Dollars to $ense

Spot the Energy Savings Opportunities Guidebook

Natural Resources Canada
Ressources naturelles Canada

Canada

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Chapter 1
Getting Started

1.1 Managing Energy Costs

Energy management takes many different forms. It may vary from the "capital intensive" installation of new, more efficient technology to simple maintenance and operational activities that ensure equipment and systems use energy efficiently and effectively. However, since we cannot manage what we do not understand, it is important for those responsible for energy costs to learn how energy behaves, how it can be most effectively used and how energy efficiency technologies can benefit their operations.

The truth is that most facility managers are able to devote only a small amount of time directly to energy management. This does not rule out effectiveness, however. Experience has shown that as an owner, manager or operator involved with an industrial or commercial facility, you already possess invaluable knowledge about its operation. This – together with some basic knowledge about energy and the rules by which it works – will allow you to identify energy saving opportunities and to make changes that will save your organization money.

Hot Energy Tip:

People can play a valuable role in managing energy costs. A British firm implemented energy management using technology and people differently at a selection of sites with surprising results:

Site	Method	Savings
1.	Technology Only	–4%
2.	Technology Only	3%
3.	People Only	16%
4.	People & Technology	23%

1.2 The Purpose of this Guide

This guide will introduce you to the basics of thermal and electrical energy and the fundamental principles of energy management. You will follow purchased energy into the plant and through the primary conversion process to the various forms of electrical, mechanical and thermal energy that are used to operate your facility or plant. You are then introduced to ways of visualizing and analyzing energy flows within the plant. A simple method for identifying savings opportunities is outlined in this guide, along with a checklist of opportunities. Finally, a criteria is provided for the assessment of the benefits associated with a savings opportunity.

1.3 A Framework for Analysis

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 usage and identifying savings opportunities.

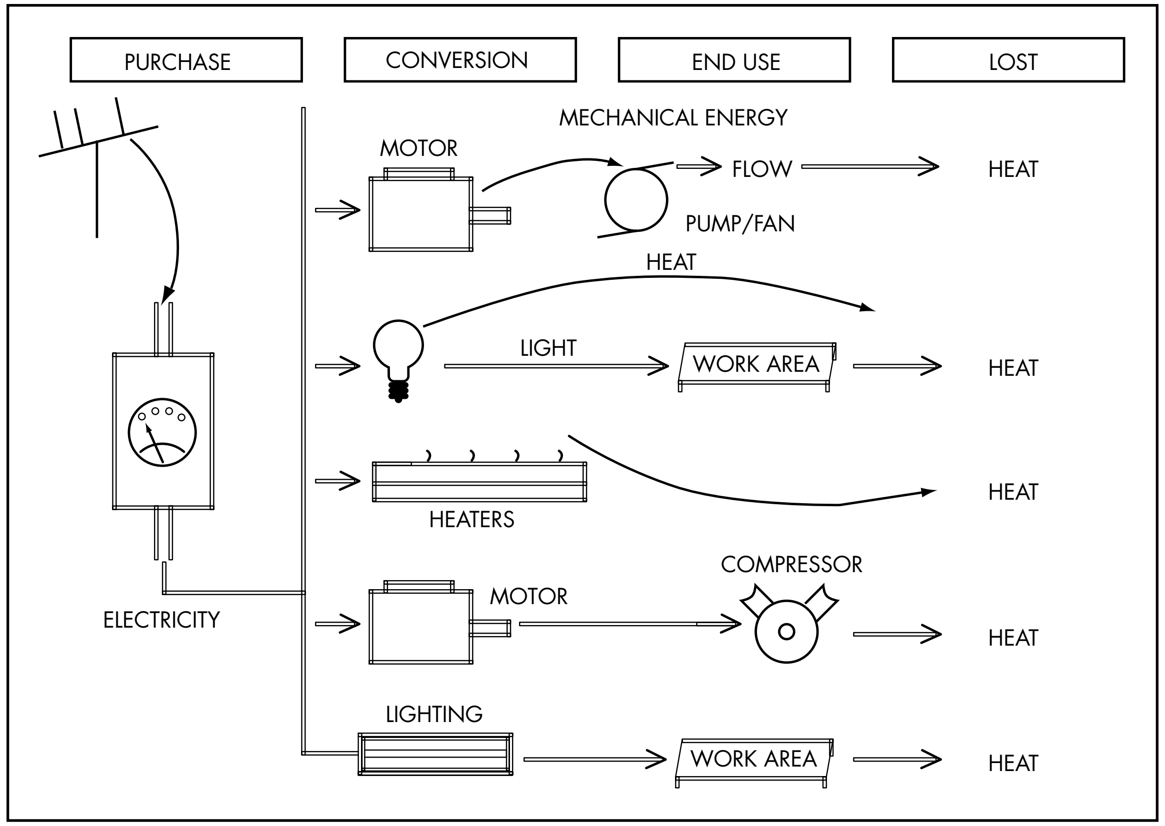


Figure 1.1: Sample Electricity from Purchase to End Use

1.3.1 Electricity: From Purchase to End Use

Electricity provides a method of moving energy from one point to another. Some energy will be lost during its travel 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 in the case of an electric welder where the flow of electric current heats and melts metal.

Hot Energy Tip:

The people in your facility have a large impact at the point of end use. After all, they are making the energy buying decisions, one unit at a time. Starting at the point of end use means starting with your people.

Figure 1.1 shows the path of electricity from the utility meter to the 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:

i) ensure that the end use serves a useful purpose;
ii) minimize the amount of energy required at the point of use; and
iii) minimize the losses incurred between the meter and the point of use.

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

1.3.2 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 of these examples, significant energy is lost from the boiler 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.

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

i) ensure that the end use serves a useful purpose, i.e., avoid unnecessary air leakage from doors and windows;
ii) minimize the amount of energy required at the point of use, i.e., utilize temperature setbacks during unoccupied hours;

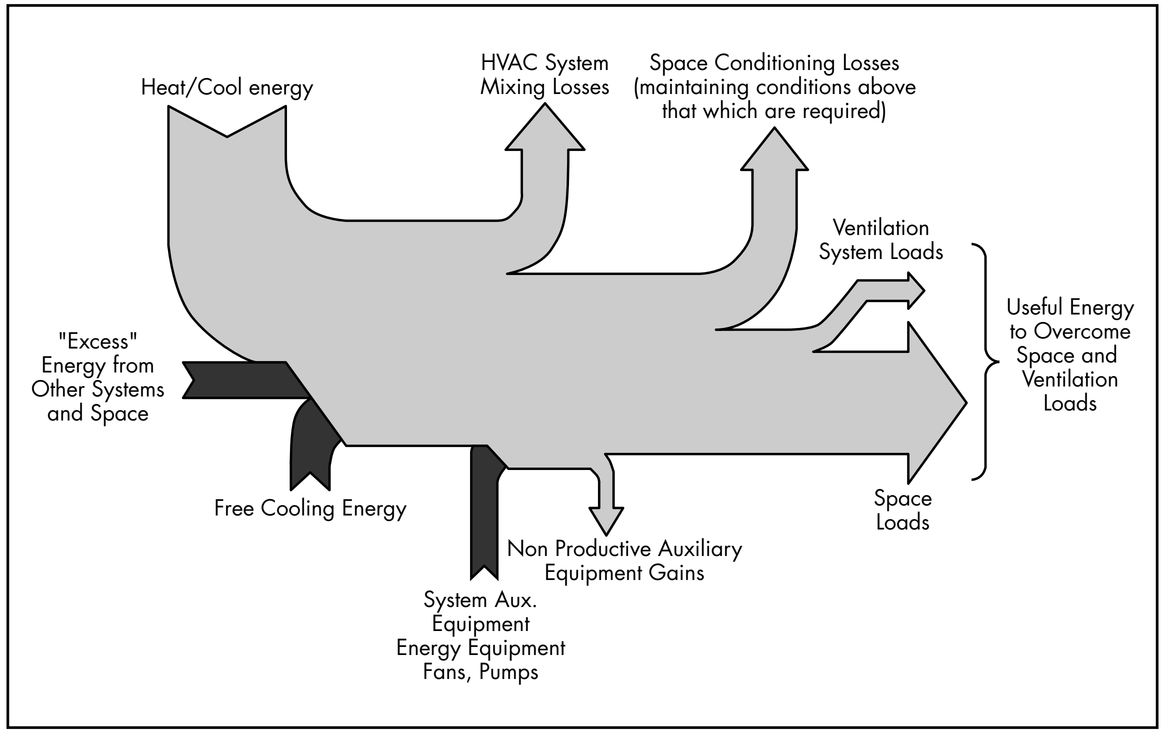


Figure 1.2: Thermal Energy Losses in an HVAC System

iii) minimize the losses incurred between the meter and the point of use, i.e., ensure the HVAC system is efficient; minimize the losses as outlined in Figure 1.2.; and

iv) examine the mechanical system design for meeting the requirements now that they have been rationalized. Is the original system oversized?

1.4 The Energy Assessment Process

The energy assessment process is a series of actions that analyse energy cost and use from the point of purchase to end use and seeks savings opportunities starting at the point of end use. This is outlined in the flow chart in Figure 1.3.

The energy assessment process analyses the flow of energy through the facility as a system, determining when, where and how it is used. Then, with its usage ascertained through the end-use inventories, energy-saving opportunities can be identified that meet the criteria outlined in the previous section.

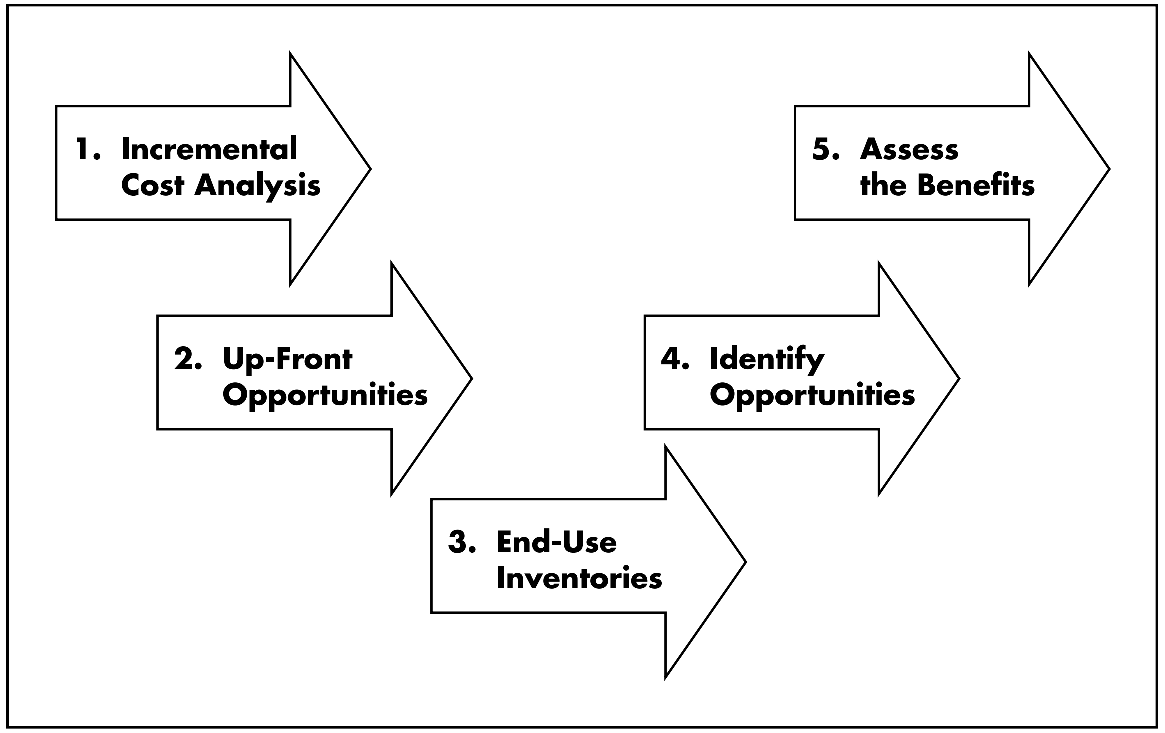


Figure 1.3: Overview of the Energy Assessment Process

1.4.1 Incremental Cost Analysis

It is important to appreciate the actual cost of the next unit of energy purchased or, in turn, the actual savings of the energy saved by our actions. Determining exactly when and how fast energy is being consumed will be important factors in this step.

1.4.2 Up-Front Opportunities

Demand Profile Analysis

Each facility has a pattern of energy consumption different from that of any another. Understanding a facility's present energy use patterns is essential before changes are proposed for the sake of energy management. The electrical demand profile will provide insight into the pattern of electrical use.

Combustion Efficiency Analysis

Thermal systems, by nature, burn fuels for their heat content. The efficiency of the combustion process relates directly to its operating cost. Controlling and optimizing combustion efficiency can lead to fruitful dollar savings all by itself. We will look at the factors influencing combustion efficiency and how we can effect change.

1.4.3 End-Use Inventories

Thermal End-Use Inventory

Rationalizing the requirement for thermal energy within a facility is the next step. Where, when and how much thermal energy is presently being used and leaving our facility must be determined.

Electrical Load Inventory

All the electricity we use within our facility becomes heat. The same questions apply to electricity as to thermal energy: "where, when and how much?" It is worth contemplating that energy is probably the only purchased commodity within your organization that isn't inventoried. One method to accomplish this will be presented in detail.

1.4.4 Identify Savings Opportunities

Some opportunities for energy and cost savings will become apparent in the steps previously discussed. However, a logical method is required for the identification and prioritization of opportunities. The maximum effectiveness of energy efficiency efforts and capital outlay will only be realized when changes and actions are not in conflict with each other or with the facility's energy-use patterns. The quadrant analysis will ensure that present and future opportunities will be organized in a fashion to optimize the benefits to be realized.

1.4.5 Assessment of Benefit

The environmental benefits of reduced energy use may not be as obvious as the monetary savings, but are equally as important to those organizations that actively practise environmental stewardship. We will discuss the various benefits, including the positive environmental impact of practising energy management, and outline an approach to quantifying them.

References

Managing and Motivating Staff to Save Energy, ETSU, Harwell, U.K., 1994 (tel.: 0235 436747, fax: 0235 432923)

Smart Energy Management, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1995 (tel.: (902) 368-5010)

Chapter 2
Energy Basics

Objectives

To be able to describe the basic principles behind thermal and electrical energy and list the units of measure.

2.1 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 nor destroyed, only converted from one form to another. The forms of energy discussed in this guide include chemical energy, nuclear energy, thermal energy, mechanical energy and electrical energy.

Hot Energy Tip:

Many energy savings opportunities can be found at the points when energy changes form. Conversion from one form to another is never perfect and may at times be much less than 100%. Boilers and furnaces typically only convert 70-80% of the fuel they consume to useful heat; pumps and fans typically only transfer 50% of the energy they consume. Understanding and improving these devices often proves to be very cost effective.

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 or 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.

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, also called a gas. If enough heat is removed from liquid water at 0°C, it eventually turns into the solid we call 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. Throughout this guide, much of the discussion is concerned with understanding and managing the movement and transformations of every form of energy.

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 and wood convert mechanical energy to sensible energy that is felt as heat.

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.

2.2 Units of Energy

The basic unit of energy in the metric system is the joule (J). Energy in the form of electricity is given units of watt-hours. In the Imperial system, the basic units of energy is the British Thermal Unit (Btu). The prefix “kilo” indicates 1000 units. Common equivalences between units are:

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

2.2.1 Power

Often it is useful to express the rate of energy flow over time, or how fast energy is being used or transferred. In electrical and mechanical terms, this is the same as speaking about 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/h). Mechanical power is usually measured in kilowatts (kW) in the metric system and in horsepower (hp) in the Imperial system. Some useful power unit equivalents are:

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

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

A more extensive listing of energy and other units and their equivalences is provided in Appendix B.

2.3 Electricity Basics

The information presented here is limited to the concepts necessary to understand the topics to follow in subsequent chapters.

2.3.1 Fundamentals

In this section we will 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 a man 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:

$$Power = Voltage \times Current$$

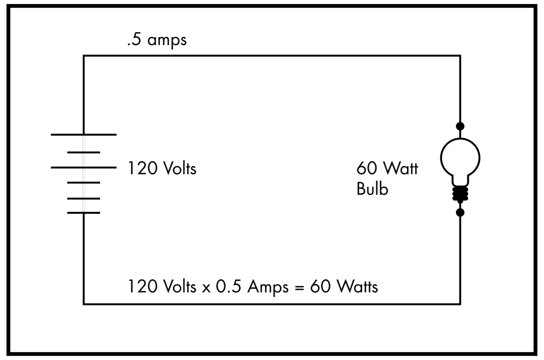
The units of power are watts:

$$Watts = Volts \times Amps$$

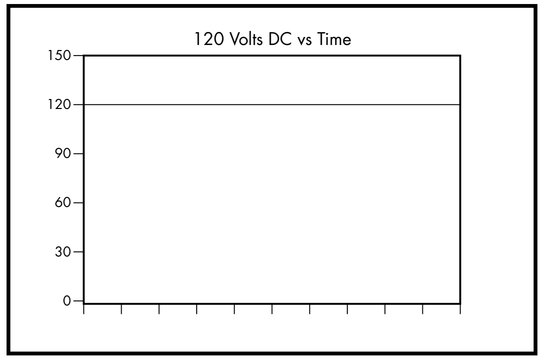
4) *Demand* is the rate of use of electrical energy. The term “demand” is essentially the same as electrical power, although demand generally refers to the average power measured over a given time interval.

2.3.2 *Alternating Current and Power Factor*

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



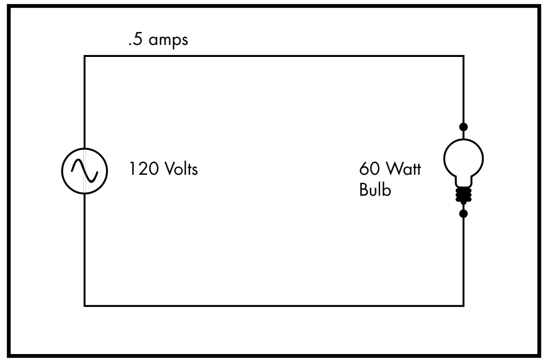
DC Circuit



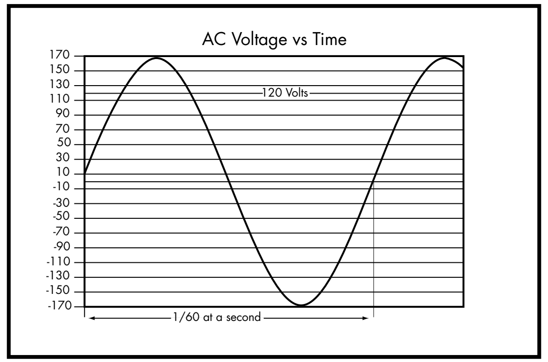
DC Voltage Waveform

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 periodically, 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:



AC Circuit



AC Voltage Waveform

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 0 to 100 percent. Using the analogy of a man pushing a child on a swing, if he pushes the swing at the very top of the swing cycle, he gets the maximum benefit of the push (100 percent PF). If the push is started at a point less than the top of the cycle, some of the push is lost, and the power factor is less than 100 percent.

Things That Affect Power Factor

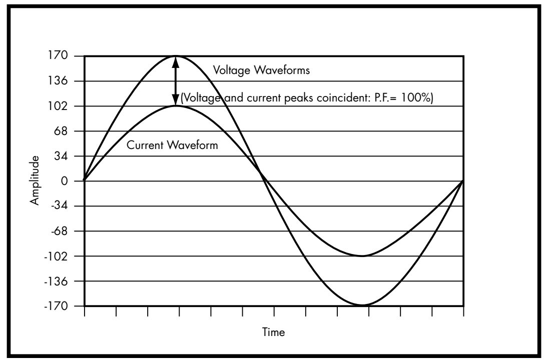
Electric heaters and incandescent lamps are called "resistive loads". These loads do not reduce power factor. They allow the voltage and current to work together (100 percent PF).

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

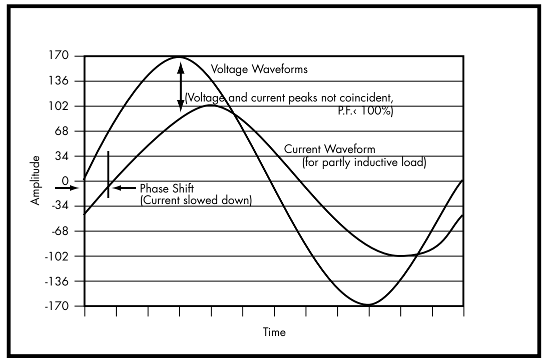
The effect of inductive loads is counteracted by that of capacitive loads by means of devices called capacitors, which consist of wires or metal plates separated by an insulating material to slow down the voltage. The power factor could range from 100 percent to 0.

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 percent.

Graphically, resistive and inductive circuit waveforms are represented as such:



Resistive Circuit Waveforms



Inductive Circuit Waveforms

2.3.3 *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:

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

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:

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

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

$$(kW) = kVA \times PowerFactor$$

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

$$PowerFactor = \frac{kW}{kVA}$$

Note the use of the prefix "kilo" meaning "thousands of", the most common multiple used when dealing with power. (At the utility level, it is also common to use "mega", meaning "millions of".)

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.

2.3.4 Electrical Energy

In the previous section, we talked about 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 (kW/h)**.

$$\text{Energy} = \text{average demand} \times \text{time}$$

Kilowatt-hours are the units of energy:

$$\textbf{kilowatt-hours} = \textbf{kilowatts} \times \textbf{hours}$$

2.4 Thermal Basics

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

2.4.1 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.

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. In 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 another set of reference points. The relationship between the Celsius and Fahrenheit scales is as follows:

$$\text{degrees C} = (\text{degrees F} - 32)\ 5/9$$

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.

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 us with 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 relative to the prevailing atmospheric pressure (101.325 kPa) at sea level. This is the *gauge pressure* that would be indicated on a pressure gauge. Pressure can also be stated as absolute pressure, the gauge pressure plus the prevailing atmospheric pressure.

$$\text{Absolute Pressure} = \text{Gauge Pressure} + \text{Prevailing Atmospheric Pressure}$$

Units of measure of pressure:

Metric (SI):	kilopascals (kPa)
Imperial:	pounds per square inch (psi)

2.4.2 Heat Capacity

In many everyday situations, we move thermal energy from one place to another by simply heating a substance, 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 at 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. This capacity can be measured in the same way as a truck's capacity to haul freight.

The heat capacity of a substance may 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 is also referred to as *specific heat*. Typical specific heats are listed below and in Appendix C.

Substance	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 brackets):

$$\text{Heat (kJ)} = \text{Mass (kg)} \times \text{Heat Capacity (kJ/kg °C)} \times \text{Temperature Change (°C)}$$

or

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

This is a useful formula in energy management. Thermal energy is often transferred via the flow of water, air or other fluid. This formula, or one based on it, may be used to calculate the energy flow that is associated with this mass flow. Section 2.6 examines the various ways that heat moves.

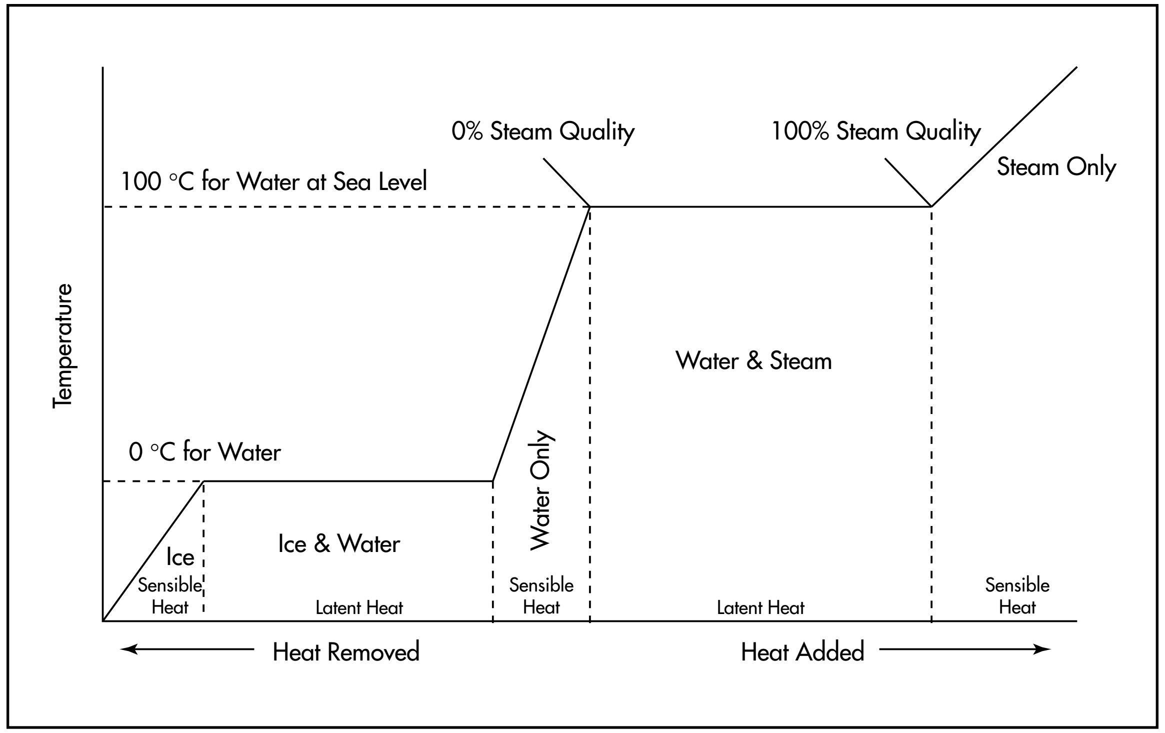


Figure 2.1: Changes of State for Water

2.4.3 Sensible and Latent Heat: A Closer Look

Unlimited sensible heat cannot be added to a substance. If enough heat is added to any given substance, a point is reached when the form of the substance changes. Putting this another way, 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. Again, at 100°C, water becomes water vapour. As illustrated in Figure 2.1, 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*, 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.

Looking back at the increase in temperature, we can make the following observations:

The ability of the ice (solid), water (liquid) or vapour (gas) to absorb heat is called its *heat capacity*. This determines the rate of the temperature increase on the sloped sections 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 may be measured by measuring 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 liquid water. Because it holds a lot of energy, steam is popular for thermal energy systems. The latent heat of vaporization is 2256.9 kJ/kg at 100°C and 101.325 kPa absolute pressure.

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.

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.

Steam

The term *steam* often refers to a mixture of water and vapour. Strictly speaking, steam is water vapour. At the beginning of the vaporization plateau there is 0 percent vapour and 100 percent water. At the end of the plateau, there is 100 percent vapour and 0 percent water. In the middle, there is 50 percent vapour and 50 percent water. The water in the middle may be in the forms of very small droplets, just like fog. Sometimes people will refer to the quality of steam from 0 percent to 100 percent. This is a reference to the amount of vapour in the steam.

Hot Energy Tip:

Steam is valuable. The energy in 1000 kg of steam is worth at least $10 to $15, and possibly more depending upon the price of fuel. The water used in steam production is often purchased and then chemically treated, adding to the cost. Use the information in chapters 2 and 3 to determine the value of the energy in your steam. Tracking down and repairing steam leaks pays dividends.

Steam's many properties have been extensively studied and tabulated. Steam tables (see Appendix E) provide values for the energy content of steam at various conditions. The latent heat of vaporization is 2256.9 kJ/kg at 100°C and 101.325 kPa absolute pressure.

These will be used in Chapter 6 to estimate energy losses due to steam leaks.

Typical units related to steam measurement are:

Conditions:	temperature (°C) and pressure (kPa)
Mass:	kilograms (kg)
Mass Flow:	kilograms per hour (kg/h)
Energy Content:	kilojoules per kilogram (kJ/kg)

Moist Air and Humidity

Another very common form of latent heat encountered in a facilities systems is that which is 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, the process of condensation.

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

- moist air that is moist has a greater heat capacity; thus, if we are going to heat it, we will need more heat; and

- if we reduce the temperature of the air, we may reach a temperature at which the water vapour turns to liquid, releasing its latent energy and making it more difficult to cool the air than if the water vapour was not there. 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 (r.h.), a percentage from 0 to 100 percent. We use the term "relative" because it tells us how much vapour is present compared to the maximum that dry 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 percent at 20°C dry bulb.

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

The properties of moist air have been studied and tabulated on a psychometric chart (see Appendix C).

Hot Energy Tip:

Moist or humid air leaking into a cooled space, such as a cooler or freezer, increases the cost of cooling dramatically and, in the case of freezers, increases the need for defrosting. Controlling the flow of humid air is a good way to reduce cooling costs.

Measures and units of humidity are:

Humidity Factor	grams of water per kilogram of dry air (g/kg)
Relative Humidity	percentage (%) at temperature (°C)

2.5 The Importance and Usefulness of Thermal Energy

At this point, we must consider what constitutes the 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. To do so, we must first understand what useful thermal work is.

Some simple forms of useful thermal work might be:

- 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; and
- evaporating water from milk with a steam coil.

The one thing each of these processes has in common is that 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 2.2. Which has the greater ability to do work for us? 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.

If the heat capacity of the water is 4.2 kJ/kg, we will need 16 800 kJ of heat. Should we use 1000 litres of water at 40°C, which contains 84 000 kJ of heat more than 1000 litres of water at 20°C? Or, should we use 250 litres at 100°C, which has 84 000 kJ more energy than 250 litres of water at 20°C?

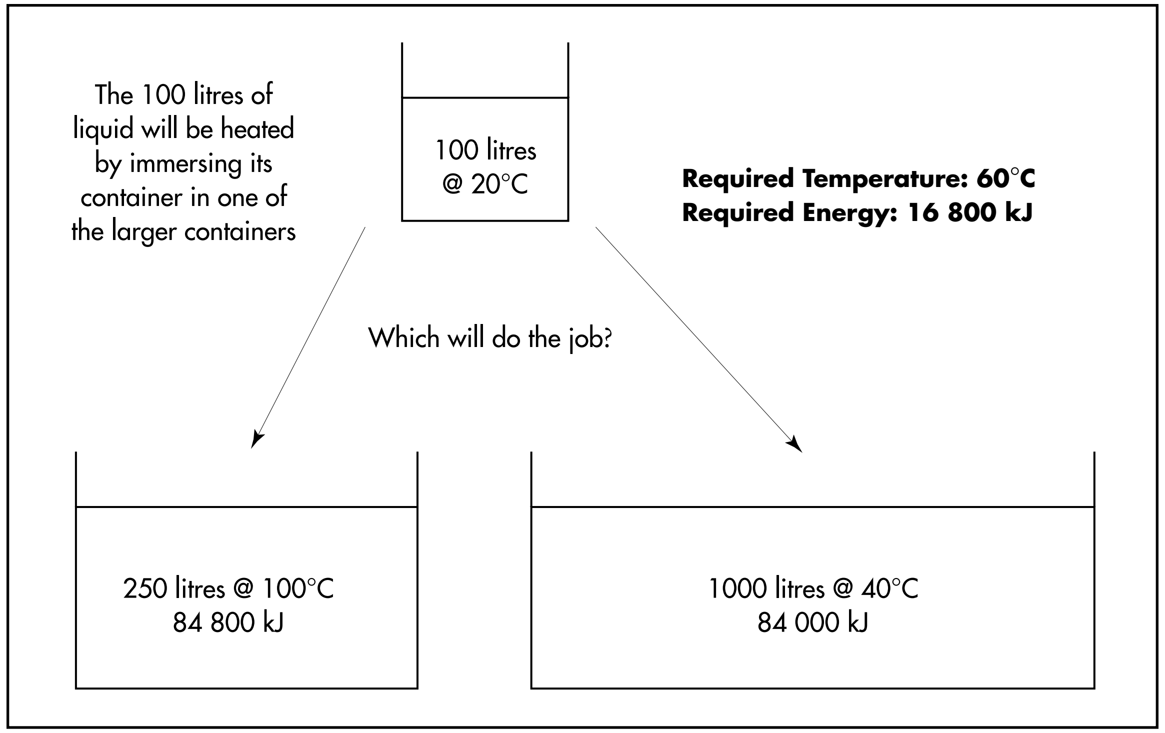


Figure 2.2: A Question: The Usefulness of Thermal Energy

Both contain the same energy, the same amount of sensible heat compared to water at 20°C, far more heat than is required. But, can both do the amount of useful work necessary? No, 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 ability to do work is not related to the quantity of energy contained in a substance, but rather to the temperature of that substance. Another way to think about this is that heat and thermal energy will only flow from higher to lower temperatures. Much of thermal energy management is concerned with manipulating temperatures to get the maximum amount of useful work from thermal energy or heat that we have purchased.

