ENERGY
MANAGEMENT
SERIES

FOR INDUSTRY
COMMERCE
AND INSTITUTIONS

Conducting an Energy Audit

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

Canada

Catalogue No.: M91-6/02E

ISBN 0-662-14150-4

PREFACE

Much has been learned about the art and science of managing energy during the past decade. Today, energy management is a seriously applied discipline within the management process of most successful companies.

Initially, in the early 1970's, energy conservation programs were established to alleviate threatened shortages and Canada's dependency on off-shore oil supplies. However, dramatic price increases quickly added a new meaning to the term "energy conservation" — reduce energy costs!

Many industrial, commercial and institutional organizations met the challenge and reduced energy costs by up to 50%. Improved energy use efficiency was achieved by such steps as employee awareness programs, improved maintenance procedures, by simply eliminating waste, as well as by undertaking projects to upgrade or improve facilities and equipment.

In order to obtain additional energy savings at this juncture, a greater knowledge and understanding of technical theory and its application is required in addition to energy efficiency equipment itself.

At the request of the Canadian Industry Program for Energy Conservation, the Commercial and Institutional Task Force Program and related trade associations, the Industrial Energy Division of the Department of Energy, Mines and Resources Canada has prepared a series of energy management and technical manuals.

The purpose of these manuals is to help managers and operating personnel recognize energy management opportunities within their organizations. They provide the practitioner with mathematical equations, general information on proven techniques and technology, together with examples of how to save energy.

For further information concerning the manuals listed below or material used at seminars/workshops including actual case studies, please write to:

Business & Government Energy Management Division
Energy Conservation Branch
Department of Energy, Mines and Resources
580 Booth Street
Ottawa, Ontario
K1A 0E4

Energy Management/Employee Participation
Conducting an Energy Audit
Financial Analysis
Energy Accounting
Waste Heat Recovery
1 Process Insulation
2 Lighting
3 Electrical
4 Energy Efficient Electric Motors
5 Combustion
6 Boiler Plant Systems
7 Process Furnaces, Dryers and Kilns
8 Steam and Condensate Systems
9 Heating and Cooling Equipment (Steam and Water)
10 Heating Ventilating and Air Conditioning
11 Refrigeration and Heat Pumps
12 Water and Compressed Air Systems
13 Fans and Pumps
14 Compressors and Turbines
15 Measuring, Metering and Monitoring
16 Automatic Controls
17 Materials Handling and On-Site Transportation Equipment
18 Architectural Considerations
19 Thermal Storage
20 Planning and Managing Guide

Available in Canada through

Associated Bookstores
and other booksellers

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

Catalogue No. M91-6/02E ISBN 0-662-14150-4

Price subject to change without notice

TABLE OF CONTENTS

1. INTRODUCTION

2. SELECTING THE AUDIT SITE

3. DATA COLLECTION

4. PRELIMINARY DATA ANALYSIS

5. SURVEY PLANNING

6. THE AUDIT SURVEY

7. EVALUATION OF ENERGY MANAGEMENT OPPORTUNITIES

8. AUDITING, MONITORING AND TARGETING

9. BOILER PLANT AND SYSTEMS

10. PROCESS FURNACES DRYERS AND KILNS

11. STEAM DISTRIBUTION AND CONDENSATE RETURN SYSTEMS

16. ELECTRICAL SYSTEMS

17. HEATING VENTILATING AND AIR CONDITIONING

18. BUILDING ENVELOPE

19. UTILITY RATE STRUCTURES

1-INTRODUCTION

1.1 - Background

In recent years the growth in Canadian energy consumption has been about five percent per year. At this rate, the amount actually consumed doubles every fourteen years. In each 'doubling time' the amount of energy consumed is equal to the amount consumed since Canadian production began.

While Canada is fortunate in having a substantial renewable energy source in hydro electricity, fossil fuels such as coal and petroleum products account for a large proportion of our total energy consumption.

In the early days of Canadian petroleum extraction, an increase in demand could be accommodated by an increase in supply. This is no longer the case; the peak of oil extraction has passed and is currently decreasing. Since the 1960's the amount of oil discovered has fallen; in the 1970's, more oil was being consumed than discovered. "Canadian Energy Supply and Demand 1983 - 2005" reports that based on projected reserves and past consumption Canada has used half of what was originally in the ground. The same source states that overall demand for oil will outstrip Canadian production by 1990, and, at present growth rates, current reserves will last only to the year 2030. After this time, Canada will be totally dependent on imports for its petroleum supply, and prices can be expected to increase dramatically.

Building new power stations is becoming an increasingly difficult and lengthy process. Consequently supply authorities are more and more looking to energy conservation as an alternative when faced with rising demand. Using rate structure or direct financial incentives energy conservation costs less in dollars per kilowatt than power station construction.

The implementation of an **Energy Management Program** will help to forestall future price increases. The efficient use of energy therefore represents the most tangible contribution to maintaining the supply of energy that can be made.

In addition to supply issues, a wide range of environmental ills, such as acid rain, the greenhouse effect, smog and pollution have been identified as arising from the combustion of fossil fuels. Correcting inefficiencies in the use of energy contributes significantly toward reducing these problems. From a more directly tangible standpoint, energy management is a sound investment. It offers investment opportunities with attractive pay back periods and above average returns. An energy audit, followed by the implementation of energy management opportunities can represent a most cost effective way of reducing operating costs in a building or plant.

