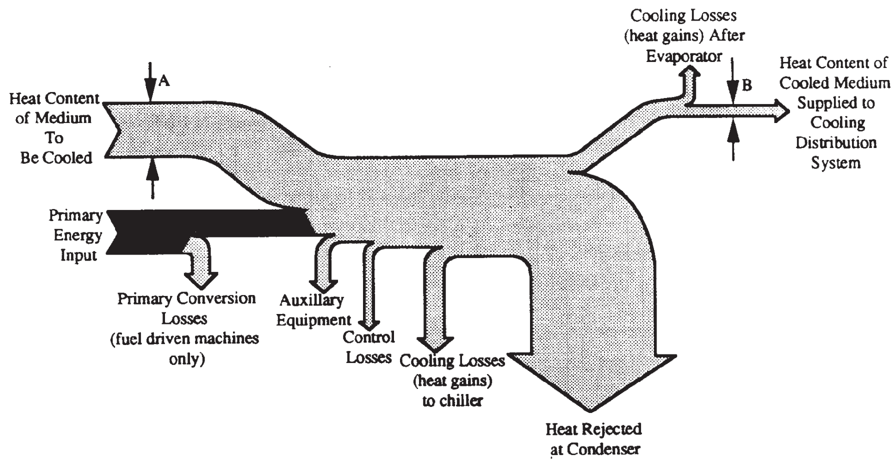


Table 2.17 Energy Flows in a Refrigeration System

| Energy Flow | Description | Key Factors for Evaluation of Flow | Portable Instrumentation Used for Evaluation |
|---|---|---|---|
| Heat content of medium to be cooled | Both sensible and latent heat content of load | Temperature and relative humidity | Temperature and humidity measurement device |
| Primary energy input | (Electrical) energy input to system | % of rated load, PF | Handheld power meter (should indicate watts and power factor) |
| Primary conversion losses | Electric – motor and shaft losses between motor and compressor, pump, fan, etc. | % of rated load, PF | |
| Auxiliary equipment | Support equipment – fans, pumps, heaters, etc. | Continuous (unnecessary) operation, type of control | Power meter |
| Control losses | Losses due to drop in efficiency at part load | Type of capacity control (speed control, hot gas bypass, etc.) | Recording power meter (track input over wide load range) |
| Cooling losses | Heat gained externally or internally before coolant reaches destination | Poor insulation and air leaks | Temperature measurement device |
| Heat rejected at condensor | | Flow, pressure and temperature difference of refrigerant across condensor | Temperature measurement device, system gauges, airflow meter |
| Cooling losses after evaporator | A measure of the evaporator delivery efficiency | Temperature at evaporator and at cooled medium | Temperature measurement device, airflow meter |
| Heat content of cooled medium supplied by cooling distribution system | The heat remaining in the air or water after it is cooled | | Temperature measurement device |

Table 2.18 Energy Management Opportunities in Refrigeration Systems

| Step | Actions |
|---|---|
| Determine the Need | ❑ Document the cooling load and temperature requirement – ideally with a profile.<br>❑ Consider the varying requirement for temperature:<br>  ❑ in process, possibly by product or process stage<br>  ❑ in HVAC, according to season and occupant requirement<br>❑ Consider the effect that other energy management actions at the point of end-use may have upon the needs of the system – this may change over time. |
| Match the Need | ❑ Use conservative practices at the point of end-use to minimize the cooling load.<br>❑ Calibrate controls and set temperatures to highest acceptable levels.<br>❑ Avoid, if possible, simultaneous heating and cooling.<br>❑ Ensure appropriate capacity control of refrigeration systems:<br>  ❑ Controls for multiple units<br>  ❑ Modulation (without false loading) for single units<br>❑ Avoid the use of hot gas bypass for capacity control.<br>❑ Investigate the possibility of raising the evaporator temperature through such actions as chilled water reset to higher temperatures. Use as high a temperature as possible while still maintaining the cooling requirement.<br>❑ Ensure that defrost controls are set properly and review the setting regularly. |
| Maximize Efficiency | ❑ Ensure that all heat exchange surfaces are cleaned and maintained regularly.<br>❑ Lower condensing temperatures by ensuring free circulation of air around condensing units and cooling towers.<br>❑ Ensure that cooling towers are effectively maintained to obtain the lowest water temperature possible.<br>❑ Investigate floating head pressure or liquid pressure boost to reduced condensing temperature and pressure on a seasonal basis.<br>❑ Replace compressors with high efficiency units (COP). |
| Optimize Supply | ❑ Utilize thermal storage to optimize operation of cooling systems and optimize the purchase of electricity on a time-of-day basis.<br>❑ Utilize de-superheaters to recover heat rejected from condensers.<br>❑ Consider deriving a “free cooling” capacity directly from cold open air (e.g. in wintertime), thus not having to use a compressor and therefore electricity.<br>❑ Consider using only water as refrigerant for process cooling water. |

## Refrigeration System Reference

*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001
Web site: iac.rutgers.edu/manual_industrial.php

## 2.10 Steam and Condensate Systems

Steam is commonly used as the medium to distribute heat from the boiler to its point of end-use. The same characteristics that make it useful as a transport medium (high heat-carrying capacity) also make its distribution system susceptible to energy loss and waste. Steam supply and condensate return systems require regular inspection and maintenance (and sometimes a little detective work) in order to minimize or eliminate these losses.

After steam is generated in a boiler, it is delivered under pressure to the load by the steam distribution system. Typically, the latent heat in the steam is converted in a heat exchanger and the steam is condensed (returned to a liquid state). This hot condensate is returned via the condensate return system to the boiler make-up water to be reheated and start the cycle again. In some cases, live steam is injected directly into the process, in which case no condensate is returned.

Steam systems can be classified by pressure and condensate systems by their return method (gravity or pumped). Because of the inherent danger in pressurized steam systems, provincial regulations are quite stringent on system modifications. Any EMOs requiring piping or equipment changes must be designed, implemented and inspected by qualified staff.

Optimizing a steam/condensate system can be summarized by two actions – get the steam to its destination and get the condensate back to the boiler with minimal losses. Common losses are steam leaks, including stuck-open steam traps and poorly insulated or uninsulated pipes. The non-contact (infrared) thermometer is a useful tool in tracking down steam leaks in steam and condensate systems. A by-product of an optimized steam/condensate system is savings on water treatment chemicals – returned condensate contains not only heat energy but also valuable treatment chemicals.

The various losses shown in the Sankey diagram in Figure 2.10 are itemized and defined in Table 2.19.

Identifying energy savings opportunities in steam and condensate systems involves critically assessing the existing energy use. Table 2.20 provides examples of EMOs for steam and condensate systems according to the three-step method detailed in Section B-8, “Identify Energy Management Opportunities.”

Figure 2.10 Sankey Diagram of Steam and Condensate Energy Flows

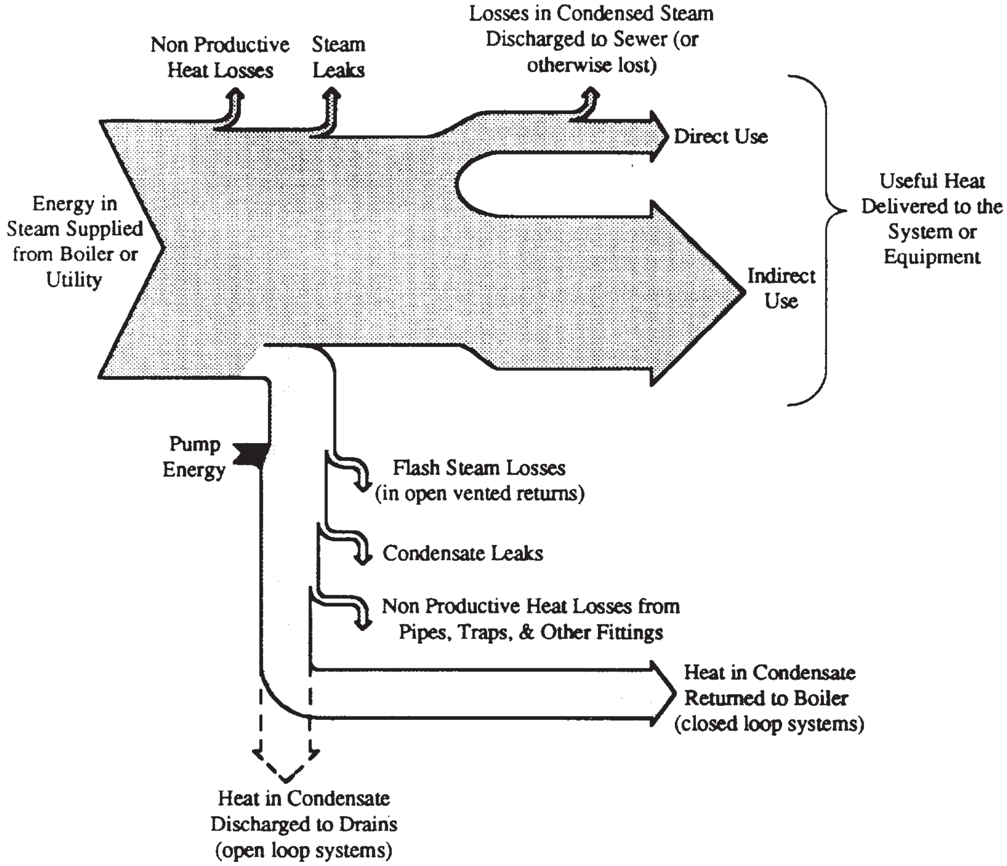


**Table 2.19 Energy Flows in Steam and Condensate Systems**

| | Energy Flow | Description | Key Factors for Evaluation of Flow | Portable Instrumentation Used for Evaluation |
|---|---|---|---|---|
| Steam | Non-productive heat losses | Heat lost from uninsulated pipe surfaces | Temperature, surface area, insulation levels | Non-contact thermometer or infrared temperature measurement device |
| | Steam leaks | Holes in steam piping | Plume size, system pressure | Non-contact thermometer or infrared temperature measurement device, ultrasonic detector |
| | Condensed steam lost | Condensate water discharged to sewer or elsewhere | Temperature, volume | Thermometer |
| | Direct use | Live steam injected into process | Control of steam injection | |
| | Indirect use | Heat delivered through heat exchanger | | |
| Condensate | Flash steam losses | When pressurized, condensate is released to atmospheric pressure, some evaporates as flash steam due to pressure drop | Temperature, pressure, flash tank design | Thermometer |
| | Condensate leaks | Holes in condensate return system | Water leaks | |
| | Non-productive heat losses | Heat lost from uninsulated pipe surfaces, traps, fittings | Temperature, surface area, insulation levels | Non-contact thermometer or infrared temperature measurement device |
| | Condensate returned to boiler | In closed-loop system, condensate is added to boiler make-up water | % return, condensate temperature, volume of make-up water | Thermometer |

Table 2.20 Energy Management Opportunities in Steam and Condensate Systems

| Step | Actions |
|---|---|
| Determine the Need | ❑ Document the end-use load – ideally an hourly profile.<br>❑ Determine design flow, pressure and steam quality requirements.<br>❑ This may require an examination of the loads downstream of the steam distribution system.<br>❑ The load on the system will change as a result of other energy management actions at the point of end-use – this step may need to be revised periodically. |
| Match the Need | ❑ Ensure that boiler temperature and operating pressure are not significantly greater than the highest requirement. Operate at the minimum possible temperature and/or pressure.<br>❑ Ensure correct pipe sizing to avoid excessive supply pressures to overcome pressure drops.<br>❑ Ensure that system is not oversized for load-increasing heat losses.<br>❑ For direct steam use, ensure that control of steam release is adequate.<br>❑ For indirect use, ensure that heat exchanger is matched to load and controlled.<br>❑ Regularly check steam and condensate piping systems for leaks and repair.<br>❑ Track down and repair faulty steam traps.<br>❑ Shut off steam to equipment when not being used.<br>❑ Overhaul pressure-reducing stations. |
| Maximize Efficiency | ❑ Check and adjust water treatment procedures on a regular basis.<br>❑ Disconnect and seal or valve off any unused steam or condensate branches.<br>❑ Ensure that piping and fixture insulation is up to standard.<br>❑ Insulate uninsulated pipes, flanges, fittings and equipment.<br>❑ Return as much condensate as is economically and operationally viable.<br>❑ Clean heat transfer surfaces regularly. |
| Optimize Supply | ❑ Reclaim heat from any condensate or steam that must be dumped.<br>❑ Redirect or reuse "flash steam."<br>❑ Replace pressure-reducing valves with back-pressure small steam turbines. |

### Steam and Condensate System References

*Modern Industrial Assessments: A Training Manual*, Version 2.0, Rutgers, The State University of New Jersey, September 2001
Web site: iac.rutgers.edu/manual_industrial.php

*Team Up for Energy Savings – Steam and Condensate Piping Systems* (fact sheet), Natural Resources Canada, 2005
oee.nrcan.gc.ca/publications/industrial/cipec/steam-condensate.cfm

# 3 CONDITION SURVEY CHECKLISTS

## 3.1 Windows

**In this checklist and those that follow, points are awarded in each category according to the guidelines that follow; the maximum that can be accumulated for each system is as indicated in the table (i.e. maximum possible for windows is 10; the actual total is compared to this).**

| Date: ____________________<br>Auditor: __________________<br>Comments: ________________<br>__________________________ | | Storms | Solar Protection | Tight Fit | Minor Infiltration | Major Infiltration | Cannot Be Opened | Can Be Opened | Weatherstripped | | | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No.** | **Max Points = 10**<br>**Location** | **2** | **2** | **2** | **1** | **0** | **3** | **0** | **1** | | | | | | |
| | | | | | | | | | | | | | | | |

**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 a 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. Weatherstripping 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. It will be opened to “regulate” room temperature.

**1 point** if window is weatherstripped all around and the weatherstripping is in good condition.

## 3.2 Exterior Doors

| Date: ______ Auditor: ______ Comments: ______ | | Air Lock | Door Has Closer | Closer Has No Hold-Open | Closer Has a Hold-Open | Snug Fit | Average Fit | Loose Fit | Weatherstrip 4 Edges | Weatherstrip Jamb Head | No Weatherstrip | Wind Screens or Other | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 10<br>Location | 2 | 1 | 1 | 0 | 2 | 1 | 0 | 2 | 1 | 0 | 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 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 weatherstripping exists on all four edges and is in good condition. (Thresholds with elastic or fibre to close the space and astragals on double doors are considered weatherstripping.)

**1 point** if weatherstripping exists on jambs and head only.

**0 points** if no weatherstripping exists or if it exists and is in poor condition.

**1 point** if door is protected from outside wind. This can be building design, windscreen or shrubbery.

## 3.3 Ceilings

| Date: ____________<br>Auditor: ____________<br>Comments: ____________<br>____________ | | Drop Ceiling | Insulated Drop Ceiling | Insulated Regular Ceiling | Space Not Mech. Vented | All Panels in Place | Panels Broken | Panels Missing | | | | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 6<br>Location | 1 | 1 | 1 | 1 | 2 | 1 | 0 | | | | | | | |
| | | | | | | | | | | | | | | | |

**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 there is no insulated regular ceiling.

**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 and 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.

## 3.4 Exterior Walls

| Date: ____________ Auditor: ____________ Comments: ____________ ____________ | | Insulated | Not Insulated | Solar Protection | Watertight | Cracked or Broken | Open to Unconditioned Space | | | | | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 7<br>Location | 3 | 0 | 2 | 2 | 1 | 0 | | | | | | | | |
| | | | | | | | | | | | | | | | |

**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 sunscreens.

**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.

## 3.5 Roofs

Date: ______________________

Auditor: ____________________

Comments: ___________________

____________________________

| No. | Max Points = 6 / Location | Dry Insulation | Wet Insulation | Reflective Surface | Ventilation Under Roof | No Leaks | Small Leaks | Many Leaks | | | | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 0 | 1 | 1 | 2 | 1 | 0 | | | | | | | |
| | | | | | | | | | | | | | | | |

**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 colour and condition of surface (gravel, etc.).

**1 point** if mechanical ventilation exists between roof and ceiling below. This should be properly sized so adequate airflow exists.

**2 points** if no leaks exist in the roof.

**1 point** if minor leaks exist.

**0 points** if there are many leaks.

## 3.6 Storage Areas

| Date: ______ Auditor: ______ Comments: ______ | | Not Conditioned | Door Closed | No Windows | One Window | Two or More Windows | Used as Designed | Not Used as Designed | | | | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 6<br>Location | 1 | 1 | 2 | 1 | 0 | 2 | 0 | | | | | | | |
| | | | | | | | | | | | | | | | |

**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 use.

## 3.7 Shipping and Receiving Areas

| | | Weather Protection Good | Weather Protection Average | Weather Protection Poor | Individual Stalls | One Large Area | Doors Closed | Doors Opened | Not Temperature-Conditioned | Temperature-Conditioned | | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date: ____ Auditor: ____ Comments: ____ | | | | | | | | | | | | | | | |
| No. | Max Points = 6 / Location | 3 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | | | | | |
| | | | | | | | | | | | | | | | |

**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 conditions. This would be an open area directly exposed to the outside conditions.

**1 point** if individual truck stalls exist so that 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.

## 3.8 Lighting

| Date: ____ Auditor: ____ Comments: ____ | | No Decorative Lighting | Light Work Area | Light Entire Room | Diffusers Good | Diffusers Average | Diffusers Poor | Reflection Good | Reflection Average | Reflection Poor | Source Appropriate | Source Not Appropriate | Lights Vented | Lights Turned Off | Illumination Adequate | Excessive Illumination | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **No.** | **Max Points = 10**<br>**Location** | **1** | **1** | **0** | **2** | **1** | **0** | **2** | **1** | **0** | **1** | **0** | **1** | **1** | **1** | **0** | |
| | | | | | | | | | | | | | | | | | |

Lighting level measurements can be made with small, low-cost portable light meters that are available in a variety of lux ranges. The lux is the unit of illuminance, where one lux is equal to one lumen per square metre; the lumen is the unit of measure for the light emitted by a source. Portable light meters have a typical accuracy of ±15%; therefore, care needs to be taken that they are used in accordance with operating instructions.

Guidelines for recommended levels of illumination are provided in Table 3.1.

**Table 3.1 Illuminating Engineering Society of America (IES) – Recommended Levels of Illumination for Different Classes of Visual Task**

| Class of Visual Task | Examples | Illumination (lux) |
|---|---|---|
| Public Areas with Dark Surroundings | Lobbies | 20 – 50 |
| Simple Orientations for Short Temporary Visits | Corridors; Storage Rooms | 50 – 100 |
| Working Spaces where Visual Tasks Are only Occasionally Performed | Waiting Rooms | 100 – 200 |
| Performance of Visual Tasks of High Contrast or Large Size | Conference Rooms; Printed Material; Typed Originals; Ink Handwriting; Rough Industrial Work | 200 – 500 |
| Performance of Visual Tasks of Medium Contrast or Small Size | Engineering Office; Medium Pencil Handwriting; Poorly Printed or Reproduced Material; Medium Industrial Work | 500 – 1000 |
| Performance of Visual Tasks of Low Contrast or Very Small Size | Hard Pencil Handwriting on Poor Quality Paper; Faded Copies; Difficult Industrial Work | 1000 – 2000 |
| Performance of Visual Tasks of Low Contrast and Very Small Size over a Prolonged Period | Fine Industrial Work; Difficult Inspection | 2000 – 5000 |
| Performance of Very Prolonged and Exacting Visual Tasks | Extra-fine Work | 5000 – 10 000 |
| Performance of Very Special Visual Tasks of Extremely Low Contrast and Small Size | Surgical Procedures; Sewing | 10 000 – 20 000 |

## ILLUMINATION RATING INSTRUCTIONS

**1 point** if extensive decorative lighting has been eliminated where used for appearance only (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 the light source (T8, HPS, MH, LED ''Exit'' lamps) are appropriate for the application.

**0 points** if an inappropriate light source is used.

**1 point** if lights are properly vented 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 "overilluminated" for designed use.

**0 points** if two or more lamps have blackened ends or are glowing without lighting.

## 3.9 Food Areas

| Date: ____ Auditor: ____ Comments: ____ | | Equipment Turned Off | Equipment Left On | Refrigeration Doors Closed | Refrigeration Doors Ajar | Faucets Not Leaking | Faucets Leaking | Access Doors Closed | Good Vent Hoods | Average Vent Hood | Poor Vent Hood | Adequate Ventilation | Refrigeration Equip. Good | Refrigeration Equip. Average | Refrigeration Equip. Poor | Heat Recovery System | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 15<br>Location | 2 | 0 | 1 | 0 | 1 | 0 | 3 | 2 | 1 | 0 | 1 | 2 | 1 | 0 | 3 | |
| | | | | | | | | | | | | | | | | | |

### 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 outside or inside 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, and air passage over condenser is clear.

**1 point** if refrigeration equipment is in average condition, dust and dirt exist on condensers but the airflow is not restricted, and 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 airflow, and 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 wastewater or the refrigeration equipment.

## 3.10 Heating and Boiler Plant

| Date: ________ Auditor: ________ Comments: ________ | | Insulation Good | Insulation Average | Insulation Poor | Flanges Insulation | No Leaks | Some Leaks | Many Leaks | Automatic Controls | Standard Op. Procedures | Steam Meter | Fuel Meter | Make-Up Water Meter | Preventive Maintenance | Fix as Required | Energy Recovery | Economizer Controls | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 15<br>Location | 2 | 1 | 0 | 2 | 2 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 3 | 2 | |
| | | | | | | | | | | | | | | | | | | |

**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 points** if the steam system has many leaks, and if 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 water-to-water heat exchanger, an air wheel or any of several types in common use.

**2 points** if heat generation is controlled by a system using an economizer and comparing inside and outside temperature.

## 3.11 Heat Distribution

| Date: ____ Auditor: ____ Comments: ____ | | Insulation Good | Insulation Average | Insulation Poor | Flanges Insulation | No Leaks | Some Leaks | Many Leaks | Control Good | Control Average | Control Poor | Standard Op. Procedures | Preventive Maintenance | Fix as Required | Condition as Required | Minimum Fresh Air | Zone Control Good | Zone Control Average | Zone Control Poor | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 14<br>Location | 2 | 1 | 0 | 2 | 2 | 1 | 0 | 2 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 2 | 1 | 0 | |
| | | | | | | | | | | | | | | | | | | | | |

**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, and if valves, regulators and traps have dripping leaks, steam plumes, etc.

**2 points** if the control system for each area is adequate. The control system maintains the temperature in each room close to the thermostat setting.

**1 point** if the control system for 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.

**1 point** if the ventilation system controls provide a minimum fresh air volume for a healthy environment rather that a fixed fresh air volume.

**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 allows only general areas to be secured when conditions dictate.

**0 points** if zone control cannot be secured without securing a large general area.

## 3.12 Cooling Plant

| Date: ____ Auditor: ____ Comments: ____ | | Insulation Good | Insulation Average | Insulation Poor | Flanges Insulated | Standard Op. Procedures | Ind. Power Meter | Preventive Maintenance | Fix as Required | Energy Recovery | Outside Air Used (Free Cool) | Enthalpy Control (T & RH) | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 12<br>Location | 2 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 3 | 2 | 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 that 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 water-to-water heat exchanger, an air wheel or any of several types in common use.