The only time when this doesn't work is in the case of latent energy, where the ability to do some useful work is stored, but temperature may not indicate how much. In fact, this is the case in other situations. 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 to the surrounding temperatures.

2.6 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 2.3 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.

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 of Figure 2.3, 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 upon 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*.

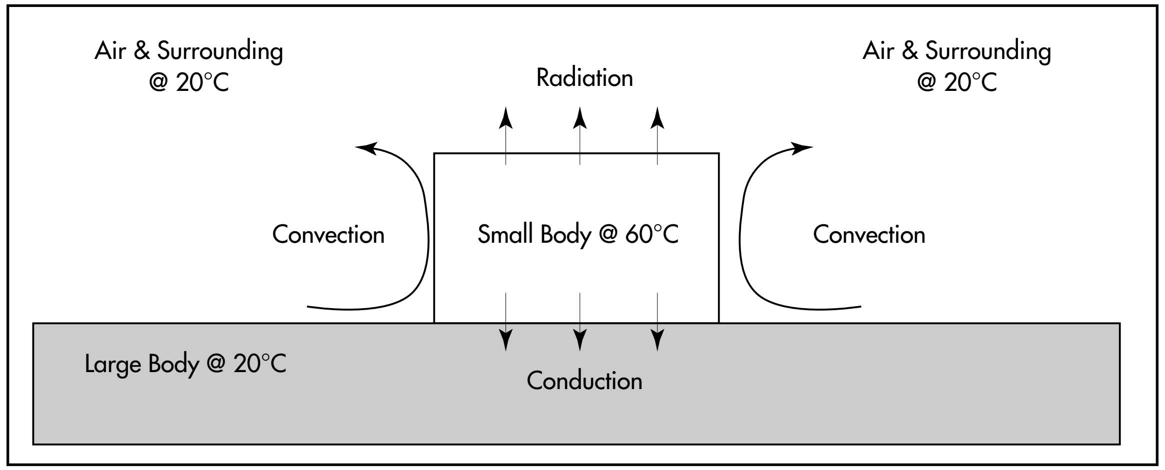


Figure 2.3: The Basic Heat Transfer Processes

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 metric). The R-value is generally the inverse of the conductance, the ability to conduct.

Typical units of measure for conductive heat transfer are:

Per Unit Area (for a given thickness):

Metric (SI)	watts per square metre (W/m^2)
Imperial	Btu per hour per square foot (Btu/h/ft^2)

Overall

Metric (SI)	watts (W) or kilowatts (kW)
Imperial	Btu per hour (Btu/h)

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. In Figure 2.3 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:

Metric (SI)	watts (W) or kilowatts (kW)
Imperial	Btu per hour (Btu/h)

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 substance with thermal radiation are:

- **Absorption** – the process by which radiation enters a body and becomes heat;
- **Transmission**. – the process by which radiation passes through a body; and
- **Reflection** – the process by which radiation is neither absorbed or transmitted through the body: it bounces off.

Objects receive thermal radiation when they are struck by electromagnetic waves, agitating 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 nature of the surface. Some bodies, commonly called *low emissivity* materials (abbreviated low-E), only emit 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 it. Polished and smooth surfaces will not absorb, but reflect, a large part of the incoming radiant energy.

Typical units of measure for rate of radiative heat transfer:

Metric (SI)	watts per square metre (W/m^2)
Imperial	Btu per hour per square foot (Btu/h/ft^2)

References

Modern Industrial Assessments: A Training Manual, Rutgers, The State University of New Jersey, 1995. (available online at: http://oipea-www.rutgers.edu/documents/doc_f.html)

1997 Handbook – Fundamentals, ASHRAE, Atlanta (www.ashrae.org)

Commercial Energy Manual Applications, Ontario Hydro, 1991

Commercial Energy Manual Fundamentals, Ontario Hydro, 1991

Chapter 3
The Cost of Purchased Energy

Objectives

To quantify the incremental cost of the next kWh of electricity, the next cubic metre of natural gas or the next litre of fuel to be purchased. Similarly, the incremental cost represents the value of the first units saved.

3.1 Purchased Energy Sources

In Canada there is a wide variety of energy sources available. The characteristics of each are as follows:

Fuel Oils (Primarily Bunker C and No. 2 Oil)

- Can be transported to remote locations via train, truck, ship, etc.
- Can be stockpiled on site (with adequate storage).
- High heat content. #2 Oil – 39 MJ/L ; Bunker C – 41 MJ/L.
- On-site tank storage required.
- Larger boiler equipment necessary than for propane or natural gas.
- Bunker C must be heated to flow and atomize properly.
- Burns dirtier, produces more pollution than propane or natural gas.
- Potentially high sulphur content can damage stack as well as environment if the fuel is not burned properly.
- Non-renewable resource.
- Canadian reserves are dwindling, some must be imported to meet demand.

Natural Gas

- No on-site fuel storage required.
- Still readily available and relatively inexpensive.
- Clean-burning, low sulphur content.
- High heat content (37.6 MJ/m^3)
- Combustion equipment design is relatively compact and simple.
- Domestic reserves still reasonably stable.
- Transported under pressure – potential for safety hazard if mishandled.
- Only available through pipeline distribution network.
- Non-renewable resource.

Propane
- Readily available.
- Clean-burning, low sulphur content.
- High heat content (25.3 MJ/L or 109 000 Btu/gal (UK))
- Combustion equipment design is relatively compact and simple.
- Transported under pressure – potential for safety hazard if mishandled.
- Non-renewable resource.

Coal
- Large domestic reserves.
- Relatively inexpensive.
- Potential for use in different forms (chunk, powder, slurry, etc.).
- Higher sulphur and ash content, burns dirty.
- Large on-site storage required.
- Combustion and waste handling equipment necessarily large and complex.
- Low heat content.
- Non-renewable resource.

Wood
- Potentially obtained from waste material (sawmills, forest thinning, etc.)
- Renewable resource.
- Low-sulphur content.
- Lower net greenhouse effect.
- Combustion and waste handling equipment necessary is large and complex.
- Low heat value.
- Supply/distribution infrastructure relatively immature.

Electricity
- High grade energy.
- No on-site storage required.
- Widespread, mature distribution system.
- Conversion equipment design is relatively compact, simple and inexpensive.
- Heating equipment can be distributed for better control.
- Virtually no pollution at site.
- Potentially low polluting (depending on generating fuel).
- Possibility to take advantage of future developments in energy sources.
- Relatively high cost.

3.1.1 *Thermal Energy Content of Fuels*

There are two values for the energy content of fuels – *Higher Heating Value* (HHV) and *Lower Heating Value* (LHV). The difference between them is that the LHV does not include the latent energy in the water formed during combustion (and thus is a lower value). In Europe the LHV is commonly used as the energy content value while in North America the HHV is the standard.

All thermal energy values quoted in this document refer to the HHV.

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)
#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/ft^3	
Electricity	3.6 MJ/kWh		3 413 Btu/kWh	

3.2 Purchasing Electrical Energy

The next step in developing an energy management strategy is understanding how your facility's electricity use is metered. Although there are a number of metering technologies in use which differ in various ways, the key issues for all are essentially the same, including:

- Whether or not demand is metered
- Which demand rate (kW or kVA) is measured.
- How the information is measured, stored and displayed, thermal (dials) or electronic (digital display).

As with the basics (Chapter 2), the following information on metering is limited to what is necessary to place it in the overall energy management picture.

3.2.1 *Demand and Energy, How Fast and How Much?*

As we have seen in Chapter 2, *power* (kW) is the rate of use of electrical energy. In other words, power is how fast electrical energy is being used. The electrical power used in a circuit depends on the two fundamental quantities, voltage and current, measured instantaneously. 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, 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.

3.2.2 Average versus Instantaneous Demand

When a load is applied to a utility demand meter, the demand pointer does not follow the load at once. The demand pointer slowly rises until it is at 99% of the applied load, typically after thirty minutes, as illustrated by the graph of figure 3.1.

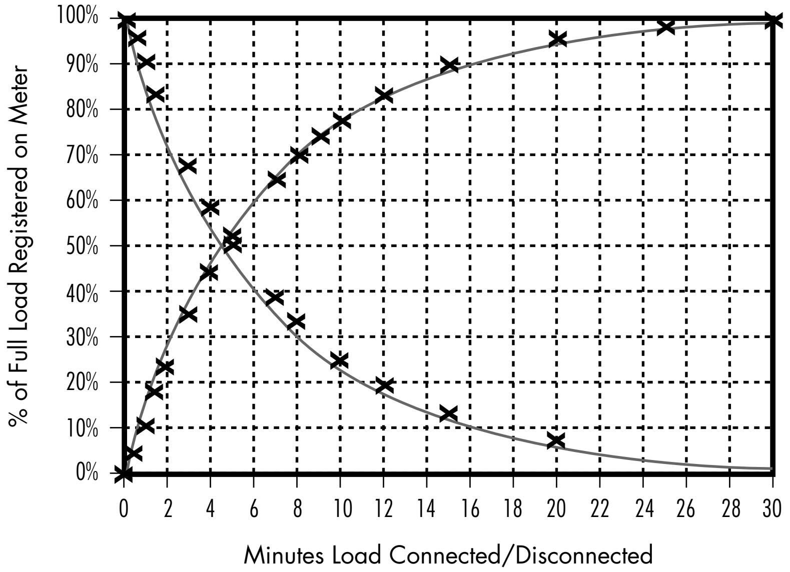


Figure 3.1: Response of a Thermal Demand Meter to a Load

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 the graph for Figure 3.2

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

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

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

Hot Energy Tip:

Newer electronic demand meters may have a different response to that of the thermal demand meter. Check with your electric utility for details on the meter installed on your service entrance.

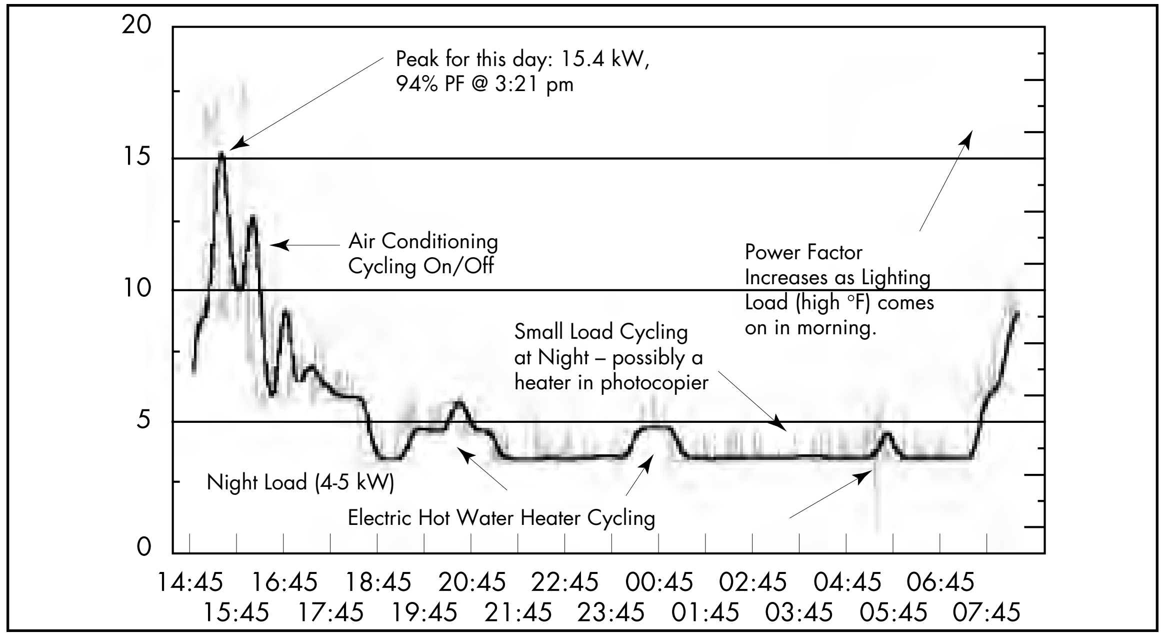


Figure 3.2: Smoothing Effect of a Thermal Demand Meter (90% @ 15 mins)

3.2.3 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 and are discussed further in section 3.2.6.

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

- Fifteen-minute average demand
- Sixty-minute sliding window and rolled averages

The *fifteen-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 1 000 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 rolled average. Re-using 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 rolled 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 completing a comparative analysis between conventional and TOU rates. The relevant information lies in a facility's *electrical demand profile*, *load inventory* and *load flexibility*. (These topics are covered in Chapters 4 and 7.)

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 results in a more accurate picture of a facility's energy use patterns. Utilities use interval metering for *real time pricing* rate structures. (As discussed in section 3.2.6.)

3.2.4 From Meter to Bill

Electric meters measure the power and the energy used by a facility. The readings taken from them ultimately determine the customer's bill. For these reasons start an energy management program by determining the following:

- Where is the meter or meters? (There could be more than one.)
- How and when is the meter read?
- On what rate am I being billed?
- How is the bill calculated?

The best source for this information is your local electrical utility. Today, electrical meters vary widely, from basic energy meters similar to, those found on residential dwellings to complex remotely read digital (electronic) meters. Your utility can give you details of the type of meter and, if applicable, instruct you in taking manual readings at your meter.

Regardless of the type of meter used, its purpose is to measure the two fundamental quantities of electrical usage, as follows:

Demand, how fast you utilize electricity in units of **kW** and/or **kVA**.

Energy, how much electricity you use in units of **kWh**.

3.2.5 The Electric Bill

The next step after developing an understanding of how electricity is metered is applying billing rates to those metered values to determine your monthly costs. This section describes the rate structures and the calculations necessary for the conversion of metered values to cost.

The electricity bill for each utility is unique, but the information provided on the bill, in most cases, will include the following items:

- *Kilowatt Hours Used* (kWh), This is the energy consumed since the previous meter reading. (Also referred to as consumption.)
- *Billing Demand* (kW and/or kVA), This is the maximum demand recorded during the billing period. One or both of these values may be measured and listed. If both are provided, the power factor at the time of the maximum demand can be calculated.

Hot Energy Tip:

Time of Use rates offer lower energy rates during off peak periods. This may save you money providing your consumption profile corresponds with the on peak and off peak periods. If you use too much energy on peak, a time of use rate may actually increase your electricity bill. Make sure a proper analysis is conducted before switching rates.

- *Rate Code*, Determines which billing rate is 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 anywhere within ± 5 days, making some monthly billed costs artificially higher or lower than others.
- *Reading Date*, This is 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 dependent factors.
- *Load Factor*, The 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. (Section 4.1.4 describes load factor in detail.)
- *Power Factor*, The ratio of recorded maximum kW to kVA. This is usually expressed as either a decimal or a percent.

3.2.6 Understanding How You are Billed (The Rate)

The tariff or electrical rate determines how much a customer is charged for different units of electrical use. The type of rate structure applied to a customer depends on such things as:

- the historical, annual kilowatt-hour consumption and peak demand
- the voltage level at the metering point
- any interruptibility agreement with the customer
- the ownership of transformers serving the customer
- in some cases, the nature of the facility (commercial vs. industrial).

All electricity rate structures are designed to recover the costs associated with the generation and delivery of electricity to the end users. A generating utility incurs both fixed and variable costs. Its fixed costs arise from the capital expenditures for distribution equipment and generating facilities; variable costs are incurred with the actual production of electricity (e.g. fuel). Typically, demand charges are designed to recover fixed costs, and energy charges recoup the variable costs.

When developing a demand management strategy, be aware that any large reductions in a facility's demand may not save costs for up to one full year. This is due to "ratchet clauses" written into some utilities' rate structures. These clauses predetermine a minimum demand based on previous monthly demand readings. Typically, a percentage of the maximum of the previous eleven monthly demand readings is compared to the present reading during the billing calculation. If the present demand is below that of the "ratcheted" demand, the greater of the two will apply.

As previously mentioned, demand charges are designed to recover the fixed costs of a utility's "installed capacity" for both electricity generation and distribution. When a customer's monthly demand drops, the utility's fixed costs don't necessarily change. Hence, "ratchet clauses" provide a level of stability for the utility's capital cost recovery.

Recently, two new rate structures have come into use. They both rely on the ability to measure energy consumption as a function of time, with greater resolution than a complete billing period. Hourly energy consumption information is typically used for both. Customers may benefit from the reduced off-peak energy costs associated with the following rates:

- **Time-of-Use**
- **Real Time Pricing**

Time-of-Use rate structures define certain periods as "on peak" with the remainder considered "off peak". Typically, the time between 0700 hours and 2300 hours, from Monday to Friday is "on peak". All other hours, weekends and statutory holidays are deemed "off peak". As demand on the generation and distribution systems is less in the "off peak" periods, the cost of the energy consumed during these times is less than the cost of the energy consumed "on peak". Some utilities will even waive demand charges when a customer's peak occurs during "off peak" periods. Others define a "shoulder peak" period where the energy charges fall between the "on peak" and "off peak" rates and a reduced demand charge applies.

Real Time Pricing (RTP) is the next logical step to time-of-use rate structures. Demand charges under this rate structure can take two forms.

- Contracted (firm) demand charge, which is charged whether or not the actual demand reaches the contracted amount.
- A fixed "adder" to the energy charge, which can vary with time of day. The demand charge simply becomes part of the energy charge. While this rate structure seems to eliminate the demand charge, demand is actually being charged continually, with a higher rate during the utility's designated 'on-peak' hours. This is possible due to the metering technology which, in effect, continually records demand, energy and time.

Energy charges in RTP rates will fluctuate on an hourly or sub-hourly basis, potentially creating hundreds of different hourly energy prices over the billing period.

To accurately evaluate the potential effect of TOU and RTP rates, detailed knowledge of your facility's electrical demand profile, load inventory and load flexibility. (These topics are covered in Chapters 4 and 7.)

Sample Large User Rate (50 to 1000 kW)
An example of a standard rate is provided below. Its structure is typical of many industrial and commercial rates used in Canada. This rate has charges as follows:

Monthly Service Charge

For each service	$10.00/month

Demand Charges

For the first 50 kW	No Charge
All additional kW	$5.10/kW

Note: kW value is the greater of metered kW or 90% of meter kVA.

Energy Charges

For the first 12 500 kWh	7.50¢/kWh
For the next 2 237 500 kWh	5.50¢/kWh
All additional kWh	3.65¢/kWh

Minimum Demand Charge

For the highest kW demand in the previous 11 months.	$0.60/kW

Transformer Credit

For customer owned	$0.60/kW

High Voltage Metering Credit

One percent of energy and demand

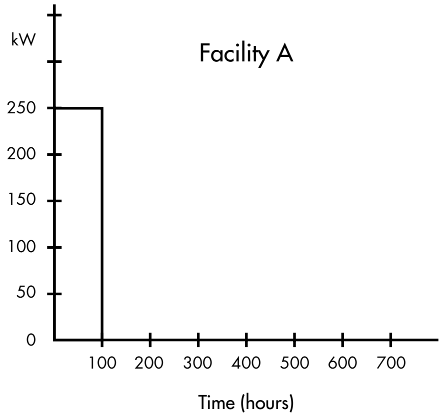
3.2.7 Calculating the Monthly Cost of Consuming Electricity

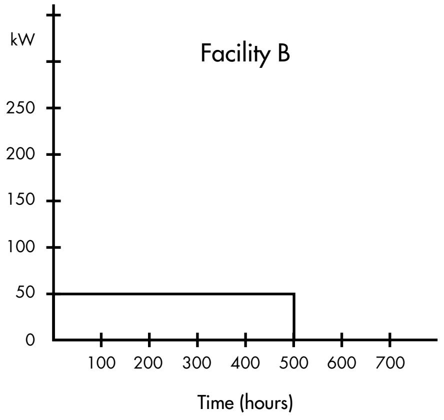
Two facilities consuming the same energy will be used in the following example. The consumption and the rate are simplified to demonstrate the effect of different usage patterns:

Facility A consumes energy at a rate of 250 kW for 100 hours (25 000 kWh).

Facility B consumes the same energy at a rate of 50 kW for 500 hours.

Pictorially, their respective consumption patterns look like this:





Billing Calculation for Facility A

From the Sample Rate in 3.2.5

Monthly Charge	**$10.00**
Demand Charge	
(1st 50 kW @ $0.00)	**$0.00**
(Remaining 200 kW @ $5.10)	**$1,020.00**
Subtotal, Demand Charge	**$1,020.00**
Energy Charge	
(1st 12 500 kWh @ $0.075)	**$918.75**
(Remaining 12 500 @ $0.055)	**$673.75**
Subtotal, Energy Charge	**$1,592.50**
Total (Monthly Charge + Demand Charge + Energy Charge)	**$2,622.50**
Average Cost per kWh ($2,622.50/25 000 kWh)	**10.49¢**

For this particular bill, 61 percent of the charges are for energy, while 39 percent covers the cost of the demand purchased. From a cost management perspective this is significant. Managing demand can have a significant impact on the bill.

Billing Calculation for Facility B

From the Sample Rate in 3.2.5

Monthly Charge	**$10.00**
Demand Charge	
(1st 50 kW @ $0.00)	**$0.00**
(Remaining 0 kW @ $5.10)	**$0.00**
Subtotal, Demand Charge	**$0.00**
Energy Charge	
(1st 12 500 kWh @ $0.075)	**$918.75**
(Remaining 12 500 @ $0.055)	**$673.75**
Subtotal, Energy Cost	**$1,592.50**
Total Amount	
(Monthly Charge + Demand Charge + Energy Charge)	**$1,602.50**
Average Cost per kWh ($1602.50/25 000 kWh)	**6.41¢**

For this particular bill, a demand charge was not incurred. Hence the average cost per kWh dropped from 10.49¢ to 6.41¢ for the identical amount of energy consumed. If **Facility A** could manage the rate of energy consumption to that of **Facility B**, the cost reduction would be 39 percent of their existing bill or $1,020 a month.

3.2.8 Incremental Cost

In the above example, what will the next kWh purchased or saved be worth? A common, **but incorrect** answer to this question is the average cost per kWh. In the case of **Facility A**, is 10.49¢ per kWh.

Why is the average cost per kWh wrong? Subtracting 1 kWh from these sample bills would only influence the “remainder” of 12 500 kWh, which is at a rate of 5.5¢ per kWh. This is the **incremental** cost per kWh, and for **Facility A** is 47 percent less that the average cost. If the average cost per kWh had been used for a simple payback calculation for an energy savings measure, the calculated time to pay down the initial investment would be only 53 percent of the actual time. For example, a two-year simple payback would actually be close to four years!

What if the savings measure influenced the demand (kW) and energy (kWh)? If, associated with the energy saving (kWh), a demand saving reduced the maximum demand (kW), the cost savings would be increased. If the saving was 1 kWh and 1 kW, the cost reduction would be 5.5¢ plus the demand charge of $5.10 for a total saving of $5.16. What would be the incremental cost of the kWh saved? Simply $5.16/kWh (5.5¢ + $5.10), quite an expensive kWh!

Clearly, understanding the **incremental cost** of electricity is important for correctly estimating the value of our actions. Check the rates for your utility to understand the impact on actual costs or savings in your situation.

3.2.9 Wright Rate Structures

Wright rate structures are similar to standard rate structures. The difference lies in the variable size of the energy blocks. Where standard rate structures have fixed energy block sizes, Wright rate structures adjust the size of the energy blocks as a multiple of the peak demand reading. The following example details both a sample Wright rate and a sample bill calculation.

Demand Charge

This is the *peak demand* multiplied by the demand charge. (The peak demand is the maximum metered kW or kVA demand during the billing period.)

First Block Energy Charge

The energy charges are broken down into two "blocks". The size of the first block is equal to the billing demand multiplied by 200 per month. If you use more energy than the first block size, the formula for the first block energy charge will be: billing demand multiplied by 200 per month multiplied by the first block energy rate.

If your total consumption is less than the billing demand × 200 per month, then the formula for the charge is equal to: consumption multiplied by the first block energy rate.

Second Block Energy Charge

This charge applies only if the monthly energy use is greater than 200 multiplied by the billing demand. If the total monthly energy is more than the first block size, the second block energy is the remainder of the energy after the first block. This charge is equal to the second block energy multiplied by the second block energy rate. The second block energy rate is less than the first block energy rate.

Note the two-fold effect on the electric bill with a high demand relative to the consumption. The first is the demand charge itself. The second is the effect the demand has on the first energy block size (i.e. the cost of first block energy is greater than second block; therefore, the higher the facility load factor, the lower the average cost per kilowatt-hour).

Sample Calculation using the Wright Rate Structure

When calculating the dollar amount of electrical readings, always use the most recent rates that are available. They are listed on your latest electric bill. A detailed example for calculating a monthly bill is provided below.

Readings: 110 kVA
48 000 kWh

Rate: Sample General Service Rate

Demand: = $6.14 per kVA
Energy:
1st block = $.0799 per kWh for the first 200 kWh per month per kVA of maximum demand

2nd block = $.05948 per kWh for all additional kilowatt hours

Calculations:

Demand:	110 kW × $6.14/kVA	=	$675.40
Energy:			
1st Block Size:	110 × 200	=	22 000 kWh
1st Block $:	22 000 kWh × $.0799/kWh	=	$1,757.80
2nd Block $:	(48 000 kWh – 22 000 kWh) × $.05948/kWh	=	$1,546.48
Before Taxes/Adjustments Total		=	**$3,979.68**

3.2.9 Competition in Electricity Markets; Preparatory Considerations

A few provinces have introduced competition in their electricity markets, others may or may not follow suit in the near future. Theoretically, (as in the private sector) competition in the electricity industry should be the catalyst for increased efficiencies, reduced operating costs and, hence, lower electricity costs.

Most utilities in Canada are vertically-integrated and publicly owned. Typically, competition is proposed for two functions of the existing utilities; *generation* and *retail sales*. Transmission and distribution of electricity will remain regulated. To facilitate competition, most utilities must separate their retail sales from generation and distribution. This "levelling of the playing field" for competition has been coined "de-regulation" or, in some cases,"re-regulation". It has proven to be a lengthy process, affording end-users an opportunity for such preparations as the following:

- Generating and analyzing the facility *demand profile*.
- Generating a load inventory and determining the facility *load flexibility*.

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 electricity. It is, in essence, the "electrical fingerprint" of the facility. (The demand profile is discussed in detail in Chapter 4.)

Load Flexibility can be defined as the degree to which the pattern of electrical use can be changed in a facility, by either re-scheduling electrical loads or disconnecting them altogether. (A methodology for determining a facility's load flexibility is outlined in Chapter 7.)

3.3 Purchasing Natural Gas

Natural gas is the most common thermal energy source presently being utilized in Canada. Natural gas rates are set by the gas company but must be approved by a provincial regulatory body. The rate applied to a large volume customer may depend on such things as:

- Total yearly purchase.
- Maximum (negotiated) daily consumption (i.e. "Contracted Demand").
- Number of days using an amount equal to the Contracted Demand.
- Number of days exceeding the Contracted Demand ("Overrun").
- Direct purchases at source delivered through the utility's pipeline network.
- A clause obliging the customer to turn off the service within a specified (typically 4 hour) time frame ("Interruptible Rate").
- Time of year the gas is purchased.

3.3.1 Understanding How You Are Billed – The Rate

Definitions of Gas Billing Terms

The various gas companies use terms that sometimes have different meanings within different rates. An attempt has been made to clarify any ambiguities. To accurately calculate individual bills, refer to the latest rate tariffs for the appropriate rate along and to the contract between the company and the utility.

Hot Energy Tip:

An alternative natural gas supplier may be able to offer a contract price for the supply of natural gas at a lower rate then your existing utility or supplier.

Month:	Period beginning at 0800 hours on the first calendar day of the month and ending at 0800 hours of the first calendar day of the following month.
Day:	A period of 24 consecutive hours commencing at 0800 hours local time.
Contracted Demand (CD):	Negotiated maximum daily usage (m^3/day).
Overrun:	Gas 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 while subsequent blocks get 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 (Commodity) Charge:	The product charge (¢ per m^3) for gas purchased.
Delivery Charge (re: CD):	A fixed or block monthly charge based on the CD but independent of actual usage.
Delivery (Commodity) Charge (re: gas delivered):	The fixed or block delivery charge (¢ per m^3) for gas purchased.
Overrun Charge:	Rate paid for all gas purchased as overrun.

Sample Large User Rate

(i) Monthly Demand Charge

1st 8450 m^3 of daily contracted demand	$0.273840 per m^3
Next 19 700 m^3 of daily contracted demand	$0.244026 per m^3
All over 28 150 m^3 of daily contracted demand	$0.214211 per m^3

(ii) Monthly Delivery Commodity Charge

1st 422 250 m^3 delivered per month	$0.009247 per m^3
Next volume =15 × daily CD	$0.009247 per m^3
Remainder	$0.005697 per m^3

(iii) Monthly Gas Supply Commodity Charge

All volumes purchased in the month	$0.118613 per m^3

(iv) Overrun Charge

Authorized	Delivery Rate	$0.018250 per m^3
	Supply Rate	$0.118613 per m^3
Unauthorized	Delivery Rate	$0.092058 per m^3
	Supply Rate	$0.118613 per m^3

3.3.2 Calculating the Monthly Cost of Natural Gas

The rate is applied to a set of values representing the use for the present billing period, which is often one month. The following sample values will be used to calculate a bill using this rate:

Contracted Demand:	20 000 m^3/day
Total Monthly Consumption:	250 000 m^3
Unauthorized Overrun Consumption:	5000 m^3

Bill Calculations

Demand Charge:	
8450 m^3 @ .27384	= $2,313.95
(20 000-8450) @ .244026	= $2,818.50
Delivery Commodity Charge:	
250 000-5000 m^3 @ .009247	= $2,265.52
Gas Supply Commodity Charge:	
(250 000-5000) m^3 @ .118613	= $29,060.19
Unauthorized Overrun Gas Delivery Charge	
5000 m^3 @ .092085	= $460.43
Unauthorized Overrun Gas Supply Charge	
5000 m^3 @ .118613	= $593.07
Total:	**$37,511.66**

3.3.3 Incremental Cost

Using the $, volume and energy content numbers, the following can be calculated:

Unit Cost per m^3 = $37,511.66 ÷ 250 000 m^3 = 15¢ per m^3

Cost per gigajoule = $37,511.66 ÷ (250 000 m^3 × .0376 GJ/m^3) = $4.00 per GJ

It should be noted that this is the overall average cost of gas energy. For increments in the amount of gas consumption, the incremental cost could be calculated by comparing bills calculated before and after the increased consumption.

This could be approximated for small increments in consumption with no overrun as the increased cost due to the *Supply Commodity Charge* and the *Delivery Commodity Charge*.

The approximate incremental cost is:

Unit Cost per m^3 = $0.009247 per m^3 + $0.118613 per m^3 = $0.127860 per m^3

The table in section 3.3 provides values for the energy contents of various energy sources. Based upon a thermal energy content for natural gas of 37.6 MJ/m^3, the cost per unit of energy can now be calculated:

Cost per gigajoule = $0.127860 per m^3 ÷ 0.0376 GJ/m^3) = $3.40 per GJ

The difference is due to the absence of the “fixed or base” charges in the incremental cost.

3.4 Propane and Fuel Oil Rates and Billing

Propane and Fuel Oil rates are set by the fuel companies, but typically must be approved by a provincial regulatory body. Propane and Fuel Oil are both sold on a per litre basis, and are delivered to the user via delivery truck. The purchase price is uniform per litre per fuel type, regardless of quantity purchased. Although the price paid per litre to the supplier can be negotiated, the contracted price will be dependent on the quantities used.

3.4.1 Worked Fuel Oil Billing Example

When calculating a fuel oil bill, use previous delivery records to determine the amount of oil consumed for a specific time frame. A detailed example is presented here where the time frame is one month.

Delivery Records:

Date	Amount Delivered (Litres)
31 May	30 500
15 June	29 000
30 June	31 000

Cost Per Litre:
$0.33/Litre

Assumption:
Oil deliveries fill the tank

Consumption:
Total consumed for 30 day period
= 29 000 + 31 000 *
= 60 000 litres

* Remember the initial delivery of 30 500 litres only fills the tank for the start of the month.

Heat Input:
Total heat input = Fuel Consumption × Fuel HHV
= 60 000 litres × 38.7 MJ/Litre
= 2 322 000 MJ
= **2322 GJ per month**

Cost:
Total Cost = Cost per Litre × Number of Litres
= $0.33/Litre × 60 000 Litres
= **$19,800. per month**

Hot Energy Tip:

Although the cost of energy from propane may be comparable to that of fuel oil, propane combustion systems may offer significantly higher combustion efficiencies making the net cost of energy lower.

From the above information it is possible to calculate the cost per gigajoule of energy. It should be emphasized that this is not a preferred calculation for comparisons over time. That is, the value of money and the cost of the fuel change with time. However, this is a useful figure for *Assessing the Opportunity* (Chapter 8).