1.2 - The Manual

This manual, which is part of the Energy Management Series (EMS) has been designed to assist in organizing and conducting an energy audit using 'in-house' resources; the intent being that the process of controlling energy usage can start by:

- identifying Energy Management Opportunities (EMOs) for immediate implementation.
- identifying EMOs for further detailed in-house study.

- identifying areas where outside specialist help is required.

The manual also provides a first line source of technical information on such aspects as system basics and energy saving retrofit ideas. This material is complimented by and expanded upon in the other EMS manuals.

1.3. - Energy Management Program

The establishment of an **Energy Management Program** within an organization is the first step to improving energy efficiency. Such a program would include the following major elements:

- establishment of a management framework.
- monitoring of existing usage.
- an **Energy Audit.**
- implementation of recommendations.
- ongoing monitoring.

Further detailed information can be found in the Energy Management Manual.

An Energy Audit is only one part of the overall program and by itself cannot achieve the primary objective of saving energy. A management framework must first be in place to ensure that the resources are available to deliver the Program and that the authority exists to implement any **Energy Management Opportunities** (EMOs) identified.

The extent to which a company may perform an audit internally will depend upon the following:

- resources available.
- time available.
- staff skills available.
- management commitment.

The auditor should obtain a mandate from management defining the above items before commencing the audit.

Implementation of the audit findings is fundamental to improving the efficiency of energy usage. In order to allow a phased implementation of measures, EMOs discussed in this and other manuals of the Energy Management Series are categorized as **Housekeeping, Low Cost or Retrofit.**

Following the implementation of EMOs it is essential to develop an ongoing monitoring program to ensure that the benefits are attained and maintained.The use of targets for consumption allows a simple check of the improvements achieved. It also represents an excellent motivator for staff to become involved and, as such, the establishment of a monitoring and targeting system may itself be a significant means of attaining energy savings.

1.4 - Energy Audits

An energy audit is defined as **a series of actions aimed at the identification and evaluation of**

energy management opportunities (EMOs) within a defined site. In this manual energy auditing is presented as a **"two-stage, system-based"** procedure ; a **"walk-through audit"** being the first stage, and a **"diagnostic audit"**,the second. The **walk-through audit** is intended to be a qualitative examination of a building or facility. This permits identification of:

- EMOs for immediate implementation without further evaluation These will be primarily Housekeeping measures and low cost items which need no further evaluation to demonstrate their cost benefit.
- areas or systems which should be examined in more depth, either by in house staff or specialist consultants.

The **"two stage"** approach maximizes the effectiveness of the audit by ensuring efforts are directed to areas of greatest potential savings with as little detail as possible.

The objectives of the **"diagnostic audit"** are to ensure that adequate data is collected to permit a more detailed evaluation of an EMO. These diagnostic surveys will address specific areas or actions rather than the whole facility.

Information on carrying out **walk-through audits** is described in this manual. For detailed information on specific energy systems and diagnostic audits the reader is referred to the other Energy Management Series (EMS) documents.

"System-based" means that the individual components or sub-systems can be examined separately. The following categorization is used:

- Boiler Plant Systems.
- Process Furnaces, Dryers and Kilns.
- Steam Distribution and Condensate Return.
- Domestic Hot and Cold Water systems.
- Process Refrigeration.
- Lighting.
- Electrical.
- Heating, Ventilation and Air Conditioning.
- Building Envelope.
- Rate Structure.

This system-based approach permits individual services such as lighting or hot and cold water to be examined separately if, for example, these areas have been identified as the most likely areas for savings, or to suit the availability and expertise of resources.

The main steps in conducting an energy audit are shown in Figure 1.1.