**2 points** if outside air is used 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.

## 3.13 Cooling Distribution

| Date: ________________<br>Auditor: ______________<br>Comments: ____________ | | Insulation Good | Insulation Average | Insulation Poor | Flanges Insulation | Standard Op. Procedures | Control Good | Control Average | Control Poor | Preventive Maintenance | Fix as Required | Condition as Required | Constant Conditioning | Zone Control Good | Zone Control Average | Zone Control Poor | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 11<br>Location | 2 | 1 | 0 | 2 | 1 | 2 | 1 | 0 | 1 | 0 | 1 | 0 | 2 | 1 | 0 | | | |
| | | | | | | | | | | | | | | | | | | | |

**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 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.

**2 points** if the control system for each area is adequate. The control system maintains the temperature in each room close to the thermostat setting.

**1 point** if the control system for 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 allows only general areas to be secured when conditions dictate.

**0 points** if zone control cannot be secured without securing a large general area.

## 3.14 Electrical Power Distribution

| Date: ______ Auditor: ______ Comments: ______ | | Recording Meter | Usage Pattern | Power Co. Coordination | Power Peak Warning | Power Demand Limited | Standard Op. Procedures | Preventive Maintenance | Fix as Required | 90% Power Factor | | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 10 / Location | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 2 | | | | | |
| | | | | | | | | | | | | | | | |

**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 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 definite standard operating procedures are used. These must be written and posted near the control panel.

**1 point** if a 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.

## 3.15 Hot Water Service

| | | Insulation Good | Insulation Average | Insulation Poor | No Faucet Leaks | Faucet Leaks | Standard Op. Procedures | Preventive Maintenance | Fix as Required | DHW Temperature < 60°C | Process HW Temp. Optimized | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date: ____ Auditor: ____ Comments: ____ | | | | | | | | | | | | | | | |
| No. | Max Points = 8<br>Location | 2 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 2 | | | | |
| | | | | | | | | | | | | | | | |

**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.

**1 point** if the DHW temperature is set less than 60°C.

**2 points** if process hot water temperatures have been optimized for the particular requirement.

## 3.16 Water Service

| Date: ____ Auditor: ____ Comments: ____ | | No Faucet Leaks | Faucet Leaks | Standard Op. Procedures | Preventive Maintenance | Fix as Required | No Equip. Use Water Once | Equipment Off | | | | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 5<br>Location | 1 | 0 | 1 | 1 | 0 | 1 | 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.

## 3.17 Compressed Air

Date: ______________________

Auditor: ____________________

Comments: __________________

| No. | Max Points = 8<br>Location | No Outlet Leaks | Outlet Leaks | Compressors Sized | Compressors on Demand | Standard Op. Procedures | Preventive Maintenance | Fix as Required | Supply Pressure Minimized | Air Quality Appropriate | Controls Prevent Blow-Off | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 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.

**1 point** if the compressor discharge (supply) air pressure has been minimized for application.

**1 point** if the air quality (dew point, temperature, cleanliness) is appropriate, not better than required.

**1 point** if the controls prevent blow-off of air for centrifugal compressors.

## 3.18 Process Heating

| Date: ____<br>Auditor: ____<br>Comments: ____ | | Flue Gas Waste Heat | High Temp. Areas Insulated | Insulation Poor | Exhaust Process Air | Standard Op. Procedures | Combustion Efficiency | Preventive Maintenance | Fix as Required | | | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = 6<br>Location | 1 | 2 | 0 | 1 | 1 | 1 | 1 | 0 | | | | | | |
| | | | | | | | | | | | | | | | |

**PROCESS HEATING RATING INSTRUCTIONS**

**1 point** if the flue gas waste heat from processing equipment is extracted to heat relatively low temperature make-up, 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 process air is exhausted.

**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.

## 3.19 Checklist Template

| Date: ___________________<br>Auditor: _________________<br>Comments: _______________ | | | | | | | | | | | | | | | | | | Total Points |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Max Points = P<br>Location | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | | | | | | |
| Total Points for Section | | | | | | | | | | | | | | | | | | |
| Rating for Boiler Plant Systems $= \frac{(100 \times \text{Total Points})}{\text{Number of Items} \times P}$ | | | | | | | | | | | | | | | | | | |

### Reference

*Energy Efficiency Planning and Management Guide*, Natural Resources Canada, 2002
oee.nrcan.gc.ca/publications/infosource/pub/cipec/efficiency/index.cfm

# 4 INSTRUMENTATION FOR ENERGY AUDITING

## 4.1 Introduction

This section describes the instrumentation and measurement techniques relevant to energy audit activities. A brief review of measurement principles is provided. Finally, a number of useful, relatively easy-to-use and readily available instruments have been selected from the toolboxes of experienced auditors and are presented in practical terms. Basic instrument types and usage are described along with sample specifications, sources and tips for effective use. While these will meet all the requirements of the type of energy audit described in this guide, the more experienced auditor can supplement them with more advanced sensors and recording devices.

An energy auditor must have a basic understanding of measurement techniques and instrumentation in order to be knowledgeable about the purchase or rental and use of the equipment. Both the correct instrument and its correct use are fundamental requirements for obtaining useful measured data.

### 4.1.1 | Safety First

Measurements of any physical system or process should always be undertaken with due regard for safety procedures by persons trained in and familiar with the specific equipment and processes involved. Measurements of electrical energy use, amps, volts, watts, etc. are generally made on live equipment and conductors and should be undertaken only by properly trained and qualified technical staff. Under no circumstances should live electrical equipment be opened by unqualified persons.

## 4.2 Understanding Measurement for Energy Auditing

### 4.2.1 | Representative Measurement

Ordinarily, an energy audit of the type discussed in this guide takes place over a limited period of time, usually of no more than a month in length. During the course of the audit measurements will be taken to form the basis for the many energy calculations involved in developing energy inventories, profiles and eventually estimates of energy savings. Most audit measurements provide instantaneous or short-term records of performance over a short time interval. On the other hand, most savings calculations are made on an annual basis, because most organizations want to know what the energy management measures will save them next year.

While the accuracy of any of these measurements is important, as discussed in the next section, just as important is the relevance of these short-term audit measurements to the conditions that exist over the long term, that is, the annual period for which savings calculations are being made. While it may be easy to measure the power consumption of an air compressor motor accurately with a handheld power meter and then multiply by the hours of operation per year to determine annual energy consumption, we need to consider whether the reading that we took is representative of the power consumption tomorrow, next week or next month.

The most accurate instantaneous measurement may be accurate only to +/– 50% on an annual basis. Clearly, care must be exercised when extrapolating short-term measurements to longer-term results. A useful technique for avoiding such errors is to attempt to take measurements during periods that are representative of the operation of the particular equipment involved. Tips for taking valid and representative measurements with each instrument are included in the following sections.

To some extent, the energy balance techniques presented in this guide provide a check against gross errors. For example, power measurements taken on equipment must sum to the total load as registered on the utility's demand meter and recorded on the bill. Likewise, the individual energy consumptions derived from the application of operating hours must sum to the total metered energy on the bill. While this is not a guarantee against this type of error, looking for these balances also forces the auditor to think in terms of long-term conditions.

### 4.2.2 | Measurement Accuracy

The accuracy of the measuring device (instrumentation) and the proper use of the instrument are two items that can affect measurement accuracy. Before purchasing or leasing instrumentation, it is important to determine how accurate the measurement needs to be and to select instrumentation and measurement strategies that meet those needs. One can generally expect to pay more for more accurate instrumentation, but more expensive and accurate instruments often demand more careful and time-consuming measurement techniques.

For specialized and "once only" measurements it may often be beneficial, both in terms of accuracy and overall cost, to engage competent independent technicians to do the measurement.

When evaluating instrumentation for purchase or lease, it is useful to know how different manufacturers define the accuracy of their equipment. Some common ways of defining accuracy are:

- percentage of full scale
- percentage of actual reading value, a "resolution"; this is common for instruments with digital read-out and is often stated as the number of digits

In most cases, particularly for quality instruments, the stated accuracy will be for a particular set of circumstances: e.g. the type of wave forms or frequency might be stated for electrical measurements. Often some indication will be given of loss of accuracy that will occur when the instrument is used outside the particular circumstances.

For the purposes of the macro energy audit, the requirement for accuracy may not be extremely demanding. As stated previously, a highly accurate measurement today may be of only limited accuracy over the long term. Accordingly, the auditor may redirect effort and expense from the purchase and use of highly accurate instruments to better interpretation of less accurate data over a long period.

### 4.2.3 | Spot and Recording Measurements

Although many of the measurements taken in any energy audit are instantaneous or “spot” measurements, there may be an opportunity to perform short-term recording measurements. Recording measurement, applied over carefully selected time intervals, can provide far more representative data for long-term calculations.

For example, the auditor may have noted from spot measurements of an air compressor that its “idle” power, consumed when not supplying an air demand, was 70% of expected full power. This suggests that application of a controller to shut down the compressor when not required might be a good energy savings opportunity. But, does this condition exist for a significant period of time? Plant staff report that the compressed air demand is “fairly steady.” In this situation the use of a recording power meter, taking minute-by-minute readings for 48 hours over the course of a full production day and possibly one shutdown day, could provide a better picture of the situation. The recording power meter is an extremely valuable tool for the energy auditor.

Other useful recording tools, often called data loggers, include the following:

- temperature logger
- illumination logger
- occupancy logger
- event logger
- general purpose data logger

### 4.2.4 | Useful Features of Digital Instrumentation

For auditing and many other purposes, digital meters (DMs) are replacing conventional analogue instruments because of lower cost and ease of use. Their accuracy is normally more than adequate for most auditing purposes. Some features that are notably useful include:

***Multiple measurements*** – integrated instruments that can measure and in some cases record two or more parameters such as temperature, humidity, on/off states, illumination levels and one or more general-purpose analogue inputs (see below) for other sensors.

***Reading freeze function*** – facilitates readings where the display cannot be read as the measurement is taken.

***Display invert*** – may make reading the meter easier in difficult locations – tachometers often feature this capability.

***Analogue output*** – a standard analogue signal (0–10 V, 4–20 mA, etc.) proportional to the reading – it can be used with a strip chart recorder or general-purpose data logger to provide a recording function.

## 4.3 The Auditor's Toolbox

The following sections include details of the instruments commonly found in the energy auditor's toolbox:

- electric power meter
- combustion analyser
- digital thermometer
- infrared thermometer
- psychrometer (humidity measurement)
- airflow measurement devices
- tachometer
- ultrasonic leak detector

### 4.3.1 | Other Useful Tools & Safety Equipment

In addition to the instruments, there are a few other items that have been found to come in handy:

- binoculars and a small flashlight – for reading nameplates
- duct tape and tie wraps – for securing recording meters
- multi-screw driver, adjustable wrench and pliers
- tape measure
- bucket and stopwatch – for gauging water flows to drain
- safety glasses, gloves and ear plugs
- caution tape – for alerting others to the presence of recording meters

## 4.4 Electric Power Meter

Electric power measurement instruments, are some of the most powerful and useful tools available to the energy auditor. With existing measurement and data-recording technology, a modest investment will provide a wealth of information. Electrical power and energy measurements provide an operational fingerprint of the many systems and pieces of equipment in a facility. They show clearly where and how electrical power and energy are used and provide insight into how equipment and systems consume other forms of energy. Typical audit applications are provided below.

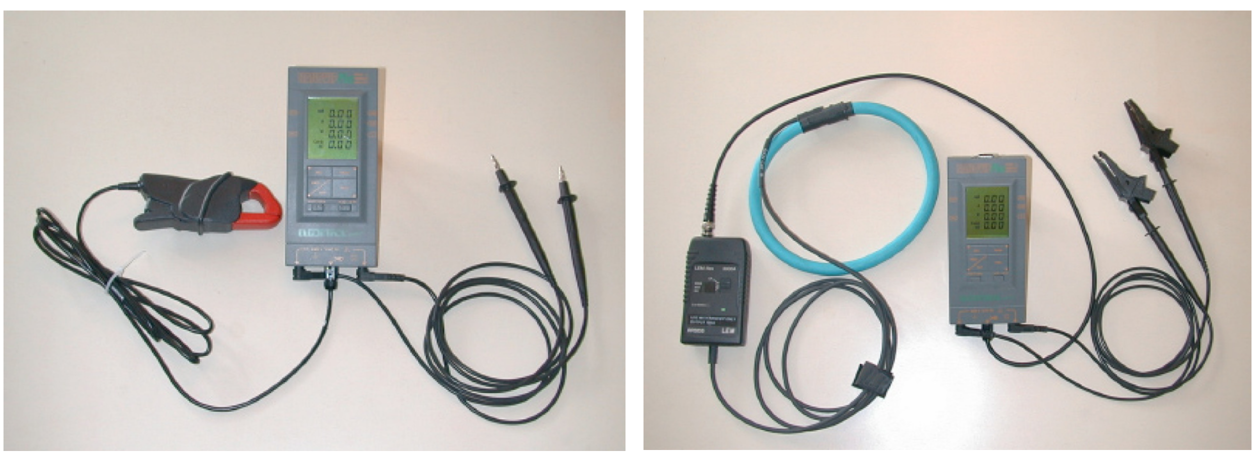
With today's technology there is no need for an auditor to carry separate volt, amp and power factor meters in order to be able to measure electrical power in watts. The modern portable wattmeter provides all of these measurement functions, integrated in one package. This section describes selected types of wattmeters applicable to energy audits and incorporating all the above measuring functions. For the reader requiring knowledge of basic electrical measurements, a technical overview of current, voltage and power factor is provided in the energy basics section. Further information can be found in any basic electricity textbook.

As stated previously, any measurements with these types of instruments should be taken only by trained staff who are authorized to work on live electrical equipment.

### 4.4.1 | Handheld Single-Phase Digital Wattmeter

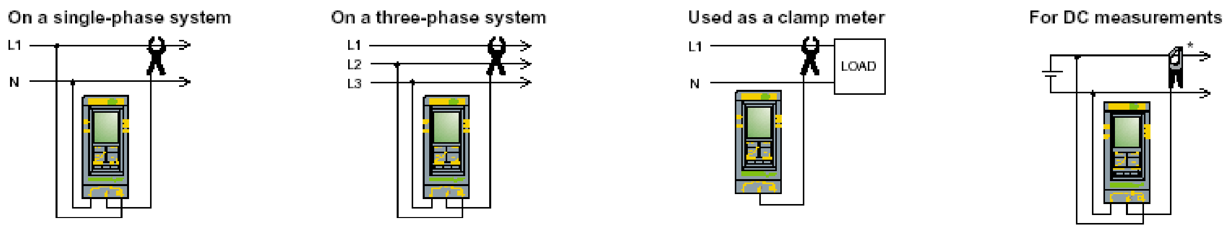
The single-phase wattmeter will measure voltage via two contact probes and current with the use of a clip-on current transformer, commonly referred to as a current clamp. A typical meter is illustrated in Figure 4.1. The configuration shown on the left-hand side of Figure 4.1 is capable of metering 600-V systems up to a maximum current of 200 amps. Using the flexible current transducer shown on the right-hand side of Figure 4.1, this type of meter can meter currents from 30 to 3000 amps. The particular metering shown can also record or log up to 4000 data points for short-term surveys or profiles. While spot measurements require only instantaneous contact with conductors for voltage readings, the recording measurements require the use of optional alligator clips as shown in Figure 4.1.

**Figure 4.1 Handheld Wattmeter**



Primarily intended for measurements in single-phase circuits, these meters often provide the functionality required to perform measurements on balanced three-phase power systems. Typical connections are illustrated in Figure 4.2.

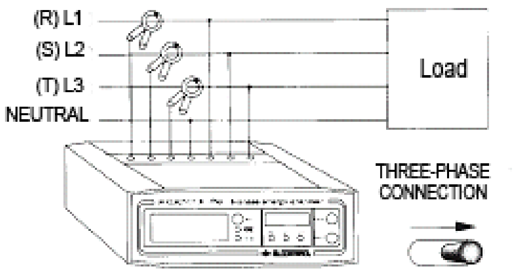
Figure 4.2 Typical Connection for Single-Phase Wattmeter




## 4.4.2 | Three-Phase Digital Wattmeter

For true measurements on three-phase systems, depending upon whether the system is three- or four-wire, two- or three-phase currents and three-phase voltages must be measured. Figure 4.3 shows a three-phase typical connection diagram.

Figure 4.3 Three-Phase Typical Connection




## 4.4.3 | Applications

***Development of load inventories*** – As detailed in the “Energy Inventory” Section B-7.2, the handheld wattmeter can expedite collection of individual load kW values.

***Demand profiling of a service entrance, sub-station or MCC*** – For developing plant, building or system-wide demand profiles as detailed in the “Demand Profile” Section B-6.2. This will require the use of a three-phase meter, often with optional current transducers similar to those shown in Figure 4.1, to meter the large currents in the buss bars and conductors.

***Process system or equipment*** – It may be possible to isolate a group of loads specific to a particular system, equipment, manufacturing cell or plant process.

***Individual load metering*** – For motor loads, either one-or three-phase, a single-phase wattmeter may be deployed for spot or recording measurements with the recording function, typical operating profiles of fans, pumps and compressors can be developed.

***Electric process characterization*** – Electrical energy consumption data can be measured and correlated to production data over a sample interval to characterize the consumption patterns of a process. This is particularly useful for processes such as electric furnaces, dryers and kilns. Depending upon the configuration of the equipment and power supply, it may be possible to conduct such a survey with a single-phase power meter; the three-phase meter will work in most situations.

***Measuring consumption of office equipment*** – Using a simplified power meter for determining energy consumed over a typical period of operation, as illustrated in Figure 4.4.

**Figure 4.4 The Brultech ECM1200 Measuring Computer Monitor Energy Consumption**

## 4.4.4 | Sample Specifications

### For handheld wattmeter

- Volt, amps, watts, VAr, VA, W, Hz, kWh (import/export), kVArh.
- All measurements are true RMS.
- Memory adequate for recording multiple measurements over a varying interval.
- 1% accuracy – including clamp error.
- Backlit LCD display.
- Battery-powered.

**For three-phase wattmeter**

- ❑ Portable power meter for both single-phase and three-phase systems, providing measurement of true RMS values for up to 33 parameters including volts, amps, watts, VAr, VA, W, Hz, kWh (import/export), kVArh.
- ❑ 1% accuracy – including clamp error.
- ❑ High-contrast backlit LCD display.
- ❑ At least 1MB on-board memory for data storage over extended survey periods including waveform capture for current and voltage.
- ❑ Supplied complete with CTs, voltage leads and all accessories in a strong carry case.
- ❑ Download to PC via high-speed serial link.
- ❑ PC (Windows-based) software for data download, analysis and export to spreadsheets.
- ❑ Fully programmable for all CT/VT ratios, star/delta/single-phase connection and power integration period.
- ❑ Dual voltage power supply 230/110VAC with internal rechargeable backup battery.
- ❑ On-board clock/calendar.

### 4.4.5 | Useful Features

There are many features available on these types of meters beyond the basic power measurement functions. While handy, these additional functions are not entirely necessary. Some that have proven useful for energy-auditing activities are listed below.

**For handheld single-phase wattmeter**

- ❑ Measurement and analysis of power quality parameters including harmonics.
- ❑ DC measurement with optional Hall effect sensor.
- ❑ Automatic recognition of clamp type.
- ❑ PEAK feature captures max current/power values.
- ❑ MEM function provides data hold and allows real time comparison of new readings against stored values.

**For three-phase wattmeter**

- ❑ Stand-alone battery-powered function to allow installation in, and safe closure of, electrical cabinets.
- ❑ Measurement and analysis of power quality parameters including harmonics.
- ❑ Suitable for DC measurement (via optional DC clamp).
- ❑ Optional inputs for recording of other parameters such as temperature.

### 4.4.6 | Tips for Effective Use

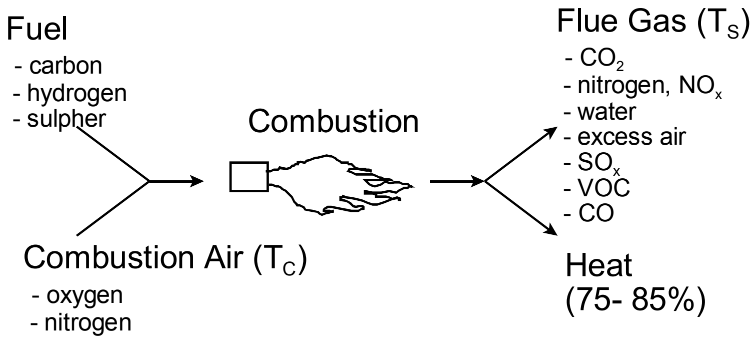
***Validate readings at time of collection*** – When deploying meters for recording ensure that the instantaneous readings are reasonable. Many data collection errors are the result of a misconnected meter and can be avoided at connection time. By checking readings against any existing metering such as panel meters or utility meters, the auditor can validate readings quickly. Unexpectedly low or high power factor readings are a common clue to incorrect connections. Power readings may appear valid while power factors will not.

***Utilize as short an integration or averaging time interval as possible for recording power and energy readings*** – Ideally, one-minute intervals. Power meters will typically average the measured values over the recording interval. Information is lost in the averaging process. Shorter intervals provide more electrical fingerprints of loads, simplifying interpretation of the resulting profiles.

## 4.5 The Combustion Analyser

Modern combustion analysers are portable electronic instruments used to measure the combustion efficiency boilers, furnaces or other equipment with fuel combustion systems. Figure 4.5 illustrates the essential elements of the combustion process. The primary objective of combustion analysis is to ensure that the optimum ratio of air to fuel is being utilized. Excess air will appear in the flue gases and carry away heat that could otherwise be used. Insufficient air will lead to incomplete combustion often indicated by significant levels of carbon monoxide (CO) in the flue gases.

**Figure 4.5 The Combustion Process**




The determination of combustion efficiency is based on multiple measurements including flue/stack temperature and the composition of stack gases – typically carbon dioxide ($CO_2$) or oxygen ($O_2$). Often instruments measure a number of other parameters indicative of combustion system performance, as described below.

### 4.5.1 | Instrument Description

All electronic combustion analysers integrate a number of measurement functions into one unit, which is often battery-powered and uses a digital display and keypad as a user interface. A basic analyser will measure:

- ❑ flue/stack gas temperature
- ❑ combustion air temperature
- ❑ oxygen ($O_2$)
- ❑ carbon monoxide (CO)

The user selects from a display menu the fuel being used in the combustion system. Based upon an internally programmed algorithm containing data regarding fuel composition, the analyser will then compute and display the combustion efficiency and determine the excess air and carbon monoxide (CO) level.

A typical combustion analyser is shown in Figure 4.6. This unit is appropriate for testing boilers, plant-heating equipment and a limited set of process combustions systems. In addition to the parameters above, this unit can also measure stack draft – the pressure in the stack/flue driving the flow of hot gases from the combustion system.

**Figure 4.6 Electronic Combustion Analyser**

### 4.5.2 | Applications

Combustion analysers can be used in a wide variety of combustion equipment, fired by gas, oil, coal and a number of other fuels including wood. Applications include but are not limited to:

- boilers
- unit heaters
- hot water heaters
- heating furnaces
- process furnaces
- process ovens
- kilns
- dryers
- ladle preheater
- material preheaters

For applications other than building heating equipment, the reader is encouraged to consult with instrument suppliers to ensure selection of appropriate instrument ranges and functions.