Cost per Giga-joule = Total Cost/Total input heat
= $19,800/2322 GJ
= $8.53/GJ

This may be obtained directly by dividing the cost per litre by the HHV of the fuel.

References

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

Electricity rate information provided by:
BC Hydro
Manitoba Hydro
Nova Scotia Power Inc.
Hydro One (formerly Ontario Hydro)
Quebec Hydro

For further reading on fuel types and content please see:
CANMET's Energy Management Series Handbook #5 – Combustion Systems

Chapter 4
Up-Front Opportunities

Objectives

To describe and identify opportunities in the demand profile and combustion systems.

The cost of purchasing electrical energy is influenced by the demand charge. Likewise, the efficiency of fuel combustion systems influences the cost of all thermal energy delivered for end use. Often, significant cost savings opportunities may be realized through:

- minimizing the maximum monthly electrical demand for the facility, and
- maximizing the combustion efficiency of fuel combustion systems.

These opportunities may be pursued to some extent prior to conducting the end-use inventories discussed in subsequent chapters.

4.1 Savings Opportunities in the Demand Profile

Realizing savings opportunities through managing peak demand requires some form of measurement of a facility's demand for electricity. The demand profile provides this type of information. The demand profile described below, in conjunction with the load inventory described in Chapter 6, are useful tools for managing a facility's maximum or peak demand and electrical energy usage.

4.1.1 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. It is, in essence, the "electrical fingerprint" of the facility. To the electrical auditor, the demand profile is an extremely useful tool for tracking energy use.

The simplest demand profile would be 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 3.1. is a sample of a manually recorded hourly demand profile.

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

Table 4.1: Manual (Tabular) Demand Profile

The information required for a monthly demand profile is present on most utility invoices. In that case there would only be twelve values available for a year.

An alternative to the tabulation of demand readings shown in Table 4.1 would be a graph similar to that shown in Figure 4.1. This method of presentation facilitates comparison of the relative demand levels throughout the day, and a quick identification of the hours of peak power demand along with start-up and shut-down characteristics.

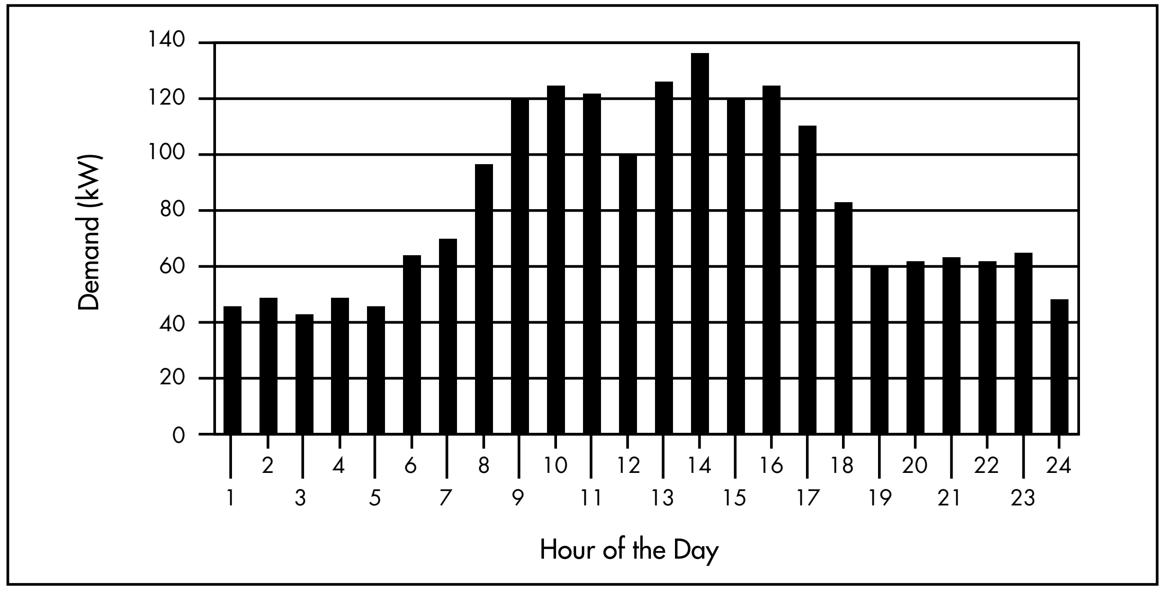


Figure 4.1: Daily Demand Profile from Hourly Data

The most commonly used form of the demand profile is similar to that illustrated in Figure 4.2. The profile covers a period of approximately 24 hours; slightly more than 24 hours is better than less. The power demand appears on the vertical axis, while the time, in hours, appears on the horizontal axis.

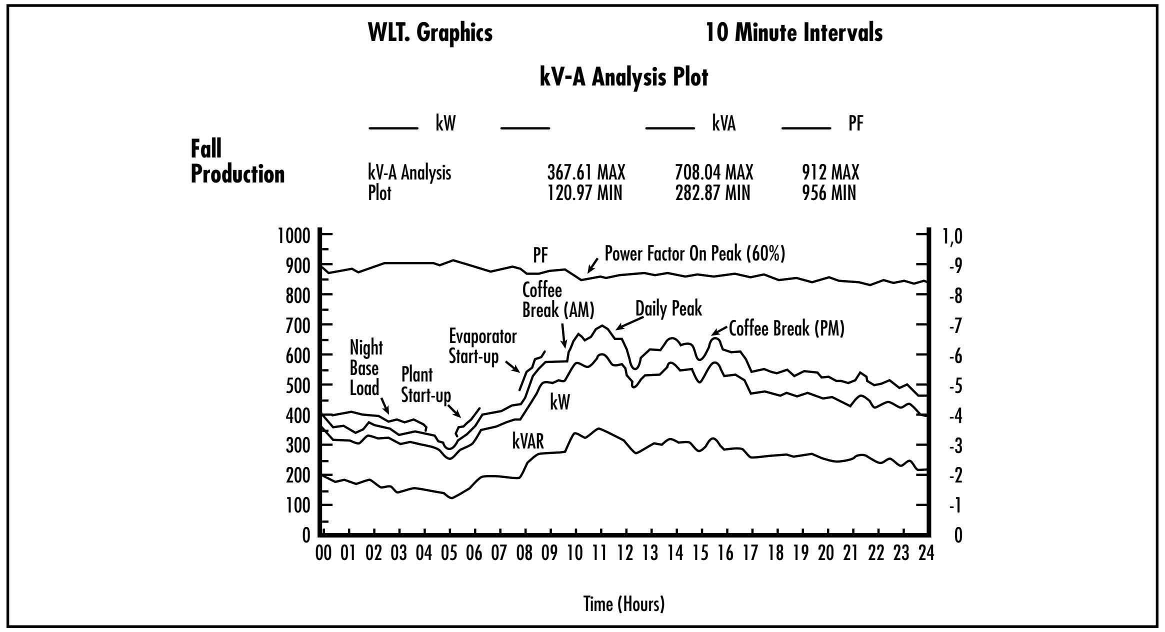


Figure 4.2: Detailed Demand Profile

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

The profile shown in Figure 4.2 contains real power information measured in kilowatts (kW), kilovolt-amps (kVA) and power factor. More sophisticated recording power meters are capable of recording these values and others, including three phase voltage, current, and power quality parameters.

Comparing Figure 4.1 and 4.2 shows clearly the advantage of using a recording power meter. Significantly more detail is available, although the hour by hour profile remains a valuable starting point.

A great deal of useful information may be derived from the demand profile, as is illustrated in table 4.2:

Hot Energy Tip:

Many electrical utilities can provide demand profiling services for a modest fee. Contact your local utility representative to determine the availability of services in your area. Some utilities may also provide profile analysis services. Experience shows that there is almost always an opportunity in the demand profile. Accordingly, the cost of this service can quickly be recovered through savings.

Information	Description
Peak Demand	The time, magnitude and duration of the peak demand period or periods may be determined.
Night Load	The demand present at night (or during unoccupied hours) is clearly identified.
Start-Up	The effect of operation start-up(s) upon demand and the peak demand may be determined.
Shut-Down	The amount of load turned off at shut-down may be identified. This should equal the start-up increment.
Weather Effects	The effect of weather conditions upon the 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 on the demand profile. This can be compared to what is expected.
Interactions	Interactions between systems may be evident, for example, the 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, this could identify 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, its absence may be evidence of problems.
Problem Areas	A short-cycling compressor is usually easy to spot from the demand profile.

Table 4.2: Events To Look For In A Demand Profile

The information that may be gleaned from the demand profile is not limited to that mentioned above, these are some of the most obvious items. Profiling not only the facility as a whole, but also departments or sections, will allow the development of detailed knowledge of the facility's power demand habits.

4.1.2 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 (EMS).
- A dedicated monitoring system.

While the first method above is the cheapest and simplest to implement, the data it produces is limited. At the other end of the spectrum, the multi-channel recorders are expensive and complex to use, but yield a wealth of information, from real power to power quality.

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

Periodic Utility Meter Readings

Usually recorded hourly, this method requires a meter that is accessible for readings. The major limitations of this manual method are its limited time resolution (forcing the interpreter to "guess" about the load in between readings) and the demand that it places on staff, but it might make a good student job. The advantages of this method are its simplicity, freedom from capital cost outlay, and the fact that readings match exactly the utility's readings. Attaining this match becomes an issue for the other methods.

Recording Ammeter

A recording ammeter is a single or three phase ammeter connected to a device that will store 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 a power factor to yield an estimated demand reading. The recording device may be a computerized unit but is usually a strip chart recorder of some description.

Hot Energy Tip:

Peak demands that are infrequent represent a cost saving opportunity since it may be possible to easily identify and avoid the infrequent activity that is setting the peak.

Try to identify the "peak" time of day for consumption in your facility. Check your demand reading at this time for a week of so to determine if your peak demand reading is regular or infrequent.

As little as 10 kW of demand saved could reduce costs by $50-$100 per month, contingent upon your rate.

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 only true when two conditions exist:

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

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 only record one value such as kilowatts (kW) or kVA, whereas the multichannel method could record kW, kVA, phase current, voltage, overall power factor and possibly more.

The recording power meter measures current and voltage simultaneously on up to three phases and 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. They are capable of registering very fast changes in power demand (See Figure 4.4). Utility meters are not. The standard utility meter averages the demand over the previous 15 minute period. Some models of power meter will perform an average; others will not. Interpretation of the demand profile (section 4.1.3) could take this into consideration.

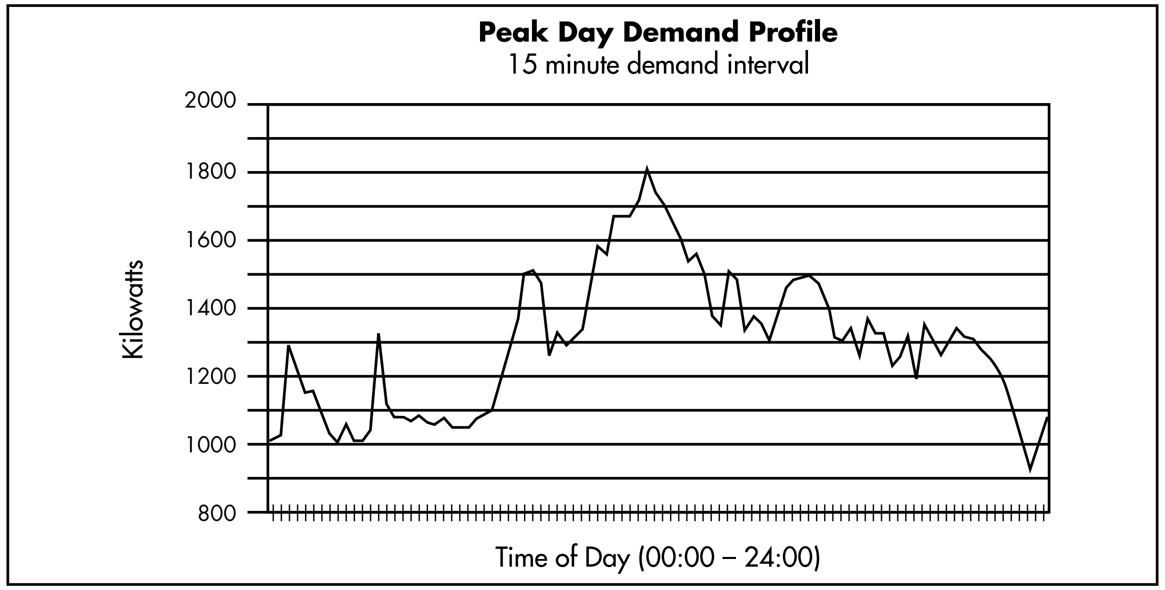


Figure 4.3: Demand Profile from Interval Data

A Facility Energy Management System

The key advantage to 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 have the capability to perform these measurement, but they simply lack the necessary power (watt) sensors. Disadvantages may include a lack of memory to store values requiring printing or downloading of data periodically, limited time resolution of measurements, low accuracy readings due to transducers, or minimal installations.

A Dedicated Monitoring System

At a minimum, such a 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 aid in the analysis of the demand profiles. Dedicated monitoring system are generally at the core of larger fully integrated monitoring and tracking systems.

4.1.3 Analysing the Demand Profile

The demand profile is the electrical "fingerprint" of a facility's electrical consumption patterns. Key information may be obtained by reading or interpreting the profile, loads that operate continuously and could be shut down, loads that contribute unnecessarily to the peak demand, or possibly 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, there's a bit of interpretive art involved, too. Good knowledge of the facility, its loads, operational patterns, and the examples in this section should be a good beginning for the development of that art.

Step – 1 Compare the measured demand profile with the estimated profile that was prepared in Section 3.2. Did the peak occur when it was expected and was it equal to that taken from the utility invoice? Was the night load greater than, less than, or equal to what was expected? Did the facility shut down and start up as anticipated?

Step – 2 It is useful to begin with a list or inventory of electrical loads within a facility. Chapter 6 describes a method of compiling such a list.

Step – 3 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; each and every demand profile will be different. Mark anything that looks significant.

Step – 4 Mark along the time scale the time of day when significant operational events occur. Such events would include:

- start-up and shut-down
- coffee breaks
- lunch hour
- shift changes
- notable events (operation of a certain process)

The purpose here is to spot some correlation between the features noted in Step 3, and work patterns in the facility.

Step – 5 Study the examples presented in the next section, noting the patterns and the interpretations given. Try to match the patterns and shapes of your operation with these. The overall result should be an annotated profile similar to that illustrated in Figure 4.1.

4.1.4 Electrical Load Factor

Electrical Load Factor (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 on the electricity bills. Mathematically, this is written as follows:

$$\textbf{Load Factor (\%)} = \left(\frac{\textbf{kWh used in period}}{\textbf{Peak kW} \times \textbf{24 hrs per day} \times \textbf{\# days in period}}\right) \times 100$$

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

Assume the two sample facilities in section 3.2.6 consume 25 000 kilowatt-hours over a billing period of 28 days. Their respective Load Factors can be calculated as follows:

Facility A

$$\textbf{Load Factor (\%)} = \left(\frac{\textbf{25 000 kWh}}{\textbf{250 kW} \times \textbf{24 hrs per day} \times \textbf{28 days in period}}\right) \times 100$$

$$\textbf{Load Factor (\%)} = \textbf{15\%}$$

Facility B

$$\textbf{Load Factor (\%)} = \left(\frac{\textbf{25 000 kWh}}{\textbf{50 kW} \times \textbf{24 hrs per day} \times \textbf{28 days in period}}\right) \times 100$$

$$\textbf{Load Factor (\%)} = \textbf{75\%}$$

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

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

4.1.5 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, this should be calculated over the same period of time as the electrical load factor (24 hours, one week, one month, etc.). Completing this exercise is an initial step for determining the present use of electricity and 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 1. The UF/LF calculations can be done without any demand profile metering. All that is required is one or more electric bills and a knowledge of the operation of the facility's operation.

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 percent. Assume that the LF calculations (by the method described in section 4.1.4) yield a LF of 45 percent. The fact that the LF is roughly 1/3 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?

Example 2. With sufficient data, more detailed LF and UF calculations can be done. This example illustrates an industrial facility operating in the following manner:

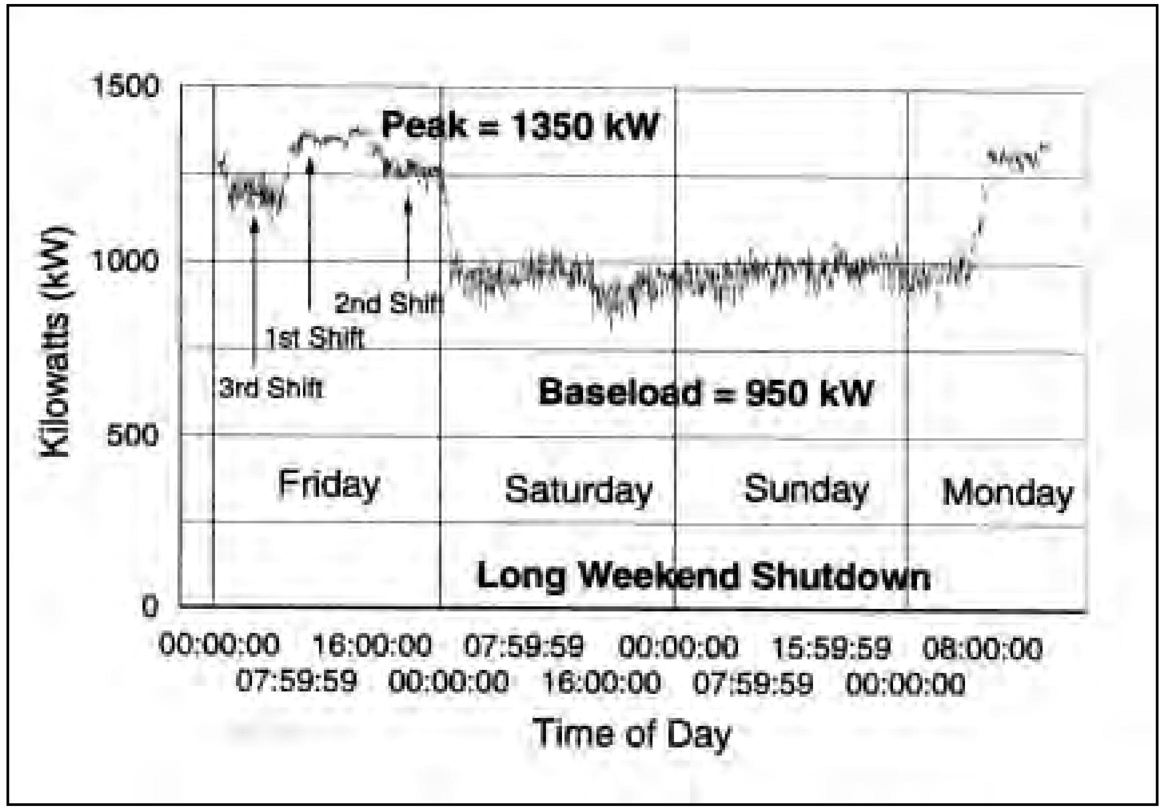


Figure 4.4: Example Demand Profile (One-minute Data)

Three, eight-hour shifts, five days per week.

Shift 1	100 percent production output
Shift 2	60 percent production output
Shift 3	20 percent production output

From the utility bills, the facility had a peak demand of 1 350 kW. It consumed 806 400 kWh in a four-week billing period (28 days) and 31 200 kWh during the production day (Friday) as shown in the above demand profile.

Two electrical load factors can be calculated.

Monthly Load Factor

$$\textbf{Load Factor (\%)} = \left(\frac{\textbf{806 400 kWh}}{\textbf{1 350 kW} \times \textbf{24 hrs per day} \times \textbf{28 days in period}}\right) \times \textbf{100}$$

Load Factor (%) = 89%

Production Day Load Factor

$$\textbf{Load Factor (\%)} = \left(\frac{\textbf{31 200 kWh}}{\textbf{1350 kW} \times \textbf{24 hrs per day} \times \textbf{1 day in period}}\right) \times \textbf{100}$$

Load Factor (%) = 96%

The following are calculations for the two corresponding utilization factors:

Production Day Factor of Utilization;

33.3% of a production day at 100% production	= 33.3%
33.3% of a production day at 60% production	= 20%
33.3% of a production day at 20% production	= 6.7%
Factor of Utilization for one production day is the sum	**= 60%**

Monthly Factor of Utilization;
Production day Factor of Utilization (60 percent) times the number of production days in the period (20) divided by the total number of days in the period (28).

$$\textbf{Monthly Factor of Utilization (\%)} = \left(\frac{\textbf{Production day L.F.} \times \textbf{\# production days/period}}{\textbf{Total days in period}}\right)$$

$$\textbf{Monthly Factor of Utilization (\%)} = \left(\frac{\textbf{60\%} \times \textbf{20}}{\textbf{28}}\right)$$

Monthly Factor of Utilization = 43%

Comparing the monthly electrical load factor and monthly utilization factor reveals a poor correlation; 89 percent vs. 43 percent. A high LF can result from excessive energy consumption during the month. To find a reason, the demand profile provides us with more information; specifically, the energy consumed during both production and non-production days.

Comparing the electrical load factor (96 percent) and the utilization factor (60 percent) on the production day also reveals a poor correlation. The culprit may be excessive energy consumption during both periods of reduced production and no production. Obviously, more investigation of the electrical loads and their operating characteristics is warranted. Various methods of load analysis are detailed in Chapter 5, The Electrical Load Inventory.

4.1.6 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 is an opportunity for demand reduction by scheduling.
- A high night load in a facility without night operations presents an opportunity for energy savings through better control or possibly time clocks.
- Loads that cycle on/off frequently during unoccupied periods suggests that possibly they could be shut down completely.
- High demands during breaks in a production operation or insignificant drops at break times suggests that equipment idling may be costly, consider shutdown.

- Make sure that systems are not starting up before they are needed and shutting down after the need is past. Even $^{1}/_{2}$ hour per day can save a significant amount if the load is high.
- Peak demand periods at start-up times suggests an opportunity for staged start-up to avoid the peak.
- If the billed demand peak is not evident on a typical demand profile, this suggests that the load (or loads) which determine the demand may not be necessary (if they only operate 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 frequently may result in a higher peak demand and a lower utilization efficiency than a smaller machine running continuously. Consider the use of smaller staged units or machines. Such a strategy may also reduce maintenance since machine start/stop results in increased wear and tear.
- Short cycling loads are a clue to potential 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*.

Power Factor Correction Savings Opportunities

The demand profile in Figure 4.2 shows power factor values throughout the day, including the time of the peak or maximum demand. For customers billed on kVA demand there is an opportunity to reduce the peak or maximum kVA demand by increasing your power factor. As detailed in Chapter 2, 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 the kVA demand while maintaining the real power consumption, the kW demand.

In practice it is only the on-peak power factor that really is of concern from the perspective of demand costs.

- Correct power factor at service entrance

  This can be done with the addition of a fixed capacitor bank provided that the load and power factor are constant. Otherwise, variable bank (one that adjusts itself 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 an added 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 partly loaded, it may be operationally advantageous to install power factor correction capacitors at the point of use (i.e. at the motor). In this manner the correction capacitors are brought on-line with the motor and removed as the motor is stopped.

4.2 Savings Opportunities in Maximizing Combustion Efficiency

Boilers, furnaces and kilns utilize fuel combustion to convert chemical energy embodied in fuels to thermal energy or heat. In addition to fuel, oxygen from combustion air is required at the input to the combustion equipment. The result is a hot gaseous mixture including water vapour. The combustion process is illustrated in Figure 4.5.

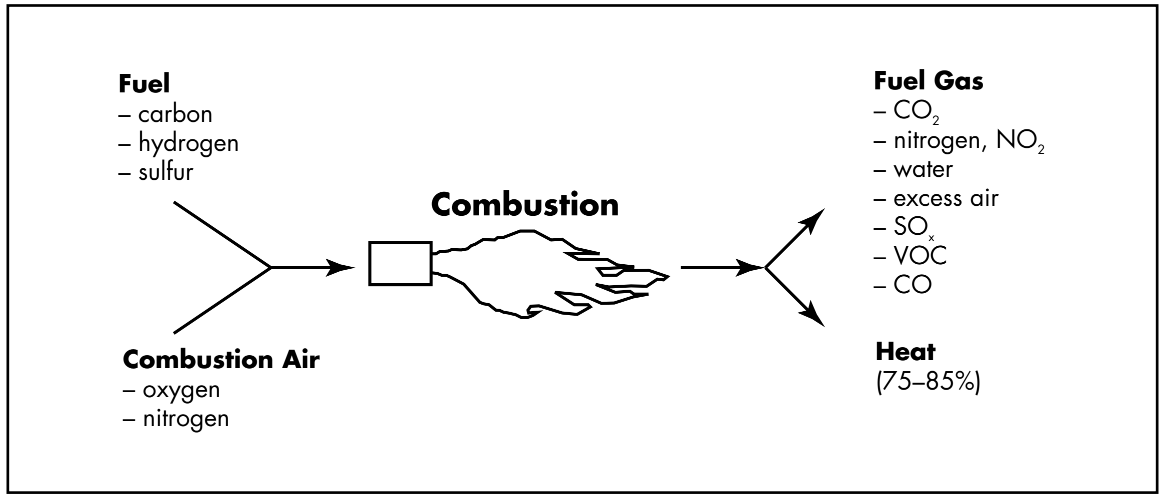


Figure 4.5: The Fuel Combustion Process

4.2.1 Energy Consumption Issues

Fuel combustion systems are not end-use systems; the resulting heat is delivered by other systems to individual requirements in the form of steam, hot air or water. Consequently, the opportunities for savings in fuel fired systems lie in maximizing the losses in the combustion process, thereby maximizing the combustion efficiency.

The losses incurred during the combustion process are primarily lost up the stack and are commonly known as stack or flue gas losses. To a lesser degree, there are also radiant and convective losses from the combustion chamber. The three main components of stack losses are:

- Dry flue gas heat-loss.
- Heat lost due to water formation during combustion of hydrogen in the fuel.
- Heat loss due to the evaporation of moisture in the fuel.

Note that the first loss is an example of sensible heat while the second and third are losses of latent heat. When looking for, and considering, energy management opportunities, this difference can be meaningful.

4.2.2 *Combustion Efficiency Measurement*

Several operating conditions of the boiler are measured to determine its combustion efficiency. Among these are:

- Flue gas temperature.
- % carbon dioxide in the flue gas.
- % oxygen in the flue gas.
- Combustion air inlet temperature.
- % carbon monoxide in the flue gas.

Smoke and flame conditions may be observed visually. A smoke test, which measures soot in the flue gas, is typically used on an oil-fired system and is comparable to, but not as accurate as, a carbon monoxide (CO) test. The flue gas can be sampled for analysis by either chemical or electronic means. The results can then be referenced to a combustion efficiency table, for the applicable fuel, to determine the combustion efficiency. Visual observations should be made by someone familiar with the operation and maintenance of the equipment. The target for maximum efficiency is illustrated in Figure 4.6.

Hot Energy Tip:

An electronic flue gas or combustion efficiency analyser can be purchased for as little at $800. If the purchase and use of an analyser improved the overall annual efficiency by 1%, the cost of the unit could be paid back within 2 years with a fuel bill of $40,000 per year.

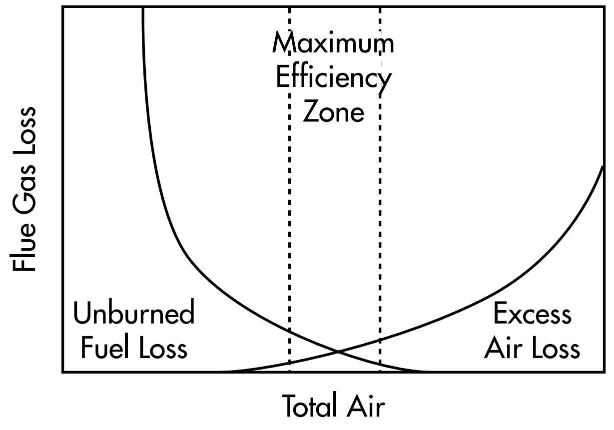


Figure 4.6: Maximum Combustion Efficiency

4.2.3 *Equipment Factors*

Within a fuel-burning system, air, consisting of 21% oxygen, is required for combustion. The optimum combustion efficiency of a fuel-burning system is attained by reducing the amount of air supplied to the combustion process to the lowest possible level without producing unburnt or partially burnt fuel. This is referred to as the minimum O_2 or minimum excess air setting.

Auxiliary equipment-design characteristics can affect the amount of excess air required. These include control fans, pulse technology, air design burners and optimally sized fuel nozzles.

Operational and Seasonal Factors

The equipment's minimum O_2 setting adjustment should be based on a range of operating conditions; however, a cushion of excess air must be allowed to minimize sooting and CO production. The size of cushion depends on the frequency of adjustments and on the load. For example, as the load on a boiler is reduced, excess air is required, reducing overall efficiency.

Other operational factors include variations in fuel composition, barometric pressure variations, ranges of loads on boiler, fuel and air-input temperatures, and fuel input pressure.

4.2.4 *Operational Opportunities for Savings*

Operational actions tend to be lower cost. They include such things as regular maintenance and adjustments:

- Check combustion efficiency regularly.
- Verify fuel energy content by periodic fuel analysis.
- Monitor excess air regularly and ensure that it meets manufacturers' specs.
- Relocate combustion air intake to increase temperatures.
- Manage load/condition swings to maintain optimal combustion conditions.
- Ensure a clear and unhindered exhaust stream in reciprocating engines.
- Keep burner assemblies in proper and regular adjustment.
- Maintain seals, air ducts, breeching, access doors.

Hot Energy Tip:

A simple action such as adjustment of excess air levels on a monthly basis could improve combustion efficiency by 2 to 4%. The savings in fuel that this would represent would be approximately 2 to 4% of you entire fuel bill – assuming all fuel was consumed in the equipment affected by the adjustments.

4.2.5 *Technological Opportunities*

These tend to be higher cost opportunities

- Verify combustion system design for size and variation of load.
- Install an air pre-heater.
- Upgrade burner equipment.
- Install new combustion controls.
- Consider flue gas heat recovery systems with or without condensation often referred to as economizers.

4.3 Summary

Taking advantage of the savings opportunities in the demand profile and through combustion efficiency improvement may provide your energy management efforts with some early successes.

References

CANMET's Energy Management Series Handbook #5 – Combustion Systems

CANMET's Energy Management Series Handbook #6 – Boiler Plant Systems

Energy Efficient Process Heat, PEI Dept of Economic Development and Tourism, Charlottetown PEI, 1996 (tel.: (902) 368-5010)

Using Control Technology to Cut Energy Costs, PEI Dept of Economic Development and Tourism, Charlottetown PEI, 1995 (tel.: (902) 368-5010)

Modern Industrial Assessments: A Training Manual, Rutgers, The State University of New Jersey, 1995 (available online at: http://oipea-www.rutgers.edu/documents/doc_f.html)

Boiler Efficiency Improvement, Boiler Efficiency Institute, Auburn, AL, 1992 (tel.: (205) 821-3095)

Chapter 5
The Electrical Load Inventory

Objectives

To be able to estimate the amount of electricity consumed by a single electrical load, a group of loads or by all loads in a facility.

5.1 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 often leads to low-cost savings opportunities. Identifying the high-consumption loads lets you consider the best savings opportunities first. Because the inventory also quantifies the demand (or the "how fast") associated with each load or group of loads, it is invaluable in further interpretation of the demand profile. See Chapter 4, The Demand Profile.

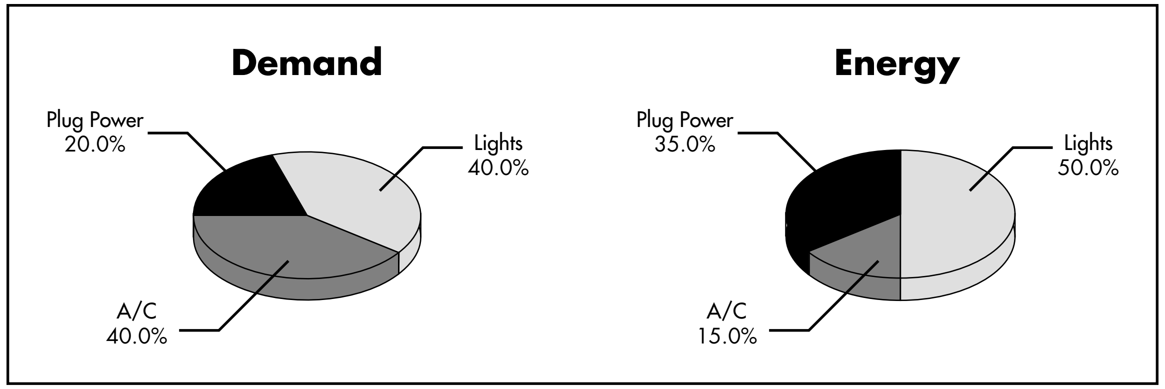


Figure 5.1: Summary Results of the Load Inventory

Figure 5.1 provides one possible presentation of the result of the load inventory.