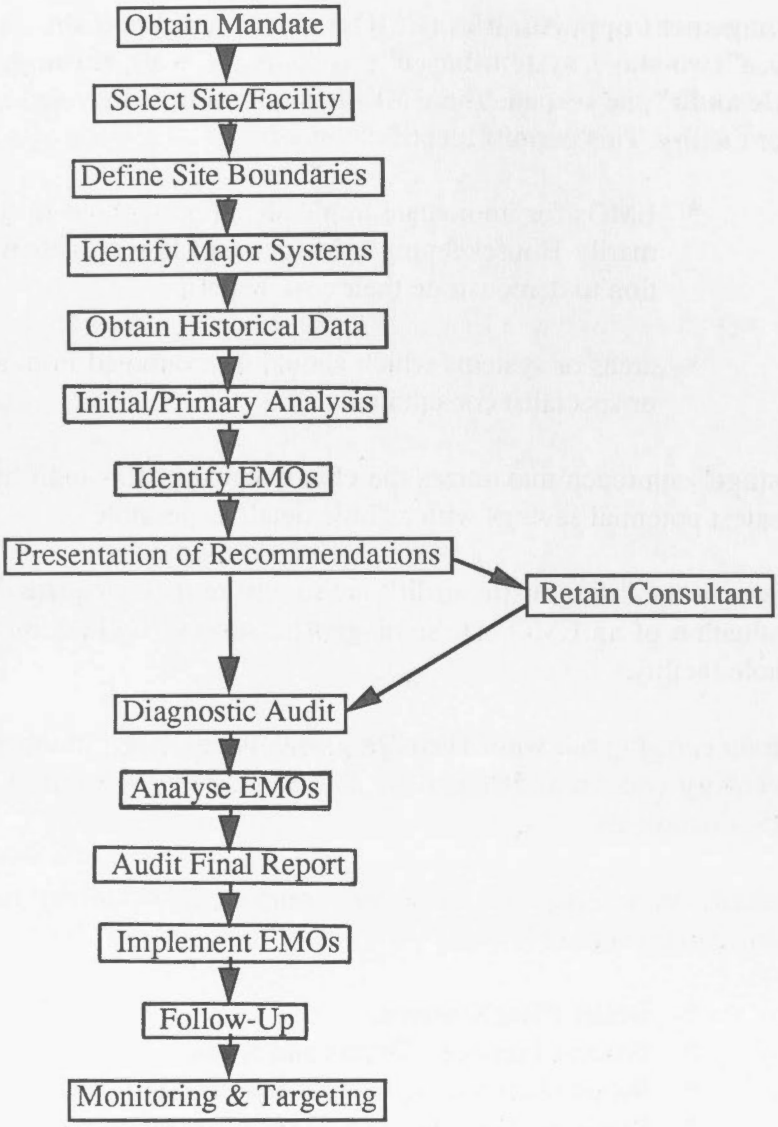


Figure 1.1 The Audit Process

Each of these steps is discussed in more detail in the following sections.

There are more potential paths through the procedure than are shown and experience may allow short cuts to be taken. For instance, on a small site or where time or funds are severely restricted, the process may be simplified to:

Figure 1.2 Simplified Audit Process

This approach is satisfactory provided the walk-through audit clearly identifies the primary or major causes of inefficiency or loss. However the walk-through audit may more often raise further questions or point out areas needing detailed examination or analysis. In these cases, diagnostic survey work and analyses of measures may be essential to ensure that EMOs are appropriate and cost effective.

1.5 - Benefits of Improving Energy Efficiency

Apart from the global importance of conserving valuable resources for future generations, there are a number of benefits arising from improved energy efficiency

- the opportunity for substantial monetary savings which continue year after year.
- the reassurance that energy is being used wisely.
- a better understanding of how the energy is being used in the facilities.
- the opportunity to improve the interior environment.
- reduction of the risk of nuisance breakdowns.

Energy audits on over 14000 commercial and industrial companies in Canada found opportunities for saving money in every audit. The dollar savings averaged 20 percent of the annual energy costs of the facilities audited and remained relatively consistent over the nine year period during which the audits were conducted. Such savings can represent significant reductions in overheads.

IT IS THEREFORE PROBABLE THAT IT WILL BE PROFITABLE FOR COMPANIES AND ORGANIZATIONS TO INVEST THE TIME AND RESOURCES NECESSARY TO IMPLEMENT AN ENERGY MANAGEMENT PROGRAM.

1.6 - Connected Issues

Before the auditor prepares recommendations for evaluation by management, there are often other factors that may affect the way changes are presented. Indoor air pollution, environmental pollution and future sources of non-renewable energy supplies are all connected with the consumption of energy. The actions being recommended by the auditor may involve one or more of these factors. Issues are flagged where appropriate in later chapters where individual EMOs are discussed.

1.7 - Obtaining Help

Probably one of the biggest mistakes management can make is not to seek outside help and assistance for finding solutions to problems related to energy usage. Recognizing that energy availability and rising energy prices are global problems, it is certain that no organization's problems are unique. However, many industrial, commercial and institutional organizations are finding solutions to these problems. No one person knows and understands the mall. Therefore, outside advice may at times be desirable and necessary.

Private consultants, utility companies, trade associations, task forces, governments, suppliers and contractors can all provide some specialized assistance - sometimes at no charge and with a depth of experience that is not readily available in-house.

1.7.1 - Private Consultants

Many consulting firms specialize in energy auditing. In doing so, they will often have developed particular skills and detailed knowledge of equipment and retrofit measures. However, consultants rarely have the in-depth knowledge or experience specific to a particular facility and they will always require support from on-site staff.

1.7.2 - Utility Companies

Most utility companies are now offering technical advice on the most efficient methods of utilizing their products.

1.7.3 - Trade Associations

Trade associations whose members are concerned with similar manufacturing process, products or services can be of assistance by sharing energy related problems.

One of the more useful services a trade association can often provide is the sharing of results of detailed surveys of energy usage and energy profiles for its particular industry. Results of the survey can be used to show how a facility compares on energy usage relative to size, structure, location, production, etc. of similar operations.

1.7.4 - Government Organizations

Governments, both at the Federal and Provincial level, can provide guidance on energy related problems. The Federal government maintains offices in each Province where knowledgeable staff and comprehensive libraries of information are available to assist companies. Most Provincial governments also maintain offices which are geared to helping companies improve their energy efficiency. Local offices may be found in the blue pages of the telephone directory.

1.7.5 - Contractors

Specialist suppliers and contractors are frequently an excellent source of information. In some cases it may be available free (with the company speculating that it may lead to a contract) or there may be a fee attached for a specialized service such as a combustion efficiency test, lighting survey, steam trap survey, thermographic scan, insulation survey, specialized metering, or complete energy audit.