### 4.5.3 | Sample Specifications

- Measure $O_2$, $CO_2$, efficiency, excess air, draft and CO (325-1 only)
- Large, menu-driven display
- Optional NOx measurement
- **Temperature measurement**

| | |
|---|---|
| Measurement range/resolution: | −40 to +1112°C / 0.1°C |
| Accuracy: | ±0.5°C |
| Sensor: | Thermocouple Type K |

- **Draught/pressure measurement**

| | |
|---|---|
| Measurement range/resolution: | ±16 in $H_2O$ / 0.1 in $H_2O$ |

- Gross/net efficiency

| | |
|---|---|
| Measurement range/resolution: | 0 to 120% / 0.1% |

- $O_2$ measurement

| | |
|---|---|
| Measurement range/resolution: | 0 to 21 vol.% / 0.1 vol.% |
| Accuracy: | ±0.2 vol.% absolute |

- $CO_2$ measurement

| | |
|---|---|
| Measurement range/resolution: | 0 to $CO_2$ max. (calculation from $O_2$) / 0.01 vol.% |
| Accuracy: | ±0.2 vol.% |

- CO measurement (325-1 only)

  Measurement range/resolution: 0 to 2000 ppm/1 ppm

  Accuracy: ±20 ppm (to 400 ppm)

### 4.5.4 | Useful Features

- Alarms for abnormally high carbon monoxide levels – to protect both the equipment and user.
- For industrial and high temperature applications, optional high temperature sensors may be required.
- Multiple gas analysis capability including, in addition to $CO_2$ or $O_2$ and CO, NOx, SOx and combustibles.
- User-entered fuel composition data for off-standard fuels.
- An integrated printer for printing individual sample results.
- Optional, longer probes for use on larger pieces of equipment.

### 4.5.5 | Tips for Effective Use

***Take multiple measurements under a range of different firing rates*** – The efficiency of combustion equipment is a function of firing rate, and the calibration of fuel/air controls may change over the range of firing rates at which the combustion equipment operates.

***Ensure steady state conditions for measurements*** – Allow combustion equipment to reach normal operating temperature before taking readings.

***Calibration*** – Typically, gas analysis equipment is not as stable as many types of temperature and pressure measurement devices. This means that the equipment should be calibrated frequently. The frequency will depend upon the importance of the readings for successful operation and the drift tendency of the calibration. This could mean that the calibration check should be conducted weekly or, with experience, it might be determined that it could be extended to a monthly basis before the calibration drifted significantly. Gas analysis instruments are calibrated with bottled test gases that have a certified composition similar to that of measured gases. A frequently calibrated analyser with good repeatability should provide good performance.

## 4.6 Light Meters

Light or illuminance meters provide a simple and effective method for determining actual delivered light levels. It is useful to compare actual levels with suggested or recommended levels for specific activities or areas.

An illuminance meter typically utilizes a sensor corrected for:

- light colour – light sources vary in colour
- angle of incidence – the cosine law is used to correct for reduced apparent illumination at small angles to the horizontal

A basic meter is shown in Figure 4.7. It is battery-powered, can measure from 0 to 50 000 lux and has a separate light sensor with a flexible cord.

**Figure 4.7 A Basic Light Meter**


### 4.6.1 | Sample Specifications

- Measures 0–50 000 lux in three ranges (0–2000/0–20 000/0–50 000)
- Accuracy to 5%
- Automatic zero adjustment
- Sensor housed in a separate unit from display with flexible cord connection
- Battery-operated
- LCD display

### 4.6.2 | Useful Features

- Analogue output function for recording

### 4.6.3 | Tips for Effective Use

***Ensure measurements are taken under steady state conditions*** – Many lamps require a warm-up period before reaching full light output.

***Ensure that daylight does not influence readings*** – Take readings at night, use blinds, or take two readings with and without lights and subtract daylight contribution to yield artificial illumination levels.

***Assess wall reflectance*** – By taking the ratio of the reflected light to the incident light on the wall with a light meter. Take incident light reading about 0.5 metres from wall, turn sensor to face wall and take reflected light reading.

***Ensure that the light colour range of the sensor being used is appropriate for the light source present*** – If not, apply correction factors as per light meter manual instructions.

***Ensure comparable readings*** – Lamp light output decreases with age, so avoid comparing old lamps with new ones.

## 4.7 Temperature Measurement

Temperature measurements provide the auditor with opportunities to quantify thermal energy consumption and losses in a variety of ways. Air, gas, fluid and surface temperatures are commonly measured in any audit.

### 4.7.1 | Types of Instruments

Temperature may be determined by mechanical or electrical means using a variety of contact measurements and by others using non-contact or radiation-based measurements.

***Bimetallic thermometers*** – are constructed from two thin strips of metal with dissimilar coefficients of expansion bonded together in a coil. The coil is attached to a hand or pointer on a scale, which rotates as the metals expand or contract with varying temperatures.

***Thermocouples*** – are based upon the principle that a voltage proportional to the temperature is produced at the junction of two dissimilar metals. It is widely used since the sensor can be used with wires for remote reading or recording.

***Resistance temperature detectors (RTDs)*** – are based on the fact that, in the case of certain metals, the resistance increases as the temperature increases. These devices require an external current source for the sensor to create a voltage that can be sensed and related to temperature.

***Pyrometers (non-contact thermometers)*** – operate on the principle that objects radiate different amounts of energy according to their temperatures. These instruments measure radiation without making contact with the object and operate under an assumption concerning the object's emissivity (ability to radiate energy), which may be fixed or set by the user.

The following chart summarizes the temperature measurement options available to the energy auditor.

| Type | Pros | Cons | Typical Ranges | Accuracy % of Span |
|---|---|---|---|---|
| **Glass stem thermometer** | Low cost | Fragile<br>Hard to read | −50°C to +800°C | 1% to 2% |
| **Bimetallic** | Low cost | Limited range<br>Not a remote sensor | −60°C to +425°C | 1% to 4% |
| **Thermocouple**<br>Type T<br>Type J<br>Type K<br>Type R & S | Simple<br>Rugged<br>Wide variety<br>Wide temp. range<br>Self-powered | Non-linear<br>Reference required<br>Least stable<br>Least sensitive | −150°C to +260°C<br>−160°C to +800°C<br>−150°C to +1500°C<br>−15°C to +1700°C | 0.3% to 1% |
| **RTD**<br>Nickel<br>Platinum | Most stable<br>Most accurate | Expensive<br>Current source required | −150°C to +260°C<br>−255°C to +650°C | 0.1% |
| **Pyrometers (non-contact)**<br>Optical<br>Infrared<br>Radiation | Safe<br>Easy to use<br>Convenient | Relatively expensive<br>Accuracy may be compromised by other sources in field of view | +760°C to +3500°C<br>0°C to +3300°C<br>+500°C to +3900°C | 1% to 2%<br>1% to 2%<br>0.5% to 1% |

Figure 4.8 shows a typical thermocouple-based temperature measurement device. This consists of a thermocouple probe, in this case housed in a rugged stainless steel sheath, and a digital display unit to convert the junction's output voltage to a temperature reading.

**Figure 4.8 Thermocouple-Based Digital Thermometer**

Figure 4.9 illustrates a pyrometer or non-contact temperature measurement. The unit is for close proximity readings (0.05 to 0.5 m).

**Figure 4.9 Infrared Temperature-Measuring Device**

### 4.7.2 | Selecting an Instrument for Energy Auditing

For most energy auditing purposes thermocouples provide adequate range and accuracy. There is a wide range of sensors incorporating thermocouples for virtually any application. The sensor shown in Figure 4.8 is an immersion probe appropriate for air and water applications. Most suppliers provide a wide range of probes for many applications and temperatures.

Digital thermometer display units similar to the one shown in Figure 4.8 can accommodate a range of thermocouple styles and types, making them a versatile auditing tool.

### 4.7.3 | Sample Specifications

**For thermocouple-based digital thermometers**

- ❑ Accuracy of 0.1% reading + 0.5°C
- ❑ Input ranges for Type K: –200°C to 1300°C
- ❑ Resolution: 0.1°C
- ❑ Ambient: 0 to 50°C, 0 to 90% RH
- ❑ Reading rate: 1 per second
- ❑ Battery-powered
- ❑ 6-digit LCD display

**For infrared (non-contact) thermometers**

- ❑ Circle or dot laser sighting
- ❑ Range: –20 to 420°C (0 to 788°F)
- ❑ Resolution: 1°C/1°F
- ❑ Emissivity: 0.95 fixed
- ❑ Spectral response: 6-14 mm
- ❑ Optical field of view: D:S = 8:1
- ❑ Response time: 500 ms
- ❑ Accuracy: –20°C to 100°C: 2°C; 101°C to 420°C: ±3%
- ❑ Operating ambient: 0 to 50°C, less than 80% RH

### 4.7.4 | Useful Features

**For thermocouple-based digital thermometer**

- ❑ Analogue output to allow recording measurements using a general-purpose data logger
- ❑ Max./min. capture functions – unit will display maximum and minimum temperature sensed (the unit shown in Figure 4.8 has this function)
- ❑ Two thermocouple inputs with a differential function to display difference between the two thermocouple readings (the unit shown in Figure 4.8 has this function)

**For infrared (non-contact) thermometer**

- ❑ Variable emissivity for materials where emissivity not close to 0.95
- ❑ Laser sighting with a narrow field of view

### 4.7.5 | Tips for Effective Use

***Surface temperature measurements should be shielded from external influences*** – Insulating material should be used to shield a contact temperature measurement sensor from contact with the air. For example, when using a themocouple sensor to measure pipe surface temperature, hold the sensor against the pipe with a piece of insulating foam (providing surface will not melt the material).

***Shield sensor from sources of thermal radiation*** – Often ambient radiation sources such as a hot radiator, coil or the sun will influence temperature readings if the sensor is not shielded from the radiation. This also applies to air or gas temperature sensors located near hot surfaces or in the sun. Specifically, a flue gas temperature sensor may be influenced by radiation from hot surfaces within the combustion equipment if readings are taken too close to the combustion zones.

***Take multiple readings over a representative area*** – In order to reduce error in readings due to local hot spots on a surface.

***Ensure that sensor is not influenced by leakage into a duct or air stream*** – When airflow readings are being taken in ducts under negative pressures, the access hole may introduce air into the duct that will influence readings. This also applies to sensing temperatures in combustion flues or vents that may be under negative pressure.

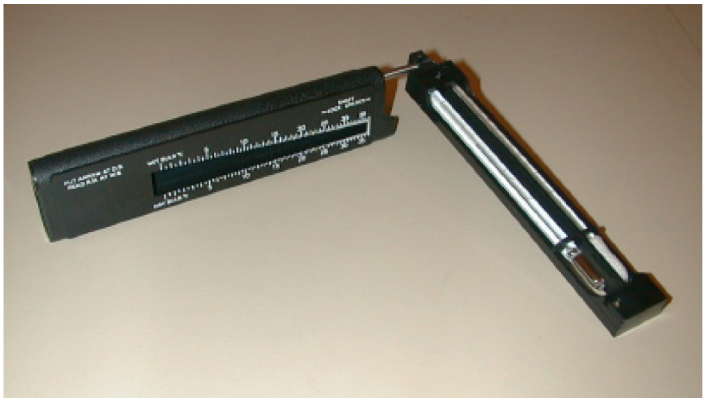
## 4.8 Humidity Measurement

Humidity measurements are often used in the energy audit to assess the cooling load present in a system or to determine the amount of latent energy present in an exhaust airflow.

### 4.8.1 | Types of Instruments

The psychrometer, or wet and dry bulb thermometer, is the most common instrument used and contains two temperature sensors, one of which has a cotton sock soaked with distilled water. The sensor with the sock will register a temperature close to the thermodynamic wet bulb temperature. Knowing the dry bulb temperature, wet bulb temperature and the barometric pressure, the auditor can determine the relative humidity from psychrometric tables or software. Figure 4.10 depicts the so-called sling psychrometer, named for the manner of use. The thermometers are rotated like a sling in the air to obtain a representative reading.

**Figure 4.10 The Sling Psychrometer**



Electronic or digital psychrometers offer not only basic wet and dry bulb readings but also computations and direct reading of humidity- and data-recording capability.

In addition to dedicated humidity-measuring instruments, a number of the general-purpose data loggers described in Section 4.12 include RH measurement functions.

For basic energy auditing activities, the sling psychrometer offers reliable and low-cost measurement, unless you have a requirement for data-logging/recording of humidity measures.

### 4.8.2 | Tips for Effective Use

***Calibration of digital meters is important.*** The various types of sensors used are susceptible to contamination or damage. Recalibration or sensor replacement may be required. When selecting a unit, ensure that the sensing element is suitable for the environment in which it will be used. Some sensors are particularly sensitive to high humidity, oil vapours and other organic compounds that may be present in the air.

***Psychrometers cannot be used when the air temperature is below 0°C.*** They need frequent cleaning and replacement of the cotton sock. If they are properly maintained, the accuracy is about +/– 0.5°C above 20% RH.

## 4.9 Airflow Measurement

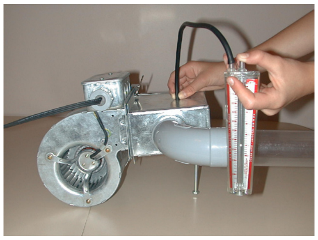
Airflow measurements are useful when analysing facility HVAC and exhaust systems. Accurate airflow measurements are generally difficult to make and require specialized equipment. Within the context of a macro or basic micro energy audit, there are some simple airflow measurements that can be made to provide data for initial estimates of energy use and savings. For more accurate measurements, we recommend retaining the services of a competent air balance contractor or technician.

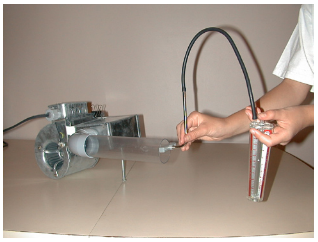
### 4.9.1 | Types of Instruments

These relatively low-cost and simple-to-operate instruments are suggested for basic energy audit purposes:

- ✓ ***Digital vane-anemometer*** – a rotating vane whose speed is proportional to the air speed. The uses for this device are limited due to the size of the unit and difficulty in placing the sensor in the air stream. Typically, it could not be used for in-duct measurements.
- ✓ ***Digital thermo-anemometer*** – sensing air speed by sensing the temperature of a hot wire being cooled in the air stream. This instrument can be used in ducts and plenums.
- ✓ ***Air meter*** – a very simple manometer and pitot tube assembly for low air pressures and velocity (Figure 4.11).

**Figure 4.11 Simple Pitot Tube and Manometer Measuring Airflow (left side) and Manometer Measuring Pressure (right side)**





- ✓ ***Pitot tube and manometer*** – is perhaps the most versatile airflow measurement device. More sophisticated manometers than the one pictured in Figure 4.11 are available. Handheld digital manometers with data-logging functions are available for advanced applications, as are more robust analogue manometers for instantaneous reading. The added benefit of the pitot tube and manometer is that the manometer can measure pressure – required for assessment of air power.

## 4.10 Ultrasonic Leak Detectors

When gas is forced through a small opening – a leak in a pressure or vacuum system – an ultrasonic sound is created. This sound is very directional, and this directionality is used to locate the source or leak. The ultrasonic leak detector is sensitively tuned to this frequency of sound. Typically, these units have a display to indicate the strength of a leak signal, and the adjustable sensitivity makes it possible to pinpoint the location of the leak.

**Figure 4.12 Ultrasonic Leak Detector and Transmitter**


Figure 4.12 shows a typical ultrasonic leak detector with its companion, the ultrasonic transmitter. In areas where leaking gases are at low pressure or where a system is yet to be filled with gases, there may be no ultrasonic sound to detect. This unit allows an area to be artificially "pressurized" with ultrasound so that small cracks and openings can be detected. Leaks can be detected in refrigeration and air-conditioning systems, heating systems, steam traps, compressors and compressed air systems. This unit is useful for checking air leaks around door and window seals and gaskets, water leaks in roofs and leaks in vacuum vessels.

Typically, the detector and transmitter are available in a kit that includes earphones or headphones and extensions for leak detection in areas that are difficult to access.

## 4.11 Tachometer

Tachometers are useful to the energy auditor for determining the speed of a motor or driven device. Fan, pump and compressor speeds are useful when comparing actual performance with nameplate or specification performance. For fans and pumps, flow is directly proportional to pump or fan speed. Motor speeds, when compared with the nameplate rated speed of the motor, can be an indication of the load on a motor.

**Figure 4.13 Typical Tachometer**


A practical tachometer for energy auditing is shown in Figure 4.13. This unit is capable of contact or non-contact measurements.

Contact measurements require the unit to be held against the end of a rotating shaft or against a belt on a conveyor to determine rotational or linear speed.

Non-contact measurements require a light beam to be reflected off the rotating shaft. Typically, a patch of reflective tape is applied to the shaft when the device is locked off. This provides an easy target with high reflectivity.

The unit in Figure 4.13 is battery-powered and has a memory function. This allows a reading to be taken, for example, near the end of a shaft where the display is not visible and then viewed with the memory button.

## 4.12 Compact Data Loggers

With compact data loggers, the energy auditor can quickly and easily collect data from a wide variety of sensors and other instruments. These devices range from self-contained temperature and humidity loggers to general-purpose multi-channel loggers with standard analogue and digital inputs.

### 4.12.1 | Description

A data logger is an electronic instrument that records measurements of temperature, relative humidity, light intensity, on/off and open/closed state changes, voltage and events over extended periods of time. Typically, data loggers are small, stand-alone, battery-powered devices equipped with a microprocessor, memory for data storage and sensor or group of sensors. Sensors may be internal or external.

Data loggers have some form of interface with a PC and come with software for configuration and retrieval of data collected. Configuration enables the user to set operating parameters for the logger including

- ✓ external sensor types connected
- ✓ sampling intervals
- ✓ survey start and stop times (if not immediate)
- ✓ real-time clock

Typically, the memory installed in these loggers is sufficient for the collection of 10 000 or more data records, which could span many hours or days depending on the measurement interval selected. Measurement intervals may be as frequent as one second or as long as one hour or more. Once a data survey is completed, the data must be downloaded from the logger for viewing or analysis with the software provided or exported to a spreadsheet for further analysis.

### 4.12.2 | Applications

- ✓ Temperature and humidity and illumination level logging with internal sensors
- ✓ Logging of other analogue signals such as pressure and $CO_2$ sensors or any sensor with a standard current or voltage interface
- ✓ Event logging such as motor, lights or heater on/off events
- ✓ Logging of signals from other instruments such as light meters, digital thermometers, airflow meters and electric current clamp meters

### 4.12.3 | Useful Features

***Data collection/shuttle/transfer capability*** – This feature of some data loggers enables you to download and restart the data loggers while in the field. The data transfer device is portable and connects to a computer for the final download of data.

***Small size*** – Some of the newer data loggers are very small and easy to install in tight locations.

***Self-powered*** – A data logger that is self-powered is much easier to deploy in locations without power or where accessing power may be hazardous or inconvenient.

# 5 ELECTRICAL INVENTORY METHOD

## 5.1 How to Compile a Load Inventory

This section outlines a method for compiling a load inventory using forms, samples of which are shown below. The forms contain instructions.

In addition to these forms, a clipboard, pencil and calculator are required. Instrumentation is not a necessity; a simple clip-on ammeter is probably adequate in most situations. Other instrumentation is discussed in Section C-2.

**Step 1** The following information is required:

***A period of time*** on which the inventory will be based, usually a month, corresponding to the utility billing period; it could also be a day, week or year. Select a period that is typical of your operations.

Determine the ***actual demand in kilowatts*** (kW) and the ***energy consumption in kilowatt-hours*** (kWh) for the period selected. If the period selected is a month, information is available from the utility bill. If the facility demand is measured in kVA, this will require a calculation based on the peak power factor to convert kVA to kW. (See "Energy Fundamentals" for details.)

Record the actual values on Summary Form LD1, as "Actual Demand & Energy."

**Step 2** Identify each of the major categories of electricity use in the facility. You may have to take a walk through your facility and list categories as you notice them. Record each category on Form LD1. When identifying the various categories of use, it is useful to consider both the type of electricity use and the activity in each area. Selecting categories with similar operation patterns is a good approach.

The example on the sample form separates the motor use from the lighting use in the office, production (multiple categories) and exterior areas.

**Step 3** Guess the percentage of demand attributable to each category. This may be based on prior knowledge, a rough idea of the size of the loads, the size of the distribution wiring, etc. You can also use any information available from the demand profile when preparing this estimate. Record the demand percentages on Form LD1 and calculate the estimated demand for each category of use based on the actual demand.

**Step 4** Guess the percentage of energy used in each category. This should be based on occupancy, production, or other such factors relating to the intensity of use in each category. Record the energy percentages on Form LD1 and calculate the estimated energy for each category of use based on the actual energy.

**Step 5** Select the category of largest demand or energy use.

**Step 6** Use forms LD3, LD4 and LD5 to list each and every load in the category selected. Only record nameplate and kW load information up to and including the total kW. Each form is designed for a different type of information. Use Form LD2 to summarize the information collected on each of these forms.

For each load, select one method of recording information according to the following criteria:

**LD3 – Simple Load Information**

Use this form for such things as lighting, electric heat, office equipment, or any load for which the load in kW is known.

**LD4 – Current Voltage Method**

Use this form to record detailed nameplate data from loads such as coolers, small motors and appliances when kW load data is not known. This form should also be used for any device for which measurements have been taken.

**LD5 – Motor Load Method**

This form should be used only for motors. It provides a method of estimating kW load based on motor horsepower, loading and efficiency. Do not use this method if actual motor currents and voltages have been measured. Instead, use Form LD4.

**Step 7** For each load, estimate the hours of operation for the period selected and indicate if this load is on during the peak demand period or at night. At this point, do not attempt to estimate the diversity factor.

**Step 8** Repeat steps 6 and 7 for each category of use, working down from highest energy use and demand to the lowest. If the estimated energy use or demand in a category is relatively small (less than 5%), it is probably not worthwhile conducting a detailed inventory.

## 5.2 Load Inventory Forms

Load inventory forms are provided in the “Spreadsheets” section of this guide. Samples of each form are shown here, with guidelines for completing them.