5.1.1 How to Compile a Load Inventory

This section will outline a method for compiling a load inventory using forms, samples of which are illustrated on the next few pages. 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 briefly in section 5.1.2.

Hot Energy Tip:

Conducting a load inventory can identify any loads that operate unnecessarily. A load inventory of a soft drink bottling operation determined that two large air compressors could be replaced by one small unit during non-processing time. The cost of the replacement compressor was only $1,500, while the savings exceeded $10,000 per year.

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 which 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 Chapter 2 for details.)

Record the actual values on the Summary Form LD1, as Actual Demand and Energy.

Step – 2 Identify each of the major categories of electricity use in the facility. This may require that you 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.

Hot Energy Tip:

Are you considering installing a monitoring system? A load inventory can help you select the best points for continuous measurement.

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. 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 use in which the largest amount of demand or energy is used.

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. 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, appliances, etc. 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 only be used for motors. It provides a method of estimating kW load based upon 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. Also 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 the categories of highest energy use and demand to the lowest. If the estimated energy use or demand in a category is relatively small (less than five percent), it is probably not worthwhile to conduct a detailed inventory.

5.1.2 Instrumentation Used in the Load Inventory

Electrical instrumentation can provide detailed current, voltage and power information for the load inventory. Some care must be taken when interpreting measurements to ensure that the results are not misleading.

All measurements, other than multiple readings taken with a recording device (e.g., the demand profile), are instantaneous. This means that the value measured only indicates the state of the device at the time when the measurement was taken. In the case of lighting (without dimmers) and loads that do not experience varying levels of operation, such readings are a good indication of long-term conditions such as power consumption. This is not true for most motor loads such as fans, pumps, refrigeration units and compressors. For measurements on varying loads, a number of supplementary or alternative techniques are available:

- When taking readings, try to determine the load level on the device in terms of production or operational levels. This can be used to adjust the measured value to a long-term average.
- Always take more than one reading, possibly over a period of time appropriate to the load rate of change. Consider averaging the measured values.
- Use a recording device (ammeter, power meter, etc.) as an effective means of gathering long-term data.
- Use other operational records such as maintenance records and chart recorders to develop long-term average values.

Hot Energy Tip:

Consider hiring an engineering or technology student to compile a load inventory. The questions asked by a fresh set of eyes may uncover hidden savings opportunities.

Experience in electrical energy auditing has shown the following type of instrumentation to be of value:

- *handheld clip-on meter*, for instantaneous current and voltage measurements;
  Approximate cost, $300.00
- *power factor meter*, for determination of load, distribution, or service entrance power factor. The utility demand meter remains a good method of determining on-peak service entrance power factor;
  Approximate cost, $300.00
- *AC power meter*, for complete motor power measurements;
  Approximate cost $900.00
- *non-contact tachometer*, for motor speed measurement, to assist in estimating motor load percentages;
  Approximate cost, $300.00
- *flow meters (water and air) and a temperature measuring device*, for estimating load levels on motors. Costs vary with application requirements.

The use of instrumentation is discussed further in sections 5.1.4., 5.1.5 and 5.1.6, along with other methods for obtaining load information.

5.1.3 Load Inventory Forms

Five data collection forms are provided to assist in the compilation of the load inventory:

Form LD1:	Load Inventory Summary
Form LD2:	Category of Use Summary
Form LD3:	Simple Load Information
Form LD4:	Detailed Information (Current-Voltage Method)
Form LD5:	Detailed Information (Motor Load Method)

Samples of each form are provided in the following sections. Guides for filling them out are provided on the accompanying pages.

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	.235
LD4	Detailed Load Information	30 680	76.1	0
LD5	Motor Load Information	432	1.9	1.9
	Total Calculated	**35 199**	**93.9**	**2.1**

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, then add the three columns.

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 the period used.			✓	

Form LD1: Load Inventory Summary

This form is the starting point and ending 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 electric 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 LD3: Simple Load Information

Category of Use: Lighting

Description	Qty (a)	Unit Load (b)	Total kW (c) = a × b	Hrs/ Period (d)	kWh/ Period (e) = d × c	On @ Peak Y or N	Div'ty Factor (f)	Peak kW (g) = f × c	On @ Night Y or N	Night kW
Office floor	50	.047	2.35	290	682	Y	100	2.55	N	0.
Warehouse	30	.45	13.5	250	3375	Y	100	13.5	N	0.
Corridor	5	.047	.235	129	30	Y	30	.07	Y	.235
Totals	n/a	n/a	n/a	n/a	4087	n/a	n/a	15.9	n/a	.235

Form LD3: Simple Load Information

This form is used to record simple load information, and to calculate demand and energy for each item. The total kWh/Period, Peak kW, and Night kW should be entered 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 of this particular load.
Total kW	kW	Quantity × Unit Load
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	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 × 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	.85	126.8	242	30 680	Y	.6	76.1	N	0
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) × (b) × (c) × (d) × (e)

for single phase, use (d) = 1

for three phase, 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. The total kWh/Period, Peak kW, and Night kW should be entered on the last row of the form.

Data Entry Item	Units	Description
Quantity	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. Either 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	Quantity × Voltage × Amps × 1,73 × Power Factor
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	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 × 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
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 Information (Motor Load Method)

This form is used to estimate motor power loads from motor loading and efficiency data. The total kWh/Period, Peak kW, and Night kW should be entered on the last row of the form.

Data Entry Item	Units	Description
Quantity	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	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 × 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.

5.1.4 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, a checklist would enable you to add up the various types by category and run time. The sample table on the following page could be customized to include only the fixture types in use at your plant. Transfer the totals to Form LD3 when complete.

Hot Energy Tip:

A lighting inventory makes a lighting retrofit easy to assess. Lamp changes can be quickly evaluated for savings potentials.

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	5
Compact Fl. (7, 9, 11 or 13 watts typical)	3

- Check to make sure fluorescent fixtures from which the lamps have been removed have also had the ballasts disconnected. A fluorescent ballast will still consume power even if there are no lamps 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.

5.1.5 Collecting and Assessing Motor and Other Data

Some rules of thumb and suggestions for data gathering and assessment:

- If motors are supplied at 600V/3φ, 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:

  $\text{kVA} = V \times I \text{ (per phase)} \times \sqrt{3}$

  For example, if a motor is rated at 600V/5.7A, the full-load kVA would be:

  $600 \times 5.7 \times 1.73 = 5.9 \text{ kVA}$

  The power factor must then be applied to this to obtain the kW load as noted in Form LD4. This can range from 50 percent to 90 percent, 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. One such table is included in Appendix C.

- 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 stop watch). If this is done at a time when the load on the equipment is typical, then an accurate load factor (percentage of operating time) can be calculated. Note that the load factor during off hours would generally be somewhat less.
- Load inventory data can be verified 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. the equipment fed by the feeder is known with reasonable accuracy; 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.

5.2 Reconciling the Load Inventory with Utility Bills

Once the load inventory information is collected it can be reconciled 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.

5.2.1 Peak Demand Breakdown

For each of the loads identified in the load inventory a total load 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 of each total load contributes to the peak demand?

For a given load, the relationship between the total load and the amount that it contributes to the peak demand is:

Peak Load = Total Load × Diversity Factor

The diversity factor takes into account a number of situations that could lead to less than the total load contributing to the peak demand:

- 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 percent of the total load. (The response of the demand meter is detailed in Chapter 3.)

On-Time of Load	Percentage 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 particular load may or may not be on during the peak demand periods; the diversity factor in this situation becomes a coincidence factor relating the chance that the load is on coincidentally with the demand peak.

5.2.2 Reconciliation of the 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; and
- 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:

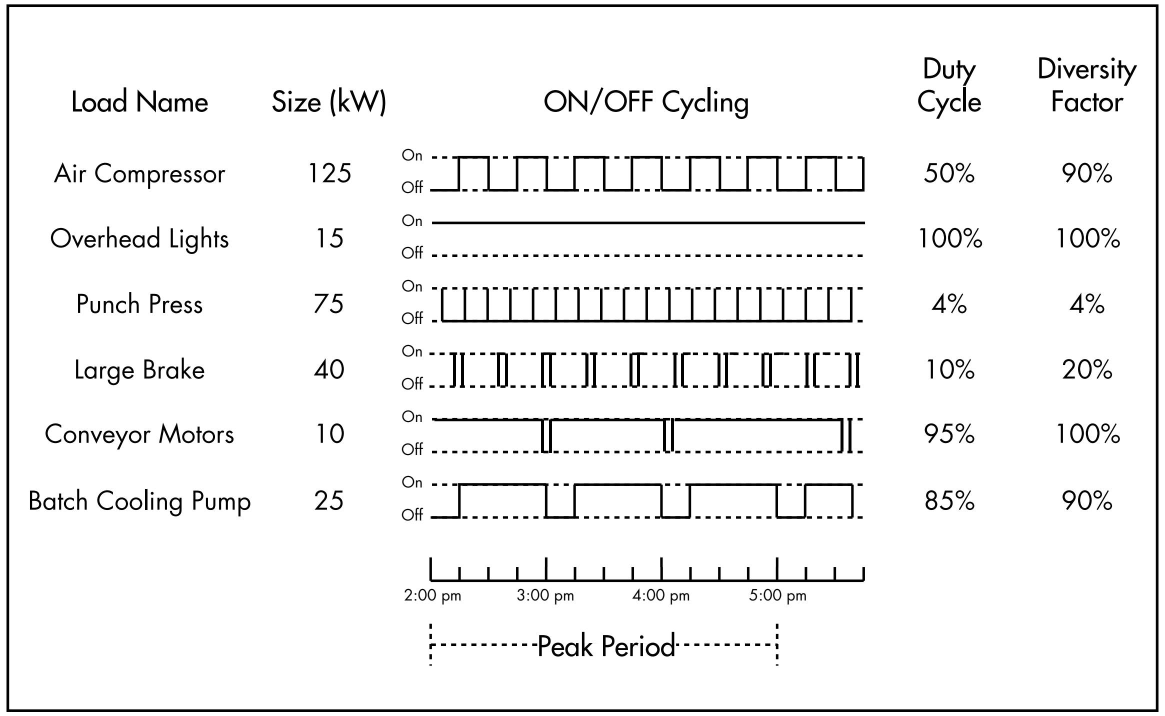
i) What effect does the duty cycle of any given load have upon the demand meter – considering the response of the meter?

ii) What is the coincidence between the particular load and all other loads in the facility?

Hot Energy Tip:

The starting of a large motor, that could take up to 5 – 10 seconds will not have a significant impact on the peak demand.

As described previously, the diversity factor takes into account these two effects; this is illustrated in Figure 5.2. 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 pm and 5:00 pm.



Load Name	Size (kW)	ON/OFF Cycling	Duty Cycle	Diversity Factor
Air Compressor	125		50%	90%
Overhead Lights	15		100%	100%
Punch Press	75		4%	4%
Large Brake	40		10%	20%
Conveyor Motors	10		95%	100%
Batch Cooling Pump	25		85%	90%

Figure 5.2: Estimating Diversity Factors for Various Loads

The diversity factors were estimated by the following reasoning.

Air Compressor – The unit cycles on and off every 15 minutes. The demand meter will register 90 percent of demand in 15 minutes. This load is on at the same time (coincidentally) with a number of the other loads during the peak period. Therefore the full 90 percent is used.

Overhead Lights – These are on continuously during the peak period, so the demand meter will register 100 percent of full load in coincidence with all other load.

Punch Press – The punch press motor operates for only 0.6 minutes; the demand meter would register about eight percent in that time. However, since the load is not completely coincident with all other loads, a 50 percent allowance is made for coincidence. The result is a four percent 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 percent is used for the diversity factor here.

Conveyor Motors – Since the off-time of the conveyors is not significantly long enough to allow the meter indication to drop significantly, a 100-percent 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 percent allowance is made for the non-coincidence of this load and other short running large loads. Therefore, 90 percent is used for a diversity factor.

There are alternative methods for estimating diversity factors. One method that may be useful follows:

Step – 1 Assume that all diversity factors are 100 percent, and calculate the sum of all the total loads. This is called the *Maxload.* This 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 percent. Add each of these loads; this total is called the *Contload.* Subtract the Contload from the Actual Peak Demand; this 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). This 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 five percent, repeat Steps 5 and 6. Some judgment will be required 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 not only adjust the diversity factors but also the basic load data to achieve a reconciliation.
- Many devices use less than their nameplate ratings. In the 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.

5.2.3 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 × Amps × Power Factor (if applicable) × 1/1000 (× $\sqrt{3}$ for 3-phase) × Loading (%).
- Operating Time (hours) is the total time the equipment is energized during the period being evaluated × 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, the Duty Cycle = 100 percent.
- 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 load.

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 H.I.D. 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 × 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 × .75 × 1/1000 × 5 days/week × 5 h/day × 33/7
   = 3812 kWh

5.2.4 Energy Reconciliation with Utility Bills

After calculating the energy use of all the different loads in the load inventory, these calculations should be reconciled 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 may help reconcile the differences:

- 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.
- If you are averaging weeks into a monthly period, this can introduce errors depending on where weekends fall within the billing period.
- When estimating heating equipment run-times, if the oil consumption is known, the operating hours can be calculated as (oil consumed in the period) / (firing rate of the burner). This would only work 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.

References

Energy Efficient Motor Selection Handbook, US Department of Energy, DOE/CE 0384

Commercial Energy Manual Applications, Ontario Hydro, 1991

Commercial Energy Manual Fundamentals, Ontario Hydro, 1991

1996 Handbook – HVAC Systems and Equipment, ASHRAE, Atlanta (www.ashrae.org)

Chapter 6
The Thermal Energy-Use Inventory

Objectives

To be able to estimate the amount of energy consumed by a variety of thermal energy-use processes.

6.1 Identification of Energy Flows

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

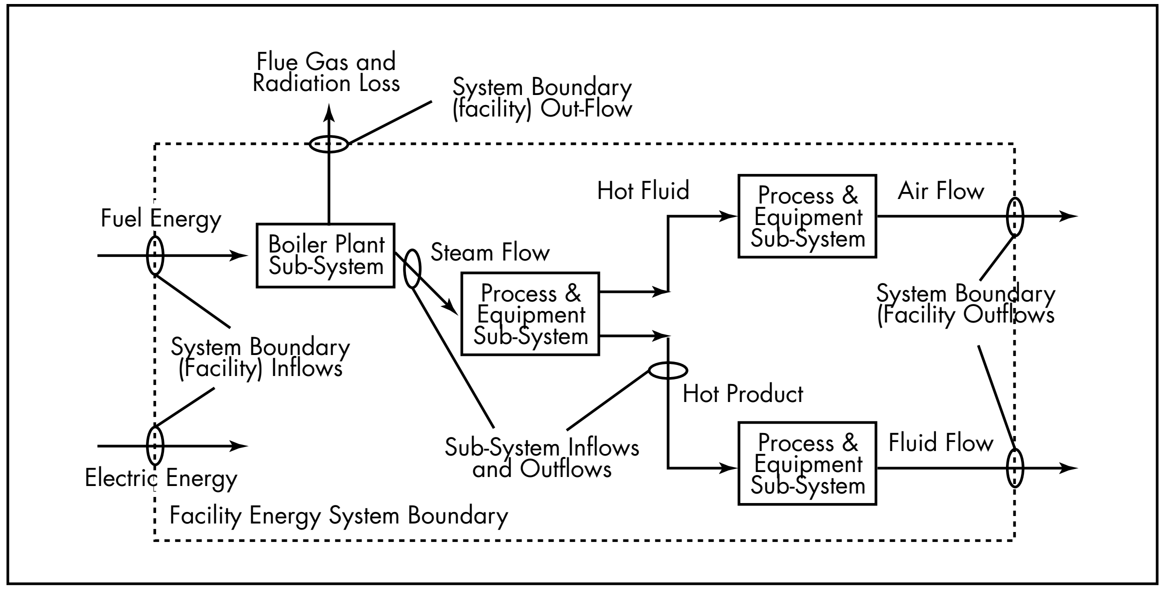


Figure 6.1: Generalized Facility Energy Flow Diagram

Because the purpose of such a diagram is to illustrate energy flows, not to describe a process in detail, the diagram will not generally show the specific devices and equipment that are found in its various subsystem “blocks”. The flows are the important thing here.

The magnitude of the energy outflows must equal the purchased energy inflows. When we have the complete picture, a picture of the important internal energy flows as well as those from and to the external world, it is often possible to see opportunities for energy reduction and recovery.

Hot Energy Tip:

Are you considering a heat recovery application. The thermal energy-use inventory provides valuable information about waste heat sources and potential uses. A good example is proved in section 6.6.

Identifying the Type of Energy Flow

The table below can be used as a checklist to assist in the identification of thermal energy outflows from a subsystem or a facility. While 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.

Energy Flow Type	Example	Equipment/Functions
Conduction	Wall, windows	Building structure
Air Flow – Sensible	General exhaust	Exhaust and make-up air systems, combustion air intake
Air Flow – 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

Calculations for Estimating Energy Outflows
The following sections provide simple methods for estimating the amount of energy involved with each energy flow. The methods detailed 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.

6.2 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 6.2 and described below:

- Ventilation air is drawn in and heated. The exhaust flow is necessary to balance the air pressures and exchange air.

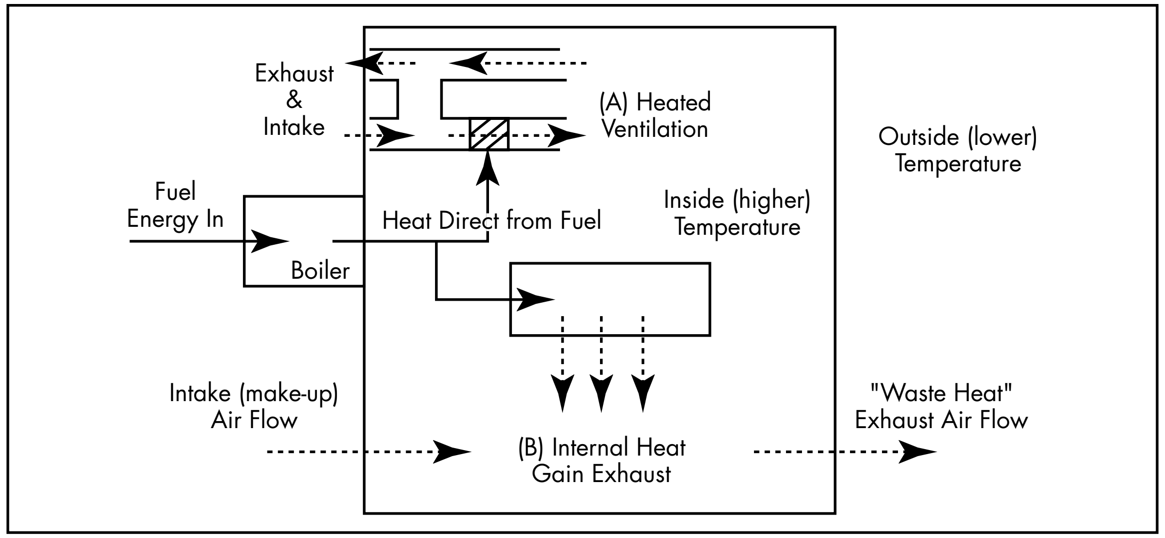


Figure 6.2: Energy Inflows versus Energy Outflows

- 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 may be only partially heated.

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

6.3 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.

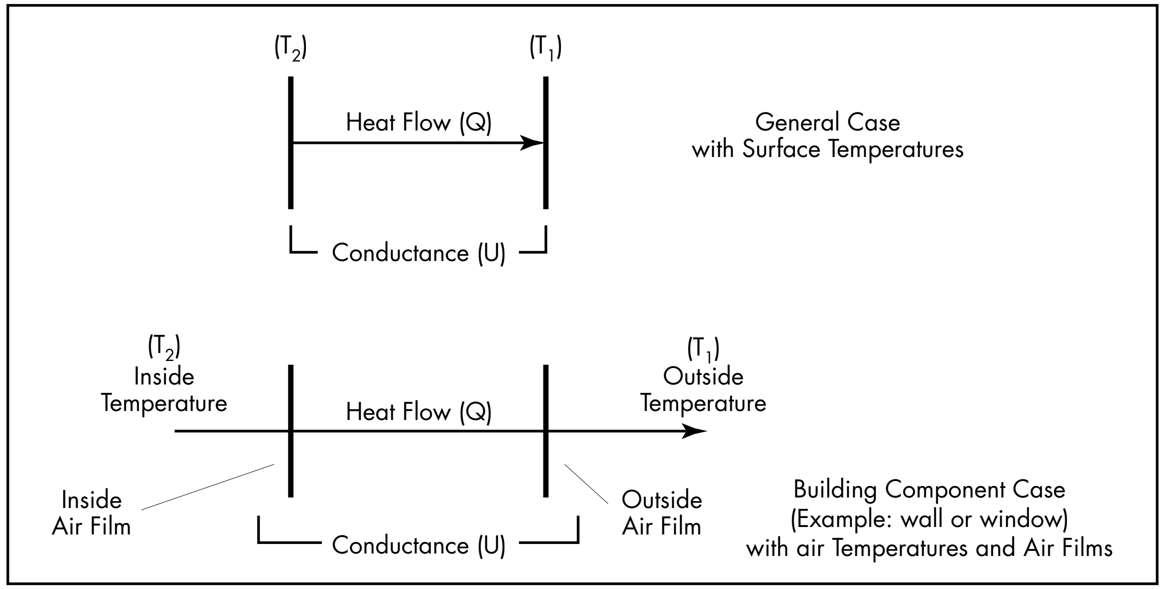


Figure 6.3: Heat Transfer by Conduction

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 metric system, this is called the *RSI- value*. (Thermal resistance and thermal conductance are related. One is the reciprocal of the other.) Appendix C 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.

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 on either side 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 h °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/ [ft^2 h °F] (Imperial).

Parameter	Symbol	Units	Sample	Method of Determination
Conductance	U	W/m² °C	0.9 W/m² °C	See below and Appendix C
Surface Area	A	m²	100 m²	Measurement
Higher Temperature	T_2	°C	20 °C	Measurement, estimation
Lower Temperature	T_1	°C	5 °C	Measurement, estimation
Time	t	hours	n/a	Estimation, calculation
Heat Flow	Q	kW	1.35	kW Formula below

The resistance to heat flow per unit of thickness, or per unit area for a specific thickness. This is commonly termed 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 m² °C/W respectively. Imperial units are [ft hr °F]/Btu and [ft hr °F]/Btu respectively.

The tables, charts, and diagrams provided in Appendix C give conductance, conductivity and resistance values for various materials and layers of common materials. The conductance of an *assembly* of materials (layers) is often referred to as the *transmittance*.

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. The diagrams provided in Appendix C for common building components illustrate this and give resistance and conductance values for these layers of air.

Appendix D illustrates a method (Degree Day Method) of estimating monthly, seasonal, or annual energy flows given the heat or energy flow rate (Q) at some temperature difference between outdoors and indoors (T_2 or T_1).

Equation for rate of heat transfer:

$Q = U \times A \times (T_2 - T_1)$ 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 variation in temperatures over time will reduce accuracy.
- The temperature does not vary across the surface area involved.
- Temperatures used must be surface temperatures if conductances do not include allowance for air films as discussed in Appendix C.

Reference: EMS Handbook #18 – Architectural Considerations

6.4 Air Flow – Sensible Heat

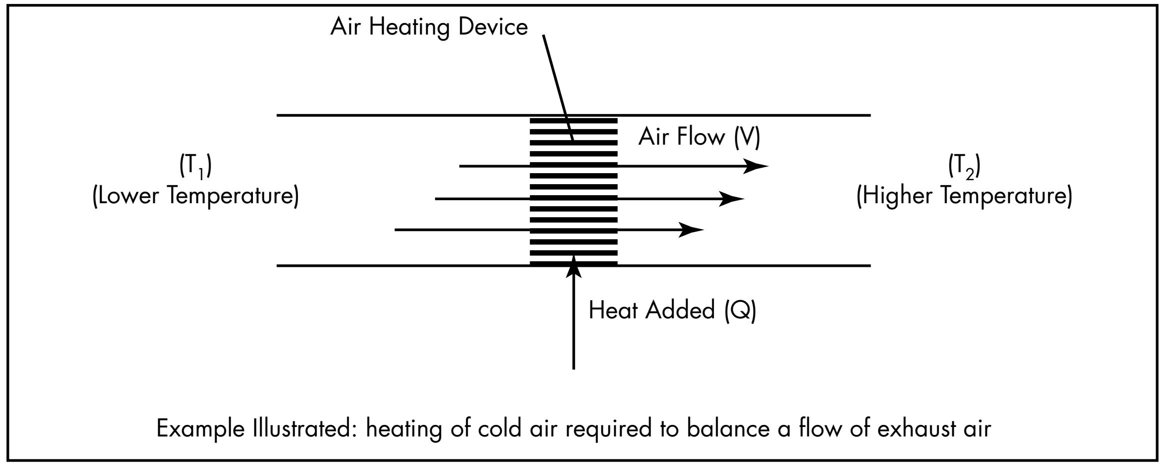


Figure 6.4: Air Flow with Sensible Heat

This type of forced convective energy flow is common in the heated or cooled air streams that provide ventilation and exhaust in industrial buildings. As this estimation method only considers the sensible heat in the air and the moisture contained in the air, but 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 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	Units	Sample	Method of Determination
Air Flow 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	hours	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 – see Appendix.

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)

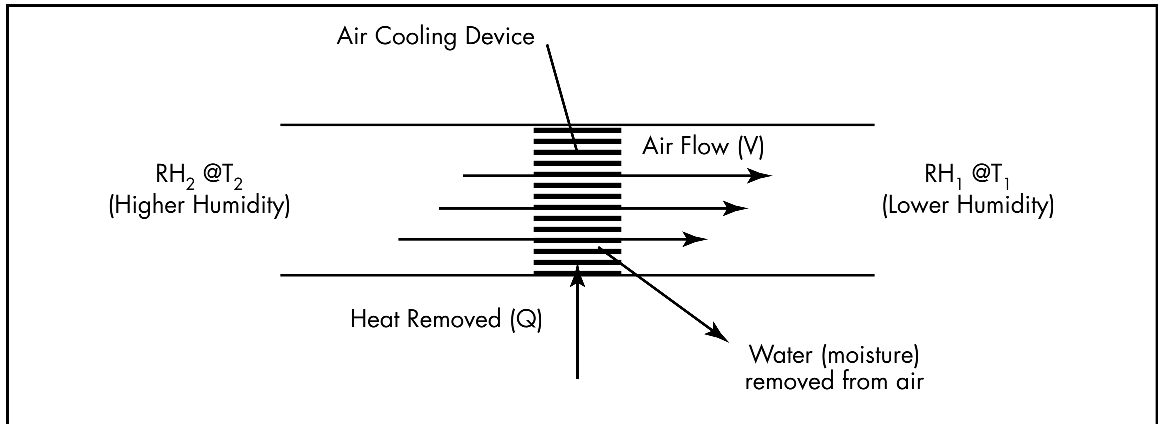
Assumptions and Cautions

- The relative humidity of the air involved is 50 percent at a temperature of 21°C. The constant 1.232 take these conditions into account.
- This method should not be used for very high temperature and high humidity air flows. It is primarily intended for building heating and cooling calculations.
- For any given air flow into a building there is a balancing outflow, either by fan system, vents, or exfiltration through the structure. The reverse is also true. In an *Energy Outflow Inventory*, only account for the energy needed to heat the incoming stream or lost in the outgoing stream. Accounting for both would be double accounting.

Reference: EMS Handbook #10 – Heating, Ventilating and Air Conditioning

6.5 Air Flow – 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.



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

Figure 6.5: Air Flow with Latent Heat

This energy flow accounts for condensation or evaporation that may take place as a result of temperature and humidity changes associated with the air flow. It does not take into account the sensible heat involved in the air flow. 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 by an air conditioning system of outside air supply stream 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.

Determining the Humidity Factor

At any given humidity and temperature, the air will hold a certain amount of moisture. This is customarily measured in terms of the number of grams of water per kilogram of dry air (air with 0 percent relative humidity). Appendix C provides a chart known as a Psychrometric(1) Chart along with instructions for determining the *humidity factor*, given the dry bulb temperature (T_1 or T_2) and the humidity (RH_1 or RH_2).

(1) Psychrometry: determination of the thermodynamic properties of moist or humid air.

Parameter	Symbol	Units	Sample	Method of Determination
Air Flow Rate	V	L/s	1831 L/s	Measurement, estimation
Temperature (Dry Bulb)	T_1	°C	24°C	Measurement, estimation
Lower Relative Humidity	RH_1	%	50%	Measurement, estimation (See Section 2.4, Chapter 2.)
Temperature (Dry Bulb)	T_2	°C	31°C	Measurement, estimated
Higher Relative Humidity	RH_2	%	50%	Measurement, estimation (See Section 2.4, Chapter 2.)
Humidity Factor (High)	H_2	g/kg	14.5 g/kg	Humidity measurement and chart (See details below.)
Humidity Factor (Low)	H_1	g/kg	9 g/kg	Humidity measurement and chart (See details below.)
Time	t	hours	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:

$\text{Heat} = Q \times t/1000$ in units of kilowatt-hours (kWh)
$\text{Heat} = Q \times t \times 3600$ 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, either by 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.

Reference: EMS Handbook #10 – Heating, Ventilating and Air Conditioning

6.6 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.

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

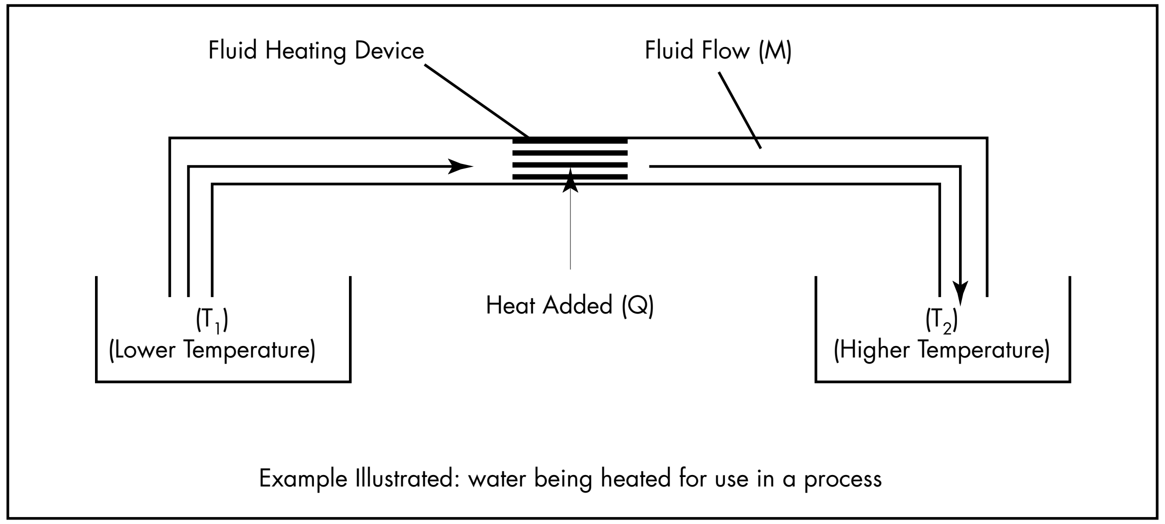


Figure 6.6: Thermal Energy in a Hot or Cold Fluid

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

Parameter	Symbol	Units	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 Appendix C, or the table in Section 2.4 of Chapter 2.
Time	t	hours	n/a	Estimation, calculation
Heat Flow	Q	kW	44.1 kW	Formula below

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

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.

Mass Flow Rate

The mass flow rate is related to the fluid volume flow rate by the density. Standard SI units of density are kilograms per cubic metre (kg/m^3) in SI and pounds per cubic foot (lb/ft^3) in Imperial measurement. Flow rates are often given in litres per second L/s, or gallons per minute (gpm). It is therefore necessary to knowing 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)

Assumption and Cautions

- Ensure that the lower or reference temperature is determined in consideration of the usefulness of the thermal energy as discussed in Chapter 2.

Reference: Any basic physics textbook.

6.7 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 must be treated differently than from a flat surface because of the geometry of a round pipe.