2 - SELECTING THE AUDIT SITE

2.1- Introduction

Defining the location for the energy audit may be a very simple or quite a complex procedure. If a management decision has been made to include the whole site or alternatively just a particular building or section, then no further consideration is necessary. However, the auditor may be faced with a choice of a number of sites or one site with a number of buildings or even a very complex single building. The decision must be made as to which facilities are to be examined and in what order. If time or funds are limited, wise selection of the location and order of sites will maximize the cost effectiveness of the auditing process. For simplicity, reference will be made to potential sites as 'buildings' but the techniques can equally apply to groups of buildings, manufacturing plants or parts of a complex.

2.2- Rating Buildings for Audit

The aim of establishing a rating is to allow a direct comparison of energy saving potential between buildings which may be very dissimilar. In order to establish any ratings, certain basic energy consumption information is required. This is normally available from utility company billings. In addition, it is important to compare buildings over similar time periods; twelve months is the best analysis period as it represents a complete heating and cooling load cycle and as data on energy costs, production, etc., is normally collected annually for accounting purposes.

Often the consumption data will not be available for exactly the same time periods and if periods vary by more than a few days, it would be worthwhile making an adjustment to the figures (or take a two year period to limit the effect). The Energy Accounting Manual, in the EMS, provides detailed guidance on this procedure.

There are a number of methods which can be used to provide a comparative rating. They should normally be used in the order listed, with subsequent methods used only when the previous method fails to rate the buildings satisfactorily.

2.2.1 - Method 1

The simplest form of rating is to rank the buildings in order of energy consumption. The ranking is most easily done at this stage in terms of dollars as it accounts for different fuel types and data is normally available in this form from utilities billings or accounting records. When there is a choice of a number of potential audit sites, the largest energy users should always take preference. This rating does not take account of the efficiency of the building but a 5% saving on a building consuming $100,000 per annum is more valuable than a 40% saving from a building using $10,000, and is normally easier to achieve. The inadequacies of this selection technique are greatest where a number of buildings use similar amounts of energy or where process energy use inflates consumption in some buildings.

2.2.2 - Method 2

A more sophisticated approach is to use consumption per unit floor area. This method will often determine the best audit site where different sized buildings have similar energy consumption. This approach may be adequate in most cases but its drawback is that it takes no account of hours of use, ie a building operating 24 hours a day using twice the energy (per unit floor area) of a building operating 8 hours a day may not be the best of the two to audit.

2.2.3 - More complex methods

More complex rating techniques may be necessary if the first two methods prove inadequate to clearly rank the buildings. Ratings based on a per unit output basis should be examined. For example, energy use may be compared based on hours per year occupied, number of occupants (eg. for hotels), production levels, or meals served (in restaurants).

Other factors which may affect the decision as to which building to audit include:

- type of energy systems installed.
- type of fuel used.
- planned refurbishment or upgrade of facility.

2.3 - Definition of Audit Boundaries

It is important to define the boundaries of the audit site at an early stage. This may appear trivial if one is considering a single building but even here a decision may be necessary for the grey areas, for example, on whether or not to include external car park lighting or production and distribution losses from an adjacent boilerhouse.