Form LD1 Load Inventory Summary Form

| Category of Use | Estimated Demand (%) (a) | Estimated Energy (%) (b) | Estimated Demand (kW) (c) | Estimated Energy (kWh) (d) | Calculated Demand (kW) (e) | Calculated Energy (kWh) (f) | Calculated Night Load (kW) (g) |
|---|---|---|---|---|---|---|---|
| Air Compressors | 22 | 6 | 113 | 13 500 | | | |
| Lights | 10 | 10 | 51 | 22 500 | | | |
| HVAC | 35 | 33 | 179 | 74 250 | | | |
| Refrigeration | 30 | 50 | 154 | 112 500 | | | |
| Outside | 3 | 1 | 15 | 2 250 | | | |
| | | | | | | | |
| Estimated Percentages | | | | | | | |
| Actual Demand & Energy | | | 512 | 225 000 | | | |
| Calculated Demand & Energy | | | | | | | |
| Calculated Night Load | | | | | | | |

| Period for Energy Calculations | Day | Week | Month | Year |
|---|---|---|---|---|
| Hours per period | 24 | 168 | 732 | 8 760 |
| Check period used | | | ✔ | |

**Form LD1 Load Inventory Summary**

This form is the starting point and finishing point for the load inventory. Initial estimates of the load breakdown are entered here, and the final totals of calculated loads in each category of use are summarized on this form.

| Data Entry Item | Units | Description |
|---|---|---|
| Estimated Demand | % | A percentage representing the fraction of demand in this category |
| Estimated Energy | % | A percentage representing the fraction of energy in this category |
| Estimated Demand | kW | The Estimated Demand % multiplied by the Actual Demand Total |
| Estimated Energy | kWh | The Estimated Energy % multiplied by the Actual Energy Total |
| Calculated Demand | kW | The total Calculated Demand from Form LD2 for each category of use |
| Calculated Energy | kWh | The total Calculated Energy from Form LD2 for each category of use |
| Calculated Night Load | kW | For each category of use, the Calculated Night Load from the detail forms |
| Estimated Percentages | % | Should always be equal to 100%, the total of each of the demand and energy percentages |
| Actual Demand & Energy | kW & kWh | The Actual Demand and Energy Consumption for the period – possibly from the electricity bills |
| Calculated Demand & Energy | kW & kWh | The total of the Calculated Demand and Energy columns |
| Calculated Night Load | kW | The total of the Calculated Night Load column |

**Form LD2 Category of Use Summary for: The Entire Facility**

| Form No. | Description | kWh/ Period | Peak kW | Night kW |
|---|---|---|---|---|
| LD3 | Simple Load Information | 4 087 | 15.9 | 0.235 |
| LD4 | Detailed Load Information | 30 680 | 76.1 | 0.000 |
| LD5 | Motor Load Information | 432 | 1.9 | 1.900 |
| | **Total Calculated** | **35 199** | **93.9** | **2.100** |

**Form LD2 Category of Use Summary**

This form is used to summarize the detailed load information from forms LD3, LD4, and LD5. Enter the total value for kWh/Period, Peak kW and Night kW from each of the forms, and then add the three columns.

**Form LD3 Simple Load Information Category of Use: Lighting**

| Description | Qty (a) | Unit Load (b) | Total kW (c) = a x b | Hrs./ Period (d) | kWh/ Period (e) = d x c | On @ Peak Y or N | Div'ty Factor (f) | Peak kW (g) = f x c | On @ Night Y or N | Night kW |
|---|---|---|---|---|---|---|---|---|---|---|
| Office Floor | 50 | .047 | 2.350 | 290 | 682 | Y | 100 | 2.55 | N | 0.000 |
| Warehouse | 30 | .45 | 13.500 | 250 | 3375 | Y | 100 | 13.50 | N | 0.000 |
| Corridor | 5 | .047 | .235 | 129 | 30 | Y | 30 | 0.07 | Y | 0.235 |
| | | | | | | | | | | |
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| | | | | | | | | | | |
| **Totals** | **n/a** | **n/a** | **n/a** | **n/a** | **4087** | **n/a** | **n/a** | **15.90** | **n/a** | **0.235** |

**Form LD3 Simple Load Information**

This form is used to record simple load information and to calculate demand and energy for each item. Enter the total kWh/Period, Peak kW, and Night kW on the last row of the form.

| Data Entry Item | Units | Description |
|---|---|---|
| Quantity | (a number) | The quantity of this particular item |
| Unit Load | kW | The load in kW for one item of this particular load |
| Total kW | kW | Quantity x Unit Load |
| Hrs./Period | hours | The estimated hours of use per period |
| kWh/Period | kWh | Total kW x Hrs./Period |
| On @ Peak | Yes/No | Is this load on during the peak period identified in the demand profile? |
| Diversity Factor (Div'ty Factor) | 0–100% | That fraction of the total load that this particular item contributed to the peak demand |
| Peak kW | kW | If the load is on peak, then this value is equal to the Total kW x Diversity Factor |
| On @ Night | Yes/No | Is this load on at night? |
| Night kW | kW | If this load is on at night, then this is equal to the Total kW; otherwise, it is 0 |

**Form LD4 Detailed Information (Current-Voltage Method) Category of Use:** ______________________

| Description | Qty. (a) | Volts (b) | Amps (c) | Phase (d) | PF (e) | Total kW (f) | Hrs./ Period (g) | kWh/ Period (h) = g × f | On @ Peak Y or N | Div'ty Factor (i) | Peak kW (j) = i × f | On @ Night Y or N | Night kW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Roofing Units | 10 | 575 | 15 | 3 | 0.85 | 126.8 | 242 | 30 680 | Y | 0.6 | 76.1 | N | 0 |
| | | | | | | | | | | | | | |
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| **Totals** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** | **n/a** | **30 680** | **n/a** | **n/a** | **76.1** | **n/a** | **0** |

Total kW = (f) = (a) x (b) x (c) x (d) x (e) for single phase, use (d) = 1

for three phases, use $(d) = \sqrt{3} = 1.73$

**Form LD4 Detailed Information (Current-Voltage Method)**

This form is used for collecting detailed data when current and voltage nameplate data or measured data is available. Enter the total kWh/Period, Peak kW, and Night kW on the last row of the form.

| Data Entry Item | Unit | Description |
|---|---|---|
| Qty. | N/A | The number of units in operation |
| Volts | volts | The line voltage (measured or nameplate) for this load |
| Amps | amps | The current drawn by this load, measured or from the nameplate; for a three-phase load, record only the current per phase |
| Phase | 1 or 3 | The number of AC phases used by this load |
| Power Factor | 0–100% | The estimated or measured power factor of this load |
| Total kW | kW | Qty. x voltage x amps x 1.73 x power factor |
| Hrs./Period | hours | The estimated hours of use per period |
| kWh/Period | kWh | Total kW x Hrs./Period |
| On @ Peak | Yes/No | Is this load on during the peak period identified in the demand profile? |
| Diversity Factor (Div'ty Factor) | 0–100% | That fraction of the total kW for this particular load that contributed to the peak demand |
| Peak kW | kW | If the load is on peak, then this value is equal to the Total kW x Diversity Factor |
| On @ Night | Yes/No | Is this load on at night? |
| Night kW | kW | If this load is on at night, then this is equal to the Total kW; otherwise, it is 0 |

**Form LD5 Detailed Load Information (Motor Load Method) Category of Use:** **Air Compressor**

| Description | Qty. (a) | Motor hp (b) | Motor Load % (c) | Motor Eff. % (d) | Total kW (e) | Hrs./ Period (f) | kWh/ Period (g) = e × f | On @ Peak Y or N | Div'ty Factor (h) | Peak kW (i) = e × h | On @ Night Y or N | Night kW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5-hp Air Compressor | 1 | 5 | 75 | 78 | 3.6 | 120 | 432 | Y | 5 | 1.9 | Y | 1.9 |
| | | | | | | | | | | | | |
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| | | | | | | | | | | | | |
| **Totals** | **1** | **5** | **75** | **78** | **3.6** | **120** | **432** | | **5** | **1.9** | | **1.9** |

Total kW (e) =(a) × (b) × 0.746 × (c) ÷ (d)

**Form LD5 Detailed Load Information (Motor Load Method)**

This form is used to estimate motor power loads from motor loading and efficiency data. Enter the total kWh/Period, Peak kW, and Night kW on the last row of the form.

| Data-Entry Item | Unit | Description |
|---|---|---|
| Qty. | N/A | The number of units in operation |
| Motor hp | hp | The nameplate motor horsepower |
| Motor Load % | 0–100% | The fraction of the nameplate horsepower that this motor is estimated to be delivering to its driven load |
| Motor Efficiency % | 0–100% | The estimated or measured motor efficiency from electrical power input to shaft power output (this value will depend on the Motor Load % – it is not simply the nameplate efficiency) |
| Total kW | kW | Qty. × Motor hp × 0.746 × Motor Load % ÷ Motor Eff. % |
| Hrs./Period | hours | The estimated hours of use per period |
| kWh/Period | kWh | Total kW × Hrs./Period |
| On @ Peak | Yes/No | Is this load on during the peak period identified in the demand profile? |
| Diversity Factor (Div'ty Factor) | 0–100% | That fraction of the total load that this item contributed to the peak demand |
| Peak kW | kW | If the load is on peak, then this is equal to the Total kW × Div'ty Factor |
| On @ Night | Yes/No | Is this load on at night? |
| Night kW | kW | If this load is on at night, then this is equal to the Total kW; otherwise, it is 0 |

## 5.3 Collecting and Assessing Lighting Information

Lighting is generally the easiest data to collect. Normally there are only a few different wattages and lamp types in use in any given facility. Once the basic types and wattages are identified, use a checklist to add up the various types by category and run time.

Note the following when gathering lighting data:

- Do not forget to include the ballast wattage in your total fixture wattage. Here are some typical ballast wattages.

| Ballast Type | Ballast Watts |
|---|---|
| Standard 4’ 2-tube Fluorescent | 14 |
| Energy-Efficient 2-tube Fluorescent | 9 |
| Electronic Fluorescent Ballasts | 5 |
| Compact Fluorescent Lamps (7, 9, 11 or 13 watts typical) | 3 |

- Check fluorescent fixtures from which the lamps have been removed to make sure that the ballasts have been disconnected as well. A fluorescent ballast will still consume power even if no lamps are installed.
- Use time clock settings or operation schedules whenever possible to get a good estimate of run times.
- Group the load information by lamp type and operating hours in order to make your kWh estimates accurate.

## 5.4 Collecting and Assessing Motor and Other Data

Some rules of thumb and suggestions for data gathering and assessment:

- If motors are supplied at 600V/3ø, the full-load kVA is approximately equal to the full-load amps (nameplate). This is due to the relationship between kVA and current on three-phase systems:

$$kVA = V \times I \text{ (per phase)} \times \sqrt{3}$$

For example, if a motor is rated at 600V/5.7A, the full-load kVA would be

$$600 \times 5.7 \times 1.73 = 5.9\ kVA$$

The power factor must then be applied to this to obtain the kW load as noted in Form LD4. This can range from 50% to 90%, depending on motor type and loading and whether power factor correction capacitors have been installed.

- kWh consumption of household and office type equipment such as refrigerators and photocopiers can sometimes be evaluated from tables.
- Loads on refrigeration equipment will vary with the ambient temperature and load. On large refrigeration compressors, it may be useful to actually measure the operating periods over a given time span (time with a stopwatch). If you do this at a time when the load on the equipment is typical, you can calculate the load factor (percentage of operating time) accurately. Note that the load factor during off-hours would generally be somewhat lower.
- Verify load inventory data using a clip-on ammeter to measure the amps on a feeder circuit if
  1. the feeder circuit serves one specific type of load (e.g. a lighting panel);
  2. reasonably accurate data is available on the equipment powered by the feeder; and
  3. the loads being measured are not cycling.

This type of spot current metering can sometimes show up loads that may be operating unnecessarily, such as out-of-the-way electric heaters or small motors.

## 5.5 Reconciling the Load Inventory with Utility Bills

Once the load inventory information is collected, you can reconcile it against the peak or maximum demand and energy consumption registered by the utility meter. The result will be a detailed breakdown of energy consumption and maximum demand.

### 5.5.1 | Peak Demand Breakdown

For each of the loads identified in the inventory, a total demand in kilowatts (kW) was calculated. The electrical demand that the particular load contributes to the peak demand must be less than or equal to this value. The question that must be answered at this point is: How much does each load contribute to peak demand?

For a given load, the relationship between the total load and the amount that it contributes to peak demand is

*Peak Load = Total Load × Diversity Factor*

The diversity factor takes into account a number of situations that result in the contribution to peak demand being less than the total load:

- The load cycles on and off and is on for less than 30 minutes at a time. After 15 minutes, the utility thermal demand meter will register 90% of the total load. (The response of the demand meter is detailed in Section C-1, "Energy Fundamentals.")

| On-Time of Load | % by Thermal Demand Meter | % Registered by Digital Demand Meter (15 min. window) |
|---|---|---|
| 1 minute | 15% | 33.3% |
| 5 minutes | 52% | 33.3% |
| 10 minutes | 78% | 66.7% |
| 15 minutes | 90% | 100% |
| 30 minutes | 97% | 100% |
| >30 minutes | 100% | 100% |

- The load may or may not be on during the peak demand periods; the diversity factor in this situation becomes a coincidence factor rating the chance that the load is on at the time of the demand peak.

### 5.5.2 | Reconciliation of Peak Demand

Reconciling the peak demand from utility invoices with the calculated peak demand derived from the load inventory involves

- determining from the utility bill or the utility meter the peak demand for the period of interest
- if billed in kVA, converting the billed kVA to kilowatts (kW) using the on-peak power factor. The on-peak power factor should be determined with a power meter or a power factor meter
- estimating the diversity factor for each load that is on during the peak, calculating the total diversified demand
- comparing the calculated peak to the actual peak and adjusting the calculations to reconcile the values as required

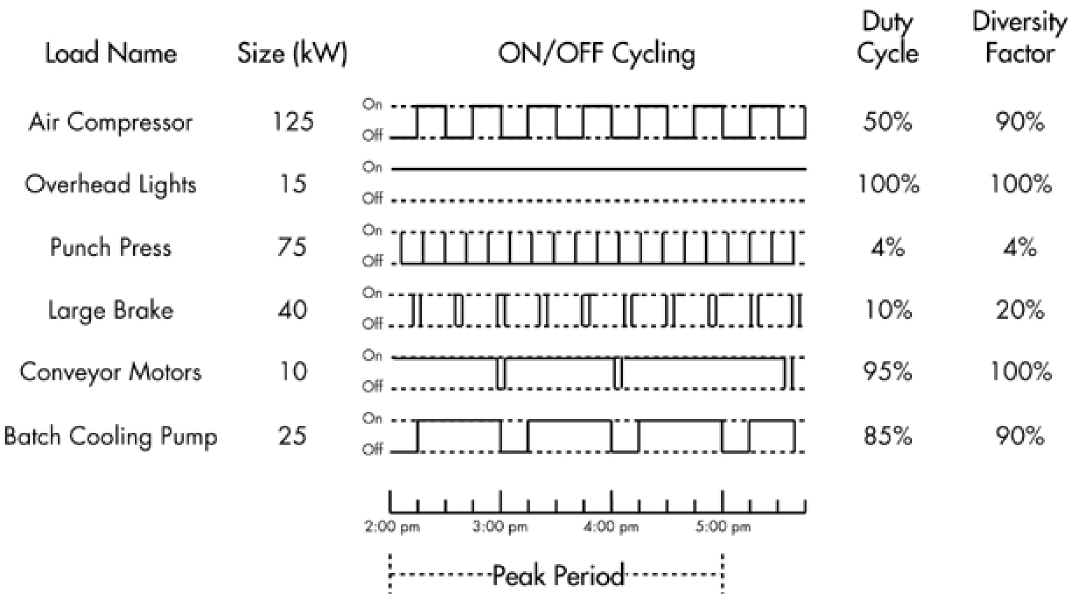
The task of estimating the amount of peak demand that is attributable to a particular load involves two questions:

i) What effect does the duty cycle of any given load have upon the demand meter, considering the response of the meter?

ii) What is the coincidence between the particular load and all other loads in the facility?

As described previously, the diversity factor takes into account these two effects; this is illustrated in Figure 5.1. In the example, the duty cycles of various loads are shown along with an estimate of the diversity factor, and it is assumed that the peak period occurs between 2:00 p.m. and 5:00 p.m.

**Figure 5.1**




The following rationale underlies diversity factor estimates.

*Air Compressor* – The unit cycles on and off every 15 minutes. The demand meter will register 90% of demand in 15 minutes. This load is on at the same time as (coincidentally with) a number of the other loads during the peak period. Therefore the full 90% is used.

*Overhead Lights* – These are on continuously during the peak period, so the demand meter will register 100% of full load in coincidence with all other loads.

*Punch Press* – The punch press motor operates for only 0.6 minutes; the demand meter would register about 8% in that time. However, since the load is not completely coincident with all other loads, a 50% allowance is made for coincidence. The result is a 4% diversity factor.

*Large Brake* – The motor on this machine operates for 1.5 minutes at full load; and is coincident with the other loads at least once during the peak period. Therefore, the 1.5-minute meter response of 20% is used for the diversity factor here.

*Conveyor Motors* – Since the off-time of the conveyors is not long enough for the meter indication to drop significantly, a 100% diversity factor is used.

*Batch Cooling Pump* – The pump cycles on for a long period (35 to 40 minutes); the meter should register the entire demand. A 10% allowance is made for the non-coincidence of this load and other short running large loads. Therefore, 90% is used as a diversity factor.

There are alternative methods for estimating diversity factors. The following method may be useful:

**Step 1** Assume that all diversity factors are 100% and calculate the sum of all the total loads. This is called the *Maxload*. It represents the demand that would occur if all loads were on continuously. Subtract the Actual Peak Demand from Maxload. This difference will be referred to as Diff-A.

**Step 2** Determine which loads are on continuously – for these loads the diversity factor will be 100%. Add each of these loads; the total is called the Contload. Subtract the Contload from the Actual Peak Demand; the difference is Diff-B.

**Step 3** Divide Diff-B by Diff-A and multiply by 100. This value is an average diversity factor for all loads that do not operate continuously (intermittent loads). It is called the *Average Factor*.

**Step 4** For each of the intermittent loads, determine what factor their duty cycle results in at the utility meter from the table listed above. If this factor is less than the Average Factor, then use this value; otherwise use the Average Factor as the diversity factor for this load.

**Step 5** For each diversity factor that is adjusted downwards, you will need to adjust another load upwards to maintain the average. This implies that a load contributes more to the peak demand than the Average Factor allows. These adjustments should take into account the coincidence between the loads.

**Step 6** Review each of the loads in this manner and then calculate the peak demand again. Compare this with the Actual Peak Demand. If the difference is greater than 5%, repeat steps 5 and 6. Exercise some judgment when adjusting loads upwards. Remember that the overall objective here is to make the best estimate possible of what each load contributes to the peak demand.

**Useful Hints**

- Use the information in the demand profile, such as load patterns and duty cycles.
- It may be necessary to adjust not only the diversity factors but also the basic load data to achieve a reconciliation.
- Many devices use less than their nameplate ratings. In such a case, use an ammeter.
- It may be necessary to proceed to the reconciliation of energy use (described in the next section) to assist in reconciliation of the peak demand. If the basic load data is incorrect, it will affect both energy and demand. The energy reconciliation may provide more information.
- Use a recording meter if possible on groups of loads for which the duty cycle is unknown.
- Differences are usually a result of bad assumptions, not bad nameplate or measured data.

### 5.5.3 | Energy Breakdown

The load inventory (kW) information, along with the estimated run times, is used to generate an energy breakdown. As with the peak demand breakdown, the aim is to match the total energy metered in a period to the sum of individual loads calculated for the same period.

The basic relationship for energy consumed by an individual piece of equipment is

*Energy (kWh) = Load (kW) × Operating Time (hours)*

- Rated Load (kW) is the nameplate draw on the equipment or Volts x Amps x Power Factor (if applicable) x 1/1000 (x $\sqrt{3}$ for 3-phase) x Loading (%).
- Operating Time (hours) is the total time the equipment is energized during the period being evaluated x Duty Cycle (%).
- Duty Cycle (%) is applicable only for loads that cycle on and off automatically while energized. An example of this would be refrigeration equipment. If they do not cycle, Duty Cycle = 100%.
- Loading (%) is applicable to equipment that can run under less than full load conditions, such as motors driving centrifugal loads. Note that here we are referring to the percentage of the full load in kW being drawn by the device.

**Examples**

1. A refrigeration compressor runs on a 30-percent duty cycle with a nameplate rating of 600V/22A, and its power factor is 75 percent. The evaluation period is 33 days. The compressor is energized all the time and runs fully loaded. The consumption would be

   *600(V) × 22(A) × $\sqrt{3}$ × 75% (PF) × 1/1000 × 33 (days) × 24 (h/day) × 30% (duty cycle) = 4074 kWh*

2. A bank of 20, 400W HID lights is operated 10 hours per day, 5 days per week. Each has a 50-watt ballast. For the same evaluation period of 33 days, the consumption is

   *20 lamps × (400 + 50) watts/lamp x 10 h/day × 5 days/week × 1/1000 × 33/7 weeks = 2121 kWh*

3. A 50-hp motor is rated at 600V/50A/83 percent PF. It runs for 5 hours per day, 5 days per week at a 75 percent loading. For 33 days, the consumption is

   *600 × 50 × $\sqrt{3}$ × .83 x .75 × 1/1000 × 5 days/week × 5 h/day × 33/7 weeks = 3812 kWh*

### 5.5.4 | Energy Reconciliation with Utility Bills

After calculating the energy use of all the different loads in the load inventory, you must reconcile these calculations with the utility bills. If you have evaluated all the loads carefully, the numbers may be reasonably close. If there is a large difference, the following points may help to reconcile the variance:

- If you have more than one meter or have your own sub-metering, break down the energy to match the individual meters.
- Evaluate the loads you know the most about first – general lighting, equipment on time clocks, motors running at constant loads, etc. Assume these are correct and the errors are in other less constant loads such as refrigeration.
- Go back to your first general assumptions (percentage of breakdown) and see how they match up with your more detailed breakdown.
- Double-check schedules, time clocks, etc. to see if equipment is running longer than you thought.
- Averaging weeks into a monthly period can introduce errors, depending on where weekends fall within the billing period.
- When estimating heating equipment run times, if the oil consumption is known, you can calculate the operating hours as (oil consumed in the period)/(firing rate of the burner). This would work only for a single-stage burner.
- If available, use your demand profile (strip chart) to estimate duty cycles of cyclical loads.
- Night loads are often continuous. Try to account for all of your night loads.

# 6 GUIDE TO SPREADSHEET TOOL

## 6.1 General Instructions

Each spreadsheet is designed as a stand-alone template to assist in each step of the audit methodology. The sheets provide data entry instructions to complement the energy application information contained in each chapter of the audit guide. Users are encouraged to become familiar with the information in the audit guide prior to using the templates.

### 6.1.1 | Compatibility

The spreadsheets were created in Microsoft Excel 2000 and should function properly in Excel 97 and later versions.

### 6.1.2 | Data Entry Fields

Each spreadsheet is protected to prevent data entry in cells that contain formulas. Cells that will accept data have a blue text or number colour. Each data entry cell is described in the sections below. Selected cells have drop-down lists to assist in selection of the correct input data.

You can clear sample data from the data entry fields by highlighting the field and using the delete key. After clearing data from a template, save it under a new filename ready for use. In many situations you will want to create more than one copy of the template for different plant areas or buildings.

### 6.1.3 | Printing

Each tab (or sheet) of each spreadsheet workbook has been formatted to fit on one page. Simply click on the printer tool button or select Print from the File menu. In some cases with long data lists, only the first part of the data range is printed. The print range will need to be respecified using the menu command File | Print Area | Set if you need to print the entire list.

### 6.1.4 | Save Your Data

You may save your data under the original spreadsheet name or select a new one. In some cases you may need to create multiple versions of the spreadsheets for different sets of data. As with any software application, saving your data frequently is a good idea. Be warned – many versions of Excel do not have Auto File Save features.

### 6.1.5 | Advanced User Modification to Spreadsheets

Advanced users may wish to modify the spreadsheets to meet their own needs. While each sheet is protected, it may be unprotected from the Tools menu of Excel. There is no password protection, and only sheet-level protection is applied. For those familiar with Visual Basic, there is VBA code in a number of the sheets, providing additional functions for technical calculations. Those that are modifiable are not protected with passwords. Advanced users are encouraged to explore the spreadsheets and adapt, enhance or otherwise modify them to meet their own needs.