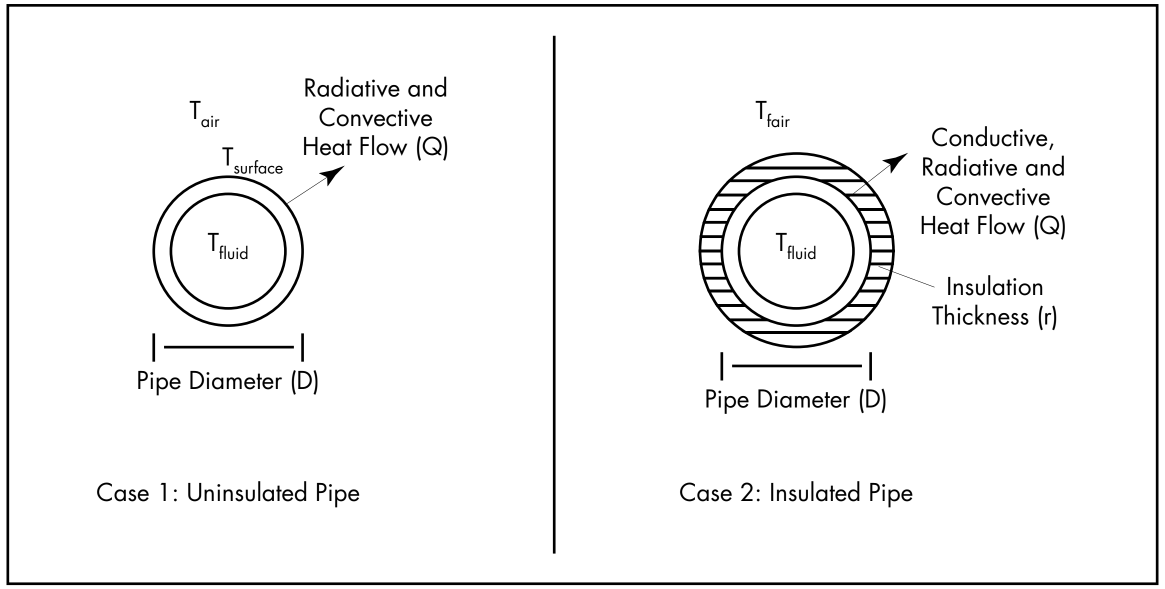


Figure 6.7: Pipe Heat Loss

This heat loss estimation method is simplified. It is based on the fluid temperature (and assumed surface temperature for the bare pipe) and an assumed surrounding air temperature of approximately 20°C. The heat mechanism is a combination of conductive, convective and radiative.

Parameter	Symbol	Units	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	in. NPS	3" NPS	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	Formula to follow

Heat-Loss Factor

The graphs and tables in Appendix C along with the fluid temperatures (or pipe temperatures) and pipe diameter provide values for the heat-loss factor in watt-hours per hour per metre of pipe. This is the same as watts per metre (W/m) of pipe.

The graph labelled *Heat Loss from Bare Steel Pipe* in Appendix C is for uninsulated pipe. In this case, use the pipe surface temperature instead of the fluid temperature. The table labelled *Heat Loss Through Pipes of Various Thicknesses of Insulation* provide values of the heat loss factor for three common pipe insulating materials and a specified thickness listed (in mm).

Equation for rate of heat transfer (Loss):

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

Total heat transferred:

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

$\text{Heat} = Q \times t \times 3600$ in units of joules (J)

Assumptions and Cautions

- The temperature surrounding the pipe is 21.1°C for bare pipes and 18°C for insulated pipes.
- The pipe is bare steel or steel insulated with the materials specified in the tables.
- If the pipe is outside a building, then the heat lost from it will definitely be a facility outflow. However, if the pipe is inside the building, the heat may contribute to general building heating (or overheating in some cases). In this case the heat lost from the pipe is not, itself, a facility outflow. The facility outflow occurs when the heat which the pipe 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.

Reference: EMS Handbook #1 – Process Insulation

6.8 Tank Heat Loss

Tanks holding fluid will incur a heat loss or heat gain depending upon the relative temperatures inside and outside the tank. This heat loss estimation method presented is simplified. It is based on the fluid temperature and an assumed surrounding air temperature close to 20°C.

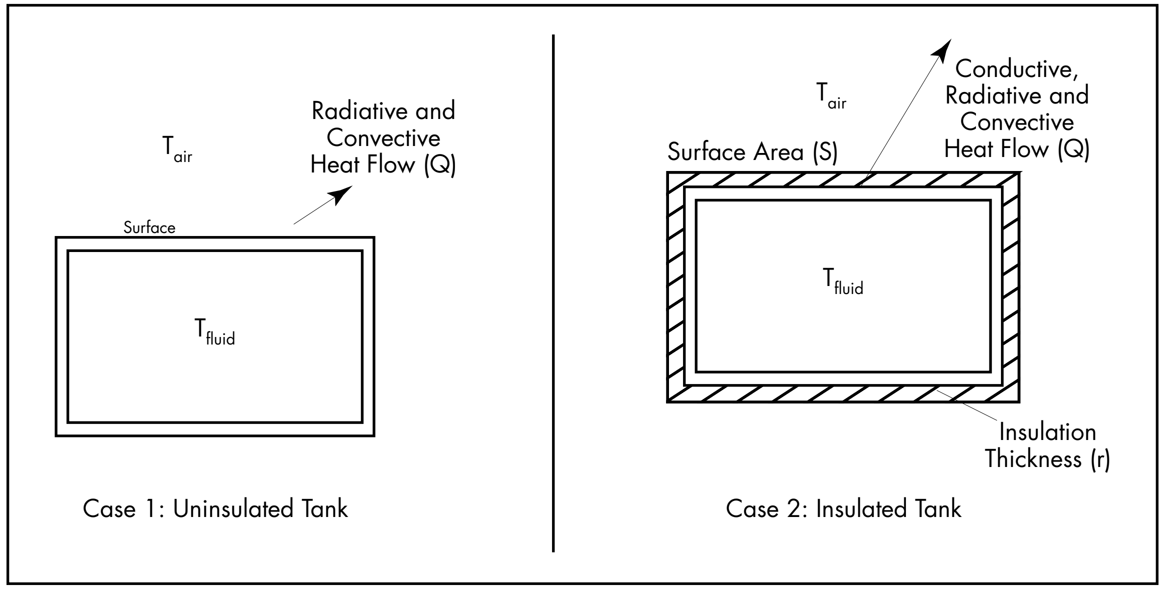


Figure 6.8: Tank Heat Loss

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

Parameter	Symbol	Units	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	m^2	20 m^2	Measurement
Heat Loss Factor	F	W/m^2	950 W/m^2	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	Formula to follow

Heat Loss Factor

The graphs and tables in Appendix C along with the fluid temperatures (or tank temperature) provide values for the heat loss factor in watt-hours per hour per square metre of surface. This is the same as watts per square metre (W/m^2) of surface.

The graph in Appendix C labelled *Heat Loss from Bare Flat Steel Surface* is for uninsulated tanks. In this situation, use the tank surface temperature instead of the fluid temperature. Table 3, entitled *Heat Loss Through Pipes of Various Thicknesses of Insulation*, provides values of the heat loss factor for three common tank insulating materials for a specified thickness listed (in mm). For the situation of estimating heat flows from tanks, the row entitled *Flat* should be used.

Equation for rate of heat transfer:

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

Total heat transferred:

$\text{Heat} = Q \times t/1000$ in units of kilowatt-hours (kWh)
$\text{Heat} = Q \times t \times 3600$ in units of joules (J)

Assumption and Cautions

- The temperature surrounding the tank is 21.1°C for the bare tank, and 18°C for case of the insulated tank.
- The tank is bare steel, or steel insulated with the materials specified in the tables.
- 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 which 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.
- 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.

Reference: EMS Handbook #1 – Process Insulation

6.9 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 time.

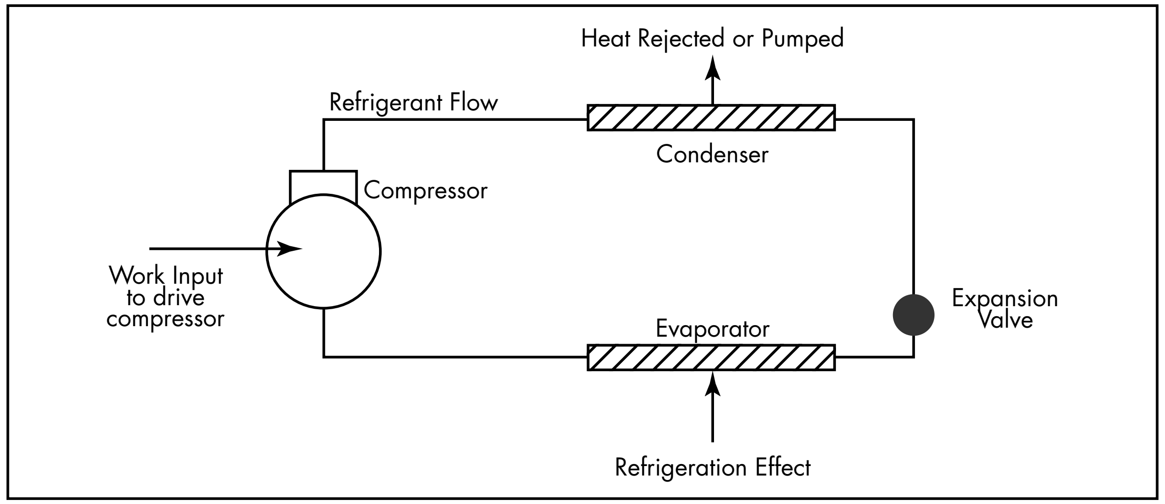


Figure 6.9: Heat Flow in a Refrigeration System or Heat Pump

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 air flow 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 which is to provide cooling or a refrigeration effect, the refrigerating COP is defined mathematically as:

$\text{COP}_R = \text{Refrigeration Effect/Work Input}$

When a refrigeration system's purpose is to heat, as with *heat pumps*, the *heating* COP is of interest. It is:

$\text{COP}_H = (\text{Refrigeration Effect} + \text{Work Input})/\text{Work Input}$

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:

$Q = \text{COP} \times \text{Power to Compressor}$ in units of kilowatts (kW)

Total heat transferred in time t, measured in hours is:

$\text{Heat} = Q \times t$ in units of kilowatt-hours (kWh)
$\text{Heat} = Q \times t \times 3\,600\,000$ 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:

$Q = 3.2 \times 21\text{ kW} = 67.2\text{ kW}$

Accurately determining the COP is a complex task. Furthermore, the COP of a system can vary widely depending upon the operating conditions, equipment design, and type of refrigerant. Operating conditions can vary daily, depending on temperatures. The manufacturers and service companies of refrigeration equipment can provide performance information for systems at various operating conditions.

For smaller systems, the table contained in Appendix C summarizes typical performances in terms of watts of heat removed per watt of power required. Data provided is for a range of compressor sizes, operating conditions, and refrigerants.

Assumptions and Cautions

- As this method is at best only a rough approximation, use results with caution.

Reference: EMS Handbook #11 – Refrigeration and Heat Pumps

6.10 Steam Leaks and Vents

Steam is the most common medium of transporting large amounts of thermal energy in commercial and industrial facilities. Steam is generated in the boiler plant from fuel at various pressures dependant 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 in Section 6.7.

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.

6.10.1 Steam Leak or Vent from an Orifice of Known Diameter

If the diameter of the leak or orifice through which the steam is flowing is known, then using the tables in Appendix C, an estimate of the energy flow can be obtained. Imperial and metric units are mixed in this example since tables are given in metric units, and pressures are commonly known in Imperial units.

Parameter	Symbol	Units	Sample	Method of Determination
Steam Pressure	P	psig kPa	75 psig 517 kPa	Measurement, estimation Note: 1 kPa = 0.145 psi
Orifice Diameter	D	inch	1/4 in.	Measurement, 1 mm = 0.039 in.
Steam Flow	M	lb/hr kg/h	165 lb/hr 75 kg/h	Look up in Table 5 of Appendix C Note: 1 kg/h = 2.205 lb/hr
Steam Enthalpy[1]	h	kJ/kg	2747 kJ/kg	Look up in the column (hg) for pressure (P) in Table 1 of Appendix C
Time	t	hours	n/a	Estimation, calculation
Heat Flow	Q	kW	53 kW	Formula below

Note 1: See the following section on enthalpy.

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.

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 is:

$\text{Heat} = Q \times t$ in units of kilowatt-hours (kWh)

$\text{Heat} = Q \times t \times 3.6$ in units of joules (J)

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.

Reference: EMS Handbook #8 – Steam and Condensate Systems

6.11 General Cautions

The methods detailed in this chapter are simple estimation methods and should only be used as a first approximation for energy use in a given situation. They can help identify potential energy saving opportunities, but proper engineering calculations should be used 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.

Hot Energy Tip:

Building and system simulation software automatically perform the same type of calculations described in this chapter. The Internet is a good source of software to purchase and in some cases is free of charge. Simply search for "energy simulation software" using your favourite search engine.

6.12 Application to a Sample Energy System

Section 6.1 introduced the concept of the energy flow diagram as a means for developing a thermal energy-use inventory for a facility. Figure 6.10 is a simple industrial food processing system.

Figure 6.11 represents the simplified energy flow diagram that was used to build the energy use inventory found in the table that follows. All calculations were performed using the methods outlined in this chapter.

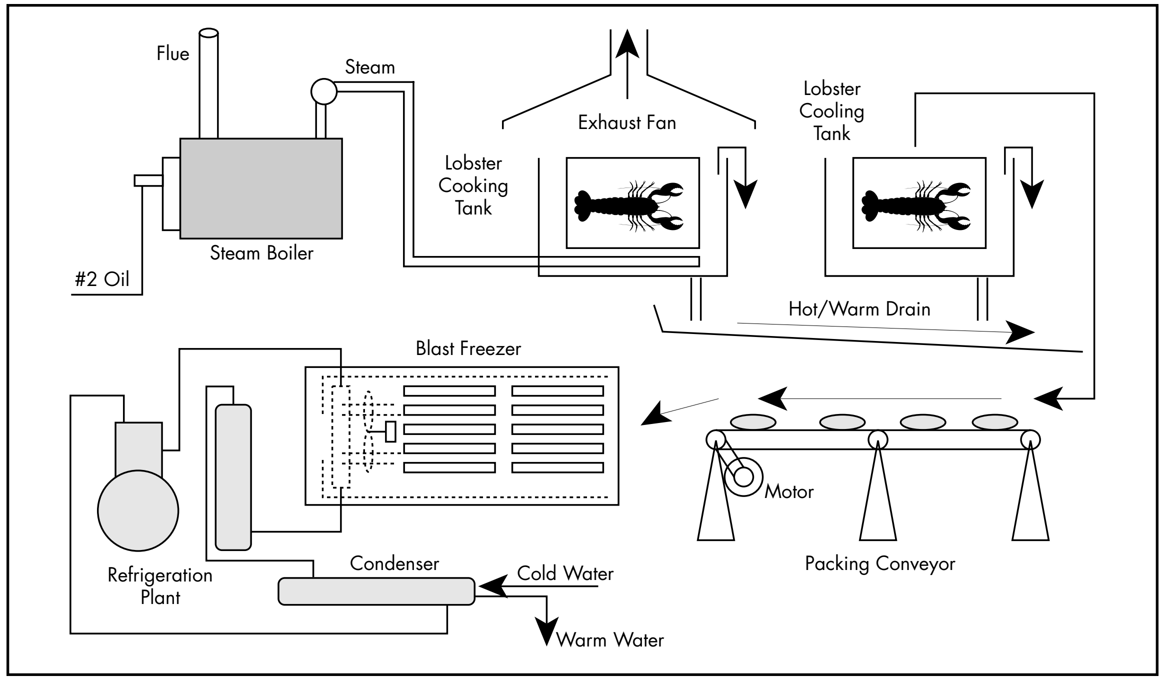


Figure 6.10: Sample Energy System – Lobster Packing Plant

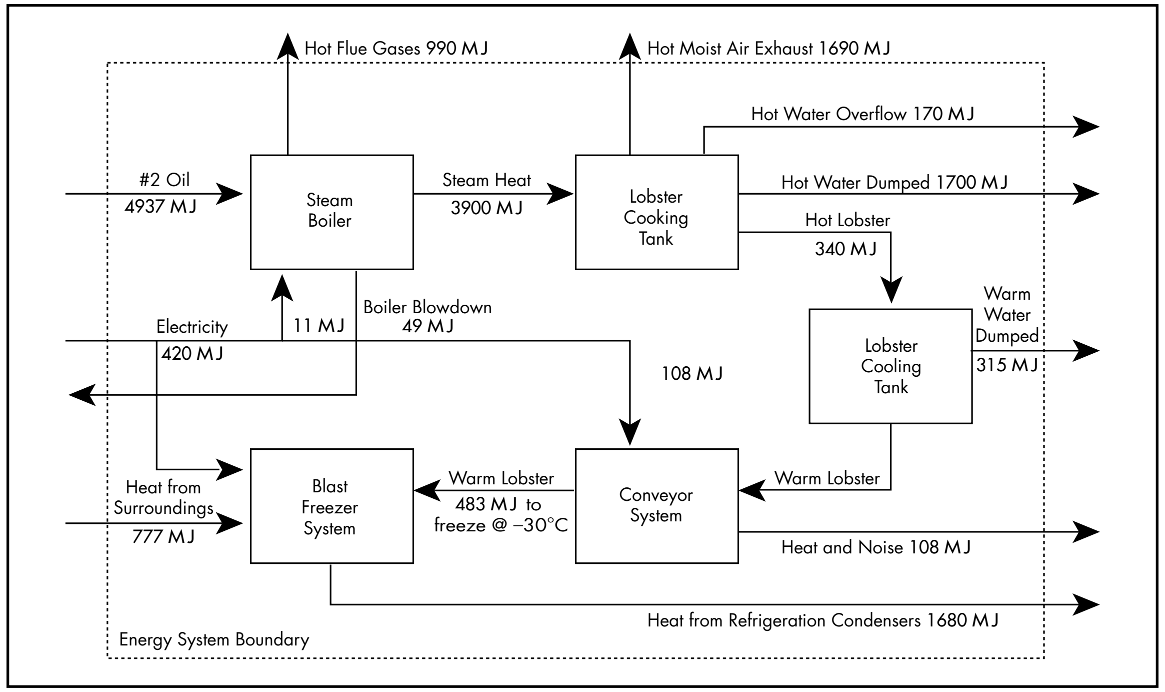


Figure 6.11: Energy Flow Diagram with Calculated Energy Flows

All energy figures are for one day's operation of the plant – a 10-hour operating period. The heat of fusion (freezing) 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.

The Energy Use Inventory

Energy Flow	Basis for Energy Calculations	Energy (MJ)
#2 Oil	127 litres 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) Latent Heat (1000 L/s from 50% to 70% r.h.)	430 MJ 1260 MJ 1690 MJ total
Hot Water Overflow	450 litres per day @ 90°C	170 MJ
Hot Water Dumped	4500 litres per day @ 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 litres 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 Lobster is frozen at 0°C Lobster is cooled to −30°C. (Equivalent to 1000 kg of water)	63 MJ 360 MJ 60 MJ 483 MJ total
Electricity to Compressor	11.6 kW for 10 hours Freezer is 10 tons (35 kW) with a COP of 3.0	420 MJ
Condenser Cooling Water	33 litres/min from 10°C to 30°C	1680 MJ
Heat from Surroundings	Cooling Water to Lobster to Electricity	777 MJ

References

Modern Industrial Assessments: A Training Manual, Rutgers, The State University of New Jersey, 1995 (available online at: http://oipea-www.rutgers.edu/documents/doc_f.html)

Engineering Fundamentals in Everyday Language, Boiler Efficiency Institute, Auburn, AL, 1992 (tel.: (205) 821-3095)

1997 Handbook – Fundamentals, ASHRAE, Atlanta (www.ashrae.org)

Commercial Energy Manual Applications, Ontario Hydro, 1991

Commercial Energy Manual Fundamentals, Ontario Hydro, 1991

Chapter 7
A Process for Identifying Savings Opportunities

Objectives

To describe a simple process which can be used to examine energy consuming system for the identification of opportunities.

7.1 Actions at the Point of End-Use Save More

Where is the best place to begin to look for opportunities? 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!**

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; in a commercial facility chilled water pumps may also be found cooling process equipment. Figure 7.1 is a simplified picture of this system showing each component involved in the conversion of energy is this system. Energy passes through each element of the system, 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.

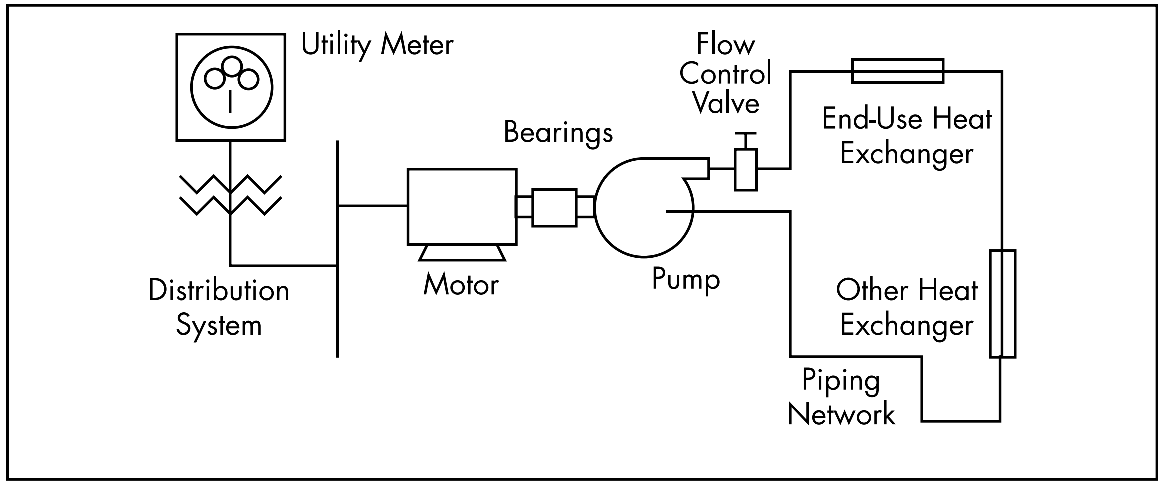


Figure 7.1: Chilled Water Pumping System Components

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

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

Each component that has 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 may be calculated from:

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

Table 7.1 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 (10 to 100HP) size.

Component	Losses	Typical Efficiency
Utility Meter	Negligible	100%
Distribution System	Electrical Resistance	96%
Motor	Electrical Resistance, Friction, Magnetic Losses	85%
Bearing	Friction	98%
Pump	Fluid and Mechanical Friction	60%
Valve	Minimal Throttling	70%
Piping Network	Fluid Friction	60%
Overall System Efficiency		**20%**

Table 7.1: Component and System Efficiencies

From the overall efficiency it can be seen that only one-fifth of the energy actually gets to the point where it is required. Or, in other words, the system required five times the actual end-use energy requirement, which in this case is water movement to overcome all the losses in the system. The impact upon the unit cost of energy is illustrated in Table 7.2.

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%	14.9	24.81
Ratio of Overall Unit Cost			**5:1**

Table 7.2: Unit Cost of Energy Through the System

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 large savings, on the order of five times larger, at the point of purchase.

Hot Energy Tip:

How valuable is the energy at the point of end use in your system?

Make an estimate of the overall efficiency of some of your major energy consuming systems. A good source of efficiency data for major components such as fans, pumps and motor, is the manufacturers specifications and performane date.

7.2 Waste-Loss Analysis

The Waste-Loss Analysis of an energy system provides a simple process for examining the variety of ways in which energy consuming systems and equipment can be made to consume less energy. Two distinct classes of action are considered:

- **Matching the use to the need.**
  Those actions that directly reduce use of the system/equipment by meeting the need or requirement with minimal ***waste*** or excess.
- **Increasing the efficiency** of the systems/equipment.
  Those actions that reduces ***losses*** of the various components of the system while still meeting the need or requirement.

  It is important to note that in both cases the need for energy use is met. For example, the need for lighting might be 700 LUX for 8 hours per day.

  Matching the need may require the verification of the 700 LUX as the required illumination level, and that there is occupancy for 8 hours per day.

  The second step, maximization of efficiency, looks for lowest total cost system/equipment capable of delivering the need. The key variable is the efficiency of the components involved.

Cost Considerations
The actions that may be taken range in implementation costs. The quadrant analysis considers two distinct action/cost categories:

- **Lower Cost**
  Those actions that could be funded from operational/expense budgets and tend to be a result of **operational actions**.
- **Higher Cost**
  Those actions that may require capital funding of some kind and tend to involve the installation of equipment or new **technology**.

The Waste-Loss Analysis combines these categorizations of actions into a table with four quadrants as numbered below. Example of actions 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 lamps with lighter wall colours	**4.** Install new lamps/ballasts and fixtures

Typically, those actions that fall into the 4th quadrant have the highest cost while those in the 1st quadrant have the lowest cost. The relative cost of the 2nd and 3rd quadrants will vary depending on the specific actions and equipment.

A general form of the Waste-Loss Analysis table is given 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
Maximize Efficiency	**3.** Maintenance & operating conditions	**4.** New & more efficient devices and equipment

7.3 Optimization of Energy Supply

The final step in the identifying savings opportunities is to consider the supply of energy to the system and look for savings opportunities available by optimizing the supply.

Opportunities that typically fall into this category include:

Heat Recovery

Systems that utilize waste energy streams to displace inflowing energy. Two good examples of this are detailed in the examples of Chapter 9. Heat recovery systems range from simple ducting of warm air to complex heat pump systems.

Heat Pumps

In addition to facilitating heat recovery, heat pumps are also used to utilize low grade energy sources such as geothermal energy (ground heat) and air. These are commonly termed “ground” and “air” source heat pumps respectively.

Co-generation

Often referred to as combined heat and power (CHP) systems. When facilities or processes require hot water and/or steam coincident with a demand for electrical energy, an opportunity may exist to supply both from fuel fired combustion equipment. These systems take advantage of their disadvantages. Typically 15 to 30% efficient 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 50 to 80+%.

Renewable Energy Systems

The practice of replacing part or all of the existing purchased energy with energy from solar, wind, ground heat or other renewable energy source. Although often not economical, there are certain application of renewables that may be cost effective including:

- Off-grid use of photovoltaic (solar electricity) and wind energy
- Passive solar designs for new and existing buildings

Fuel Switching

Replacement of one fuel with another, less expensive energy source. A good example would be conversion of hot water heating from electric to gas.

Purchase Optimization

In short, taking full advantage of the open-marketing of natural gas and electricity. The greatest benefit from this opportunity will be realized by those operations that understand their energy usage patterns, and how they may be manipulated on an ongoing basis.

The Order of Actions is Very Important

It is important to recognize that the correct time to consider this type of opportunity is **after** each of the preceding steps.

It would be counter productive to negotiate a new electricity supply contract, prior to properly managing the demand profile for a facility. Any future changes to the demand profile could make the new supply agreement less economical. Likewise, sizing a co-generation 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 co-generation system un-economical

7.4 Savings by Inventory

The electrical load inventory and thermal energy use inventory are a good starting point in the search for savings opportunities.

The process of evaluating the breakdown or distribution of energy use can often lead to the discovery of potential savings opportunities. While considering each piece of equipment, group of loads, or heat consuming systems consider how long they are operated, and the justification for each load and its necessity to be operating at any given time.

7.4.1 Special Consideration for the Thermal Energy-Use Inventory

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

Opportunities for Energy Flow Reduction

The magnitude of each outflow depends on multiple factors, such as temperatures, flow rates, humidities, time, and the characteristics of materials. Finding savings opportunities involves giving consideration to which, if any, of these factors may be changed to effect a reduction in the energy consumed.

Can flows can be reduced? Can temperatures be changed? In most cases, there are valid reasons why present values are 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 we have been considering. Now, however, it is time to turn our attention to the hardware itself, and consider the possibility of changing some aspect or aspects of system functioning to effect an energy flow reduction.

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 air and air inside the building space, and the duration of the ventilation.

Because the building occupants have a legitimate need for fresh air, we ordinarily cannot reduce the amount of air brought in and exhausted; it is a "given," determined by the occupants' requirements, and often specified in occupational health and safety legislation. So we ask, "How else may the parameters of this ventilation system be manipulated to yield energy savings?"

Time: It may be possible to better control the operation of the system to reduce the time that the ventilating system operates, matching it more closely to building occupancy.

Flow: Although the air flow rates during occupied periods cannot be adjusted, the rate of unneeded ventilation at night might be reduced by utilizing 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 properly clear stale air, it may be possible to reduce the temperature of the air during unoccupied periods, using some sort of temperature setback scheme.

These are only simple examples but they illustrate the value of questioning each of the factors that influence energy consumption. The actual reduction in energy flows is brought about through specific changes to equipment, devices, and operational practices.

Reducible or Recoverable Energy

An energy flow can be one of two types, and the savings will be realized in different ways:

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. A example of this is the reduction of heat flow through the walls of a building by adding insulation, or reducing warm air lost by trimming the hours of ventilation.

Recoverable: A flow of waste heat, the reduction which of 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; so it could be used to replace the purchased energy being used in another system. This is called energy or heat recovery.

It is important to properly determine the type of flow that you have. In some cases, it may be a mixture. The method of calculation of savings is different for reducible and recoverable energy flows. Please refer to Chapter 9.

7.4.2 Special Consideration for the Electrical Load Inventory

As mentioned previously, examine each load in the inventory from the perspective of the quadrant analysis. Look first to the requirement that is being provided whether it be light, air or water power, process energy or heat. Consider also the following:

The Diversity Factor

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

Operating Hours

Loads with valid extended operating hours are good candidates for efficiency improvement. Could lamps be upgraded, pumps and fans the most efficient, could a higher efficiency motor be used?

Load Grouping

Are there large groups of loads with similar operating hours solely because they operate or are switched only as a group? A good example of this would be 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 runtime or power consumption? A good example of this would be a large refrigeration system or systems in a supermarket or food processing operation.

Target (Optimum) Electrical Load Inventory

The Load Inventory can be used to set energy and demand reduction targets. The order of calculation is important! First, take the "as-is" load data, determine any achievable reductions in operating hours and fill out a second table with the proposed hours. The difference between the total energy in the first and second tables is the potential energy savings achievable through load control and switching. Next, consider whether there are any possibilities to reduce the monthly demand peak (demand shaving) or to make efficiency improvements to loads or load groups (e.g. lighting retrofits). Create a third table using the hours from the second table and the proposed kW load figures. The difference between the second and third energy and demand totals is the savings potential for the demand reduction/ efficiency improvements. For example:

1. As-Is Load Inventory:

Load Description	Quantity	Unit kW	Total kW	Diversity Factor %	Demand kW	Hours	Energy kWh
Fluorescent	200	0.19	38	100%	38	500	19 000
Compressors	6	7.5	45	90%	40	300	13 500
				Total Demand kW	78	Total kWh	32 500

By controlling these two systems better, the new load inventory would be:

2. New Operating Times Load Inventory:

Load Description	Quantity	Unit kW	Total kW	Diversity Factor %	Demand kW	New Hours	Energy kWh
Fluorescent	200	0.19	38	100%	38	350	13 300
Compressors	6	7.5	45	90%	40	240	10 800
				Total Demand kW	78	Total kWh	24 100

Efficiency improvements are proposed for both of these systems. The fluorescent lighting system can be changed from 0.19 kW per fixture to 0.11 by using high efficiency T-8 lamps. The compressors can also be replaced with units that are more efficient, saving 1 kW per unit. The result:

3. Proposed Inventory: New Operating Times and Efficiency Improvements

Load Description	Quantity	Unit kW	Total kW	Diversity Factor %	Optimum Demand kW	Hours	Energy kWh
Fluorescent	200	0.11	22	100%	22	350	7 700
Compressors	6	6.5	39	90%	36	240	9 360
				Total Demand kW	58	Total kWh	17 060

Incrementally, the demand has now been reduced by 20 kW and the energy by 7040 kWh. The order of actions is very important when calculating savings for each potential change to existing systems. In the example above, if the savings for efficiency improvements (3) were calculated based on the as-is load inventory (1), the payback for the efficiency improvements would be negatively affected when the control improvements (2) were implemented.

7.4.3 Load Flexibility Assessment

Load Flexibility is 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 a less expensive time of day. A second goal might be to free up capacity on a fully loaded system by spreading out the load. The idea of flexible loads should interest customers considering alternative electricity rates, such as time-of-use and real-time pricing.

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

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

Using this knowledge you can look at your loads for any flexibility in their operation. Ultimately, flexible loads usually fall under one of the following scenarios:

1. **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. As an 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 having a large refrigeration plant to supply cooling on demand.
2. **Product Storage.** In a plant that produces several different products or where the production is in distinct stages that can be run independently, different products can be manufactured in shifts, stockpiling them for the next shift. One example of this approach is a rock quarry that staggers different processes to spread out loads on the electrical system.
3. **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 time of day.