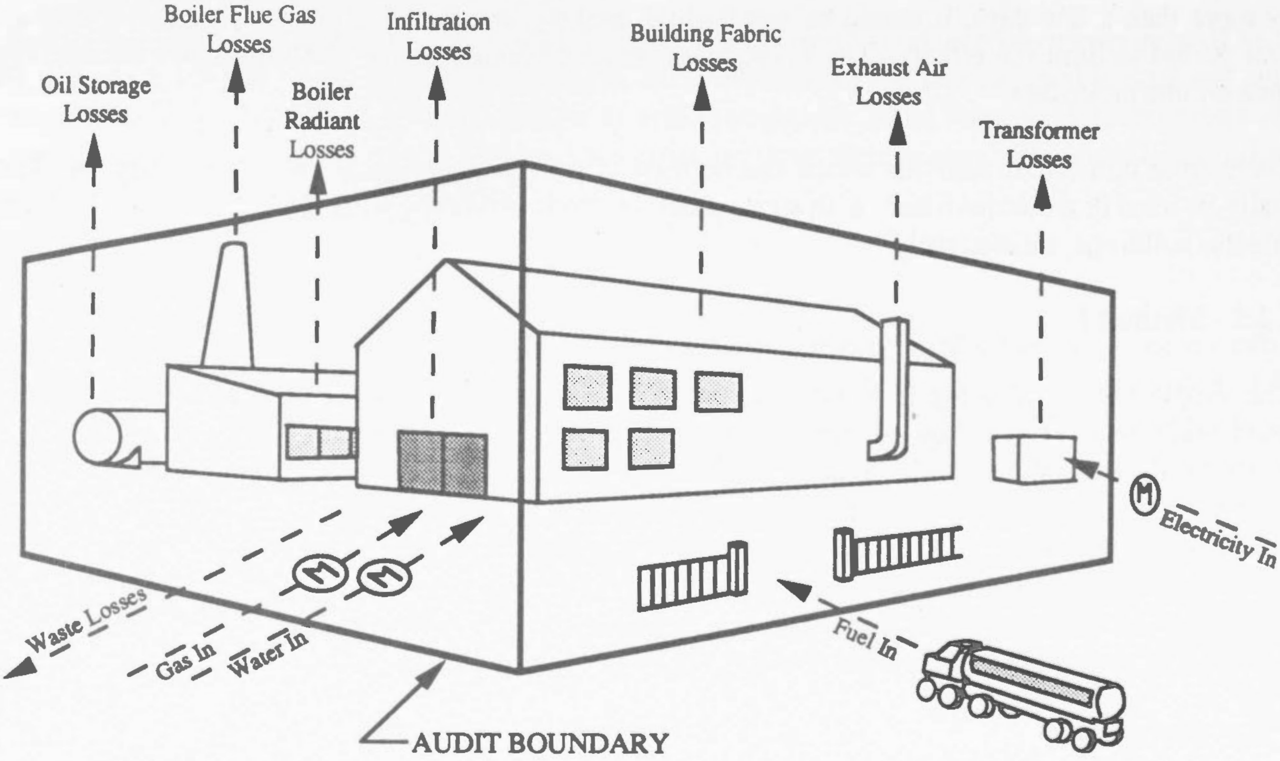


Figure 2.1 Black box approach to energy flows across audit boundary

In production environments, the boundaries may be further complicated, particularly where it has been decided to look specifically at one area, such as a specific production line.

It may help to visualize a box around the building and to look at all the energy flows into or out of the box as illustrated in Figure 2.1.

Measurement of these energy flows may play a large part in determining the audit boundary. To maximize the accuracy of auditing, direct measurement of energy flows should be used wherever possible. This will often be difficult for outputs which may be in the form of air infiltration losses, building fabric losses or energy input into a product.

Inputs are more readily measured using electricity or fuel meters and the area served by the meters may be used to define the audit boundary. For example, if the building electricity meter feeds the car park lighting, it would be simpler for it to be included. If the heating input to a building from an adjacent boilerhouse is unmetered but the boilerhouse has fuel, water and electricity metering, then the boilerhouse should be included.

In many cases the physical boundaries of the property or site may form the most logical and easily definable audit boundaries.

2.4 - Audit Mandate

Having defined the audit boundaries the auditor should check with management to ensure that the scope of activities planned is in line with their intentions. The "Audit Mandate Checklist", given in Appendix D may be of assistance in ensuring that the auditor's mandate is accurately defined.

2.5 - Identification of Major Systems

Once the auditor's mandate has been precisely defined, the energy systems to be examined can be identified.

The auditor's workload can be minimized at this stage by eliminating those systems which do not fall within the audit boundaries. There are eleven major classifications for energy systems used in this manual, these are;

- Boiler Plant
- Process Furnaces, Dryers and Kilns
- Steam Distribution
- Domestic/Process Hot and Cold Water
- Process Refrigeration
- Production Processes
- Lighting
- Electrical
- Heating, Ventilating and Air Conditioning
- Building Envelope
- Utility Rate Structures

Having identified the audit boundaries and hence the major energy systems involved, then only the relevant sections of the manual need be examined further.

3 - DATA COLLECTION

3.1 - Introduction

Data on energy consumption, and production output where appropriate, is vital to all but the simplest energy audit. To this end, the collection and monitoring of consumption and output should begin as soon as auditing is considered. The longer the period that data is available for, the better. Even where complete records are available, for instance monthly electricity bills, weekly or daily meter readings taken independently can be of assistance in analyzing energy use, loss or savings. In addition, when carrying out an energy balance, more detailed consumption data will assist in quantifying specific energy flows and increasing the accuracy of the balance.

For an energy audit the following data will be required:

- Utility bills for the audit period plus one additional bill either side of the period under evaluation.
- Production records for the same period.
- Water consumption data.
- Record drawings.
- Capacity data for major items of equipment, eg. boilers, pumps and motors.
- Weather data for the audit period.
- In-house records of electricity and fuel consumption.

3.2 - Fuel and Electricity Bills

As mentioned previously, a twelve month evaluation period is desirable. It is also important to use the most recent period for which records are available. This will minimize the effect of changes in load due to building extensions or plant replacement. This will be discussed further under Section 4.

Often meter reading dates for different fuels will not coincide. This is not critical if the overall periods examined are within a few days of the chosen evaluation period.

The greatest difficulties often encountered are 'estimated readings.' These can be a major source of inaccuracy and evaluation periods should ideally never commence or finish with an estimated bill. This may mean adjusting the evaluation period by a month or even a quarter; additional utility bills will be useful in these instances.

Techniques for analyzing monthly fuel use to obtain an energy balance are explained in the Energy Accounting Manual. These techniques require accurate consumption data for validity. This is where boilerhouse or maintenance logs of meter readings or fuel stocks will be invaluable in obtaining a realistic disaggregation of energy use.

3.3 - Production Records

For buildings with energy consuming manufacturing processes, it is important to be able to take this consumption into account. For example, a factory which shuts down for two weeks in the summer will probably have a low consumption during this month.

Even where production processes are not energy intensive the output may increase at any time due to overtime. Adjustment to consumption for these factors must be made to 'normalize' consumption for auditing purposes.