### 6.1.6 | Summary of Template Features and Benefits

| Template | Features | Benefits |
|---|---|---|
| 6.2 Condition Survey<br>Condition Survey.xls | Condition assessment of various building and plant systems<br>Accommodates multiple areas for each system<br>Examines systems from any energy use | Creates a report card for each system/area<br>Helps to prioritize areas of need<br>Can be revisited to plot progress |
| 6.3 Electricity Cost<br>Electricity Cost.xls | Tabulates demand and consumption<br>Performs/verifies billing calculations<br>Creates basic graphs | Awareness of costs<br>Spots billing errors<br>Can be used to check different rates<br>Can be used to evaluate savings based on demand and energy reductions |
| 6.4 Gas Cost<br>Gas Cost.xls | Tabulates consumption<br>Performs/verifies billing calculations<br>Creates basic graphs | Awareness of costs<br>Spots billing errors<br>Can be used to check different rates<br>Can be used to evaluate savings based on consumption reduction |
| 6.5 Fuel Cost<br>Fuel Cost.xls | Tabulates consumption<br>Performs/verifies billing calculations<br>Creates basic graphs | Awareness of costs<br>Can be used to evaluate savings based on consumption reduction |
| 6.6 Comparative Analysis<br>Comparative Analysis.xls | Tabulates energy versus weather and production data<br>Regression analysis<br>CUSUM analysis<br>Target analysis | Identifies trends in historical data<br>Identifies anomalies in historical data<br>Provides a means of establishing real targets based upon existing consumption patterns |

| Template | Features | Benefits |
|---|---|---|
| 6.7 Profile<br>Profile.xls | Plots a time series profile of kW and power factor<br>Plots load duration curves | Facilitates analysis of the electrical fingerprint of a facility<br>Helps to identify demand and energy savings opportunities |
| 6.8 Load Inventory<br>Load Inventory.xls | Tabulates demand and energy for list of loads<br>Performs peak demand and energy calculations<br>Creates a pie chart of demand and energy breakdown | Identifies major demand and energy consumption<br>Provides a summary of how a facility uses electricity |
| 6.9 Fuel Systems<br>Fuel Systems.xls | Tabulates fuel combustion system capacity and performance specs<br>Calculates combustion efficiency | Focuses attention on energy use by quantifying usage<br>Makes technical calculations easier |
| 6.10 Thermal Inventory<br>Thermal Inventory.xls | Tabulates major thermal energy use processes<br>Performs air, water, steam, psychrometric and conduction calculations<br>Provides a summary table and pie chart | Focuses attention on energy use by quantifying usage<br>Makes technical calculations easier |
| 6.11 Envelope<br>Envelope.xls | Simple building envelope heat loss calculator<br>Analyses window, door, wall, roof, slab ventilation and exhaust heat loss<br>Provides a one-page worksheet of data and results | Focuses attention on energy use by quantifying usage<br>Makes technical calculations easier |
| 6.12 Assess the Benefit<br>Assess the Benefit.xls | Provides a template for opportunity description, energy, cost and GHG saving calculations<br>Economic analysis by simple payback, NPV and IRR methods | Creates a professional-looking analysis of a saving opportunity<br>Helps to sell the opportunity |

## 6.2 Condition Survey

This sheet provides a template for recording condition survey information. The template can be copied and customized to survey those conditions deemed important for the systems present. The detailed audit methodology provides sample survey templates for various systems. Condition Survey.xls

**The Condition Survey**

| **System:** | **Sample Plant Lighting System** | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Date:** | 4-Jun-02 | | | | | | | | | | | | | | | | | | | |
| **Auditor:** | Chase A. Watt | | | | | | | | | | | | | | | | | | | |
| **Comments:** These are sample comments for the lighting systems condition survey. | | Excessive Illumination | Appropriate Illumination | Lights Controlled on Motion Sensors | Lights Controlled on Switches | Lights Controlled on Breakers | Incandescent (Inc) Lighting | Non-Inc Lighting (Fluroescent or HID) | Luminaires Clean | Luminaires Dirty | Room Surface Reflection Good | Room Surface Reflection Poor | | | | | | | **Total Points** | **Rating for Location** |
| **No.** | **Location / Points** | 0 | 1 | 2 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | | | | | | | | |
| | **Maximum Points** | | 1 | 2 | | | | 1 | 1 | | 1 | | | | | | | | 6 | **100%** |
| **1** | Office Area | | 1 | 2 | | | | 1 | 1 | | | 0 | | | | | | | 5 | **83%** |
| **2** | Production Area | | 1 | | | 0 | | 1 | | 0 | | 0 | | | | | | | 2 | **33%** |
| **3** | Warehouse Area | 0 | | | 1 | | 0 | | 1 | | | 0 | | | | | | | 2 | **33%** |
| **4** | Outside | | 1 | 2 | | | | 1 | 1 | | 1 | | | | | | | | 6 | **100%** |
| | | | | | | | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | | | | | | | 0 | **0%** |
| | | | | | | | | | | | | | | | | | | | 0 | **0%** |
| **Total Points and Overall Rating for Sample Plant Lighting System** | | | | | | | | | | | | | | | | | | | **15** | **63%** |

### 6.2.1 | Condition Template

| Input Field Name | Condition Survey Fields |
|---|---|
| System | Enter the description of the systems to be surveyed. |
| Date | Enter a date for the survey. |
| Auditor | Enter your name. |
| Comments | Enter any comments applicable. |
| Location | Enter a name for each area to be surveyed. |
| Criteria | In the vertical cells, enter each of the criteria you will use to rate the system. |
| Points | Enter the points scored if each criteria is met. *Note that some fields are mutually exclusive; for example, in the Lighting System survey above, the lights are controlled either by motion sensors (2 points) or by switches (1 point), not both.* |
| Maximum Points | Enter points to represent the maximum score that could be achieved. If there are two or more criteria that are related, with ascending scores, enter only the maximum score, as in the example above. |
| Actual Points | Enter points score for each area survey. |
| Overall Rating | The sheet will calculate a score for each area (scale of 0–100%), with 100% representing a score equal to the maximum point score specified above. The sheet will then sum all areas for an overall aggregate score. |
| Validation of Data Table | This is not an input field. Data that is input into the columns of the main table must be valid. The score assessed must not be greater than the score at the top of the column in the Location/Points row. In addition, the Maximum Points (2nd row) must not exceed the top row either. Either condition will trigger a red "X" in the appropriate column of this table. |

## 6.3 Electricity Cost

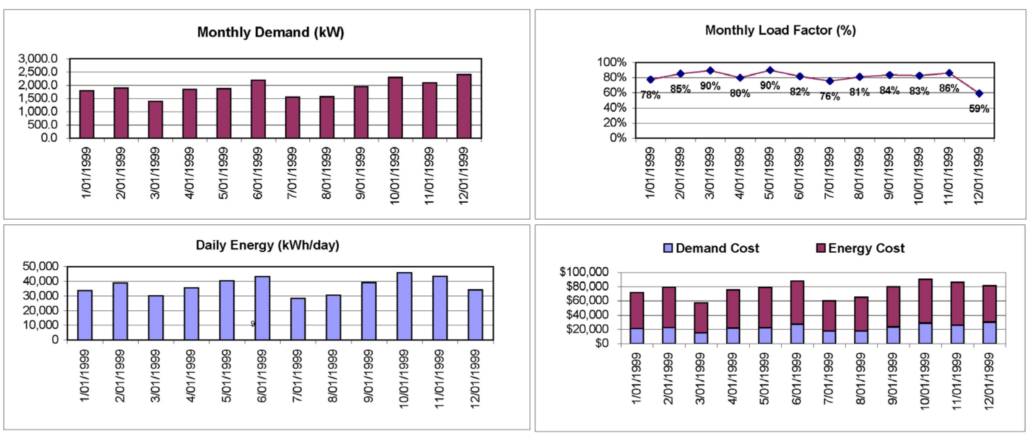
This spreadsheet provides a facility for tabulating electricity consumption, rate and cost data. It provides a breakdown of monthly costs into major bill/rate components and provides informative graphs on an annual basis.

## 6.3.1 | Electricity Consumption Data

This sheet is used to enter electricity consumption data. Costs and graphs are displayed.
Electricity Cost.xls

**Electricity Consumption Data** Location: ABC Facility

| Billing Date | Metered kVA | Metered kW | Power Factor | Billed kW | Energy kWh | Days | Daily kWh | Load Factor | Demand Cost | Energy Cost | Adjust (+/-) | Sub Total | Total Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/01/1999 | | 1,800.0 | | 1,800.0 | 1,006,703 | 30 | 33,557 | 78% | $21,250 | $50,365 | ($11,147) | $71,615 | $64,701 |
| 2/01/1999 | | 1,900.0 | | 1,900.0 | 1,206,383 | 31 | 38,916 | 85% | $22,750 | $56,441 | ($13,204) | $79,191 | $70,607 |
| 3/01/1999 | | 1,400.0 | | 1,400.0 | 842,286 | 28 | 30,082 | 90% | $15,250 | $42,144 | ($9,263) | $57,394 | $51,501 |
| 4/01/1999 | | 1,850.0 | | 1,850.0 | 1,102,176 | 31 | 35,554 | 80% | $22,000 | $53,315 | ($12,132) | $75,315 | $67,606 |
| 5/01/1999 | | 1,870.0 | | 1,870.0 | 1,213,021 | 30 | 40,434 | 90% | $22,300 | $56,641 | ($13,252) | $78,941 | $70,287 |
| 6/01/1999 | | 2,200.0 | | 2,200.0 | 1,339,599 | 31 | 43,213 | 82% | $27,250 | $60,438 | ($14,716) | $87,688 | $78,080 |
| 7/01/1999 | | 1,560.0 | | 1,560.0 | 850,195 | 30 | 28,340 | 76% | $17,650 | $42,540 | ($9,438) | $60,190 | $54,304 |
| 8/01/1999 | | 1,570.0 | | 1,570.0 | 948,747 | 31 | 30,605 | 81% | $17,800 | $47,467 | ($10,429) | $65,267 | $58,677 |
| 9/01/1999 | | 1,950.0 | | 1,950.0 | 1,213,798 | 31 | 39,155 | 84% | $23,500 | $56,664 | ($13,308) | $80,164 | $71,536 |
| 10/01/1999 | | 2,300.0 | | 2,300.0 | 1,373,054 | 30 | 45,768 | 83% | $28,750 | $61,442 | ($15,111) | $90,192 | $80,337 |
| 11/01/1999 | | 2,100.0 | | 2,100.0 | 1,347,059 | 31 | 43,454 | 86% | $25,750 | $60,662 | ($14,731) | $86,412 | $76,699 |
| 12/01/1999 | | 2,400.0 | | 2,400.0 | 1,024,475 | 30 | 34,149 | 59% | $30,250 | $50,984 | ($11,685) | $81,234 | $74,418 |
| **Totals/Max** | | **2,400.0** | | **2,400.0** | **13,467,496** | **364** | | | **$274,500** | **$639,104** | **($148,415)** | **$913,604** | **$818,752** |




| Input Field Name | Electricity Consumption Data Fields |
|---|---|
| Location | Enter the location of the electricity meter as a title. |
| Billing Date | Enter the date as shown on the bill – ideally the monthly meter reading date. |
| Metered kVA | If kVA values are shown on the bill, enter them here; otherwise, leave blank. |
| Metered kW | Enter the metered kW values for each month as shown on the bill. |
| Billed kW (kVA) | The sheet will display the kW values used for the bill – adjusted for PF, if this is specified on the rates sheet (see below). |
| Power Factor | Enter the power factor values for each month if they are shown on the bill; otherwise, leave this field blank. |
| Energy (kWh) | Enter the monthly energy consumption shown on the bills. |
| Days | The system will calculate the length of the billing period for every month but the first – since the last billing date is not entered. Enter the number of days since the last billing date. |

### 6.3.2 | Electrical Rate Data

On this sheet, the electricity rate information is entered to facilitate calculation of monthly costs on the previous page.

**Electricity Rate**

**Rate Name:** Large General Service Rate
**Month & Year:** Jan 1999
**Service Charge:** / month

**Demand Billing Units:** kW ( kVA or kW )
**Utility Desired PF:** 90%

| | | | | |
|---|---|---|---|---|
| **Demand Charges:** | | **for 1st:** | 50 | kW |
| | $10.00 | **for 2nd:** | 1,000 | kW |
| | $15.00 | for the remainder | | |

| | | | Block Size | | per kW? |
|---|---|---|---|---|---|
| **Energy Charges:** | | | | | |
| | 0.08000 | **for 1st:** | 1,000 | kWH/Month | N |
| | 0.05000 | **for 2nd:** | 10,000 | kWH/Month | N |
| | 0.05000 | **for 3rd:** | 1,000,000 | kWH/Month | n/a |
| | | **for 4th:** | | kWH/Month | n/a |
| | 0.03000 | **for the remainder** | | | |

**Transformer Credit:** $0.60 /kW
**Primary Meter Credit:** $0.01 /kWh

**Adjustments:** ( % of the entire bill, - for discount, + for surcharge )
( fixed, - for discount, + for surcharge )

**Tax:** 7.00% ( applied after adjustments )

**Estimated P.F.** 85% ( used for estimating kW in load factor calculation when metered kVA )

| Input Field Name | Electricity Rate Data Fields |
|---|---|
| Rate Name, Month & Year | Enter descriptors for the rate name and the applicable dates. |
| Service Charge | Enter the service charge per meter in dollars. |
| Demand Billing Units | Select either kW or kVA as the demand billing units. |
| Utility Desired PF | Enter the desired power factor that the utility uses to calculate billed demand (i.e. maximum of metered kW or 90% of metered kVA). |
| Demand Charges (3 fields) | Enter the charge in dollars for each of the respective demand blocks. If only one block, enter the charge in the remainder field. |
| Demand Blocks (2 fields) | Enter the size of the first two demand blocks – if applicable. |
| Energy Charges (5 fields) | Enter the charge in dollars for each of the respective energy blocks. If only one block, enter the charge in the remainder field. |
| Energy Block Size (5 fields) | Enter the size of the first three energy blocks – if applicable. If the block sizes depend upon demand, enter the block size multipliers here. |
| Per kW? (2 fields) | If the energy block size depends on demand, indicate that with a "Y" here and ensure that the energy block size entries are multipliers. |
| Transformer Credit | Enter the credit per kW if the transformers are owned by customer. |
| Primary Meter Credit | Enter the credit per kWh for primary metering. |
| Adjustments | Enter adjustment factors – either as a percentage of the entire bill or as an amount that will be negative for discount and positive for surcharge. |
| Tax | Enter the tax rate to be applied to the entire bill after adjustments. |
| Estimated PF | If the power factor is not indicated on the bill but kVA demand is, enter a PF to be used to calculate kW for the load factor calculation. |

## 6.4 Gas Cost

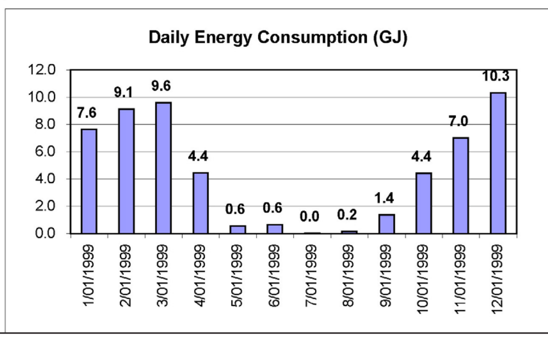
This spreadsheet provides a facility for tabulating natural gas consumption, rate and cost data. It provides a breakdown of monthly costs into major bill/rate components and provides informative graphs on an annual basis. Gas Cost.xls

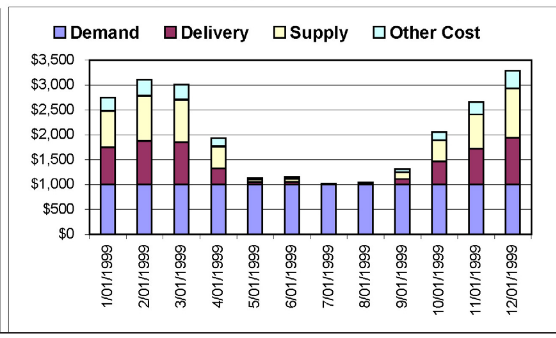
### 6.4.1 | Natural Gas Consumption

Enter natural gas consumption data on this sheet. Costs and graphs are displayed.

**Natural Gas Consumption Data** Location: ABC Facility

| Billing Date | Season S/W | Consumption $m^3$ | Days | Energy GJ | GJ per Day | Demand Cost | Delivery Cost | Supply Cost | Other Cost | Adjust (+/-) | Total Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/01/1999 | W | 6,100 | 30 | 229 | 7.6 | $1,000 | $749 | $732 | $265 | | $3,295 |
| 2/01/1999 | W | 7,525 | 31 | 283 | 9.1 | $1,000 | $877 | $903 | $324 | | $3,725 |
| 3/01/1999 | W | 7,162 | 28 | 269 | 9.6 | $1,000 | $845 | $859 | $309 | | $3,615 |
| 4/01/1999 | S | 3,662 | 31 | 138 | 4.4 | $1,000 | $326 | $439 | $165 | | $2,317 |
| 5/01/1999 | S | 450 | 30 | 17 | 0.6 | $1,000 | $45 | $54 | $33 | | $1,359 |
| 6/01/1999 | S | 525 | 31 | 20 | 0.6 | $1,000 | $53 | $63 | $37 | | $1,382 |
| 7/01/1999 | S | 25 | 30 | 1 | 0.0 | $1,000 | $3 | $3 | $16 | | $1,226 |
| 8/01/1999 | S | 125 | 31 | 5 | 0.2 | $1,000 | $13 | $15 | $20 | | $1,257 |
| 9/01/1999 | S | 1,125 | 31 | 42 | 1.4 | $1,000 | $111 | $135 | $61 | | $1,569 |
| 10/01/1999 | W | 3,525 | 30 | 133 | 4.4 | $1,000 | $468 | $423 | $160 | | $2,460 |
| 11/01/1999 | W | 5,788 | 31 | 218 | 7.0 | $1,000 | $717 | $695 | $252 | | $3,196 |
| 12/01/1999 | W | 8,238 | 30 | 310 | 10.3 | $1,000 | $941 | $989 | $353 | | $3,939 |
| **Totals/Max** | | **44,250** | **364** | **1,664** | **4.6** | **$12,000** | **$5,147** | **$5,310** | **$1,994** | | **29,341** |




| Input Field Name | Natural Gas Consumption Data Fields |
|---|---|
| Location | Enter the location of the gas meter as a title. |
| Billing Date | Enter the date as shown on the bill – ideally the monthly meter reading date. |
| Consumption ($m^3$) | Enter the monthly gas consumption shown on the bills. |
| Days | The system will calculate the length of the billing period for every month but the first – since the last billing date is not entered. Enter the number of days since the last billing date. |

## 6.4.2 | Natural Gas Rate

Enter natural gas rate information on this sheet to facilitate calculation of monthly costs on the previous page.

**Natural Gas Rate**

**Rate Name:** Large General Service Rate
**Month & Year:** Jan 1999

**Billing Units:** $m^3$ ($m^3$, GJ, Therms)
**Energy Content:** 0.0376 GJ/$m^3$

**Service Charge:** $15.00 / month

**Delivery Charges:**

| Summer rate | | Summer Block Size | | Winter rate | | Winter Block Size | |
|---|---|---|---|---|---|---|---|
| $0.10000 | for 1st: | 1,000 | $m^3$ | $0.15000 | for 1st: | 1,000 | $m^3$ |
| $0.09000 | for 2nd: | 2,000 | $m^3$ | $0.13000 | for 2nd: | 2,000 | $m^3$ |
| $0.07000 | for 3rd: | 3,000 | $m^3$ | $0.11000 | for 3rd: | 3,000 | $m^3$ |
| $0.04000 | for the remainder | | | $0.09000 | for the remainder | | |

**Demand Charge:** $1,000.00 or Contract Demand 5,000 GJ/$m^3$ x $0.20 /GJ/$m^3$ — $1,000.00

**Supply Charge:** $0.12 /$m^3$ — $0.12 /$m^3$
**Storage Charge:** $0.04 /$m^3$ — $0.04 /$m^3$

**Other Charges:** $0.00 /$m^3$ — $0.00 /$m^3$
$0.00 /month — $0.00 /month

**Adjustments:** 0.00% ( of the entire bill, - for discount, + for surcharge )
$0.00 ( fixed, - for discount, + for surcharge )

**Tax:** 20.00% ( applied after adjustments )

| Input Field Name | Natural Gas Rate Fields |
|---|---|
| Rate Name, Month & Year | Enter a descriptor for the rate name and the applicable dates. |
| Billing Units | Enter the billing units for the gas (typically GJ or $m^3$). |
| Energy Content | Enter the energy content in GJ per unit specified above. |
| Service Charge | Enter a dollar amount for the service charge. |
| Delivery Charges (4 fields each for winter & summer seasons) | Enter charges for delivery of gas, winter and summer if applicable. If only one block, enter in 4th field. |
| Delivery Charge Block (3 fields) | Enter a size for each of the delivery charge blocks. |
| Demand Charge (2 fields, one for winter, one for summer) | Enter a demand charge for delivery of gas, winter and summer if applicable. |
| Contract Demand (two fields) | Enter a contract demand – typically volume per month and an applicable rate per cubic metre. |
| Supply Charge (2 fields, one for winter, one for summer) | Enter a charge for supply of gas, winter and summer if applicable. |

| Input Field Name | Natural Gas Rate Fields |
|---|---|
| Storage Charge (2 fields, one for winter, one for summer) | Enter a charge for storage of gas, winter and summer if applicable. |
| Other Charges | Enter an amount for other charges, either as a percentage or as a fixed amount. |
| Adjustments | Enter adjustment factors – either as a percentage of the entire bill or as an amount, which will be negative for discount and positive for surcharge. |
| Tax | Enter the tax rate to be applied to the entire bill after adjustments. |

## 6.5 Fuel Cost

This spreadsheet provides a facility for tabulating fuel and other energy consumption, rate and cost data. It provides a breakdown of monthly costs into major bill/rate components and provides informative graphs on an annual basis. Fuel Cost.xls

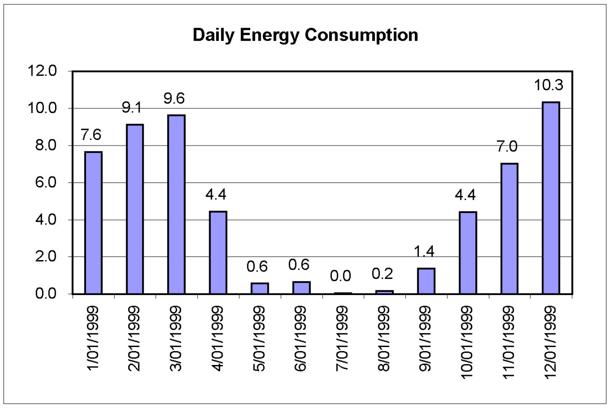
### 6.5.1 | Fuel Consumption

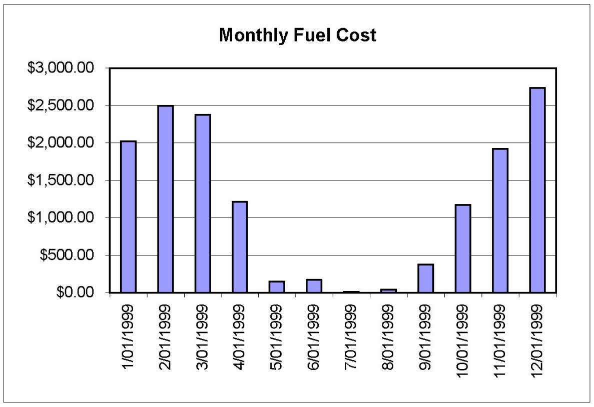
Enter fuel or other energy consumption data on this sheet. Costs and graphs are displayed.