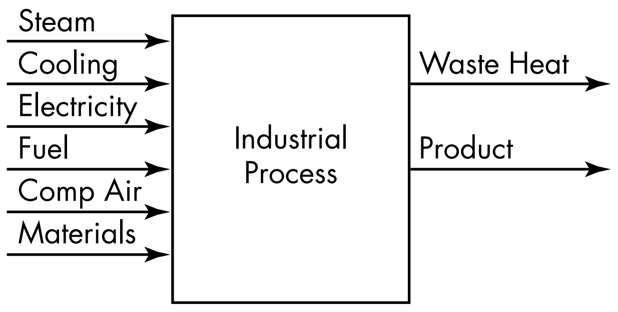
7.4.4 Special Considerations for Process Systems

Potentials for significant energy savings exist in both operational and technological actions. Often, in the search for savings, much emphasis is placed upon technological actions (such as equipment retrofits and upgrades) overlooking many high potential and low cost operational opportunities.

Industrial energy use can be broken into plant and process. Plant use includes the supporting equipment and systems, which supply the process equipment.

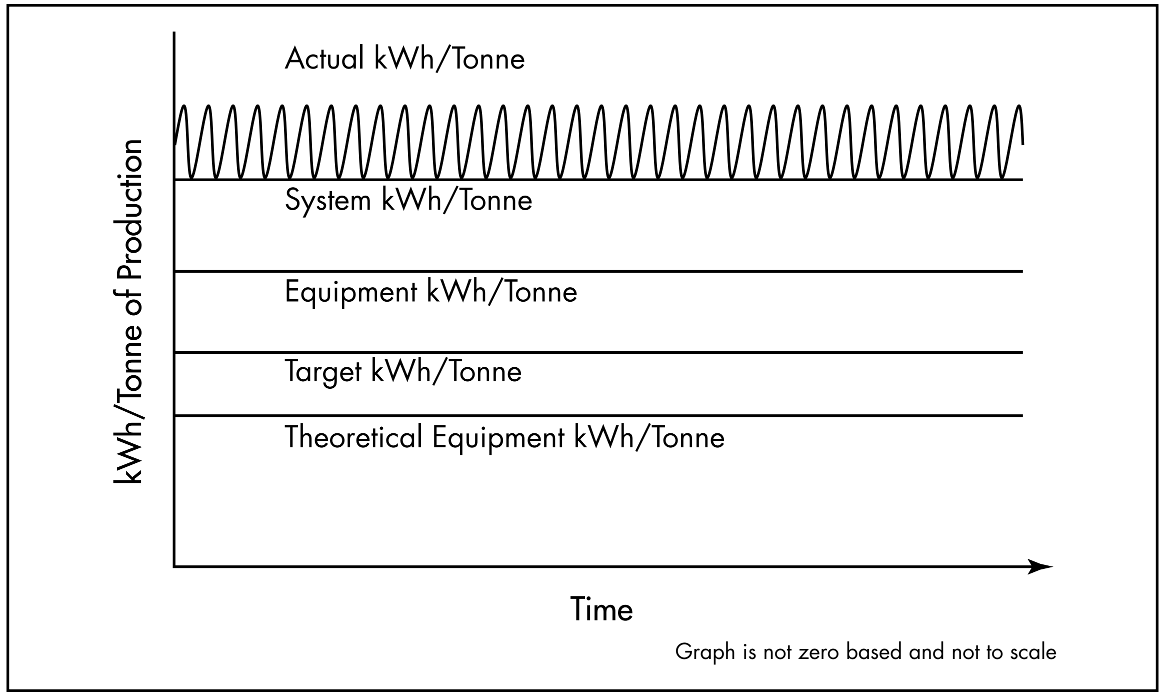
Other types of systems may be present to meet the energy needs of the process systems:

- 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, means determining how closely the process needs are being met before we consider the energy use in the system supplying the need. To analyze the need, a more in-depth look at the internals of the process follows.

Figure 7.3 provides an example of the breakdown of process energy use in terms of the ratio of kilowatt-hours per tonne (kWh/tonne).



Graph is not zero based and not to scale

Figure 7.3: The Industrial Process Energy Consumption

Equipment kWh/Tonne is the energy required when the optimum amount of equipment is operating at design efficiency.

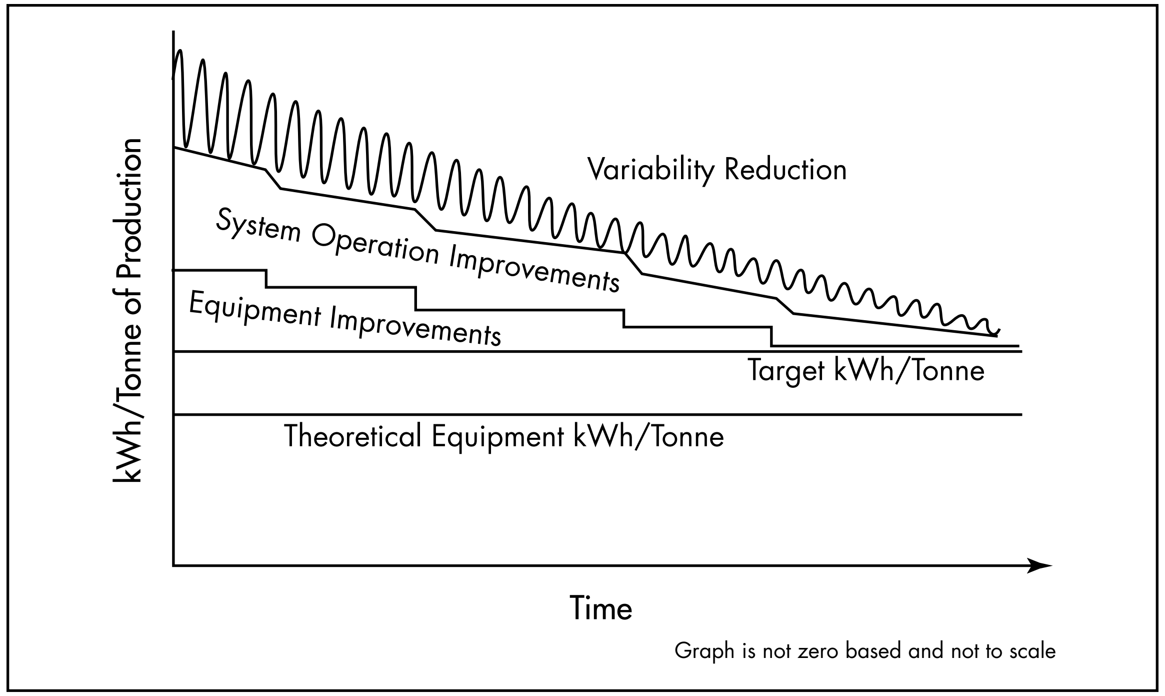
System kWh/Tonne is the energy required when the operator and machine influences are included; this takes into account operational techniques and maintenance practices.

The **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 distinction between these levels represents a potential for energy use reduction. With a real process, it may not be possible to achieve the theoretical or ideal consumption level. But there is a realistic target to which consumption could be reduced. An energy audit or assessment on each process area would examine each of these levels and the associated factors influencing consumption.

Each manufacturing or industrial process presents opportunities for energy management. However, for the unwary, each offers ways to create operating problems in the name of energy management. The best way to avoid these problems is to involve operating personnel in an auditing or assessment process.

The audit or assessment outcome often includes a set of actions encompassing both operations and technology. The operational actions typically address the variability and system consumption levels, while the technological actions would reduce the equipment consumption levels. Over time, as actions are implemented, the various consumption levels would drop, and actual consumption would approach the target level for the process. (As suggested by Figure 7.4.)



Graph is not zero based and not to scale

Figure 7.4: Process Energy Consumption Reduction

Critical Questions – A Starting Point for Assessment

An effective audit or assessment team could be assembled from staff involved directly in the process area being considered, along with staff from other process areas i.e. essentially a cross-auditing team. External, specific expertise may be required at some point during the assessment. A good starting point is a critical questioning of the process activity as follows:

Matching the requirement

- 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?

Maximizing the efficiency

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

Once the assessment begins, more questions will emerge.

7.5 Summary

The method presented in this chapter provides a way to look at each of the energy consuming systems in your facility and identify opportunities. The essence of the method is, in sequence:

1) **verify/validate the need/requirement;**

2) **apply the "Waste-Loss Analysis";**

1st, match the need, then 2nd, maximize efficiency of delivery; and

3) **optimize the energy supply.**

The electrical and thermal inventories provide valuable insight into the existence and magnitude of savings opportunities.

References

Modern Industrial Assessments: A Training Manual, Rutgers, The State University of New Jersey, 1995. (available online at: http://oipea-www.rutgers.edu/documents/doc_f.html)

Electrical Efficiency Improvement, Boiler Efficiency Institute, Auburn, AL, 1992.

Electricity Forum March/February 2000: Article "Purchasing Electricity: A Primer" authored by C. Vilcsak, President, Solution 105 Consulting Ltd.

Chapter 8
A Checklist of Opportunities

Objectives

To identify and categorize savings opportunities in the variety of systems and equipment found in commercial and industrial facilities.

8.1 Applying the Savings Identification Process

All of the standard opportunities commonly applied to equipment and systems can be categorized using the savings identification process. Doing so provides a straightforward method of prioritizing energy savings actions, performing those with the greatest benefit and lowest cost first.

As detailed in Chapter 7, the essential steps are:

1) **verify/validate the need/requirement;**

(e.g., do we need 700 LUX for 16 hours per day)

2) **apply the Waste-Loss Analysis;**

1st, match the need, then 2nd, maximize efficiency of delivery; and
(e.g., ensure lights are switched, then consider T8 lamps)

3) **optimize the energy supply.**

(e.g., application of heat recovery)

The opportunities that follow in this chapter have been selected to cover the various types of opportunities outlined in Chapter 7.

Critical Questioning
While a checklist of savings opportunities is helpful, it is also productive to first ask critical questions when seeking savings opportunities. In addition to checklists, this chapter provides a list of questions, for a variety of systems, that can help reveal some unique and, possibly, attractive savings opportunities. Following the "Waste-Loss Analysis" method, many of the questions seek answers regarding a systems end use rather than just its conversion efficiency.

8.2 Fans and Pumps

Critical Questions

- **Is the pump/fan being throttled at the discharge?**
  Capacity control by discharge throttling will result in extremely low system efficiencies. If the system is operating at low volume delivery for extended periods, it may be oversized. Sometimes throttling may not be obvious. A half open valve in a pumping system is not easy to spot.
- **Is the pump/fan being throttled at the inlet?**
  This is more efficient than discharge throttling. Check to make sure that variable flow over the range provided is necessary.

- **Is the pump/fan doing a meaningful job?**
  Sometimes standby or backup pumps (fans) will run unnecessarily.

- **Is the pump/fan correctly sized?**
  As mentioned previously, a clue to this may be the necessity to control the unit's capacity. Less obviously, the pump/fan may be operating at a condition that yields the desired capacity but in a very inefficient region of the pump/fan's operating characteristic.

- **Check pump/fan curves; is the pump/fan operating efficiently?**
  Following from the previous question, obtain the unit's characteristic curve and check the efficiency.

Hot Energy Tip:

Boiler feedwater pumps may operate continuously with a valve starting and stopping flow into the boiler. This situation may be a good opportunity for the application of a variable speed drive.

- **Does the requirement for air/liquid vary?**
  In certain circumstances this may be obvious, say in a variable volume ventilation system. Less obvious would be the case in which at present a fixed volume of ventilation air is delivered, while occupancy may vary. During certain times of the day it may be possible to reduce the flow significantly.

- **Can the pump/fan be slowed down?**
  Is there is a requirement for varying flow within the system? Could this be achieved by reducing the pump/fan's speed? Would this cause other operational problems?

- **Can the system head be reduced, ducts/pipes cleaned?**
  The system head, or resistance to flow may be increased by an accumulation of contaminants in the system. Make sure all filters/strainers are well maintained. Often, poor pipe or duct routing may unnecessarily increase the resistance to flow.

- **Is the pump/fan excessively noisy, hot or vibrating?**
  Noise, heat and vibration, cause maintenance problems, and lose energy. On a small motor drive, a loose belt could easily waste five to ten percent of the energy transmitted.

- **Is the distribution system adequate for all operating conditions?**
  Many distribution systems are no longer being used to the original design specifications. Confirm the range of operating conditions and the present system's ability to supply them throughout those conditions.

- **Are there leaks in the air distribution ducts system?**
  Losses of the active fluid in a system lead directly to energy loss. While in pumping systems these may be obvious and are usually repaired quickly, leaks in distribution ductwork go unchecked in many cases.

Opportunities

- **Reduce fan/pump speed.**
  When a centrifugal fan/pump's speed is reduced by 50 percent, the flow delivered is reduced by 50 percent, but the power required to drive that fan/pump may be reduced by up to 87.5 percent Methods of speed reductions include a two-speed motor, sheave or pulley changes, the use of a mechanical variable speed device, or the use of an electrical variable speed drive appropriate to the application at hand. Even small reductions in centrifugal fan/pump speed will result in much larger reductions in power.

- **Eliminate fluid flow control with valves / air flow reduction with dampers.**
  Controlling the capacity of fluid/air that a system delivers by speed control (as described in the previous item) is far more efficient than conventional methods of flow control such as discharge dampers/inlet guide vanes on fans or throttling valves on pump systems.

- **Clean and balance air distribution systems.**
  Air distribution systems that are poorly maintained will increase the power required by the fan to circulate air. Avoid excessive dampering when balancing a system. Consider fan speed and, hence, flow reductions after balancing a system in order to minimize the use of dampers for flow control.

Hot Energy Tip:

A filter or other obstruction that presents 1″ of static pressure in an air flow of 10 000 cfm, creates 1.5 kW of heat. Over and above the added mechanical load, this parasitic heat gain will increase air conditioning (cooling) costs.

- **Check overall fan/pump sizing and efficiency.**
  Changes after the initial design of a system can result in inefficient fan/pump operation. This results when the conditions imposed upon the fan/pump are not ideal for the type or size of the fan/pump. By re-considering the design, it may be possible to make changes to the fan/pump, the operating conditions or both, that will result in higher efficiency.

- **Use multiple smaller pumps or fans.**
  Often the need for variable flow rates can be met with sequentially controlled pumps.

- **Use a booster fan/pump.**
  In a situation where the pressure differential that a fan/pump will operate under is relatively high, it may be possible to achieve a higher system efficiency and lower power requirements by utilizing a booster fan/pump to assist the main fan/pump.

Fan/Pump References

CANMET's Energy Management Series Handbook #13 – Fans and Pumps

Energy Savings with Adjustable Frequency Drives, Allen Bradley Publication DG-2.1, 1994 (tel.: (519) 623-8310)

*Electrical Efficiency Improvemen*t, Boiler Efficiency Institute, Auburn, AL, 1992 (tel.: (205) 821-3095)

Adjustable Speed Drive Reference Guide, Ontario Hydro, 1991

8.3 Compressed Air Systems

Critical Questions

- **Are you supplying leaks in the distribution system / end use?**
  The amount of energy lost to air leaks is directly proportional to the volume of air leaked.

- **Is the supply pressure higher than required to overcome pipe loss?**
  Is the compressor delivering air at a pressure significantly above that of the highest end use requirement? If so, there may be restrictive piping in the distribution system.

- **Can you reduce the requirement for air?**
  Is compressed air being used inappropriately? The most common occurrence of this is using air for clean-up.

- **Can the compressor inlet pressure be raised?**
  Are there unnecessary restrictions in the inlet piping, could the filter be dirty?
- **Can the compressor inlet temperature be dropped?**
  Is the inlet air to the compressor outside or inside, cooler air is often available outside.
- **Is the compressor drive system efficient?**
  For smaller units, are drive belts tight?
- **Do screw compressors have proper capacity control?**
  Does the compressor have suction (inlet) throttling or slide vane control? Suction throttling is highly inefficient at low air flows.
- **Is the storage capacity large enough?**
  Does the compressor(s) cycle frequently? If so, maybe a larger receiver is necessary.

Hot Energy Tip:

In some plants, up to 50% of the compressed air capacity is consumed by leaks! Ultrasonic leak detectors make quick work of locating them, even in loud environments. A modest investment of $500.00 has, in many cases, paid back in the first hour of use!

Opportunities

- **Increase inlet air pressure.**
  By increasing the inlet pressure the compressor provides less suction thereby reducing the amount of power required to compress the air.
- **Reduce inlet air temperature.**
  Colder air is denser and thus for each volume compressed allows the compressor to deliver more air. Overall this improves the efficiency of compression, reducing energy consumption.
- **Provide sequencing control of air compressors.**
  In a multicompressor installation, sequencing of the compressors to most appropriately meet the demand for air will result in a higher overall efficiency. Such a control scheme would attempt to fully load the operating compressors by starting and stopping the various units present.
- **Use screw compressors with capacity control.**
  Screw compressors without slide vane capacity control operate with very low efficiency when they are operating at partial capacity. A fully unloaded screw compressor with only suction throttling capacity control may consume up to 80 percent of its full load horsepower. Sequencing of the compressors as described above can avoid operation at partial loads for extended periods.
- **Reduce leaks in air distribution system and at point of use.**
  A simple test (described in Chapter 9) will determine the magnitude of leaks in the system. Performing the test twice, with and without the appliances connected, will show the leakage at the point of use.
- **Reduce compressed air system pressure.**
  Any reduction in the pressure of air delivered by the compressor will directly yield power savings at the compressor. For example, make sure that if the supply air pressure is 105 psig, that it is actually required. If the system is sized properly a reduction of five to seven psig may be possible.
- **Reduce compressed air requirements.**
  In many industrial plants compressed air is the single largest consumer of electricity. For this reason a survey of where air is being used can be very useful. Just as a load inventory will uncover wasteful uses of electricity, a compressed air survey can reveal significant opportunities for air consumption reduction and hence electricity savings.

- **Consider two-stage compression with cooling.**
  A more efficient method of compressing air, but also more costly from an equipment capital cost standpoint. In some instances a retrofit may be possible.

Compressed Air References

Modern Industrial Assessments: A Training Manual, Rutgers, The State University of New Jersey, 1995 (available online at: http://oipea-www.rutgers.edu/documents/doc_f.html)

Compressed Air System Preventative Maintenance, 11-201269 Rep. 2/92:5K, Ontario Hydro, 1992

8.4 Lighting Systems

Critical Questions

- **Is the level of light appropriate for the activity/task at hand?**
  Always consider the actual activity/task present when questioning illumination levels. Refer to the table in Appendix C for a list of tasks and suggested levels.
- **Is regular maintenance performed?**
  Ensuring that the fixture and lamps are clean maximizes light output. If lamps are not replaced at the proper intervals, light levels may depreciate to unacceptable levels.
- **Is the fixture chronically dirty?**
  The fixture may not be appropriate for the environment in which it is located. Is there a better type of fixture?
- **Is the lighting system switched from breakers?**
  Breakers are not designed for frequent switching. Generally, if large banks of lights are switched from breakers which tend to be inaccessible, they tend to operate for longer hours than if switched locally in the space illuminated.
- **Are lights on when space is unoccupied?**
  This may be due in part to a lack of switching, say in an open concept office.
- **Are lights on in areas served by daylight?**
  Could curtains or blinds be open to better utilize the daylight? Caution should be exercised to avoid glare problems.
- **Are there sufficient switches available?**
  Switching too large an area or banks of lights usually means too many lights are on when not required. Are switches in convenient locations?

Opportunities

- **Use motion sensors to switch lights.**
  Motion sensors work well in areas that are limited in size, and have irregular occupancy patterns.
- **Use timer switches to control lights.**
  A good application of timers would be in a warehouse in which occupants are present infrequently, or possibly small washrooms where lights (and fans) tend to be forgotten.

Hot Energy Tip:

The number one savings opportunity for lighting is to turn off the lights when not required.

- **Use photocell switching on window fixtures.**
  Photocells can be used to switch a row of lights near a window when the amount of light from outside is sufficient for the activity present in the space. Care should be taken to avoid glare when utilizing window light.
- **Use task lighting and turn off overhead lights.**
  Using overhead lighting to illuminate very localized tasks is not optimal. Overhead lighting could be reduced to minimum levels for safety (access), and task lighting could be used with levels specific to each task. A desk lamp is a good example of task lighting.
- **Use most appropriate design and maintenance.**
  Re-consider the overall design of the existing lighting system. This should involve performing illumination level calculations, and consideration of the number, position, type and maintenance of fixtures.
- **Convert to a more efficient light source.**
  As part of the above design analysis, consideration of the light source efficiency should be made.
- **Use reduced-wattage lamps.**
  If the illumination level in a space is excessive, reduced wattage lamps can provide illumination reduction accompanied by a power reduction without the need for major lighting system redesign.
- **Use T8 tubes/reflectors/electronic ballasts.**
  This combination of equipment can yield similar illumination levels to existing (conventional) fluorescent systems at 60 percent to 70 percent of the operating energy cost.
- **Use appropriate illumination levels.**
  Always ensure the illumination levels present in a space are appropriate to the task/activity taking place, even if more illumination must be added. Occupant comfort and productivity should be the number one concern.
- **Provide more levels of switching.**
  Switches that control too large an area can result in unnecessary illumination of unoccupied spaces. Consider re-wiring and adding switch control that is appropriate to the patterns of use of the space.
- **Use time clocks or photocells on outdoor lights.**
  Outdoor lighting should almost always be automatically controlled, otherwise, it tends to be overlooked.
- **Use LED lamps in exits lights.**
  LED lamps offer the same function at a small fraction of the energy cost (10–15 percent typically), while offering a lamp life expectancy of 25 years.

Lighting References

Lighting Reference Guide, Ontario Hydro, 1992

Commercial Lighting Efficiency, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1995 (tel.: (902) 368-5010)

Commercial Energy Manual Fundamentals, Ontario Hydro, 1991

8.5 Refrigeration Systems

Critical Questions

- **Are the condensing devices clean and well maintained?**
  Has dust and debris such as leaves or paper accumulated on air-cooled condensers? Is the cooling water feeding water-cooled condensers properly treated to avoid fouling?
- **Are the evaporator devices clean and well maintained?**
  Often the evaporator is not easily accessible. Is the defrost cycle effective on small units such as coolers and freezers?
- **Are inlet refrigerant lines properly insulated?**
  Long runs of inlet refrigerant lines may pick up significant heat. This is especially important when the evaporator and compressor units are located at a distance from one another.
- **Are controls operating properly (small and large units)?**
  If the equipment is not maintained regularly, controls may be out of adjustment.
- **Do condensers and cooling towers have adequate cool air?**
  On rooftop units, do the air intakes draw hot air directly off the roof? In the case of retail food refrigeration, is the temperature of the compressor room correct?
- **Does simultaneous heating and cooling occur?**
  This is usually not as obvious as it might appear. It is more likely in the case of smaller, independent systems, but can also occur when controls on larger systems do not operate properly. It may take place in different areas of a building. Can the excess heat from one area be used in another area?
- **Can evaporator temperature be increased?**
  A question to pose to a refrigeration expert regarding the operation of the systems in your facility.
- **Can condenser temperature be reduced?**
  A question to pose to a refrigeration expert regarding the operation of the systems in your facility.
- **Is the refrigeration unit appropriate to the load?**
  Is a freezer unit being used to provide cooling only? Is the capacity of a refrigeration system much greater than the load? If the system cycles on/off frequently, it may be the case. A lightly loaded unit will not operate as efficiently as a properly loaded unit.
- **Can thermal storage avoid a higher peak demand caused by refrigeration systems?**
  This may not be as exotic as it sounds. For example, a food processing facility with a large amount of frozen product has built-in thermal storage. Even without refrigeration, the product may stay at acceptable temperatures for a period of time long enough to allow peak demand control.

Hot Energy Tip:

A modern compressor may by significantly more efficient than an existing unit and may be a good solution to the CFC based refrigerant replacement problem. Compressor sizing should also be considered during a replacement assessment.

Opportunities

- **Use conservative practices at point of use.**
  Sometimes the most attractive savings opportunities may be realized through the optimization of the ultimate end use of the energy. For example, minimizing the amount of heat that reaches the ice (otherwise called the cooling load) leads to reduced operation of the refrigeration plant. These types of opportunities are often found by considering all the factors that influence the amount of electricity used. In the case of an ice rink this would lead to consideration of a wide range of processes, including the amount of hot water applied during resurfacing, whether the ice slab is insulated, or even the possibility of installing an aluminium ceiling in order to reduce the amount of heat radiated to the ice by the surrounding structure.

- **Raise evaporator temperature (suction pressure).**
  The amount of power demanded by a refrigeration compressor is determined by the difference between the evaporator and condenser temperature (or pressure). Therefore, if the system requiring cooling can tolerate a small increase in temperature at the evaporator, an opportunity to reduce compressor power may exist. In order to determine if such a change is possible, and will not damage the compressor, you should consult a refrigeration expert. Since compressors are finely tuned systems, caution should always be exercised when considering adjustments to operating conditions.

- **Lower condensing temperature (discharge pressure)**
  The amount of power demanded by a refrigeration compressor is determined by the difference between the evaporator and condenser temperature (or pressure). Therefore, if the compressor can tolerate a small reduction in temperature at the condenser, an opportunity to reduce compressor power may exist. In order to determine if such a change is possible, and will not damage the compressor, you should consult a refrigeration expert. Since compressors are finely tuned systems, caution should always be exercised when considering adjustments to operating conditions.

- **Clean evaporators**
  If the heat exchanging surfaces of the evaporator in a refrigeration system of any size are not clean, the evaporator is forced to operate at a higher temperature than necessary, increasing compressor power. In small systems using air, dust and other contaminants accumulate, while in large liquid systems regular maintenance is required to avoid excessive fouling of exchange surfaces.

- **Clean condensers/cooling tower**
  If the heat exchanging surfaces of the condenser in a refrigeration system of any size are not clean, the condenser is forced to operate at a higher temperature than necessary increasing compressor power. In small systems using air, dust and other contaminants accumulate, while in large liquid systems regular maintenance is required to avoid excessive fouling of exchange surfaces.

- **Provide cooler air to the condensers**
  Rooftop cooling units containing compressors and condensers generally draw air from close to the rooftop. Cooler air may be available, as close as four to five feet high off the roof. Cooler air may allow the compressors to operate more efficiently.

- **Adjust control setpoints**
  Proper control maintenance is essential in operating refrigeration systems optimally. Situations may exist where the existing controls are not appropriate or not capable of controlling the systems properly. A symptom of this may be as simple as a thermostat that fails to effectively control comfort levels in an occupied space.

Refrigeration References

Energy Efficient Refrigeration Systems, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1995 (tel.: (902) 368-5010)

Electrical Efficiency Improvement, Boiler Efficiency Institute, Auburn, AL, 1992

Modern Industrial Assessments: A Training Manual, Rutgers, The State University of New Jersey, 1995 (available online at: http://oipea-www.rutgers.edu/documents/doc_f.html)

1998 Handbook – Refrigeration, ASHRAE, Atlanta (www.ashrae.org)

8.6 Electric Motors

Questions

- **Is regular maintenance performed on motors?**
  Heat is a major cause of motor failure. A 10 percent increase in motor operating temperature can reduce the motor's life by up to 50 percent.

- **Are motor voltages balanced and within specifications?**
  A motor's life and efficiency can be significantly influenced by high/low voltages. Imbalanced voltages applied to a three-phase motor can increase internal heat generation significantly.

Opportunities

- **Downsize to a regular motor.**
  A motor that is oversized by greater than about 30 percent, or one that operates at less than 75 percent of full load, may be operating at a poor efficiency. By downsizing the motor, a higher efficiency may be obtained.

- **Downsize to an energy-efficient motor.**
  The incremental cost of an energy-efficient motor versus a regular motor may be paid for by the incremental change in efficiency.

- **Replace with an energy-efficient motor.**
  A motor that operates very hot, is noisy and maintenance prone could be replaced by a new energy-efficient motor. Also, if a reliable estimate of the operating efficiency of an existing motor is low, a replacement may be justified.

- **Replace with a two-speed motor.**
  It may be possible to satisfy a requirement for variable flow or capacity with the use of a two-speed motor. Two-speed motors work well in centrifugal pumping applications in which the flow may be reduced by 50 percent for part of the time.

- **Correct motor power factor.**
  Partly loaded motors contribute to reduced power factor. Provide capacitors at the motor to improve the power factor.

- **Replace a "V" belt with cog drive belts or tighten and adjust drive belts.**
  Improving the efficiency of power transmission from the motor to load can yield significant power savings. This is especially true when numerous small motors are involved.

Hot Energy Tip:

An energy-efficient motor installed as a replacement may actually spin faster under load than the motor replaced. This can result in increased power consumption when the motor drives a centrifugal device such as a fan or pump. Pay close attention to motor speeds before and after a replacement, and may adjustments as required.

This pitfall of motor replacements in outlined in the *Energy-Efficient Motor Selection Handbook* referenced below.

Motor References

Energy-Efficient Motor Selection Handbook, US Department of Energy, DOE/CE 0384

Motors Reference Guide, Ontario Hydro, 1990

Energy-Efficient Motors, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1995 (tel.: (902) 368-5010)

8.7 Peak Demand Control

Opportunities

- **Schedule large loads or groups of loads.**
  Simple production scheduling to avoid the simultaneous use of large loads or groups of loads is a simple and “low-tech” approach to demand control.
- **Coordinate start-up.**
  In some cases production equipment may require significantly more energy upon start-up (say for warm-up) than during use. If this period is long enough to affect the metered demand, consider coordinated start-up to avoid simultaneous warm-ups.
- **Use a peak demand alarm.**
  Often, a simple announcement that the peak demand is being approached will allow operators to take action (provided they have been trained) to avoid unnecessary demand peaks.
- **Interlock motor starters on large equipment.**
  If two large pieces of equipment should never operate simultaneously, interlock their starters so that they may not inadvertently be used together.
- **Use an automatic load shedding device.**
  Loads that are considered non-essential or possibly “convenience” could be shut down automatically by a system that monitors demand continuously, and takes action as the peak demand level is approached. This “high-tech” approach tends to be very intrusive and for that reason may be unacceptable operationally.
- **Shave peaks with emergency generators.**
  It may be possible to utilize emergency generators to avoid very short, but expensive, demand peaks. The simplest implementation of this would involve using the generators during the on-peak times to supply the loads assigned to it by the initial system design.

Hot Energy Tip:

A *Load Duration Curve* shows the amount of time that a facility is at each demand level. This is a key tool when devising a peak demand control strategy. This curve may be derived from demand profile or internal data.

- **Correct power factor.**
  In practice it is only the on-peak power factor that really is of concern from the perspective of demand costs.

Peak Demand Control References

Modern Industrial Assessments: A Training Manual, Rutgers, The State University of New Jersey, 1995 (available online at: http://oipea-www.rutgers.edu/documents/doc_f.html)

Industrial Energy Monitoring & Control Systems Reference Guide, Ontario Hydro, 1992

Commercial Energy Management Control Systems Reference Guide, Ontario Hydro, 1992

Commercial Energy Manual Applications, Ontario Hydro, 1991

Commercial Energy Manual Fundamentals, Ontario Hydro, 1991

8.8 Electricity Purchase Optimization

Opportunities

- **Consolidate multiple utility meters**
  Although consolidating service entrances and thereby reducing the number of meters will not actually reduce power demand or energy consumption, it will take advantage of any load diversity that exists between service entrances. Load diversity exists if the peak demands on two service entrances do not occur at exactly the same time. Thus, when the service entrances are combined, the resulting peak demand will be somewhat less than the sum of the individual peaks. Hence, peak demand charges will be reduced.
- **Change to a more favourable rate.**
  Customers may request billing under an alternative rate class that is more attractive financially. Eligibility generally depends on the nature of a facilities type, magnitude and pattern of electricity use.
- **Take advantage of any on/off peak options.**
  Some utilities offer rate classes that provide credit for use of off-peak power. Or, in some cases new “time-of-use” rates penalize the user for consumption on-peak.

Hot Energy Tip:

Knowledge of your demand or load profile will be essential when shopping for a better electricity rate.

- **Coordinate start-up/shut-down (seasonally).**
  In most cases the peak demand for a given billing period, say one month, is set during the peak 15-minute interval in the month. In the case of a seasonal operation, if you shut down the operation (i.e., an ice rink refrigeration plant) just one day after the monthly meter reading you may incur the monthly demand charge for the remainder of the month needlessly. In this case asking for a meter reading on a specific date, in coordination with a shut-down would be to your advantage. The same applies for start-up.

8.9 Boiler Systems

Lower Cost

- Utilize and check proper water treatment procedures.
  Correct water chemistry will minimize costs and prolong the life of the boiler.
- Maintain dissolved solids at an appropriate level and monitor regularly.
  This will allow blow-down rates to be optimized.
- Operate at minimal possible steam pressure/hot water temperature (small systems).

Higher Cost

- Recover blow-down heat.
  First ensure that the blow-down rate is adjusted with regard to dissolved solids.
- Use heat recovery to increase feed-water temperature.
  Waste heat sources may include blow-down and process heat.
- Use waste/flash steam for de-aerator heating.
  This will displace the use of high pressure steam direct from the boiler, and will require the use of a flash tank.