3.4 - Water Consumption Records

While not a fuel, water is a resource and costs money, therefore conservation potential may exist. In addition water usage data often provides valuable clues to energy used, for instance, in domestic hot water heating. It can also provide evidence of problems in boiler operation, system leaks or process losses.

3.5 - Record Drawings

Accurate record drawings of the building, its systems and any process machinery should be sought. Design (as opposed to 'as-built') drawings which are more often available should be used with caution as they may be inaccurate. In an older facility drawings are frequently out of date. However, they may still be of some use in establishing design philosophy and equipment locations.

Drawings may be used to provide data which would otherwise have to be recorded on site. Examples include:

* floor areas.
* wall, window areas.
* insulation standards.
* mechanical systems types.
* lighting types and number of fixtures.
* location of meters.
* plant capacities.

Considerable time savings can be made in carrying out the audit if this type of information is available.

3.6 -Capacity Data

Capacity data is valuable for calculating the energy use of equipment or plant in the absence of direct metering. Data, though not always complete, can usually be obtained from rating plates.

The data required typically would be electrical demand (kW or amps), fuel consumption rate or heat output. This may be obtained from a number of sources if not on the equipment:

* record drawings.
* design drawings or specifications.
* maintenance manuals.
* plant log books.
* manufacturers (if serial or model numbers are available).

3.7 -Weather Data

Weather data for the evaluation period will be required if a diagnostic audit is planned or if an energy balance attempted. This is normally obtained from the local Meteorological office of Environment Canada. For most purposes data in the form of 'degree days' per month is usually adequate.

In some cases where the consumption data has to be corrected due to inappropriate reading dates, daily 'degree days' may be required. Monthly data can often be obtained by telephone but daily information for more than a few days may have to be obtained in writing in the form of a monthly report for which there may be a charge.

3.8 - Local Records

Daily meter readings might be recorded in manned boilerhouses and similarly consumption per shift for processes. In fact, there can be numerous records kept in large facilities. Alternatively there may be no records and in these cases it is beneficial to begin taking meter readings as soon as possible when considering an audit.

There is a danger of being inundated with records from different departments, some or all of which may not be required or may not be in a usable form. For instance, hourly fuel consumption of a boilerhouse may be recorded but this may prove too tedious to analyze. It may therefore be prudent not to analyze such lengthy information until it is definitely required.

4.- PRELIMINARY DATA ANALYSIS

4.1- Preliminary Energy Analysis

Prior to commencing survey work some initial analysis of the data collected will be beneficial. Before proceeding with any analysis, however, the auditor should be familiar with rate structures for the fuels used. Discussions with the fuel suppliers are recommended to review the suitability of the current rates. Some basic discussion of rate structures is given below and in Section 19.

Consumption of different fuels is recorded in units which are generally not directly comparable with each other. For example:

* Fuel oil in litres (L)
* Natural Gas in cubic metres (cu.m)
* Coal in Tonnes (T)
* Electricity in kilowatt hours (kWh)

The figures may be compared with each other, in terms of dollars or in terms of energy content; conversion factors are provided in Appendix B to convert each of these units into megajoules (MJ).

4.2- Utility Bills

Difficulties and complexities involved in rationalizing energy costs are discussed below.

4.2.1- Electricity

The amount of information provided on the bill will vary between supply companies and on the size of a particular consumer. The information available will normally be the limiting factor in the preliminary fuel analysis.

Ideally the following figures are required:

* Power factor.
* Maximum demand
* Load factor
* Average unit cost

Power factor (pf) is a measure of how 'efficiently' electricity is being used. An ideal unity power factor (ie. pf=1) means that all the electrical current supplied is converted into useful power. In most instances electrical loads such as motors or fluorescent lighting, which are inductive loads, produce a 'lagging' power factor (ie. less than one).

Power factor should be examined only where the supply authority makes a separate pf charge or charges for maximum demand in kVA. This will be apparent from the bill. If maximum demand is charged in kilowatts (kW) then there is no direct penalty for a poor pf and hence, there will be little cost benefit making an improvement.

If the pf is not given on the billing it is often possible for it to be calculated. Refer to EMS No.3 for an explanation on power factor calculation.

Maximum demand charges are not normally charged to small electrical consumers but for most commercial and industrial users a separate charge for kilowatts or kVA will be levied in addition to unit consumption. Supply authorities prefer to serve consumers with an even load pattern and hence penalize those with variable loads by a maximum demand charge. For example, a consumer who uses 90,000 kWh per month with an MD of 200 kW will pay less for electricity than a consumer using 90,000 kWh with an MD of 300 kW. A worked example of this is provided in EMS No. 3.

Load factor relates maximum demand and unit consumption as follows:

$$\text{Load Factor} = \frac{\text{Unit Consumption (kWh)}}{\text{Highest Maximum Demand x Hours}}$$

Any time period may be used in the calculation as long as the same period is used for unit consumption and maximum demand. Generally the higher the load factor, the lower the average unit cost of electricity.

Average unit cost($/kWh) may be obtained by dividing the total cost of electricity ($) by the total unit consumption (kWh). This provides a figure for comparison with other sites and for estimating potential savings from EMOs.