**#2 Oil Consumption Data**

**Location:** ABC Facility

| Billing Date | Season S/W | Consumption Litre | Days | Energy GJ | GJ per Day | Demand Cost | Delivery Cost | Supply Cost | Other Cost | Adjust (+/-) | Total Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/01/1999 | W | 6,100 | 30 | 229 | 7.6 | | | $1,891.00 | | | $2,023.37 |
| 2/01/1999 | W | 7,525 | 31 | 283 | 9.1 | | | $2,332.75 | | | $2,496.04 |
| 3/01/1999 | W | 7,162 | 28 | 269 | 9.6 | | | $2,220.22 | | | $2,375.64 |
| 4/01/1999 | S | 3,662 | 31 | 138 | 4.4 | | | $1,135.22 | | | $1,214.69 |
| 5/01/1999 | S | 450 | 30 | 17 | 0.6 | | | $139.50 | | | $149.27 |
| 6/01/1999 | S | 525 | 31 | 20 | 0.6 | | | $162.75 | | | $174.14 |
| 7/01/1999 | S | 25 | 30 | 1 | 0.0 | | | $7.75 | | | $8.29 |
| 8/01/1999 | S | 125 | 31 | 5 | 0.2 | | | $38.75 | | | $41.46 |
| 9/01/1999 | S | 1,125 | 31 | 42 | 1.4 | | | $348.75 | | | $373.16 |
| 10/01/1999 | W | 3,525 | 30 | 133 | 4.4 | | | $1,092.75 | | | $1,169.24 |
| 11/01/1999 | W | 5,788 | 31 | 218 | 7.0 | | | $1,794.28 | | | $1,919.88 |
| 12/01/1999 | W | 8,238 | 30 | 310 | 10.3 | | | $2,553.78 | | | $2,732.54 |
| **Totals/Max** | | **44,250** | **364** | **1,664** | **4.6** | | | **$13,717.50** | | | **$14,677.73** |



| Input Field Name | Fuel Consumption Fields |
|---|---|
| Location | Enter the location of the fuel delivery or metering point as a title. |
| Billing Date | Enter the date as shown on the bill – ideally the monthly meter-reading date. |
| Consumption (litres) | Enter the monthly fuel consumption shown on the bills. |
| Days | The system will calculate the length of the billing period for every month but the first – since the last billing date is not entered. Enter the number of days since the last billing date. |

### 6.5.2 | Fuel Rate

Enter fuel rate or price information on this sheet to facilitate calculation of monthly costs on the previous page.

**Other Fuel/Energy Rates**

**Supplier:** ABC Fuel Suppliers
**Month & Year:** January 1999

**Fuel/Energy Type:** #2 Oil
**Unit of Measure** Litre (litre, m$^3$, GJ, MMBtu, Therms)
**Energy Content:** 0.0376 GJ/Litre

**Service Charge:** / month

| **Delivery Charges:** | **Summer** | | **Winter** | |
|---|---|---|---|---|
| | | **Block Size** | | **Block Size** |
| | **for 1st:** | Litre | **for 1st:** | Litre |
| | **for 2nd:** | Litre | **for 2nd:** | Litre |
| | **for 3rd:** | Litre | **for 3rd:** | Litre |
| | **for the remainder** | | **for the remainder** | |
| | | **Contract Demand** | | |
| **Demand Charge:** | or | Litre | | |
| | x | /Litre | | |
| **Supply Charge:** | $0.31 /Litre | | $0.31 /Litre | |
| **Storage Charge:** | /Litre | | /Litre | |
| **Other Charges:** | /Litre | | /Litre | |
| | /month | | /month | |

**Adjusments:** ( of the entire bill, - for discount, + for surcharge )
( fixed, - for discount, + for surcharge )

**Tax:** 7.00% ( applied after adjustments )

| Input Field Name | Fuel Rate Fields |
|---|---|
| Supplier, Month & Year | Enter a descriptor for the rate name and the applicable dates. |
| Fuel/Energy Type | Enter descriptor for the type of fuel/energy. |
| Unit of Measure | Enter the units or measure for the fuel/energy. |
| Energy Content | Enter the energy content in GJ per unit specified above. |

| Input Field Name | Fuel Rate Fields |
|---|---|
| Service Charge | Enter a dollar amount for the service charge. |
| Delivery Charges (4 fields each for winter & summer seasons) | Enter a charge for delivery of fuel/energy, winter and summer if applicable. If only one block, enter in 4th field. |
| Delivery Charge Block (3 fields) | Enter a size for each of the delivery charge blocks. |
| Demand Charge (2 fields, one for winter, one for summer) | Enter a demand charge for delivery of fuel/energy, winter and summer if applicable. |
| Contract Demand (two fields) | Enter a contract demand – typically volume per month and an applicable rate per unit or measure. |
| Supply Charge (2 fields, one for winter, one for summer) | Enter a charge for supply of fuel, winter and summer if applicable. |
| Storage Charge (2 fields, one for winter, one for summer) | Enter a charge for storage of fuel, winter and summer if applicable. |
| Other Charges | Enter an amount for other charges, either as a percentage or as a fixed amount. |
| Adjustments | Enter adjustment factors – either as a percentage of the entire bill or as an amount, which will be negative for discount and positive for surcharge. |
| Tax | Enter the tax rate to be applied to the entire bill after adjustments. |

## 6.6 Comparative Analysis

This sheet performs one simple variable regression analysis on energy versus driver data to generate a linear baseline model. Comparative Analysis.xls

### 6.6.1 | Regression Analysis of Baseline

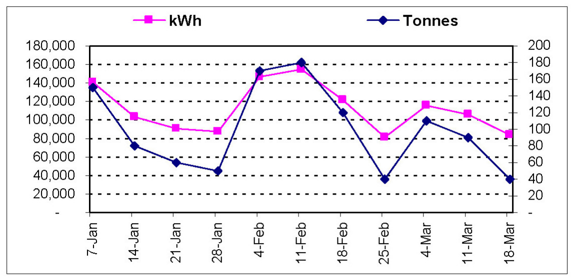
| Input Field Name | Regression Analysis of Baseline Fields |
|---|---|
| Period (heading) | Enter the description of the period you will use. |
| Period (data) | Enter a sequence number for each period. |
| Date | Optional – enter a data for each period for labels on time sequence graph. |
| Driver (unit label) | Enter the units for the driver you will use. |
| Driver (data) | Enter the value of the driver for each period. |
| Energy (unit label) | Enter the units for the energy you will analyse. |
| Energy Data | Enter the value of the energy use for each period. |
| Baseline Period Start | Select from the sequence number list the start of the period to be regressed. |
| Baseline Period End | Select from the sequence number list the end of the period to be regressed. |

**Regression Analysis of Baseline** Menu

| Measured Data | | Variables | |
|---|---|---|---|
| Period Weeks | Date (Optional) | Driver Tonnes | Energy kWh |
| 1 | 1/7/2002 | 150 | 140,726 |
| 2 | 1/14/2002 | 80 | 103,223 |
| 3 | 1/21/2002 | 60 | 90,764 |
| 4 | 1/28/2002 | 50 | 87,567 |
| 5 | 2/4/2002 | 170 | 146,600 |
| 6 | 2/11/2002 | 180 | 154,773 |
| 7 | 2/18/2002 | 120 | 121,575 |
| 8 | 2/25/2002 | 40 | 81,436 |
| 9 | 3/4/2002 | 110 | 115,586 |
| 10 | 3/11/2002 | 90 | 105,909 |
| 11 | 3/18/2002 | 40 | 83,916 |
| 12 | 3/25/2002 | 50 | 86,272 |
| 13 | 4/1/2002 | 140 | 125,892 |
| 14 | 4/8/2002 | 155 | 138,966 |
| 15 | 4/15/2002 | 165 | 139,922 |
| 16 | 4/22/2002 | 190 | 152,274 |
| 17 | 4/29/2002 | 40 | 77,788 |
| 18 | 5/6/2002 | 55 | 82,711 |
| 19 | 5/13/2002 | 150 | 124,317 |
| 20 | 5/20/2002 | 80 | 94,677 |
| 21 | 5/27/2002 | 63 | 84,628 |
| 22 | 6/3/2002 | 110 | 108,041 |
| 23 | 6/10/2002 | 70 | 89,115 |
| 24 | 6/17/2002 | 170 | 136,388 |
| 25 | 6/24/2002 | 190 | 141,428 |
| 26 | 7/1/2002 | 160 | 141,215 |
| 27 | 7/8/2002 | 120 | 118,319 |
| 28 | 7/15/2002 | 190 | 152,506 |
| 29 | 7/22/2002 | 80 | 99,267 |
| 30 | 7/29/2002 | 90 | 94,468 |
| 31 | 8/5/2002 | 180 | 140,188 |
| 32 | 8/12/2002 | 70 | 91,262 |
| 33 | 8/19/2002 | 50 | 78,248 |
| 34 | 8/26/2002 | 155 | 128,005 |
| 35 | 9/2/2002 | 167 | 131,003 |
| 36 | 9/9/2002 | 120 | 109,192 |


| Baseline Period | |
|---|---|
| Start | 1 |
| End | 11 |

| Baseline Regression Model | | $R^2$= 0.996 |
|---|---|---|
| Slope | 511.059 | kWh/Tonnes |
| Intercept | 61,366 | kWh |




### 6.6.2 | CUSUM Analysis

On this sheet, apply the CUSUM[1] technique to compare historical data with the baseline as defined by the regression analysis. This gives a period of best performance since the baseline can be selected.

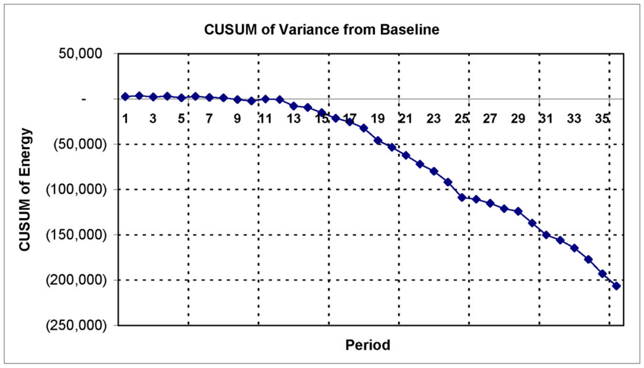
| Input Field Name | CUSUM Analysis Fields |
|---|---|
| CUSUM Period Start | Select start of period of historical data to compare against baseline period using CUSUM technique. |
| CUSUM Period End | Select end of period of historical data to compare against baseline period using CUSUM technique. |
| Period of Best Performance Start | Select start of period of historical data that CUSUM identifies as period of best performance versus the baseline. |
| Period of Best Performance End | Select end of period of historical data that CUSUM identifies as period of best performance versus the baseline. |

[1] CUSUM is the cumulative sum (running sum) of the difference between the predicted energy consumption and the actual energy consumption. See Section B-5, "Comparative Analysis," for a detailed explanation.

**CUSUM Analysis of Deviations from Baseline**

Menu

| Period | Actual Energy kWh | Baseline Energy kWh | Variance Energy kWh | CUSUM Energy kWh |
|---|---|---|---|---|
| 1 | 140,726 | 138,024 | 2,702 | 2,702 |
| 2 | 103,223 | 102,250 | 973 | 3,674 |
| 3 | 90,764 | 92,029 | (1,265) | 2,409 |
| 4 | 87,567 | 86,918 | 649 | 3,058 |
| 5 | 146,600 | 148,246 | (1,646) | 1,412 |
| 6 | 154,773 | 153,356 | 1,417 | 2,829 |
| 7 | 121,575 | 122,693 | (1,118) | 1,712 |
| 8 | 81,436 | 81,808 | (372) | 1,340 |
| 9 | 115,586 | 117,582 | (1,996) | (656) |
| 10 | 105,909 | 107,361 | (1,452) | (2,108) |
| 11 | 83,916 | 81,808 | 2,108 | 0 |
| 12 | 86,272 | 86,918 | (646) | (646) |
| 13 | 125,892 | 132,914 | (7,022) | (7,668) |
| 14 | 138,966 | 140,580 | (1,614) | (9,282) |
| 15 | 139,922 | 145,690 | (5,768) | (15,050) |
| 16 | 152,274 | 158,467 | (6,193) | (21,243) |
| 17 | 77,788 | 81,808 | (4,020) | (25,263) |
| 18 | 82,711 | 89,474 | (6,763) | (32,026) |
| 19 | 124,317 | 138,024 | (13,707) | (45,733) |
| 20 | 94,677 | 102,250 | (7,573) | (53,306) |
| 21 | 84,628 | 93,562 | (8,934) | (62,240) |
| 22 | 108,041 | 117,582 | (9,541) | (71,781) |
| 23 | 89,115 | 97,140 | (8,025) | (79,806) |
| 24 | 136,388 | 148,246 | (11,858) | (91,664) |
| 25 | 141,428 | 158,467 | (17,039) | (108,702) |
| 26 | 141,215 | 143,135 | (1,920) | (110,622) |
| 27 | 118,319 | 122,693 | (4,374) | (114,996) |
| 28 | 152,506 | 158,467 | (5,961) | (120,956) |
| 29 | 99,267 | 102,250 | (2,983) | (123,940) |
| 30 | 94,468 | 107,361 | (12,893) | (136,833) |
| 31 | 140,188 | 153,356 | (13,168) | (150,001) |
| 32 | 91,262 | 97,140 | (5,878) | (155,878) |
| 33 | 78,248 | 86,918 | (8,670) | (164,549) |
| 34 | 128,005 | 140,580 | (12,575) | (177,123) |
| 35 | 131,003 | 146,712 | (15,709) | (192,833) |
| 36 | 109,192 | 122,693 | (13,501) | (206,333) |




| CUSUM Period | |
|---|---|
| Start | 1 |
| End | 36 |

| CUSUM Stats | | |
|---|---|---|
| Max. | 3,674 | kWh |
| Min. | (206,333) | kWh |
| Final | (192,833) | kWh |

| Period of Best Performance | |
|---|---|
| Start | 19 |
| End | 26 |

| Best Performance Model | $R^2$= | 0.970 |
|---|---|---|
| Slope | 473.844 | kWh/Tonnes |
| Intercept | 56,160 | kWh |

## 6.6.3 | Setting a Target

This sheet compares the various types of targets that could be set for the improvement of energy consumption relative to the driver. The average performance represented by the historical data is compared with the following:

- ✓ baseline performance – defined by the regression analysis.
- ✓ "period of best performance" model – defined on the CUSUM sheet.
- ✓ estimated performance – defined as a percentage of the baseline model (slope & intercept).

Savings in each case are calculated for a specified number of periods as defined on the "Regression Analysis" sheet and for a specified value of the driver variable.

| Input Field Name | CUSUM Analysis Fields |
|---|---|
| Estimated % of Baseline Slope | Enter an estimate of the percentage to which the slope of the baseline model could be reduced. |
| Estimated % of Baseline Intercept | Enter an estimate of the percentage to which the intercept of the baseline model could be reduced. |
| Weeks per Year | Enter a number of periods (defined on regression analysis) per year. |
| Annual (Value of Driver Variable) Tonnes | Enter the total value of the driver variable for one year. |

**Setting a Target for Reduced Consumption**

Menu

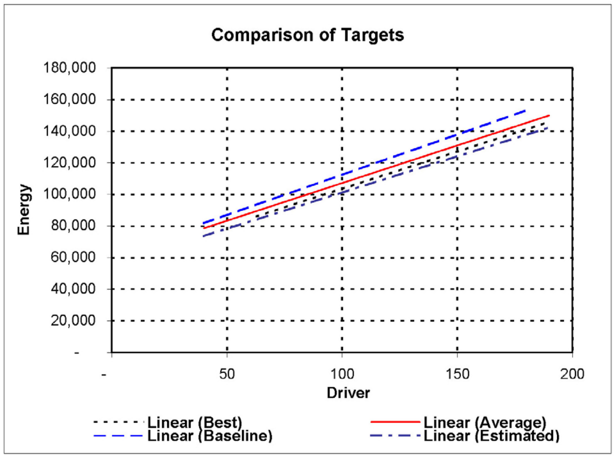
**Comparison on Possible Targets**

| | | | | |
|---|---|---|---|---|
| Baseline Regression Model | | | $R^2$= | 0.996 |
| Slope | 511.059 | kWh/Tonnes | | |
| Intercept | 61,366 | kWh | | |

| | | | | |
|---|---|---|---|---|
| Best Performance Model | | | $R^2$= | 0.970 |
| Slope | 473.844 | kWh/Tonnes | | |
| Intercept | 56,160 | kWh | | |

| | | |
|---|---|---|
| Estimated Performance Model | | |
| Slope is | 90% | of baseline |
| Slope | 459.953 | kWh/Tonnes |
| Intercept is | 90% | of baseline |
| Intercept | 55,229 | kWh |

| Estimated Performance | Tonnes | kWh |
|---|---|---|
| At Minimum Value | 40 | 73,627 |
| AtMaximum Value | 190 | 142,620 |




**Annualized Estimate of Savings**

| | | |
|---|---|---|
| Weeks per year | 52 | |
| Annual Tonnes | 6,000 | Tonnes |
| Average Performance | 999.553 | kWh/Tonnes |

| | kWh/Year | Projected Savings | |
|---|---|---|---|
| At Average Performance | 5,997,318 | | |
| At Baseline Performance | 6,257,361 | (260,043) | -4.3% |
| At Best Performance | 5,763,396 | 233,921 | 3.9% |
| At Estimated Performance | 5,631,625 | 365,693 | 6.1% |

## 6.7 Profile

This spreadsheet displays and analyses demand profile data in the form of power (kW) and optionally power factor (PF) values for up to 3000 arbitrary intervals. It generates displays and graphs of a subset of the full data set both as a time series and in the form of a load duration curve. The load duration curve shows the length of time the recorded load was above a certain value and is useful for scooping demand control opportunities. Profile.xls

**Demand Profile Analysis**

**Profile Location** Plant #2 Service Entrance

**Measurement**

| | | |
|---|---|---|
| Start on : | 23-May-02 | |
| At : | 7:00 | |
| Interval : | 1 | min |
| | 0.0694% | % of day |

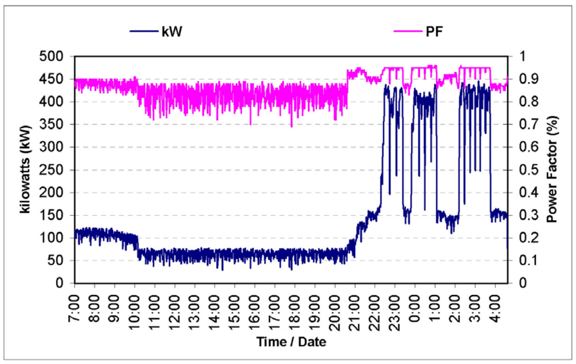
**Statistics**

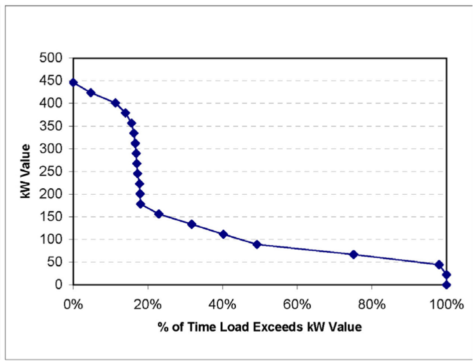
| | |
|---|---|
| # of Readings | 1298 |
| Max kW | 446.20 |
| Min kW | 29.51 |
| Max PF | 0.96 |
| Min PF | 0.69 |

Note: minimum values exclude zero values.

**Period for Analysis**

| | Date/Time | Interval |
|---|---|---|
| Start : | 5/23/02 7:00 | 1 |
| End : | 5/24/02 4:37 | 1298 |
| Duration : | n/a | 1298 |
| Time Axis Units : | Time | |




**Demand Profile**

| Date/Time | Day | Time | kW | PF (%) |
|---|---|---|---|---|
| 5/23/02 7:00 | 23 | 7:00 | 116.9 | 0.89 |
| 5/23/02 7:01 | 23 | 7:01 | 101 | 0.87 |

**Load Duration Curve**

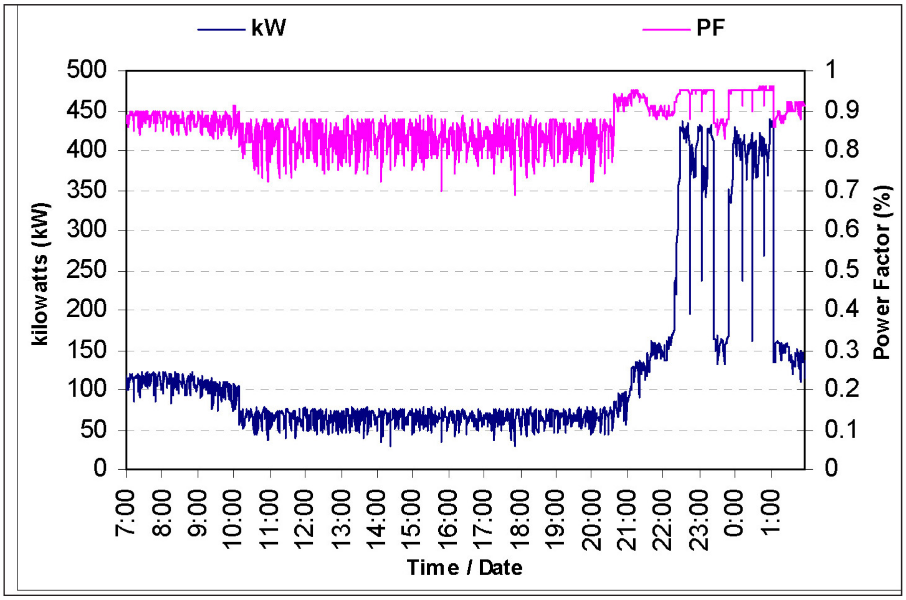
| % of Max | kW | Freq'y | % Time |
|---|---|---|---|
| 100% | 446 | 0 | 0% |
| 95% | 424 | 61 | 4.7% |

### 6.7.1 | Profile Analysis

| Input Field Name | Profile Analysis Fields |
|---|---|
| Profile Location | Enter the description of the location where the profile was measured. |
| Measurement Start-On | Enter a date for the first value in the profile data. |
| At | Enter a time for the first value in the profile data. |
| Interval | Enter the time interval (minutes) used for recording of data (1 min., 15 min., etc.) |
| Analysis Start | Enter the first time period that you want to display on the graph and include in the statistics. (Select from drop-down in cell.) |
| End | Enter the last time period that you want to display on the graph and include in the statistics. (Select from drop-down in cell.) |
| Time Axis Units | Enter the units to appear on the x-axis of the profile (time or date). |
| Demand Profile – kW | In this column enter kW data values recorded for each time interval – ensure that the first time corresponds to the first data item properly. |

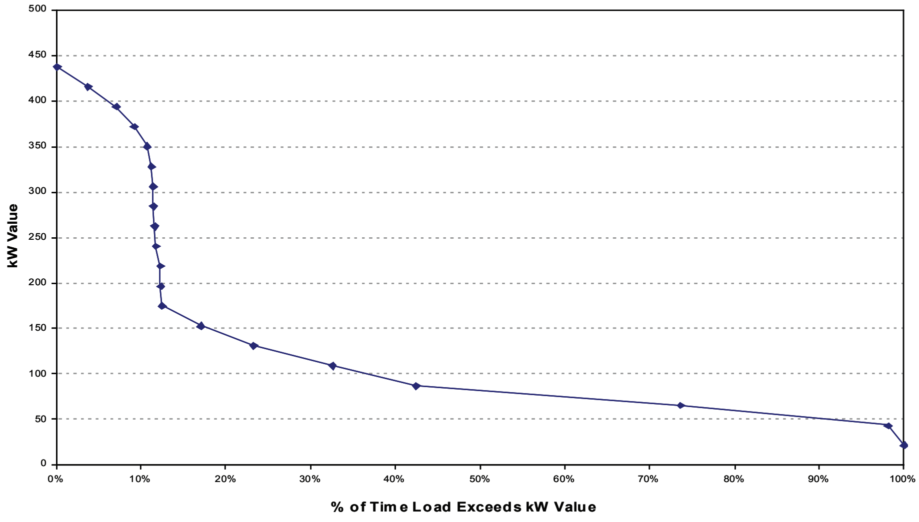
### 6.7.2 | Profile

The profile page provides a full-size demand profile graph, linked to the main data set. It is unprotected and may be formatted to suit other report purposes. This graph can then be copied and pasted (Edit | Paste Special | Picture) to any other document, as illustrated below.