- Install economizer to capture maximum heat.
- Transfer blow-down heat to storage tank for preheat of boiler feed-water.

Boiler Systems Reference

CANMET's Energy Management Series Handbook #6 – Boiler Plant Systems

Boiler Efficiency Improvement, Boiler Efficiency Institute, Auburn, AL, 1992

8.10 Process Furnace, Dryers and Kilns

Lower Cost

- Maintain proper burner adjustments.
- Monitor and maximize combustion efficiency.
- Monitor and set excess air to manufacturers specification.
- Ensure that heat exchange surfaces are clean.
- Ensure that air distribution within equipment is adequate.
- Keep insulation, door seals and covers in good condition.
- Schedule production to operate furnaces at maximum load/output.

Higher Cost

- Maintain or upgrade existing instrumentation.
- Install monitoring and instrumentation (temperature, pressure etc.).
- Recover heat from furnace/kiln cooling fluid.
- Relocate air intakes to ensure driest possible air is used.
- Relocate combustion air intake to utilize waste building heat.
- Recover flue gas heat with heat exchanger/heat recovery equipment.
- Upgrade burner assemblies if they are not maintainable at optimal efficiencies.
- Install electronic controls for combustion control and temperature control.

Process Furnace Dryers and Kilns Reference

CANMET's Energy Management Series Handbook #7 – Process Furnaces, Dryers and Kilns

Energy-Efficient Process Heat, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1996 (tel.: (902) 368-5010)

8.11 Steam Distribution Systems

Lower Cost

- Survey steam traps and repair malfunctioning units.
- When surveying steam traps, survey steam valves, flanges and unions as well.
- Repair steam/condensate leaks, regardless of size.

- Shut down steam/condensate branch lines when not in use for significant times.
- Shut off steam to equipment when not being used.
- Recover hot condensate when possible.
- Check and maintain pressure reducing stations (valves).
- Use the lowest pressure possible when using steam for heating.
- Condense steam rather than use only the superheat for heating.
- Reduce system/subsystem pressure where possible.
- Ensure appropriate and correctly functioning air vents in system.

Hot Energy Tip:

Leaking orifice type steam traps can often be detected with a relatively low cost ultrasonic leak detector.

Higher Cost

- Put in place an ongoing steam trap monitoring and repair/replacement program.
- Recover flash steam if suitable use can be found.
- Use only steam as a heat source if is appropriate (use the lowest form of energy possible to avoid downgrading high quality (temperature) energy).
- Recover heat from contaminated condensate that must be dumped.
- Monitor steam and condensate flows continuously to ensure a balance.
- Track down imbalances in steam and condensate flows.
- Replace PRV's with small steam turbines if appropriate.
- Consider simple co-generation applications.

Steam Distribution Systems Reference

CANMET's Energy Management Series Handbook #8 – Steam and Condensate Systems

Boiler Efficiency Improvement, Boiler Efficiency Institute, Auburn, AL, 1992

8.12 Steam and Water Heating Equipment

Lower Cost

- Maintain steam pressure and temperature within the correct range for equipment. Ensure that steam quality is adequate for application.
- Ensure that steam traps are correctly sized for equipment and application.
- Ensure correct slope to clear condensate from steam appliances.
- Clean heat transfer surfaces regularly.
- Shut down steam-consuming equipment when not required.

Higher Cost

- Provide better controls to optimize use.
- Operate equipment at capacity, the base or fixed heat loss reduces operating efficiencies at part load.
- Provide appropriate instrumentation for temperature and pressure.
- Use indirect rather than direct steam heat and then recover condensate.

Steam and Water Heating Equipment Reference

CANMET's Energy Management Series Handbook #8 – Steam and Condensate Systems

CANMET's Energy Management Series Handbook #9 – Heating and Cooling Equipment

8.13 Process Insulation

Lower Cost

- Repair damaged insulation.
- Maintain safety requirements, surface temperatures must be kept below 70°C.

Hot Energy Tip:

The high temperature of steam makes the proper insulation on even small steam lines a good energy cost-saving opportunity.

Higher Cost

- Insulate non-insulated pipes.
- Insulate non-insulated vessels.
- Insulate valves and flanges.
- Paint/wrap tank/pipe surfaces with low-E/aluminum paint/foil.
- Add/upgrade insulation up to the economical thickness.

Process Insulation Reference

CANMET's Energy Management Series Handbook #8 – Steam and Condensate Systems

Energy-Efficient Process Heat, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1996 (tel.: (902) 368-5010)

8.14 Ventilation/Exhaust Systems

Lower Cost

- Shut down ventilation/exhaust systems when not required.
- Maintain dampers to reduce outside air leakage when not required.
- Use correct ventilation/exhaust rates for application/occupancy.
- Balance air flows for appropriate zero, positive or negative pressure.
- Control ventilation based upon requirement, i.e. temperature, contaminant sensor or possibly an occupancy sensor.

Higher Cost

- Zone ventilated areas and sequence air flow based on contaminant levels.
- Utilize direct air make-up with heat recovery for critical contaminant extraction.
- Install air-air heat recovery equipment on exhaust/intake systems.
- Utilize waste heat from compressor intercooler/aftercooler for space heating.
- Utilize waste condenser heat from refrigeration systems, to heat make-up air.
- Utilize systems to destratify ceiling air.

Ventilation/Exhaust Systems Reference

CANMET's Energy Management Series Handbook #10 – Heating Ventilating and Air Conditioning Systems

CANMET's Energy Management Series Handbook #9 – Heating and Cooling Equipment

Energy-Efficient Heating, Ventilating & Air Conditioning, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1995 (tel.: (902) 368-5010)

8.15 Space Conditioning Systems

Lower Cost

- Control temperature and humidity according to comfort zone.
- Setback thermostats during unoccupied hours during the heating season.
- Raise thermostats during unoccupied hours during the cooling season.
- Reduce space temperatures in unoccupied or storage areas.
- Ensure automatic controls are operating correctly and are calibrated regularly.
- Interlock heating and cooling systems to avoid simultaneous heating and cooling of the same space.

Hot Energy Tip:

Morning recovery from an electric heating system temperature setback can result in demand peaking. To avoid setting new demand peaks, stage the start-up of the building heating, ventilating and lighting systems during the building warm-up period.

Higher Cost

- Adjust building heating/cooling water temperature according to outside conditions.
- Use enthalpy control on HVAC systems.
- Use more sophisticated control of HVAC systems.

Space Conditioning Systems Reference

CANMET's Energy Management Series Handbook #10 – Heating Ventilating and Air Conditioning Systems

Energy-Efficient Heating, Ventilating & Air Conditioning, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1995 (tel.: (902) 368-5010)

8.16 Process Equipment

- Maintain and monitor instrumentation.
- Maintain logs of process plant conditions and energy use statistics.
- Cover storage tanks and vats to reduce evaporative losses.

Process Equipment Reference

Energy-Efficient Process Heat, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1996 (tel.: (902) 368-5010)

Modern Industrial Assessments: A Training Manual, Rutgers, The State University of New Jersey, 1995 (available online at: http://oipea-www.rutgers.edu/documents/doc_f.html)

8.17 Cooling Systems

Lower Cost

- Monitor cooling tower water chemistry to avoid algae growth.
- Maintain a clear air flow through cooling tower, draw air from cooler areas.

Higher Cost

- Isolate cooling streams to identify high- and low-temperature sources.
- Link cooling loads (where possible) to maximize heat load of cooling water.
- Minimize cooling flow to maximize temperature rise to the extent appropriate.
- Monitor cooling tower conditions, reduce fan or pump rates in cool weather.

Cooling System Reference

CANMET's Energy Management Series Handbook #10 Heating – Ventilating and Air Conditioning Systems

Energy-Efficient Heating, Ventilating & Air Conditioning, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1995 (tel.: (902) 368-5010)

Electrical Efficiency Improvement, Boiler Efficiency Institute, Auburn, AL, 1992

8.18 Building Envelope Systems

Lower Cost

- Control openings with automatic doors, self closers, sensors etc.
- Ensure weatherstripping/seals are present and operating correctly.
- Keep loading dock seals adjusted and in good condition.
- nstall plastic strip curtains between areas of different temperatures.
- Caulk/weatherstrip old and leaky windows

Higher Cost

- Consider the use of air curtains where appropriate.
  Typical applications are in retail entrances, warehousing and shipping areas.
- Utilize vestibules in high traffic areas to reduce air infiltration.
- Apply window covering/films to reduce heat loss/heat gains.
  These are effective at reducing solar heat gain and heat loss during the winter.
- Provide window shading to reduce solar heat gain.
  External shading devices or blinds may also be used.
- Utilize a false ceiling for large warehouse types of building/spaces.
  This will reduce the effective area requiring space conditioning.
- Insulate large uninsulated loading/shipping doors.
- Replace windows with new units.
  Check windows for type and condition. If the windows are single-glazed, they should be replaced with the double- or triple-glazed type. This improvement could involve new multiple pane windows or the addition of a second storm window. If windows are cracked or broken or if there are gaps between the window frame and the building, replace panes and fill gaps to eliminate leaks. Consider recaulking major joints.
- Add/improve wall insulation levels during other repairs/construction.
  Check wall construction, particularly the insulation thickness and type. If the insulation is inadequate (check for frost or condensation) it should be upgraded by adding a new layer, to either the inside or outside of the building. If the insulation is wet, the full resistance value of the insulation is lost and a leak in the vapour barrier is a source of future problems that must be addressed.

Hot Energy Tip:

A thermographic scan can detect excessive heat loss due to poor doors, windows and missing or damaged insulation in the building envelope.

- Add/improve ceiling/roof insulation levels during other repairs/construction.
  Check roof construction, particularly the insulation thickness and type. If the insulation is not adequate, and the roof is not due for replacement, consider adding additional insulation at the first opportunity.

Building Envelope Reference

CANMET's Energy Management Series Handbook #18 – Architectural Considerations

General References

Modern Industrial Assessments: A Training Manual, Rutgers, The State University of New Jersey, 1995 (available online at: http://oipea-www.rutgers.edu/documents/doc_f.html)

Using Control Technology to Cut Energy Costs, P.E.I. Department of Economic Development and Tourism, Charlottetown P.E.I., 1995 (tel.: (902) 368-5010)

Chapter 9
Heat Recovery Systems

Objective

To identify and describe various heat recovery methods and technologies. Heat recovery constitutes an optimization of the supply of thermal energy.

Note: Heat recovery should be considered only after all other technological and operational opportunities have been examined or implemented. See Chapter 7 “A Process for Identifying Savings Opportunities” for details and methodology. **The order of actions is very important!**

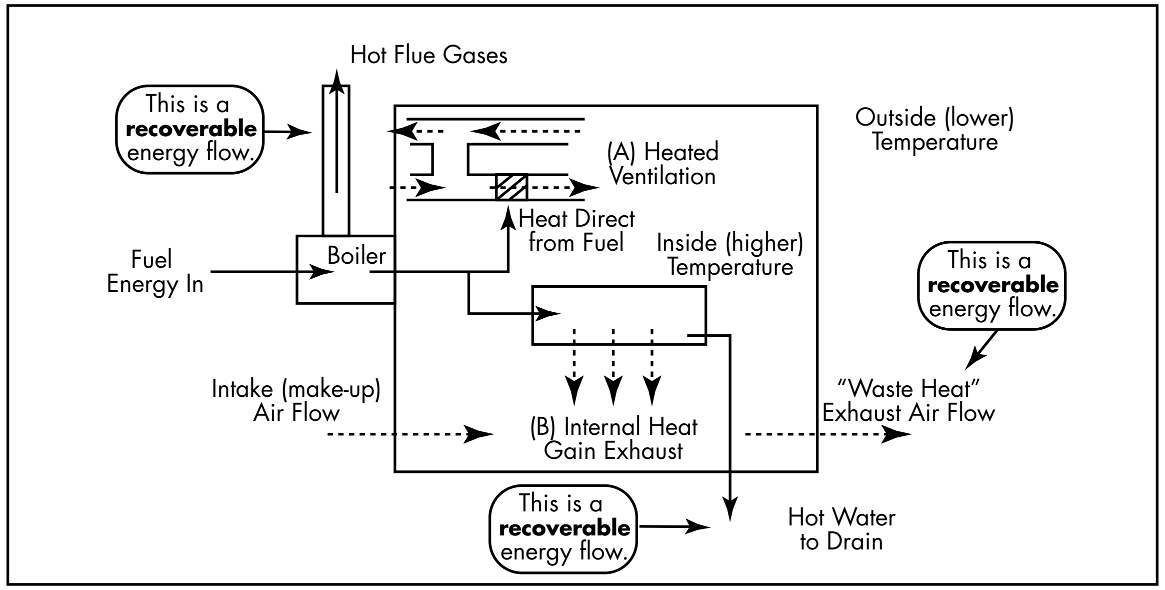


Figure 9.1: Waste Energy Flows

Figure 9.1 shows a simple energy flow diagram of a plant with a number of energy outflows identified. These energy flows are termed waste energy flows since they are no longer required by the process discharging them. But they may be useful to another process or energy consuming system. Matching waste energy streams to potential uses involves answering some key questions as follows:

What waste heat sources are available?

- What quantity of heat (energy) is available?
- At what temperature is the heat available?

Where can the heat be used?

- How much energy is required and at what temperature?
- What is the time coincidence between waste and use?
- At what location is the heat required?

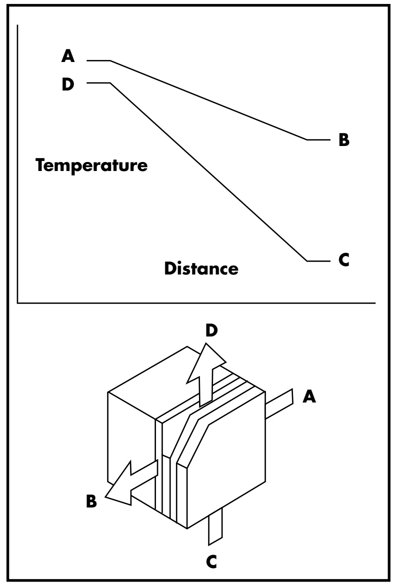


Figure 9.2: Temperature Profiles

What is the practical recovery rate; what portion of the waste heat may be used?
The existence of a “waste” energy stream from one process may provide an opportunity for using the leftover lower-temperature energy in another process. As dictated by basic thermal principles, heat can flow only from hot bodies to cold bodies, and any attempt to raise the temperature of a process must involve the use of a hotter “source”. This source is only useful (to that process) so long as its temperature is higher than the “sink” it’s supplying. At that point, the heat supply ceases to become useful for that task; this heat is often discarded. If, however, that heat supply is hotter than the temperature needed for some other task (e.g. cooling water at 40°C is hotter than is required for space heating), it should no longer be considered “waste” energy, but instead should be seen as a supply of useful energy, and a way to save money.

Heat recovery involves moving heat energy from one system to another. The piece of equipment that makes this transfer possible is the heat exchanger. To determine the capabilities of the heat exchanger (and hence the viability of performing the transfer), you need to know the availability of both the heat source and the heat sink; in terms of their flows, specific heat capacities and inlet temperatures. By balancing the energies within the two streams (see Figure 9.1), you can determine the size and capabilities of the required exchanger. Table 9.1 lists typical exchangers and their applications.

Hot Energy Tip:

Typically the cleaner the waste heat stream is, the easier will be the heat recovery. Process steam condensate, although often contaminated and not suitable for re-use in the boiler, is an excellent source of waste heat. See the example in this chapter.

Type	Regime	Exchanger	Typical Use
Direct Heat Recovery	Gas – Gas	Cross Flow Rotary Regenerative	Commercial Air Exchange Flue Gas Heat Recovery High Temp. / Low Volume Exhaust
	Liquid – Liquid	Shell & Tube Spiral Plate & Frame Heliflow	Process Water, Oil Coolers High Pressure Cooling Dairy, Process Water Oil Coolers
	Gas – Liquid	Recovery Boiler Evaporative Air Cooling	Furnace , Engine Exhaust Water Cooling, Humidification, Exhaust Gas Scrubber Oil Cooler, Space Heating
Indirect Heat Recovery	Thermal – Thermal	Heat Pump Absorption Chiller Flash Tank Mechanical Vapour Recompression Combustion of Waste Gases	Space Heating, Hot Water Production Water Chilling, Space Heating Boiler Blow down Brewing, Sugar Processing Sewage Treatment, Foundries
	Thermal – Mechanical/ Electrical	Expansion Turbine Rankine Cycle	Chemical Plants High Temperature Waste Gas

Table 9.1: Heat Exchanger Types and Typical Uses.

9.1 Direct Heat Recovery

Direct Heat Recovery is the transfer of energy from one process stream to another without the addition of work or energy from an outside source. The energy must degrade since heat will flow only from a hot “source” to a cold “sink”. But depending upon the design of the heat sink, the difference between these two temperatures may be as low as a few degrees.

Gas to Gas Heat Exchange

Heat transfer from a gas is notoriously poor and often requires a large temperature drop (>10°C) between the source and the sink to get good results. To avoid the need for extraction fans, pressure drops through heat exchange equipment must be low and this makes for large flow areas and surprisingly large components. Construction materials depend upon the temperatures, pressures, and properties of the gases. Often high conductivity materials such as aluminum or copper are involved. Typical heat exchanger designs are:

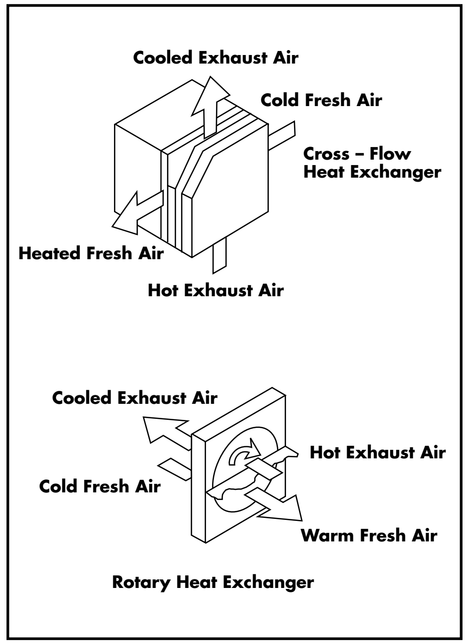


Figure 9.3: Gas to Gas Heat Exchangers

Cross-flow – often used for small volume exchangers (e.g. residential air exchangers). A series of separated plates with the two gases flowing through adjacent spaces.

Rotary – a motorised wheel turning slowly between the isolated hot and cold gas streams. The heated gas warms the wheel which rotates into the cooler stream. Used principally for large gas volumes.

Regenerative heat exchanger – where the hot and cold streams are switched periodically between two stationary, solid heat absorbing beds.

The cost of the heat exchangers depends principally upon the capacity, the materials, and the technical complexity. For example a rotary design is larger than a cross-flow, more complex, more efficient, but more expensive.

Hot Energy Tip:

Applications of heat recovery may be relatively low tech. De-stratifying hot air in a boiler room to pre-heat combustion air is a simple form of waste heat recovery. Look for other easy ways to re-use heat that might otherwise be exhausted. Locating small unitary refrigeration condensing units so that the rejected heat may be used in the winter is another good example.

Liquid to Liquid Heat Exchange

The wide variety of applications makes this the most common form of heat exchanger, with some of the equipment being designed for temperature differentials (source-to-sink) as low as 3°C. Internal pressure losses are usually low (<1 psi) even for high stream velocities, permitting good heat transfer with compact designs. System pressures and temperatures are higher than for gas-to-gas units, and equipment is often designed to meet ASME pressure vessel “code” requirements. The most common designs for liquid-to-liquid heat exchange are as follows:

Shell and tube – off-the-shelf designs, used everywhere and available with a wide variety of shell types and tubes; with and without fins, baffles and passes, head types, materials etc. This type can be designed for almost any pressure and temperature.

Plate and frame – compact design that offers the lowest temperature differential between source and sink. It can easily be dismantled for cleaning, and is used extensively in water treatment and in the dairy industry. Limited to 120°C and 300 psig by the seals between the plates.

Spiral exchangers – the most efficient type for high pressure systems. They are designed as spirally wound plates with countercurrent flow between the plates, and provide excellent heat transfer and a compact design.

Heliflow – a "tube" coil in a pot- like container. It is very efficient, leak-free and effective for oil coolers and small capacity applications.

Of the four designs, shell and tube exchangers and Heliflow are the least expensive. But they will be limited by efficiency and size. Plate and frame units are more efficient, more expensive, and limited to low pressure applications (<300 psig). Spiral exchangers are by far the most expensive, but also the most efficient for high pressure applications (300 psig and up).

Gas to Liquid Heat Exchange

Heat transfer between a gas stream and a liquid is a common means of transferring energy throughout a plant. Heat transfer is enhanced by either using fins on the gas side of the heat transfer surface or with the tube bank arranged as a coil within the (low pressure) gas duct. Space heating coils are a typical example.

Other typical exchange techniques include the following:

Recovery boilers – the hot gases (e.g. combustion gases) are used to generate steam. Usually vertical in design, with the water or steam in the shell and the hot gases in the tubes.

Evaporative cooling – the most common of the gas to liquid heat exchangers. The most compact and the least expensive. The liquid droplets are in direct physical contact with the up-flowing gas stream. (This type can be used to cool either the gas or the liquid stream.)

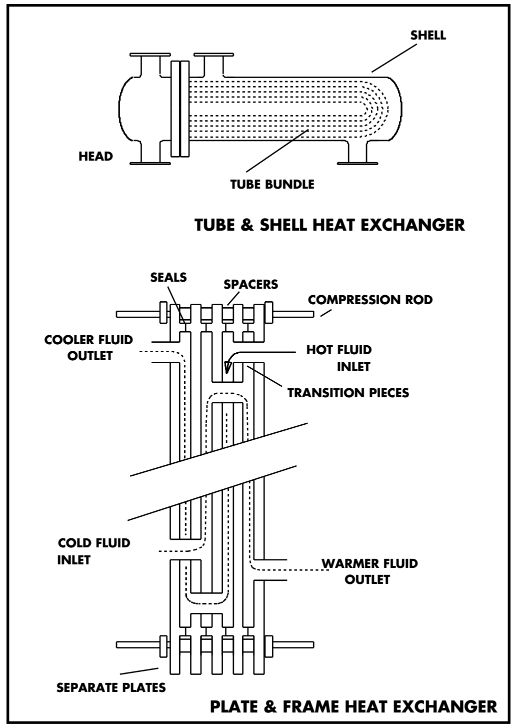


Figure 9.4: Liquid to Liquid Heat Exchangers

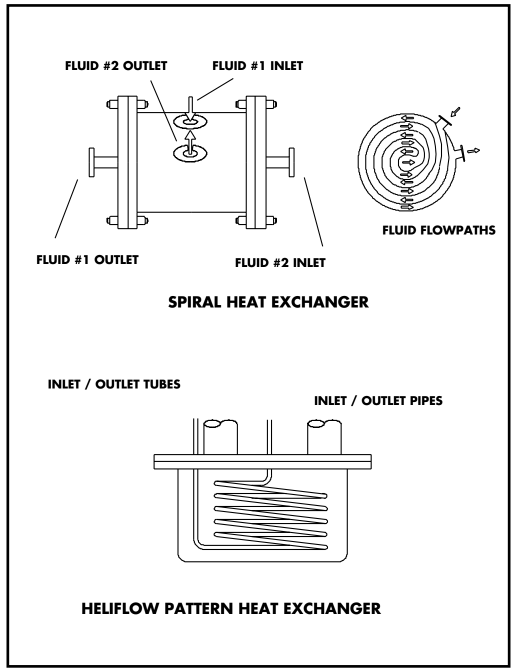


Figure 9.5: Liquid to Liquid Heat Exchangers

Air cooling – these vary in size from car radiators to very large condenser units. Requires significant fan and motor power and may be the largest and most expensive of the heat exchangers.

9.2 Indirect Heat Recovery

Indirect heat recovery describes the transfer and conversion of energy from one format to another, possibly through the addition of outside energy. It is usually considered a secondary choice to direct heat recovery because it results in either a lower level of energy recovery or the use of additional, high grade energy (e.g. electricity, fuel).

Thermal – Thermal

Upgrading a source of thermal energy may be done many ways: heat pumps, absorption chillers, mechanical vapour recompression, flash tanks, or combustion of waste gases.

Heat Pump

The heat pump is essentially a refrigeration circuit. Energy is recovered from a source of low grade heat (the inside of the refrigerator) by transfer to a lower vapour temperature refrigerant. The vapourized refrigerant is then compressed to increase its temperature to one above that of the heat sink (the kitchen). The refrigerant is then allowed to condense. This cools and liquefies the refrigerant. The cooled liquid refrigerant is then expanded to a colder liquid before being passed back to the heat source again. Applying this to a process will enable energy to be recovered from a low temperature gas or liquid stream and re-inserted into a higher temperature stream. Heat pumps have coefficients of performance (COP) of between three and four. This means that for every unit of compression energy fed into to the system, three to four units of heat leave the heat sink; making the system at least three times more efficient than electric resistance heating.

Absorption chiller

Similar to a heat pump, an absorption chiller can extract heat from a low temperature source and add it to a sink at higher temperature. The refrigerant in the system is a solution of lithium bromide and water, which absorbs water with a significant intake

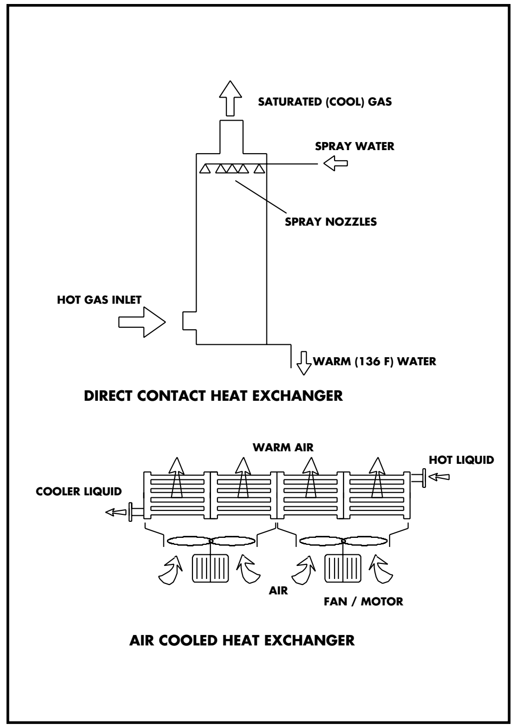


Figure 9.6: Gas to Liquid Heat Exchangers

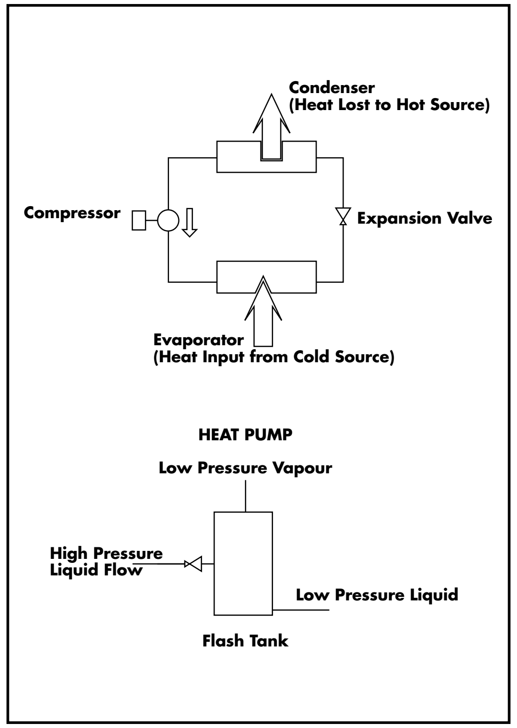


Figure 9.7: Thermal to Thermal/Indirect

of energy. By adding the heat from a supply of low pressure steam, the concentration of the solution is increased. The solution is then transferred elsewhere and re-diluted to draw heat from its surroundings. The process requires low pressure steam (15 psig) as well as a supply of cooling water and a process stream to be cooled. Both the absorption chiller and the heat pump can be used to transfer heat from an energy source that could benefit from being cooler (cooling water) to one that could be warmer (space heating, air preheat, boiler feedwater preheat).

Flash Tank
A supply of medium temperature, but high pressure, liquid may be reused by rapidly reducing its pressure. At the lower pressure, a portion of the liquid becomes vapour and may be used elsewhere in the process. Although it is not an efficient process, it is nevertheless a good method of getting clean steam from dirty water.

Mechanical Vapour Recompression
Low pressure vapour may be upgraded by mechanically compressing it. This is often performed in processes where large amounts of low pressure steam are required, e.g. evaporation of sugar solution, salt production, brewing. Because of the compressibility of steam at low pressure, the process is energy intensive with much of the energy becoming unwanted superheat for the higher pressure steam.

Combustion of Waste Gases
Certain processes (e.g anaerobic digestion) produce gases that contain combustible components. These gases may be introduced as supplementary fuel for a combustion process and reduce the regular supply of gas or fuel oil purchased.

Thermal to Mechanical or Electrical
This is the most complex, most expensive and least efficient method of energy recovery and reuse. A relatively high grade energy source is required i.e. one at high temperature and/or high pressure. Each operation will result in a further degradation of the energy source and could reasonably be considered as a source in itself for heat recovery opportunities.

Expansion Turbines
These can be used to replace pressure reducing valves in certain applications. High pressure steam, gas or other vapour can be expanded through the device. By coupling it to an induction generator, pump, etc., the recovered work can replace work currently performed by an electric motor. Expansion efficiencies may vary between 30 percent and 75 percent depending upon the design of the unit. The replacement of a reducing valve is often only feasible if the recovered electricity is greater than 250 kW.

Note that the expansion turbine does remove work from the process stream, which doesn't occur with the reducing valve. This extraction of work must be considered in the overall energy balance if the expanded stream will be used elsewhere in the process.

Hot Energy Tip:

With the opening of many electricity markets, there are greater opportunities to generate electricity on-site, even on a small scale, as excess they may be sold at attractive prices. Co-generation systems utilize heat recovery to get maximum benefit from the fuel or heat source employed.

Rankine Cycle
This is the basis of the steam-turbine power-generating cycle. It makes use of several forms of direct heat transfer to convert high grade thermal energy into mechanical energy. A high temperature heat source (>300°C) transfers its energy to a liquid stream that boils under pressure. The pressurised vapour spins an expansion turbine that is connected to an electrical generator, a compressor or another form of mechanical drive. The expanded vapour is condensed at low pressure in a condenser, thereby providing a source of recoverable waste heat, after which the condensate is returned to the boiler. This energy conversion system requires qualified operators and can be estimated at $1,000 per kW of output. It is generally practical only when generating more than 1 MW of electricity.

9.3 Calculating Savings from Heat Recovery

9.3.1 Savings Example No.1; Heat Recovery from Hot Waste Water

An Ontario polymer resin facility utilizes two batch reactors to manufacture their resin mixes. Production at the plant is continuous throughout the year, with the company supplying several long-term clients.
The reaction process is initially endothermic and therefore requires heat. As the reaction proceeds, it becomes exothermic, requiring heat to be removed. The rate of the reaction is controlled by removing the volatile mixing medium, and condensing it in an overhead condenser. The condensers are cooled using municipal water which is heated and released to the sewers. The building that houses the reactors is 71.3 m long, 29.3 m wide and 6.1 m high. It also doubles as a warehouse for the feedstock and the finished resins. They are temperature sensitive and require the building to be maintained at around 20°C. Heating is currently provided by six ceiling mounted steam heaters.

The Question
Is it possible to use the heat from the condenser cooling water to heat the warehouse?

The Answer
1. Heat Available from the Water
Total inlet water flow through the condenser = 3.5 kg/s
Average water inlet temperature to condenser = 32°C
Temperature of water leaving the condenser = 87°C
Heat available in the water = $M \times V \times (T_2 - T_1)$ = 3.5 kg/s × 4.2 kJ/kg × (87 − 32)
= 806.4 kW

2. Heat Required for the Building
Building surface area = 3313 m^2
Mean indoor temperature = 20°C
Mean outdoor temperature = 0°C
Typical U value for heat loss = 0.948 $w/m^2/°C$
Heat loss from building surface = $U \times A \times (T_2 - T_1)$ = 3313 m^2 × 0.948 $w/m^2/°C$ × (20 − 0)
= 63 kW

The heat required for ventilation and infiltration can be calculated from a standard air exchange rate of 1.8 air changes per hour. For a building with a volume of 12 743 m^3, this amounts to a flow rate of 22 937 m^3 per hour or 6371 L/s.