4.2.2 - Fuel Oil

Because fuel oil is normally delivered in bulk by tanker and paid for in advance of consumption, billings are of limited use in analysis unless deliveries are frequent.

Where deliveries are frequent, (a minimum of one per month during the heating season would be considered a minimum frequency) the oil consumed between the last two deliveries will be the amount received at the last delivery. Since the frequency of deliveries will vary, there being more frequent deliveries in colder weather, it will generally still not be possible to derive monthly consumptions like those possible for gas and electricity. With enough advance planning and co-operation of the fuel supplier, it may be possible to schedule monthly or more frequent deliveries to aid the fuel analysis process. If fuel meters are installed on the outflow from storage tanks and records are available, monthly data can be established. Where records are not available but meters are installed, a recording program should be implemented.

If fuel meters are installed on the outflow from storage tanks and meter reading records are available, monthly analysis along the same lines as for natural gas can be prepared.

4.2.3 - Coal

Coal is normally delivered in bulk and delivery periods may often vary substantially from consumption periods. For example, coal may often be purchased in summer and stockpiled until winter.

Accurate measurement of stock levels is extremely difficult, as is measurement of consumption. When examining coal-fired equipment, measurement of combustion efficiency and energy output is the only effective consumption monitoring technique.

4.3 - Fuel Analysis Worksheets

Tabulation of monthly utilities consumption may be undertaken using the blank forms provided in the Energy Accounting Manual or Appendix E of EMS No. 3. In many cases specialized worksheets may be required to suit process usage or differing rate structures.

4.4 - Energy Balance

Having collected energy and production data and undertaken a preliminary analysis of this information, an initial energy balance may be prepared to provide an indication of the major component areas of energy consumption.

An energy balance is obtained following the division of the building energy use, demand, or costs into its constituent components; disaggregation is the procedure used to achieve this. The results are best illustrated by a Sankey diagram that identifies the direction and magnitude of energy flows. Such a diagram is valuable for presenting disaggregation results. Examples of Sankey diagrams can be found in Sections 9 - 18 where they are used to illustrate sub-system energy flows. Pie charts and bar graphs, which can also be used, are easier to construct, but cannot illustrate complex energy flows.

The level of detail of this breakdown of energy use may vary from just a few components to many components. The level of detail and accuracy of the disaggregation are to a large extent determined by the size and complexity of the building, the availability of data, and the available audit budget.

Detailed breakdowns provide the most benefit, since they are more direct and specific to particular energy uses and EMOs. Inevitably, the finer the level of detail, the more work is involved. Normally this increased work leads to a more accurate and detailed picture of energy usage.

In instances the balance might be omitted, particularly where the building is small with uncomplicated heating and ventilation systems; or where the auditor is experienced and familiar with the building type.

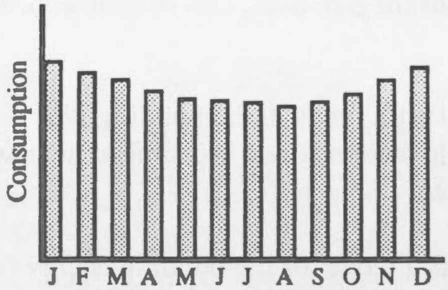
An accurate energy balance relies on techniques such as pattern recognition, regression analysis, predictive models, simple experimental procedures, and applied engineering. These methods are described in more detail in Appendix G. The process is often interactive; subsequent calculations helping refine the model and ensure balance of the components with the overall consumption. Where the results of the disaggregation are applied in subsequent stages of the audit, the energy breakdown should be reviewed and corrected as more detailed information becomes available.

For the initial analysis, ie prior to the walk-through, it is considered desirable to plot monthly consumptions of each fuel and demand levels can also be plotted for electricity. The process, which is illustrated in Figures 4.1 and 4.2, allows a number of components, such as "base load" and "electricity used for air conditioning", to be separated out from other uses. To remove the effects of an uneven number of days in the billing periods, the plot can be made using average daily consumption over the (month) billing period as opposed to actual monthly consumption.

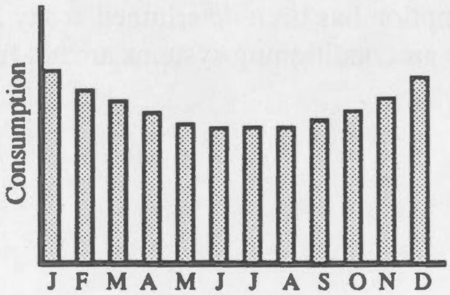
Because of uneven billing periods, it will often not be possible to make this plot for oil. In this case more sophisticated techniques, such as plots of consumption against degree days, can be followed. Such information is included in Appendix G.

This simple balance will help sensitize the auditor to the major energy flows in the building. Particular attention should be paid to these areas during the walk-through; where funds are limited it may be decided to limit the audit to the major energy consuming sub-systems.