### 6.7.3 | Load Duration

The load duration sheet provides a full-size load duration curve graph, linked to the main data set. It is unprotected and may be formatted to suit other report purposes. This graph can then be copied and pasted (Edit | Paste Special | Picture) to any other document, as illustrated below.



## 6.8 Load Inventory

The “Load Inventory” spreadsheet categorizes loads in five categories, provides a survey input for each category with appropriate input fields, and summarizes in tabular form and in a pie chart the demand and energy breakdown for the loads inventoried. Total loads counted are compared for reconciliation purposes with the monthly demand and energy values from utility invoices as input. Load Inventory.xls

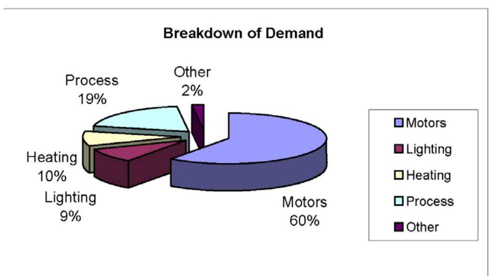
### 6.8.1 | Summary

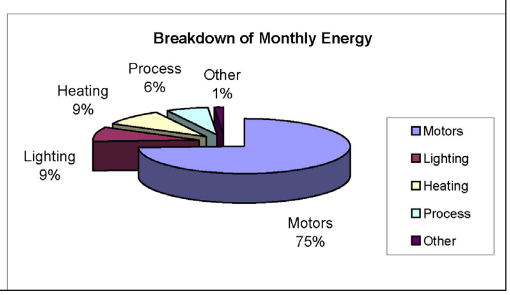
This sheet defines the categories of loads and provides a tabular and graphic summary of demand and energy by category.

**Load Inventory**

**for:** ABC Manufacturing Facility

| | | Peak Demand | | Energy | |
|---|---|---|---|---|---|
| **#** | **Description of Load Group** | **kW** | **%** | **kWh** | **%** |
| 1. | Motors | 28 | 60% | 47,247 | 74% |
| 2. | Lighting | 4 | 9% | 5,640 | 9% |
| 3. | Heating | 5 | 10% | 6,000 | 9% |
| 4. | Process | 9 | 19% | 4,000 | 6% |
| 5. | Other | 1 | 2% | 920 | 1% |
| | **Facility Totals** | **47** | **100%** | **63,807** | **100%** |
| | **Monthly Utility Bills** | **55** | **kW** | **12,000** | **kWh** |
| | **Difference from Bills** | **(8)** | **-15%** | **51,807** | **432%** |



| Input Field Name | Summary Fields |
|---|---|
| Location | Enter the description of the location for the load inventory. |
| Description of Load Group | Enter an alternative name for each of the five categories. Although the names on the graphs and at the top of each of the load inventory sheets will change accordingly, the tab at the bottom of the spreadsheet will retain the original names. Each category name is permanently hyperlinked to the appropriate load inventory sheet. |
| Monthly Utility Bills Peak Demand kW | Enter the value for peak demand in kW from a typical or selected utility bill with which you want to reconcile the load inventory. |
| Monthly Utility Bills Energy kWh | Enter the value for total energy in kWh from a typical or selected utility bill with which you want to reconcile the load inventory. |

### 6.8.2 | Motors

This sheet inventories the motor loads, using horsepower, loading and efficiency data to derive the unit kW values. Alternatively, these could be measured and entered on another sheet as unit kW values. Calculations are defined in the "Energy Inventory" section of the audit guide.

| Input Field Name | Profile Analysis Fields |
|---|---|
| Motor Description | Enter the description of the motor. |
| Qty. | Enter the quantity of this type of motor. |
| Motor HP | Enter the nameplate horsepower (HP) of this motor. |
| Motor Load | Enter the mechanical loading (% or nameplate HP) for this motor. |
| Motor Eff'y | Enter the nameplate efficiency at the specified loading of this motor. |
| Hours/Month | Enter the number of hours per month that this motor operates. |
| Diversity Factor | Enter the diversity factor – the factor representing the fraction of this motor's total load that is registered on the peak demand meter. |

**Load Inventory of Motors**
for ABC Manufacturing Facility

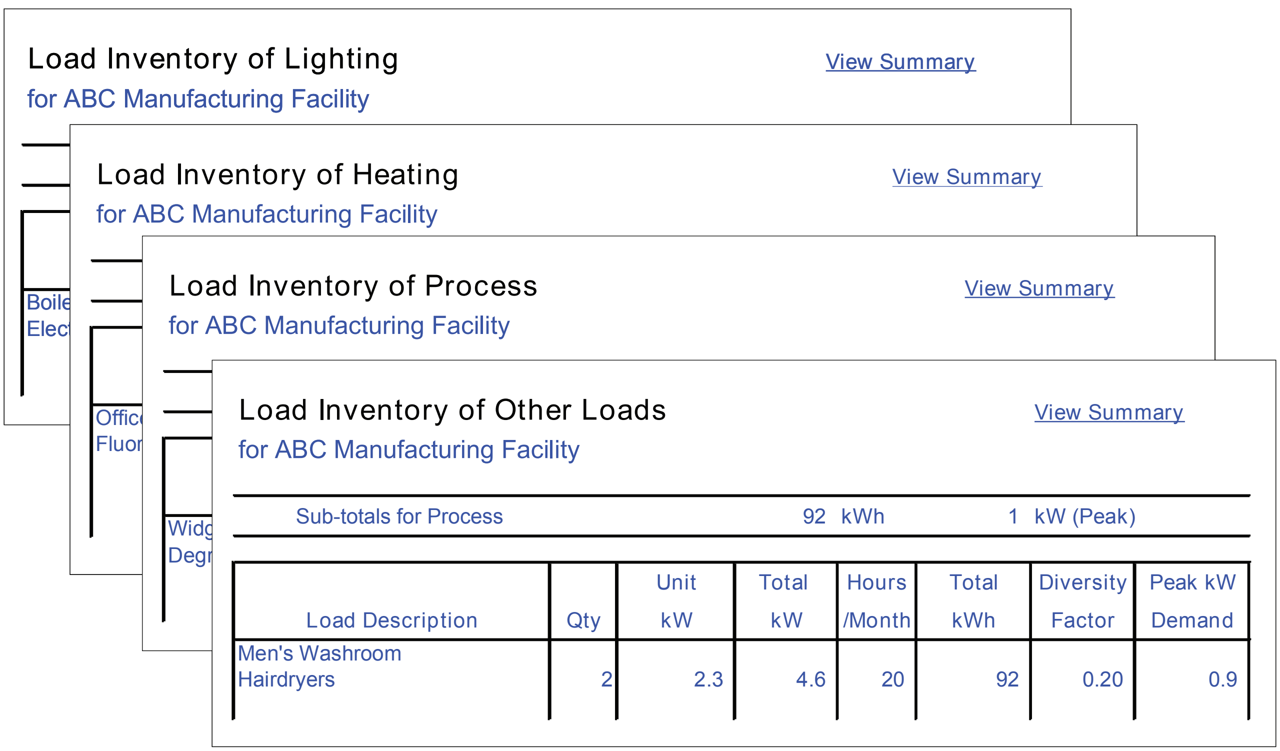
View Summary

| Sub-Totals for Motors | 47,247 kWh | 28 kW (Peak) |
|---|---|---|

| Motor Description | Qty | HP | Motor Load | Eff'y | Unit kW | Total kW | Hours /Month | Total kWh | Diversity Factor | Peak kW Demand |
|---|---|---|---|---|---|---|---|---|---|---|
| Vent Fans System 1 | 1 | 75 | 100% | 90% | 62.2 | 62.2 | 760 | 47,247 | 0.45 | 28.0 |

## 6.8.3 | Lighting, Process Loads, Heating Loads, Other Loads

The remaining four sheets (Lighting, Process Loads, Heating Loads, Other Loads) inventory loads on the basis of unit kW values, which may be estimated, nameplate or actual measured loads.



| Input Field Name | Lighting, Process Loads, Heating Loads, Other Loads Fields |
|---|---|
| Load Description | Enter the description of the particular load. |
| Qty. | Enter the quantity of this load. |
| Unit kW | Enter the nameplate, estimated or measured kW for this load. |
| Hours/Month | Enter the number of hours per month that this load operates. |
| Diversity Factor | Enter the diversity factor – the factor representing the fraction of this total load that is registered on the peak demand meter. |

## 6.9 Fuel Systems

This spreadsheet tabulates fuel-consuming systems and estimates the combustion and, if applicable, the boiler efficiency for these devices. Fuel Systems.xls

### 6.9.1 | Summary

The summary sheet simple displays the energy consumption summary for the various systems detailed on the following sheet.

**Summary of Fuel Consuming Systems**

| Equipment | Fuel Type | Estimated Fuel Usage | Units | Input Energy (GJ) |
|---|---|---|---|---|
| Main Boiler | N. Gas | 600000 | $m^3$ | 22,560,000 |
| DHW Heater | N. Gas | 50000 | $m^3$ | 1,880,000 |
| Heat Treat Furnace | N. Gas | 1000000 | $m^3$ | 37,600,000 |
| | | | | - |
| | | | | - |
| | | | | - |
| | | | | - |
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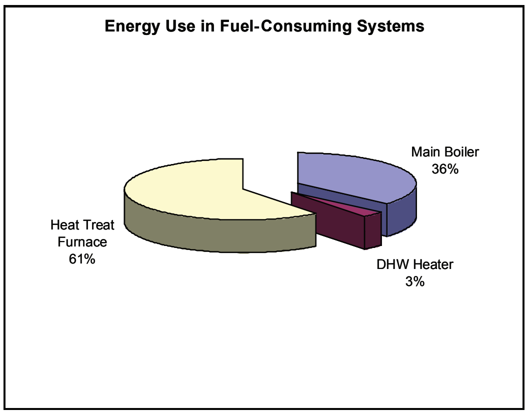
| | | | | - |
| | | | | - |
| | | | | - |
| Total | | 3 Combustion Systems | | 62,040,000 |



### 6.9.2 | Details of Fuel-Consuming Systems

On this sheet, each of the fuel-consuming systems is listed and details regarding fuel consumption, type, combustion conditions and other relevant operational data are entered. From this, a preliminary estimate of the combustion efficiency of the device is made and, if applicable, the overall boiler efficiency is estimated.

**Fuel Consuming Systems**

| | | | | | | | | For Boilers | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Equipment | Fuel Type | Estimated Fuel Usage | Units | Combustion Air Temp (°C) | Stack Temp (°C) | Stack $CO_2$ | Combustion Efficiency | Duty Cycle | Cycling Loss | Estimated Blowdown Losses | Other Losses | Estimated Overall Efficiency |
| Main Boiler | N. Gas | 600,000 | $m^3$ | 20 | 240 | 10% | 81% | 30 | 11% | 1% | 1% | 67% |
| DHW Heater | N. Gas | 50,000 | $m^3$ | 20 | 500 | 6% | 59% | 7 | 10% | 1% | 1% | 47% |
| Heat Treat Furnace | N. Gas | 1,000,000 | $m^3$ | 20 | 700 | 9% | 60% | | | | | 60% |

**Combustion Efficiency is determined from Seigert's Formula:**

$$\text{Efficiency } (\%) = 100 - \left(\frac{K \times \Delta T}{\% \; CO_2}\right) + C$$

| Fuel Type | K | C | units | MJ/unit |
|---|---|---|---|---|
| #2 Oil | 0.56 | 6.5 | litres | 38.7 |
| Coal | 0.63 | 5 | tonnes | 30.0 |
| N. Gas | 0.38 | 11 | $m^3$ | 37.6 |

**Cycling Losses are calculated from the efficiency derating factor:**

Efficiency derating for cycling of boiler = $0.00005 \times DC^2 + 0.0007\,DC + 0.8272$ where DC = duty cycle

| Input Field Name | Details of Fuel-Consuming System Fields |
|---|---|
| Equipment | Enter a description for the fuel-consuming equipment. |
| Fuel Type | Select a fuel type from the list in the drop-down. |
| Estimated Fuel Usage | Enter an estimate of the total fuel consumed by this equipment. |
| Combustion Air Temp | Enter the measured temperature of the combustion air in degrees C. |
| Stack Temp | Enter the measured temperature of the stack (flue) gases in degrees C. |
| Stack $CO_2$ | Enter the measured percentage of $CO_2$ in the stack (flue) gases. |
| Duty Cycle | Enter an estimated duty cycle for the boiler. This may be an average value for the heating season estimated by dividing the actual fuel consumed by the product of the nameplate firing rate x 8760 hours. |
| Estimated Blowdown Losses | If known, as a percentage of total fuel input, enter the blowdown losses; if not known, enter a default value of 3%. |
| Fuel Type (List) | Enter the name of the fuel, which will appear in the drop-down above. |

| Input Field Name | Details of Fuel-Consuming System Fields |
|---|---|
| K | A constant representing the composition of the fuel. |
| C | A constant representing the composition of the fuel. |
| Units | The units of measure for the fuel. |
| MJ/Unit | The energy content of the fuel. |

## 6.10 Thermal Inventory

This spreadsheet provides a selection of calculators that may be used to estimate the magnitude of energy flow or consumption in a number of common situations.
Thermal Inventory.xls

### 6.10.1 | Airflow – Sensible Heat

This sheet estimates the sensible heat flow in an air stream being heated or cooled between two temperatures.

**Air Flow - Sensible Heat** Menu

| Description | Air Flow litres/sec | $T_{high}$ C | $T_{low}$ C | Heat Flow kW | Monthly Hours | Monthly Energy kWh | GJ |
|---|---|---|---|---|---|---|---|
| Main Plant Exhaust | 18,000 | 20 | 5 | 332.6 | 732 | 243,492 | 876.6 |
| | | | | - | | - | - |
| | | | | - | | - | - |
| | | | | - | | - | - |
| | | | | - | | - | - |

Calculation assumes conditions are at or about 50% RH and 21C; for other conditions adjust constant: 1.232 $J\text{-}litre^{-1}C^{-1}$

| Input Field Name | Airflow – Sensible Heat Fields |
|---|---|
| Description | Enter a description of the situation. |
| Airflow | Enter the rate of airflow in litres per second (1 L/sec. = 2.12 cfm). |
| $T_{high}$ | Enter the hot side temperature. |
| $T_{low}$ | Enter the cold side temperature. |
| Hours Label | Enter the label for the duration of the calculation. |
| Hours | Enter the hours that the temperature difference is maintained. |
| Constant | Constant incorporating the density and specific heat of air. |

## 6.10.2 | Airflow – Latent Heat

This sheet estimates the latent heat flow in an air stream being heated/cooled and humidified/de-humidified between two temperatures and relative humidity levels. This sheet utilizes a mathematical function to calculate the psychrometric properties of moist air.

**Air Flow - Latent Heat** Menu

| Description | Air Flow litres/sec | $T_{high}$ ( C ) | $RH_{high}$ (%) | $T_{low}$ ( C ) | $RH_{low}$ (%) | $H_{high}$ g/kg | $H_{low}$ g/kg | Heat Flow kW | Monthly Hours | Monthly Energy kWh | GJ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dryer Exhaust | 2,000 | 40 | 90% | 20 | 50% | 43.8 | 7.3 | 219.8 | 732 | 160,920 | 579.3 |
| | | | | | | | | - | | - | - |
| | | | | | | | | - | | - | - |
| | | | | | | | | - | | - | - |

This calculation assumes conditions found in HVAC or plant exhaust for which the constant is: 3.012 J-litre$^{-1}$
Ambient atmospheric pressure: 101,325 Pa

| Input Field Name | Airflow – Latent Heat Fields |
|---|---|
| Description | Enter a description of the situation. |
| Airflow | Enter the airflow rate in litres per second (1 L/sec. = 2.12 cfm). |
| $T_{high}$ | Enter the hot side temperature. |
| $RH_{high}$ | Enter the relative humidity for the hot side. |
| $T_{low}$ | Enter the cold side temperature. |
| $RH_{low}$ | Enter the relative humidity for the cold side. |
| Hours Label | Enter the label for the duration of the calculation. |
| Hours | Enter the hours that the temperature difference is maintained. |
| Constant | Constant incorporating the specific heat of water. |
| Ambient Atmospheric Pressure | Enter the prevailing atmospheric pressure for correct computation of the psychrometric properties of moist air. |

### 6.10.3 | Hot or Cold Fluid

This sheet estimates the heat required to heat or cool a fluid between two temperatures.

**Hot or Cold Fluid** Menu

| Description | Flow kg/s | Heat Capacity kJ/kg °C | $T_{high}$ °C | $T_{low}$ °C | Heat Flow kW | Monthly Hours | Monthly Energy kWh | GJ |
|---|---|---|---|---|---|---|---|---|
| Chemical Reactor Cooling | 0.350 | 4.200 | 40 | 10 | 44.10 | 732 | 32,281 | 116.2 |
| | | | | | - | | - | - |
| | | | | | - | | - | - |
| | | | | | - | | - | - |

| Input Field Name | Hot or Cold Fluid Fields |
|---|---|
| Description | Enter a description of the situation. |
| Flow | Enter the flow rate in kg/second. |
| Heat Capacity | Enter the heat capacity of the fluid (for water use 4.2 kJ/kg°C). |
| $T_{high}$ | Enter the hot side temperature. |
| $T_{low}$ | Enter the cold side temperature. |
| Hours Label | Enter the label for the duration of the calculation. |
| Hours | Enter the hours that the temperature difference is maintained. |

### 6.10.4 | Steam Flow, Leak and Cost

This sheet estimates the energy involved in a flow, leak or plume of saturated steam at a given pressure for a given amount of time. It also computes the cost of steam per 1000 kg or 1000 lbs. based on a given set of conditions.

**Steam Flow, Leak & Cost** Menu

| Description | Steam Flow Type | Size Specifier | | Steam Pressure kPA guage | Steam Flow kg/hr | Steam Enthalpy kJ/kg | Heat Flow kW | Monthly Hours | Monthly Energy kWh | GJ |
|---|---|---|---|---|---|---|---|---|---|---|
| Small Dryer in Plant B | Plume | Length (mmx100) | 20.0 | 520 | 105.6 | 2,758 | 81 | 732 | 59,245 | 213.3 |

**Estimation of the Cost of Saturated Steam**

| | |
|---|---|
| **Incremental Cost of Fuel** | $0.25 **/unit** |
| **Energy Content** | 37.60 **MJ/unit** |
| **Boiler Efficiency** | 76% |
| **Saturated Steam Pressure (gauge)** | 700.0 **kPa gauge** |
| **Steam Enthalpy (Vapour + Water)** | 2769 **kJ/kg** |
| **Cost per 1000 kg** | $24.23 **/1000 kg** |
| **Cost per 1000 lbs.** | $11.01 **/1000 lbs.** |

Note: Steam enthalpies are calculated for saturated steam using an approximation with an accuracy of +/- 1%.

| Input Field Name | Steam Flow, Leak & Cost Fields |
|---|---|
| Description | Enter a description of the situation. |
| Steam Flow Type | Select the type of steam flow situation. For each situation, there is a unique method of estimating flow. |
| Size | For each situation enter the appropriate dimension:<br>Flow – enter the flow rate.<br>Leak – enter an estimate of the leak diameter in mm.<br>Plume – enter the length of steam plume in mm. (The plume is the area adjacent to a steam vent that is invisible, indicating the presence of the vapour as opposed to the visible water droplets, or fog.) |
| Saturated Steam Pressure | Enter the pressure of the steam in kPa. This sheet incorporates mathematical calculations to provide an approximation to the heat content (enthalpy) of the steam. These calculations assume saturated steam and the heat content as the total enthalpy of water and vapour. |
| Hours Label | Enter the label for the duration of the calculation. |
| Hours | Enter the hours that the temperature difference is maintained. |
| Incremental Cost of Fuel | Enter the incremental cost of thermal fuel. |
| Energy Content | Enter the energy content of the fuel. |
| Boiler Efficiency | Enter the overall boiler efficiency from fuel to steam. |
| Saturated Steam Pressure | Enter the pressure of steam generated at the boiler. |

### 6.10.5 | Refrigeration

This sheet estimates the heat flow associated with the heat rejected from a refrigeration machine operating at a given coefficient of performance (COP), power input and operating hours.

**Refrigeration** Menu

| Description | Power Input (kW) | COP | Heat Flow kW | Monthly Hours | Monthly Energy kWh | GJ |
|---|---|---|---|---|---|---|
| Molding Machine Chillers | 100.0 | 3.20 | 320.00 | 732 | 234,240 | 843.3 |
| | | | - | | - | - |
| | | | - | | - | - |
| | | | - | | - | - |
| | | | - | | - | - |

| Input Field Name | Refrigeration Fields |
|---|---|
| Description | Enter a description of the situation. |
| Power Input | Enter the power input to the compressor (measured or estimated) in kW. |
| COP | Enter the estimated COP for the unit. |
| Hours Label | Enter the label for the duration of the calculation. |
| Hours | Enter the hours that the temperature difference is maintained. |

### 6.10.6 | Conduction

This sheet estimates the heat flow associated with heat conduction through a material of known conductance, between two temperatures.