Air Ventilation/Infiltration = $V \times 1232 \times (T_2 - T_1)$
= 6371 L/s × 1.232 × (20 – 0)
= **157 kW**

Total Loss = Surface Loss + Infiltration = 157 kW + 63 kW
= **220 kW**

Thus, the condenser cooling water contains far more than the amount of heat that is normally lost from the warehouse. Also, the water is at a temperature significantly greater than the ambient air temperature within the building. It therefore appears that the use of the condenser heat as a source of space heating would be feasible.

The exact extent to which the heat within the condenser water may be used will be determined by the heat exchanger design. A typical unit for this application would be a fan-coil unit (see case study 9), with the water contained within a set of externally finned coils mounted within a duct through which air would be blown. A coil manufacturer would generate a design that balances the heat transfer capabilities of the fluids with the physical limitations (pressure drop, etc.) of the unit.

For this particular example, the optimum coil design was capable of recovering 600 000 Btu/h (176 kW). The exit water temperature was 166°F (74°C).

Although there is more than enough heat available within the condenser water stream, gaining access to that heat and putting it to use requires a capital expenditure. The viability of the project would thus be based upon the cost savings afforded by the use of recovered heat compared with the capital cost of the heat recovery project.

Cost Savings

Rate of heat replaced in the warehouse = 176 kW

This heat would replace steam heat from an inefficient "package" type boiler with an overall efficiency equal to approximately 55 percent. This heat is generated from natural gas. To keep the plant, warm the boiler must on average run ten hours per day, eight months per year.

Cost of Oil into boiler = $3.70/GJ

Total heat replaced in warehouse = 176 kW × 10 hrs/day × 30 days/month
× 8 months/year ÷ 278 kWh/GJ
= 1519 GJ/year

To determine the amount of purchased energy displaced, we must take into account the estimated conversion efficiency of the boiler.

Total energy reduction at boiler input = 1519 GJ/year ÷ 0.55
= 2762 GJ/year

Total cost saving at the oil meter = 2762 GJ/year × $3.70/GJ
= $10,220/year

The Overall Financial Benefit

An assessment of the project gave the cost for the coil and fan unit at $3,320. Ducting and other installation cost about $20,000, with a total project cost of under $28,000. The simple payback was well under three years.

9.3.2 Savings Example No.2; Heat Recovery from Hot Waste Water

A survey of process energy use in a textile plant identified that a fabric washing operation was discharging approximately 1200 litres/min (72 000 litres/hour) of hot waste water to drain at 82°C. It was determined that a counterflow heat exchanger with backflush capability could be used to preheat the incoming cold (15°C) water to be used in this process.

The optimal design of the heat exchanger provided a recovery rate of 55 percent. Savings may be estimated from the displacement of fuel oil required to heat the incoming cold water for the 4000 hours per year that the process operates, as follows:

Savings Analysis

Given:

Incoming water flow	72 000 litres/hr
Discharge temperature	82°C
Incoming water temperature	15°C
Recovery rate	55%
Steam heat cost	$6.00/GJ (including boiler efficiency)

Annual Savings

Energy = $M \times (T_{discharge} - T_{incoming}) \times C \times$ Recovery Rate

Where, M = 72 000 litres/h × 1 kg/litre × 4 000 hrs/year = 288 000 000 kg/year
C = 4.2 kJ/kg/°C

Energy = 288 000 000 kg/year × (82 − 15) °C × 4.2 kJ/kg/°C × 0.55
= 44 600 000 000 kJ/year or 44 600 GJ/year

Cost Savings = Steam Heat Cost × Energy
= $6.00/GJ × 44 600 GJ
= $267,600/year

As can be noted, the cost of lost condensate is significant.

Reference

CANMET's Energy Management Series Handbook; Waste Heat Recovery

Chapter 10
Assessing the Benefit

Objectives

To outline the qualitative and quantitative analysis of benefits and costs associated with the savings opportunities, and provide a detailed example.

10.1 A Comprehensive Assessment

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

Benefits:

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

Costs:

- direct implementation costs
- direct energy costs
- in-direct energy costs
- O&M cost increase

These key issues are explored in the following sections.

10.1.1 Assessment of Disadvantages Associated with Savings

The assessment of savings opportunities is generally conducted from a cost/benefit perspective. First, what are the savings (or the benefits) associated with the opportunity, and second, what is the cost of implementation required to realize the opportunity? Depending on the type of economic analysis used, consideration may also be given to the cost of maintenance with and without implementation.

Hot Energy Tip:

Lighting conditions can strongly impact staff productivity. Look for ways to improve the lighting conditions, you may even find energy savings. A superior quality lighting system design is often more efficient.

A further and often overlooked consideration is the indirect costs which may be associated with the action to be taken. These can include such things as a reduction in illumination level and heating cost increase when lighting is reduced, since energy for lighting will contribute to building heating in the winter. An extreme indirect cost could be the reduction in personal productivity due to unexpected reductions in light levels or, possibly, a safety problem created by an improperly located motion detector that switches lights off when a space is still occupied. It becomes clear that even the most attractive savings opportunity may not be attractive when all impacts are considered.

Often these costs are declared “unforeseen”. A thorough assessment should anticipate the majority of them, and clearly identify the associated risks before any changes are affected.

Another consideration which is neglected is the technical/economic risk associated with the planned implementation. Savings are not always guaranteed. It is unlikely that a motion detector installed to switch lighting in a heavy traffic area will pay back. Replacement of a poorly loaded motor with an energy-efficient motor may result in a lower overall efficiency owing to the partial load characteristics of the energy-efficient motor. When the savings predicted depend on varying operating conditions or occupant habits, there is a risk that the savings expected may not be realized, or realized to a lesser extent.

In these cases, the indirect costs are, in fact, uncertain savings. A conservative assessment would be based only on certain savings. If the uncertain savings actually occurred, then this would be a bonus.

In summary, consider not only the direct costs but also the impact that the planned implementation will have upon occupants, comfort, productivity, safety, equipment maintenance, along with any potential interactions between the new equipment and existing systems and the likelihood that the savings expected will be realized.

10.1.2 Savings

There are potentially three areas of savings to be directly realized from implementing a savings opportunity:

- Energy Savings: These would simply be equal to the energy saved (kWh) times the energy rate ($/kWh), almost always the last block 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 × 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 × (1st block energy – 2nd block energy)

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

- 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. Lighting kWh saved would, of course, only apply to the periods when the A/C is operating.

Hot Energy Tip:

Many incandescent lighting retrofits pay for themselves on the basis of maintenance cost reduction alone. The energy savings are a bonus.

- Less re-lamping labour and lamp cost from switching to a longer-life lamp type (e.g. replace incandescent lamps with compact fluorescent lamps offers a ten-fold increase in lamp life).
- Increase in employee productivity from converting to a higher quality, higher efficiency fixture type.

10.1.3 Costs

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

- 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 at 24 000 hours life to metal halide at 20 000 hours.
- Decrease in lamp life due to increase in switching, e.g., a standard 40W Rapid Start fluorescent tube operated for 10 hours per start will last 28 000 hours. The same tube operated 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 lighting kWh saved would only apply to periods when the heating system is operated. The heating system efficiency could typically range from .75 (oil) to .85 (gas or propane) to 1 (resistive electric) to 3 (i.e. the COP of a heat pump).

If the heating fuel is non-electric, the kWh increase must be converted to $ by dividing by the energy content per unit and multiplying by the unit fuel cost. For example:

Lighting kWh saved (heating season) = 20 000 kWh
Heating system efficiency (#2 Oil) = 0.75
#2 Oil energy content = 10.5 kWh/litre
#2 Oil cost = $0.25/litre

Heating kWh increase = 20 000/0.75 = 26 667 kWh
#2 Oil increase = 26 667/10.5 = 2540 litres
$ heating increase = 2540 × 0.25 = $635 per yr.

10.1.4 Economic Analysis

For the most part, a simple payback evaluation, i.e.:

Payback (yrs.) = Capital Cost ($) ÷ Annual Savings ($ per yr.)

is adequate when determining the feasibility of a retrofit measure. However, for larger investments, a life-cycle costing or complex payback calculation may be desired. The complex payback would take into account escalation rates of savings and borrowing, and possible changes in cost and savings amounts over the life of the measure.

A life cycle costing analysis determined the net cost/savings of a particular measure considering all cost and savings over the life of the measure. Very simply:

Net Costs/Savings = Cost Savings – Cost of Capital + Net O&M Cost Reduction*
*(summed for the life of the particular measure taken)

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 an approximation to the result of a life-cycle cost analysis, sometimes termed the complex payback period.

Hot Energy Tip:

Consider off balance sheet financing of energy projects. Energy management firms and energy service companies can provide turnkey implementation options and guaranteed energy performance. Energy savings performance for self financed projects can also be underwritten by third party insurers.

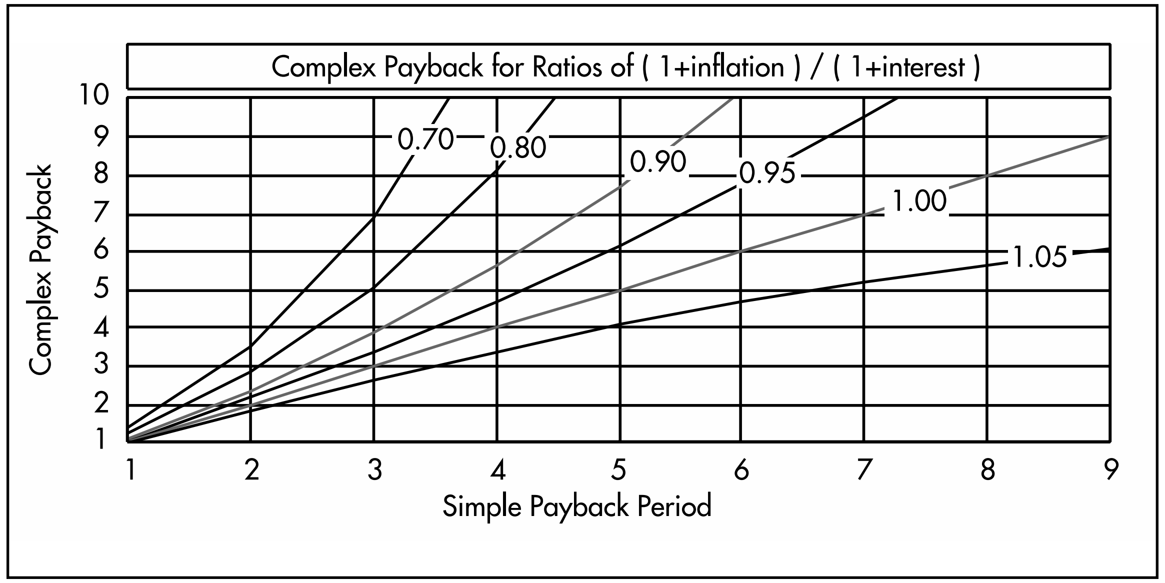


Figure 10.1: Adjustment of Simple Payback for Interest and Inflation Rates

Simple Payback versus IRR
Simple payback may not be the best indicator of the real value of a project. Table 10.1 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 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?

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%

Table 10.1: Internal rate of return estimation chart.

For example, a heat recovery project that has a simple payback of 3 years, and which is expected to deliver savings for 15 years would have an IRR of approximately 33%.

10.2 Detailed Electrical Energy Examples

The examples in this section present a variety of benefit assessments of electrical savings opportunities. They vary in terms of the equipment involved, the type of actions, the method of estimating savings and the level of detail involved. Often there is no "standard" method of benefit assessment – the method used will depend upon the situation, the data available and the quality of the estimates required.

10.2.1 Occupancy Detector Switching

Motion detectors (sensors) can be used to switch incandescent or fluorescent lighting in individual, private offices or small conference rooms with floor to ceiling walls, at either 120 or 347 volts. They can also be applied in washrooms to switch lighting and exhaust fans.

Sensors for at least two different room sizes can be purchased: rooms to 200 square feet and rooms to 700 square feet.

Hot Energy Tip:

Motion sensors can discourage staff from using the existing switches. Exercise all manual control options before installing such automatic controls.

System components consist of (i) the sensor; (ii) the control unit; (iii) line voltage (120 or 347V) wiring to the control unit and from control unit to lights; (iv) low voltage wiring from control unit to sensor (see schematic diagram in Figure 10.2 below). A standard wall switch to provide manual "off" override may be a sensible addition in rooms with substantial daylight; or manual switching may already be installed.

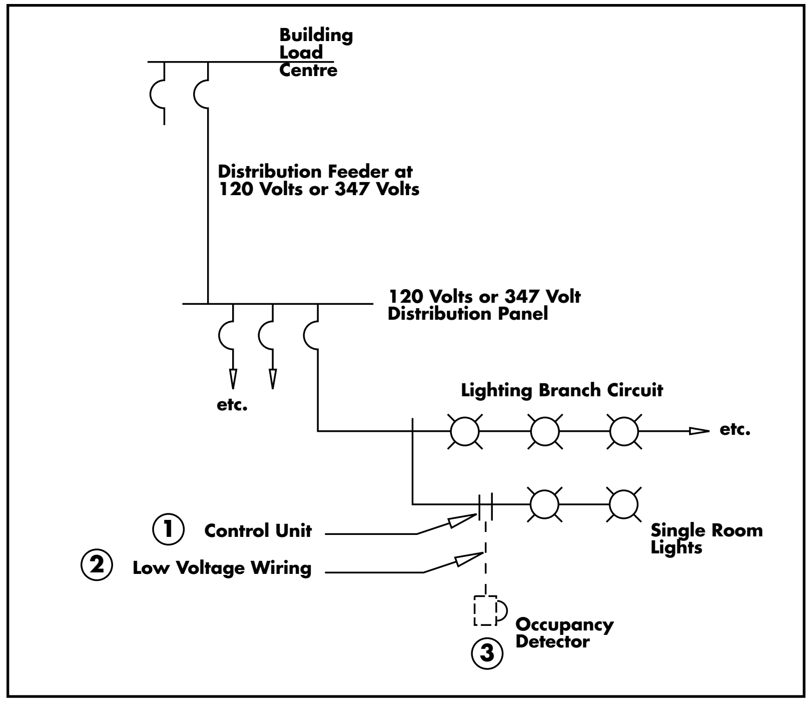


Figure 10.2: Ocupancy detector switching layout

Savings and Payback Calculation

The predicted "off" time of lights in a given room is the key factor in determining the viability of the retrofit. Sometimes this may be straightforward if a room has set occupancy patterns, but more often the patterns may be quite random (e.g., washrooms).

One method for collecting more accurate occupancy survey data would be to build or obtain a portable device which has an occupancy detector built in along with some means of recording the occupied/unoccupied periods. Some lighting suppliers have these and will loan them for surveys.

Candidates for occupancy sensor application might include washrooms, little-used hallways, offices, locker rooms, boardrooms, and stairwells.

Apart from the simple payback on kWh savings, there are other consequences of occupancy detectors which can affect the payback. These are:

- Decreased air conditioning costs due to reduced heat gain from lights.
- Reduction in lamp life due to more frequent switching.

These won't be considered here but may warrant evaluation if the payback in a given situation is marginal. No demand savings should be considered for occupancy detectors, since it is virtually impossible to ensure that the switched loads will be off during the peak demand period.

Worked Example

Given:

Lighting load to be switched (38 lamps, 19 ballasts) = 1.4 kW
Existing operating time = 4000 hrs/yr.
Lamp cost = $2.00 ea.
Ballast cost = $10.00 ea.
Electric Rate = $0.08/kWh
Proposed operating time (25% of existing) = 1000 hrs/yr.
Occupancy Detector Retrofit Cost = $800

Existing Operating Cost:

kWh = 1.4 kW × 4000 hrs. = 5600 kWh
kWh $ = 5600 kWh × $0.08 = $448.00
Relamping $ = 4000/20 000 × $2/lamp × 38 lamps = $15.20
Reballasting $ = 4000/50 000 × $10/ballast × 19 ballasts = $15.20
Total **$478.40**

Proposed Operating Cost:

kWh = 1.4 kW × 1000 hrs. = 1400 kWh
kWh $ = 1400 kWh × $0.08 = $112.00
Relamping $ = 1000/20 000 × $2/lamp × 38 lamps = $3.80
Reballasting $ = 1000/50 000 × $10/ballast × 19 ballasts = $3.80
Total **$119.60**

SAVINGS = $478.40 – $119.60 = **$358.80**

PAYBACK = $800/$358.80 = **2.2 Years**

10.2.2 Lighting Efficiency Improvement, Various Options

Lighting Basics

The light output from electric lamps is measured in **lumens**. The **efficacy** of various electric lamp types is stated in lumens/watt; in other words, the number of **lumens out** divided by the number of **watts of electric power into** the lamp.

Typical efficacies for various lamp types are:

Lamp Type	Lumens/Watt
Incandescent	10 – 18
Mercury Vapour	20 – 50
Fluorescent	40 – 80
Metal Halide	60 – 90
High Pressure Sodium	60 – 100
Low Pressure Sodium	90 – 200

The substitution or retrofit of existing lighting may involve more than simply switching to a higher efficiency lamp. **Colour rendition** must be taken into account. Light sources are rated with a Colour Rendering Index (CRI), as an indication of the colour shifting effect of the light source on an object, compared with the effect of reference source of a comparable colour temperature. CRI has a value of 0 to 100 and typical values are:

Light Source CRI Color	CRI	Color
Rendering Incandescent lamps	97	Excellent
Fluorescent, full spectrum 7500	94	Excellent
Fluorescent, cool white deluxe	87	Excellent
Compact fluorescent	82	Excellent
Fluorescent, warm white deluxe	73	Good
Metal halide (400 W clear)	65	Good
High pressure sodium (250 W, deluxe)	65	Good
Fluorescent, cool white	62	Good
Fluorescent, warm white	52	Fair
Mercury	43	Poor
High pressure sodium (400 W, diffuse-coated)	32	Poor
Mercury vapour (clear)	22	Poor
Low pressure sodium	–	(Undefined)

Table 10.2: Typical CRI values for various light sources.

Another consideration is that all of the lamp types except incandescent, require a special **ballast** to operate the lamp. So, you cannot simply substitute one lamp type for another.

The calculation of the number of lighting fixtures (luminaires) required to illuminate a specific room or process requires a degree of lighting design "know-how" which we are not trying to convey in this manual. However, lamp substitutions, such as changing from incandescent lamps to (screw-in) PL fluorescents, from a Type R lamp to Type ER, or from a conventional fluorescent lamp to an energy-efficient fluorescent lamp are decisions that can be taken by building operating personnel.

There are three components of a fluorescent light fixture which contribute to losses and inefficiencies in creating and delivering light to a task. This lamp, ballast and fixture retrofit example will address all three components.

Lamp

The T-8 style lamp achieves an increase in lumens per watt through a narrower diameter than the standard T-12 design (1" vs. $1^1/_2$"). This design, along with a highly efficient phosphor coating available in various colour renditions, has enabled manufacturers to increase the lumen output from 65 lumens/watt for a standard cool white lamp with a standard ballast to over 90 lumens/watt using T-8 lamps with an electronic ballast.

Hot Energy Tip:

34 watt and 40 watt T-12 lamps are almost indistinguishable. Most T-12 lamps today are 34 watts. The economics of a T-8 retrofit are influenced strongly by the lower wattage existing lamps.

Ballast

The function of a ballast is to provide high initial voltage to start the lamps and then regulate the flow of current to proper operating level. The standard ballast is an inefficient core and coil design which has a minimal cost but high energy losses (16 watts per two, 4' lamp fixture), audible noise, and causes lamp flicker.

Although improvements have been made to the conventional core and coil ballast (energy-efficient ballasts), the fully electronic ballast is the most efficient design presently available. The electronic ballast generates the required voltage and current using an electronic circuit. The 60 Hz incoming power is converted to a high frequency (>20 kHz) supply to the lamps. This change in frequency results in no lamp flicker and higher lamp efficiency. Additional benefits are no audible noise, a much lighter ballast weight, and very low losses within the ballast.

Hot Energy Tip:

Not all ballasts are created equal. The power consumption and light output of a T-8 lighting system can be tuned to match requirements by selecting from a range of ballast factors. Low ballast factor models reduce power consumption and light output while maintaining efficacy (lamp efficiency).

Fixture

The third loss-inducing component is the fixture itself, of which there are two parts, reflector and lens.

The lens (shield, louver) is designed to reduce visual discomfort due to glare from the bare lamps. Lenses can range from none through to parabolic to polarizing types, with widely varying cost. Since the lens is generally designed to match a particular fixture, lens retrofitting will not be examined here.

The reflector refers to any reflecting material within the fixture, such as painted surfaces. The standard strip fluorescent fixture has very little reflective surface, allowing light to radiate in all directions. By contrast, some newer fixture designs incorporate a highly polished, mirrored reflecting surface behind the lamps, directing the light in precisely designed paths. A reasonably good baked white enamel finish on a surface would be in the 80 to 90% reflectance range. A high quality silver backed polyester film would be in the order of 90 to 95% reflective. Also, the shape of the surface behind the lamps influences the pattern of the downward radiated light. All these things combine to produce the photometric characteristics of any given fixture.

A number of manufacturers are marketing retrofit reflector kits. These vary in design, construction and cost.

Savings and Payback Calculation

Given:

Existing fixtures are 4 tube, 4' standard fluorescent fixtures, total load per fixture = 192 watts

Operating Hours = 3000 hrs/year

Existing Lamp Cost = $2.00 ea.
Existing Ballast Cost = $10.00 ea.

Electric Rates Demand = $7/kW/month
Energy = $0.08/kWh

Proposed retrofit involves replacing 4 lamps, 2 ballasts with 2 T8 lamps and 1 electronic ballast, and installing reflectors.

Retrofit Cost (Per Fixture)

T8 Lamps 2@ $5.00 = $10.00
Electronic Ballast = $35.00
Reflector Kit = $20.00
Labour 0.5 hr. @ $30/hr. = $15.00
Total = **$80.00**

Existing Operating Cost:

kWh
192 w × 1/1000 × 3000 hrs/yr. = 576 kWh

kWh $
576 kWh × .08/kWh = $46.08

Demand $
192 × 1/1000 × 12 mos. × $7.00 = $16.13

Relamping $
3000 hrs/yr./20 000 hrs. × $2/Lamp × 4 Lamps = $1.20

Reballasting
3000 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. × $7.00/kW/mos. = $4.87

Relamping
3000 hrs/yr/20 000 hrs. × $5 × 2 Lamps = $1.50

Reballasting
3000 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.**

10.2.3 *Compressed Air Leak Reduction*

The major source of losses in a compressed air system is leaks in fittings, hoses, connections, etc.. Leaks can account for up to 50% of compressed air and, thus, electrical consumption. Some typical leakage rates for different hole sizes are listed in Table 10.3.

Hole Diameter	Air Leakage @ 600 kPa (87 psi) (Gauge)
1 mm	1 L/s
3 mm	10 L/s
5 mm	26.7 L/s
10 mm	105.7 L/s

Table 10.3: Leakage rates for various hole diameters.

Simplified Air Leakage Test

Step – 1 Determine the free air delivery capacity (Q) of your compressor (liters/second).

Step – 2 During a time when equipment is connected but not being used on the compressed air system, turn on the compressor and allow it to come up to full pressure.

Step – 3 Record the time (t) until the compressor starts again (loads).

Step – 4 Record the time (T) until the compressor stops (unloads).

Step – 5 Repeat the measurements at least four times.

Step – 6 Average the t and T cycles.

Step – 7 Calculate the leakage:

$$\text{Leakage} = \frac{Q \times T}{T + t} \text{ litres/second}$$

Savings and Payback Calculations

After determining the leakage using the above rate, the cost of these leaks can be calculated:

Leakage Cost ($/Yr.)

$$= \frac{\text{Leakage (L/s)}}{\text{Q (L/s)}} \times \text{Full Load (kW)} \times \text{Operating Time (hrs/yr.)} \times \text{Energy Cost (\$/kWh)}$$

Where:

Leakage: Calculated using above test

Q: Delivered air capacity (from nameplate)

Full Load kW: Measured or from nameplate (Volts × Amps × Power Factor × $\sqrt{3}$ (for 3 phase only)

Operating Time: i.e. the hours per year that the compressor is energized (not just the actual time it is running).

Energy Cost: From current electric rates, use second block energy charge.

This calculation will show the annual cost of the leaks. While it would not be possible to eliminate 100% of the leakage, the magnitude of the cost as calculated here will give you some indication of the level of repairs which can be justified on a payback calculation.

Other steps which can be taken to maintain optimum efficiency of your compressed air system:

- Operate system at lowest suitable pressure.
- Minimize pressure drops throughout distribution system (generally accomplished at design stage).
- Avoid water in system (causes corrosion, pressure drops and leaks).

Worked Example:

Given:

Q (air delivery capacity) = 236 L/s
Full load nameplate kW = 125 kW
Operating time = 4022 hrs/yr.
2nd block energy cost = $0.05/kWh

Measured:

	T (on time)	t (time between starts)
	30	180
	32	178
	33	188
	30	182
Avg.	31.25 sec.	182 sec.

Leakage $= \dfrac{Q \times T}{T + t} = \dfrac{236 \times 31.25}{31.25 + 182}$

$= 34.58$ L/s

Energy Loss Due to Leakage = (34.58/236) × 125 kW × 4022 hrs/yr.

= 73 666 kWh/yr.

$ Lost Due to Leakage = $0.05/kWh × 73 666 kWh/yr.
= $3,684/yr.

10.3 Detailed Thermal Energy Examples

The examples in this section present a variety of benefit assessments of thermal energy savings opportunities. They vary in terms of the equipment involved, the type of actions, the method of estimating savings and the level of detail involved. Often there is not “standard” method of benefit assessment – the method used will depend upon the situation, the data available and the quality of the estimates required.

The heat recovery example is in fact an actual case.

10.3.1 Warm Air for Boiler Combustion Air

During a diagnostic audit the combustion air temperature was 20°C while the air temperature near the boiler room ceiling was found to be 40°C. The potential exists to utilize the warm air from the ceiling to raise the temperature or pre-heat the boilers combustion air.

This represents an effective and inexpensive energy savings opportunity if the warm air is ducted directly to the combustion intakes and utilized for combustion. One might term this a “low tech” heat recovery system, since typically the warm air from the top of the boiler room is lost.

An analysis of the boilers efficiency including the combustion efficiency shows an existing efficiency of 77.8%.

Analysis also shows that pre-heating the combustion air by 20°C would increase the boilers efficiency to 78.9%.

Although the size of this boiler plant is large at a steam capacity of approximately 36 000 kg/hr, the cost of the retrofit is relatively small as it only would require sheet metal duct work.

Savings Analysis

Given:

Existing Efficiency:	77.8%
Proposed Efficiency:	78.9%
Annual Fuel Cost:	$560,000/year
Retrofit Cost	$10,000

Annual Savings:

Savings = Fuel Cost × Efficiency Increase ÷ Proposed Efficiency

= $560,000 × (78.9 – 77.8) ÷ 78.9

= $7,800 /year

Simple Payback:

Payback = $10,000 ÷ $7,800/yr
= 1.3 years

It should be noted that the simple savings analysis used here could be applied to any actions that would influence boiler efficiency and for which existing and proposed boiler efficiencies where known.

10.4 Environmental Impact

Measures to improve energy efficiency will reduce emissions in two ways:

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

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

10.4.1 On-site Combustion Systems – Direct Impact

The level of NO_x, VOCs and SO_x emissions from combustion systems can be estimated using the table at the end of this section. Tables from Environment Canada and the U.S. Environmental Protection Agency are available, only the Canadian data is included in Table 10.4.

The following example illustrates the use of these data tables.

- A soaking pit in a steel mill was re-insulated and the original natural gas burners were retrofitted with high efficiency burners. Annual fuel savings are estimated at 50 terajoules (TJ). What would be the corresponding reduction in the emission of NO_x, VOCs, SO_x and CO_2?

The following emission factors, from the Environment Canada Emission Factors table are used for natural gas fuel; NO_x, 59.29 kg/TJ; VOC, 1.17 kg/TJ; SO_2, 0.26 kg/TJ; CO_2, 49 680 kg/TJ.

NOx reduction
= 50 Terajoules/yr × 59.29 kg NO_x/TJ
= 2964.5 kg/yr.

VOC reduction
= 50 Terajoules/yr × 1.17 kg VOC/TJ
= 58.5 kg/yr.

SO_2 reduction
= 50 Terajoules/yr × 0.26 kg SO_2/TJ
= 13 kg/yr.

CO_2 reduction
= 50 Terajoules/yr. × 49 680 kg CO_2/TJ
= 2 484 000 kg/yr.

The calculated NO_x reduction is at best an approximation since the formation of NO_x depends on temperature as much as on the availability of nitrogen and oxygen.

Measures that improve energy efficiency can sometimes increase NO_x production. This can occur with combustion air preheat which increases the combustion temperature, and hence the amount of NO_x produced. Thus, determinations of NO_x reduction are best made by measurements with a flue gas analyzer.

10.4.2 Impact of Reductions in Electrical Consumption, In-Direct Impact

Energy management projects that reduce electrical consumption also have a positive effect on the environment. However, the emission reductions occur at the electrical generating station rather than at the site where the efficiency improvements have been made.

Thermal-electric generating stations firing coal, oil or natural gas are generally used in some provinces to provide power to their respective distribution grids during peak periods. Therefore, it can be assumed that a reduction in the use of electricity will result in reduced fuel consumption and emissions.

This may not be true in provinces where fuel fired plants may supply base load power rather than peak power. It is important that the reader first check with the local electrical utility to determine the source of this “marginal” power. If the marginal power is not from a fuel-fired plant then no claim can be made for emission reductions.

Hot Energy Tip:

Your organization’s public commitment to reduce emissions through energy management can be submitted to the Voluntary Challenge and Registry (VCR).

The method used to calculate the emission reduction is the same as previously outlined except that an additional calculation must be performed to convert a kilowatt-hour saved at the site into a fuel saving at the generating station. This is done by converting annual kilowatt-hour savings to terajoules and then adjusting the figure to account for electricity generation efficiency at the generating station and losses in the electrical distribution system. The following example demonstrates the calculations used to calculate emission reductions.

An energy management program at a large manufacturing plant involved the replacement of fluorescent light fixtures with metal halide fixtures. Several large electric motors were also replaced with high efficiency motors. The total annual energy saving was 33 600 000 kWh. The corresponding reduction in emissions is calculated as follows:

Convert kWh to TJ, where 1 kWh
= 3.6 × 10^{-6} TJ

Electrical Energy Saving (TJ)
= 33 600 000 kWh × 3.6 × 10^{-6} TJ/kWh
= 120.96 TJ

Convert to fuel equivalent saving at the generating station using a conversion efficiency of 32%, which takes into account the following:

Fuel-to-electricity efficiency
= 33.5%

Electrical transmission system efficiency
= 96.0%

Overall conversion efficiency
= 0.335 × 0.96
= 0.32 (32%)

Annual fuel saving at generating station.
This example assumes that bituminous coal is being fired.
= 120.96 TJ ÷ 0.32
= 378 TJ

NO_x reduction

= 378 TJ × 218.07 kg NO_x/TJ
= 82 430 kg

VOC reduction

= 378 TJ × 1.25 kg VOC/TJ
= 473 kg

SO_2 reduction

= 378 TJ × 1457.94 kg SO_2/TJ
= 551 101 kg

CO_2 reduction

= 378 TJ × 86 720 kg CO_2/TJ
= 32 780 160 kg

Emissions (kg/TJ)				
Fuel Type	NO_X	VOC	SO_2	CO_2
Coke				106 330.00
Coal – bituminous	218.07	1.25	1457.94	86 720.00
Coal – lignite	0.00	0.00	1628.96	101 680.00
No. 2 Fuel Oil	62.32	0.62	113.33	73 110.00
No. 6 Fuel Oil	161.37	0.83	853.43	71 540.00
Kerosene	63.69	0.64	30.67	67 650.00
Natural Gas	59.29	1.17	0.26	49 680.00
LPG	56.42	1.11	0.15	59 840.00
Fuel Wood	–	–	–	81 470.00
Diesel Oil	161.37	0.83	–146.17	70 690.00
Pulping Liquor	68.79	64.49	–	628.57
Petroleum Refinery Gas	–	–	–	12 080.00

Table 10.4: Environment Canada Emission Factors (Industrial Fuels)

10.5 Summary

The benefits that may be derived from energy management projects are clearly comprehensive in nature. So, too, must be the approaches to assessment whether it be the identification of opportunities, or as outlined in this chapter, the quantification of the benefits.

References

Commercial Energy Manual Fundamentals, Ontario Hydro, 1991

Electrical Efficiency Improvement, Boiler Efficiency Institute, Auburn, AL, 1992

Boiler Efficiency Improvement, Boiler Efficiency Institute, Auburn, AL, 1992

Modern Industrial Assessments: A Training Manual, Rutgers, The State University of New Jersey, 1995 (available online at: http://oipea-www.rutgers.edu/documents/doc_f.html)