**Conduction** Menu

| Description | Area $m^2$ | Conductance $W/m^2{}^\circ C$ | $T_{high}$ °C | $T_{low}$ °C | Heat Flow kW | Monthly Hours | Monthly kWh | Energy GJ |
|---|---|---|---|---|---|---|---|---|
| Warehouse Roof | 100 | 0.900 | 20 | 5 | 1.35 | 732 | 988 | 3.6 |
| | | | | | - | | - | - |
| | | | | | - | | - | - |

| Input Field Name | Conduction Fields |
|---|---|
| Description | Enter a description of the situation. |
| Area | Enter the area of material through which heat is conducted. |
| Conductance | Enter the conductance of the material (determine from product tables). |
| $T_{high}$ | Enter the hot side temperature. |
| $T_{high}$ | Enter the cold side temperature. |
| Hours Label | Enter the label for the duration of the calculation. |
| Hours | Enter the hours that the temperature difference is maintained. |

## 6.11 Envelope

This spreadsheet is a very simple building heat loss calculator. The envelope heat loss is calculated on the basis of building heat losses components from:

- ✓ conduction through walls, roof, doors, windows and slab heat loss
- ✓ sensible heat loss from ventilation, exhaust and infiltration

The annual heat loss is estimated from the average monthly outdoor temperature combined with indoor temperature schedules to yield a total annual temperature difference over time value expressed as degree-hours.

**A word of caution: This is a very simplistic method intended as a first approximation for heating energy requirements.** Envelope.xls

**Simple Building Heat Loss Calculator**

**Building Envelope**

| Walls | | Length m | Height m | Slab W/m°C | U-Val W/m$^2$°C | Window Qty 1. | 2. | 3. | 4. | 5. | Door Qty 1. | 2. | 3. | Schedule |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Main Walls | 180 | 6 | 0.1 | 0.6 | 30 | 8 | | | | 2 | 4 | | 24h 7d |
| 2. | Gym Walls | 120 | 10 | 0.3 | 0.9 | | | | | | 3 | | 1 | Other |
| 3. | | | | | | | | | | | | | | 24h 7d |
| 4. | | | | | | | | | | | | | | 24h 7d |
| 5. | | | | | | | | | | | | | | 24h 7d |

| Roofs | | Length m | Width m | n/a | U-Val W/m$^2$°C | 1. | 2. | 3. | 4. | 5. | Schedule |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Main Roof | 50 | 40 | n/a | 0.6 | | | 1 | | | 24h 7d |
| 2. | Gym Roof | 30 | 30 | n/a | 1 | | | | | | 24h 7d |
| 3. | | | | n/a | | | | | | | 24h 7d |

| Windows | | Length m | Width m | Infilt. L/s per m | U-Val W/m$^2$°C |
|---|---|---|---|---|---|
| 1. | Large Th'pane | 1 | 1 | 2 | 3.3 |
| 2. | Small Th'pane | 0.3 | 1 | 2 | 3.3 |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |

| Doors | | Length m | Width m | Infiltration L/s per m | U-Val |
|---|---|---|---|---|---|
| 1. | Steel Doors | 1 | 2.5 | 5 | 2.5 |
| 2. | Glass Doors | 1 | 2.5 | 5 | 4.5 |
| 3. | Overhead Doors | 3 | 3 | 10 | 2.5 |

| Slab Heat Loss | | W/m°C |
|---|---|---|
| 1. | None | |
| 2. | Insulated | 0.1 |
| 3. | Un-Insulated | 0.3 |

| Infiltration | L/s per m |
|---|---|
| Low | 2 |
| Medium | 10 |
| High | 20 |

**Ventilation**

| | Area/System | Persons | L/s per person | System litre/sec | Average O/A % | Outside Air Flow | Unocc'd State | Schedule |
|---|---|---|---|---|---|---|---|---|
| 1. | Class & Offices | 120 | 15 | | | 1800 | On | Setback |
| 2. | Gym | | | 3500 | 100% | 3500 | On | Setback |
| 3. | Kitchen | | | 500 | 100% | 500 | On | Setback |

**Schedules & Temperatures**

| Schedule Name ---> | Setback Occ'd | Setback Unocc'd | Other | 24h 7d |
|---|---|---|---|---|
| Temperatures | 20.0 °C | 15.0 °C | 17.0 °C | 20.0 °C |
| Sunday | | 24 | 24 | 24 |
| Monday | 9 | 15 | 24 | 24 |
| Tuesday | 9 | 15 | 24 | 24 |
| Wednesday | 9 | 15 | 24 | 24 |
| Thursday | 9 | 15 | 24 | 24 |
| Friday | 9 | 15 | 24 | 24 |
| Saturday | | 24 | 24 | 24 |
| Monthly Hours | 196 | 534 | 730 | 730 |
| Ave Temp | 16.3 °C | | 17.0 °C | 20.0 °C |
| Temp Diff x hours | 54109.4 °C | | 57968.4 °C | 75490.3 °C |

**Heating Plant Efficiency**

| | |
|---|---|
| Fuel Type | Natural Gas |
| Combustion Efficiency | 85% |
| Other Losses | 7% |
| Seasonal Plant Efficiency | 78% |

| Internal Heat Gains |
|---|
| 240,000 |
| kWh/year |
| 33% |

| Annual Energy Use Component | kWh/year Loss | kWh/year less IHG | GJ/year Fuel Input |
|---|---|---|---|
| Walls | 111,961 | 74,717 | 345 |
| Roofs | 158,530 | 105,794 | 488 |
| Windows | 29,329 | 19,573 | 90 |
| Door | 35,628 | 23,776 | 110 |
| Ventilation | 386,016 | 257,606 | 1,189 |
| **Total Building Energy** | **721,465** | **481,465** | **2,222** |

### 6.11.1 | Heat Loss

On this sheet the building characteristics are input and the heat loss is calculated.

| Input Field Name | Heat Loss Fields |
|---|---|
| Wall | Enter a description of each wall. |
| Wall Length / Height | Enter the length and width, in metres, of each wall. |
| Wall Slab | If this wall is on a slab on grade, select a value from the average slab heat loss table with the pull-down. Otherwise, enter zero. Edit the table on the top right of the sheet for standard values. Otherwise, enter zero. |
| Wall U-Val | Enter a conductance in watts/m$^2$°C for the wall. |
| Window in Wall Qty. (up to 5 types per wall) | Enter, for each window type present, the number of windows in this wall. |
| Door in Wall Quantity (up to 4 per wall) | Enter, for each door type present, the number of doors in this wall. |
| Wall Schedule | Select from the three defined operating time and temperature schedules (Setback, Other, 24hrs./7d) applicable to this wall. |
| Roof | Enter a description of each roof. |
| Roof Length/Width | Enter the length and width, in metres, of each roof. |
| Roof U-Val | Enter a conductance in watts/m$^2$°C for the roof. |
| Windows in Roof Qty. (up to 5 per roof) | Enter, for each window type present, the number of windows in this roof. |
| Roof Schedule | Select from the three defined operating time and temperature schedules (Setback, Other, 24hrs./7d) applicable to this roof. |
| Windows | Enter a description of each window. |
| Window Length/Width | Enter the length and width, in metres, of each window. |
| Window Infiltration | Select a value from the infiltration rate table with the pull-down applicable to this window. This is the infiltration rate per linear foot of perimeter. Otherwise, enter zero. Edit the table on the top right of the sheet for standard values. Otherwise, enter zero. |
| Window U-Val | Enter a conductance in watts/m$^2$°C for the window. |
| Door | Enter a description of each door. |
| Door Length/Width | Enter the length and width, in metres, of each door. |
| Door Infiltration | Select a value from the infiltration rate table with the pull-down applicable to this door. This is the infiltration rate per linear foot of perimeter. Otherwise, enter zero. Edit the table on the top right of the sheet for standard values. Otherwise, enter zero. |
| Door U-Val | Enter a conductance in watts/m$^2$°C for the door. |

| Input Field Name | Heat Loss Fields |
|---|---|
| Slab Heat Loss Table | This table defines the standard values of slab heat loss per linear length of wall perimeter. These values can be selected for each wall in the pull-down lists provided. |
| Infiltration Table | This table defines the standard values of infiltration rate per linear length of window or door perimeter. These values can be selected for each window or door in the pull-down lists provided. |
| Ventilation Area/System | Enter a description for each ventilation or exhaust system. |
| Persons | The outside airflow rate for each system is calculated as the maximum of the number of people multiplied by ventilation required per person or the system capacity multiplied by the outside air percentage (O/A %). Enter in this field the number of people. |
| L/s per person | Enter the required amount of outside air per person. |
| System L/s | Enter the system flow rate capacity. |
| Average O/A % | Enter an outside air % (typically the minimum OA %). |
| Schedule | Select from the three defined operating time and temperature schedules (Setback, Other, 24hrs./7d) applicable to this ventilation system. |
| Occ'd (8 fields) | Enter a temperature for the occupied period and occupied hours per day for each day of the week. |
| Unocc'd | Enter a temperature for the unoccupied period. |
| Temperature – Other | Enter a temperature for the other schedule. |
| Temperature 24hrs./7d | Enter a temperature for the 24hrs./7d schedule. |
| Fuel Type | Select from the drop-down list the fuel type used in the heating system. |
| Combustion Efficiency | Enter the measured combustion efficiency if available. |
| Other Losses | Enter other losses contributing to the overall heating plant efficiency. |
| Internal Heat Gains | Often there are significant heat gains internal to the heated space resulting from heat given off by humans and the electricity used in the space. Estimate, possibly by inventory, the heat gains that will offset the heat required of the heating plant. |

### 6.11.2 | Weather

This sheet allows the user to record average monthly temperatures and to indicate whether the heating system is on or off for that month. An overall temperature difference – time value in degree-hours – is then calculated for use on the previous page. The temperature difference is based upon the average operating temperature from the schedule and the average outdoor temperature.

**Weather Data**

Site: Vancouver

| Month | Monthly Ave Temp | Days | Heating On/Off | Average Temps for Schedule Setback 16.3 °C | Other 17.0 °C | 24h 7d 20.0 °C |
|---|---|---|---|---|---|---|
| January | 3.0 °C | 31 | On | 13.3 °C | 14.0 °C | 17.0 °C |
| February | 4.7 °C | 28 | On | 11.6 °C | 12.3 °C | 15.3 °C |
| March | 6.3 °C | 31 | On | 10.0 °C | 10.7 °C | 13.7 °C |
| April | 8.8 °C | 30 | On | 7.5 °C | 8.2 °C | 11.2 °C |
| May | 12.1 °C | 31 | Off | 0.0 °C | 0.0 °C | 0.0 °C |
| June | 15.2 °C | 30 | Off | 0.0 °C | 0.0 °C | 0.0 °C |
| July | 17.2 °C | 31 | Off | 0.0 °C | 0.0 °C | 0.0 °C |
| August | 17.4 °C | 31 | Off | 0.0 °C | 0.0 °C | 0.0 °C |
| September | 14.3 °C | 30 | On | 2.0 °C | 2.7 °C | 5.7 °C |
| October | 10.0 °C | 31 | On | 6.3 °C | 7.0 °C | 10.0 °C |
| November | 6.0 °C | 30 | On | 10.3 °C | 11.0 °C | 14.0 °C |
| December | 3.5 °C | 31 | On | 12.8 °C | 13.5 °C | 16.5 °C |
| | | 365 | | 54109.4 °C | 57968.4 °C | 75490.3 °C |

| Input Field Name | Weather Data Fields |
|---|---|
| Site | Enter a description for the location of the weather station. |
| Monthly Ave Temp | Enter monthly average temperature for each of 12 months, as available from a weather source such as Environment Canada. For typical data long-term averages. |
| Heating On/Off | Indicate the months in which the heating plant is operational. |

### 6.11.3 | Heat Loss Calcs

The "Heat Loss Calcs (calculations)" sheet contains the detailed calculations behind the result. It is provided for the advanced user who may wish to enhance or modify the calculations.

## 6.12 Assess the Benefit

This spreadsheet is a template for a simple estimate of electrical and thermal energy savings, greenhouse gas savings and a basic economic analysis. Assess the Benefit.xls

### 6.12.1 | Energy Savings

**EMO Cost Savings Analysis** **#1 Compressor Control & Heat Recovery**

**Existing Conditions**

Presently there are three 50 HP packaged air compressors supplying air to the main plant and process areas. These compressors are operating under individual control with cascaded pressure settings. During the audit it was observed that two compressors often operate when one unit can meet the demand for air. The 3rd unit is backup. The heat from the air cooled compressors is currently exhausted from the compressor room year round.

**Proposed Conditions**

Install a sequencing controller to dispatch the 3 compressors, in sequence upon demand for air, indicated by a pressure sensor in the air main to the plant. It is expected that this will result in only one air compressor operating at full load, while the second compressor will only operate during peak air demand periods, estimated to be less that 10% of the time. Second, install a simple system of ductwork and dampers to direct the heat compressor cooling air into the plant during the heating season or exhaust outside during non-heating periods.

**Expected Energy & Cost Savings**

**Electricity**

Reduce the use of the second compressor at a measured load of 30 kW for 5000 hours per year

| | | |
|---|---|---|
| Demand Savings | kW | |
| Energy Savings | 150 000 kWh | ( 30 kW for 5000 hours/year ) |
| Incremental Cost of Electrical Energy | $0.07 /kWh | |
| Incremental Cost of Electrical Demand | $8.20 /kW | |
| **Annual Electricity Cost Savings** | **$10 500 /year** | |
| GHG Factor for Electricity .... in: | Ontario | 0.276 eq kg $CO_2$ per kWh |
| **Greenhouse Gas Reduction** | | **41 400 eq kg $CO_2$** |

**Natural Gas**

The remaining compressor heat will contribute at least 40 kW to space heat for 6 heating months per year

| | | |
|---|---|---|
| Reduced Heating Load | 176 000 kWh | (40 kW for 4400 hours/year) |
| Heating System Efficiency | 75% | |
| Reduction in Fuel Energy | 234 667 kWh | |
| Fuel Type (units) | Natural Gas $m^3$ | |
| Energy Content of Natural Gas | 10.6 kWh/$m^3$ | |
| Incremental Cost of Natural Gas | 0.25 /$m^3$ | |
| Saved | 22 081 $m^3$ | |
| **Annual Gas Cost Savings** | **$5 520 /year** | |
| GHG Factor for Natural Gas | 1.9 eq kg $CO_2$ per $m^3$ | |
| Greenhouse Gas Reduction | **41 953 eq kg $CO_2$** | |

| | |
|---|---|
| **Total Cost Savings** | **$16 020 /year** |
| **Total GHG Reduction** | **83 353 eq kg $CO_2$ per year** |

| Input Field Name | Energy Savings Fields |
|---|---|
| Label/Title | Enter a title for the opportunity. |
| Existing Conditions | Enter a description of the existing conditions and assumptions. |
| Proposed Conditions | Enter a description of the proposed conditions and assumptions. |
| Demand Savings | Enter the expected demand savings in kW resulting from the EMO. This is the expected reduction in peak kW registered at the demand meter. |
| Energy Savings ↦ kW | Enter a kW value to be used in the calculation of the energy savings. This value does not need to be the same as the demand-saving value. |
| Energy Savings ↦ hours | Enter the hours to be used in the computation of energy savings. |
| Incremental Cost of Electrical Energy | Based upon an analysis of the electrical rate, enter the incremental cost of energy – the cost of the next kWh saved. |
| Incremental Cost of Electrical Demand | Based upon an analysis of the electrical rate, enter the incremental cost of demand – the cost of the next kW saved. |
| GHG Factor for Electricity | Select the province/territory in which the electricity is saved in order to select the correct provincial/territorial greenhouse gas factor, as defined on the "GHG Factors" sheet. |
| Reduced Heating Load ↦ kW | Enter the reduction in heating load that this EMO will achieve. This may be an average value of heat flow – expressed as kW, but not necessarily electrical. |
| Reduced Heating Load ↦ hours | Enter the number of hours applicable to the heating load reduction. |
| Heating System Efficiency | Enter the overall boiler or heating plant efficiency. |
| Fuel Type | Select the fuel type from the drop-down list defined on the "GHG Factors" sheet. |
| Incremental Cost of Fuel | Enter the incremental cost of the applicable heating fuel. |

## 6.13 Financial Base Case, Pessimistic Case and Optimistic Case

These sheets represent a basic life cycle costing analysis of an energy management opportunity. Net Present Value (NPV) and Internal Rate of Return (IRR) indicators are calculated.

**EMO Life Cycle Cash Flow Analysis** — Base Financial Case

**EMO Life Cycle Cash Flow Analysis** — Pessimistic Case

**EMO Life Cycle Cash Flow Analysis** — Optimistic Case

| Costs for Period | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Capital Cost | $50,000 | | | | | | | | | | |
| Maintenance | $200 | $204 | $208 | $212 | $216 | $221 | $225 | $230 | $234 | $239 | $244 |
| Asset depreciation | | | | | | | | | | | |
| Lease costs | | | | | | | | | | | |
| Taxes | | | | | | | | | | | |
| Insurance | | | | | | | | | | | |
| Labour | | | | | | | | | | | |
| Other | | | | | | | | | | | |
| **Sub-total Costs** | **$50,200** | **$204** | **$208** | **$212** | **$216** | **$221** | **$225** | **$230** | **$234** | **$239** | **$244** |
| **Savings for Period** | | | | | | | | | | | |
| Electricity | $10,500 | $10,710 | $10,924 | $11,143 | $11,366 | $11,593 | $11,825 | $12,061 | $12,302 | $12,548 | $12,799 |
| Gas or Fuel | $5,535 | $5,646 | $5,759 | $5,874 | $5,991 | $6,111 | $6,233 | $6,358 | $6,485 | $6,615 | $6,747 |
| Water | | | | | | | | | | | |
| Maintenance | | | | | | | | | | | |
| Taxes | | | | | | | | | | | |
| Insurance | | | | | | | | | | | |
| Labour | | | | | | | | | | | |
| GHG Factors | | | | | | | | | | | |
| Sub-total Savings | $16,035 | $16,356 | $16,683 | $17,016 | $17,357 | $17,704 | $18,058 | $18,419 | $18,788 | $19,163 | $19,547 |
| Net Cash Flow | ($34,165) | $16,152 | $16,475 | $16,804 | $17,140 | $17,483 | $17,833 | $18,189 | $18,553 | $18,924 | $19,303 |
| **Net Project Value** | **($34,165)** | **($18,013)** | **($1,539)** | **$15,266** | **$32,406** | **$49,889** | **$67,722** | **$85,911** | **$104,465** | **$123,389** | **$142,692** |
| **Discount Rate** | 15.00% | | | | | | | | | | |
| **Discounted Cash Flow** | ($34,165) | $14,045 | $12,457 | $11,049 | $9,800 | $8,692 | $7,710 | $6,838 | $6,065 | $5,379 | $4,771 |

**Net Present Value (NPV) : $52,642** **Internal Rate of Return (IRR) : 48%**

Notes:
Electricity and natural gas savings and maintenance costs are adjusted for inflation at a rate of 2% per year.

| Input Field Name | Financial Base, Pessimistic and Optimistic Case Fields |
|---|---|
| Description of Costs for Period (7 fields) | Modify/enter a description for each of the costs to be considered. Entries are optional. |
| Cost for Period (fields for 7 costs for 10 years) | For each cost category, enter the cost for each year, as they exist; zero or an empty cell is valid as zero. Cost can be escalated year over year by using the formula in years 2 to 10 and a base value in year 1: Previous Year Cost x (1+ e/100), where e = escalation rate in %. |
| Description of Savings for Period (8 fields) | Modify/enter a description for each of the savings to be considered. Entries are optional. |
| Savings for Period (fields for 8 costs for 10 years) | For each savings category, enter the savings for each year, as they exist; zero or an empty cell is valid as zero. Savings can be escalated year over year by using the formula in years 2 to 10 and a base value in year 1: Previous Year Savings x (1+ e/100), where e = escalation rate in %. |
| Discount Rate | Enter a discount rate, used to compute the NPV of each of the future cash flows. |

## 6.14 GHG Factors

This sheet defines the tables of GHG factors used in the savings calculations.

### Greenhouse Gas Factors

Menu

**Emission Factors for "Indirect Emissions" (Electricity)**

*kg $CO_2$ eq/kWh*

| Province/Territory | 1990 | 2000 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008(1) |
|---|---|---|---|---|---|---|---|---|---|
| Alberta | 0.98 | 0.93 | 0.89 | 0.96 | 0.89 | 0.87 | 0.88 | 0.86 | 0.88 |
| British Columbia | 0.02 | 0.03 | 0..01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 |
| Manitoba | 0.03 | 0.03 | 0.02 | 0.04 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| New Brunswick | 0.37 | 0.46 | 0.51 | 0.45 | 0.48 | 0.46 | 0.39 | 0.42 | 0.46 |
| Newfoundland and Labrador | 0.04 | 0.02 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 | 0.03 | 0.02 |
| NWT / Nunavut, Yukon | 0.27 | 0.15 | 0.11 | 0.11 | 0.11 | 0.08 | 0.08 | 0.07 | 0.06 |
| Nova Scotia | 0.75 | 0.76 | 0.59 | 0.67 | 0.79 | 0.75 | 0.76 | 0.74 | 0.79 |
| Ontario | 0.21 | 0.28 | 0.26 | 0.27 | 0.2 | 0.21 | 0.18 | 0.2 | 0.17 |
| Prince Edward Island | 1.26 | 1.15 | 0.75 | 0.68 | 0.38 | 0.26 | 0.2 | N/A | N/A |
| Quebec | 0.012 | 0.002 | 0.002 | 0.01 | 0.009 | 0.003 | 0.004 | 12 | 0.002 |
| Saskatchewan | 0.78 | 0.85 | 0.87 | 0.84 | 0.88 | 0.79 | 0.76 | 0.77 | 0.71 |

**Notes:** N/A: Not Available
(1) Data for 2008 is preliminary in National Inventory Report 1990-2008

**Source:** Environment Canada's National Inventory Report 1990-2008 - Greenhouse Gas Sources and Sinks in Canada;
Annex 13: Electricity Intensity Tables

**Emission Factors for Selected Thermal Fuels**

| Fuel Type | Factor eq kg $CO_2$ per unit (1) | Unit of Measure | MJ per Unit (2) |
|---|---|---|---|
| Natural Gas | 1.9 | $m^3$ | 38.26 |
| #2 Oil | 2.69 | litres | 38.55 |
| #6 Oil | 3.12 | litres | 42.5 |
| Propane | 1.51 | litres | 25.31 |

**Notes:** Fuel type #2 Oil factors are the average of Light Fuel and Diesel

**Sources:** (1) Environment Canada's National Inventory Report 1990-2008 - Greenhouse Gas Sources and Sinks in Canada;
Annex 8: Emission factors
(2) Statistics Canada - Catalogue no. 57-003, Text table 1 - Energy Conversion Factors

| Input Field Name | Financial Base, Pessimistic and Optimistic Case Fields |
|---|---|
| Factor<br><br>eq kg $CO_2$ per kWh | For each province/territory, enter the provincial/territorial marginal greenhouse gas factor for electricity. Defaults are as at 2001. For other factors, consult Natural Resources Canada or CSA Climate Change, GHG Registries. |
| Fuel Type | Enter a short description for each fuel type. |
| Factor<br><br>eq kg $CO_2$ per unit | For each fuel, enter the GHG factor. Defaults are as at 2001. For other factors, consult Natural Resources Canada or CSA Climate Change, GHG Registries. |
| Unit of Measure | Enter a unit of measure for each fuel type. |
| GJ per Unit | Enter the energy content of the fuel. |