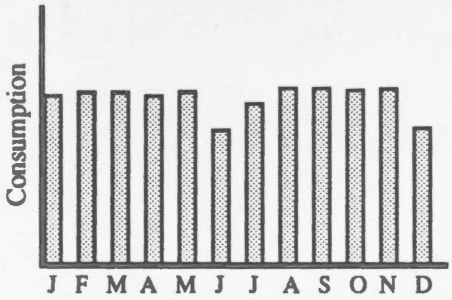
The balance also fulfills another important role in that it represents a model of the building energy flows and as such can be used to develop better estimates of energy savings when looking at possible retrofit actions. For example, once the air conditioning electrical consumption has been determined at say 20% of the overall consumption, future savings through retrofits to the air conditioning systems are not likely to account to more than 10 to 15% of the overall energy bill.



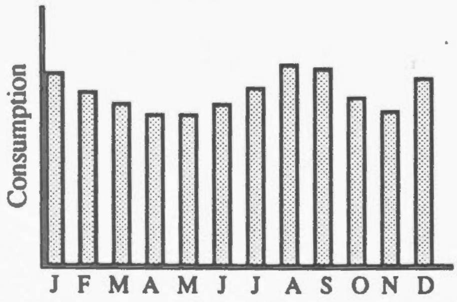
Indicates load constant except for lighting.



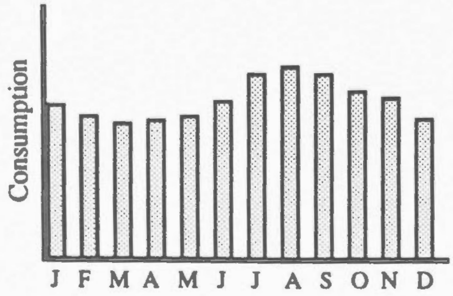
Indicates electrical heating significant part of load.



Indicates load primarily process reductions caused by summer/Christmas shutdown.

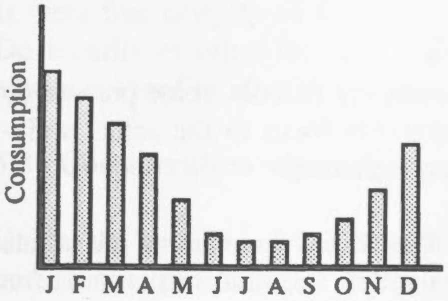


Indicates winter electric heating load and summer A/C load.

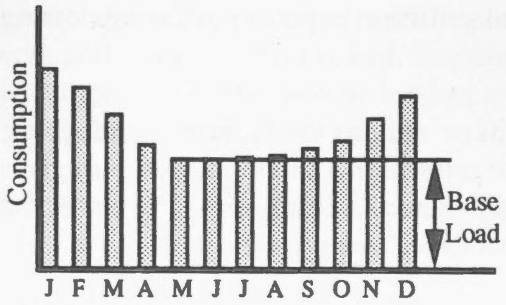


Indicates large summer A/C load.

Figure 4.1 Plots of Monthly Electricity Consumptions



Indicates load primarily space heating



Indicates load space heating with base load (i.e. hot water heating)

Indicates process use with summer and Christmas shut-down.

Figure 4.2 Typical Fuel Usage Patterns

5.- SURVEY PLANNING

5.1- Introduction

In order to maximize the effectiveness of the actual survey whilst minimizing its cost, some pre-survey preparation is essential. The major aspect of this preparation is to provide focus to the actual walk-through so that important aspects are addressed and irrelevant data is not collected.

There are two alternative approaches to undertaking survey work. The first is to examine the whole facility (within the audit boundary) one area at a time recording all the data required in that area (on heating, lighting, production etc.). The second method is to examine each energy system separately.

The latter method is recommended until the auditor has developed sufficient expertise to ensure nothing is missed on a single visit.

Looking at systems separately will inevitably mean more site visits or walking the facility several times. However, this gives more opportunities to see things that might be missed on a single visit. It also gives a better understanding of the individual energy systems. If all systems are examined at one time, the amount of equipment and paperwork required may become cumbersome.

To ensure completeness of the audit, it is desirable to start the preplanning process with a list of all possible EMOs. Blank Forms ("EMO checklists") are provided in Appendix D for this purpose. They can be found with the Walk-through Audit Checklists.

Whole categories, groups, or individual EMOs can often be eliminated from further consideration, on the basis of:

- Specific requests of management not to look at certain categories or items as retrofit possibilities.
- Low projected energy savings as identified through establishing the energy balance.

Information provided in Sections 9 to 18, in particular on the EMO descriptions, will be helpful in deciding which retrofit activities are appropriate.

The actual process of using the checklists is discussed in more detail in Section 7 where they are used to develop energy management options. At this stage it is sufficient to strike out any EMOs that are clearly not applicable to the facility being audited. Work in pencil so that data can be modified if necessary as new or better information is obtained in subsequent stages of the audit. Before conducting the survey, the auditor should have copies of walk-through audit checklists, covering those systems to be examined, with inappropriate EMOs and associated data collection needs crossed out.

The following additional aspects should also be considered.

5.2- Access to Site

Is there free entry to all building areas and rooms? If not, determine where the keys can be obtained. Do security or other factors require that escorts be provided? If so this may have to be arranged in advance. Proof of identity or authority to gain entry to restricted areas should be arranged as necessary.

5.3 - Consideration of Occupants

Unless the auditor is familiar with all the areas to be visited, and is known to the occupants, it will be necessary to give advance notice of the proposed program. In addition, the assistance of building, plant or equipment operators may be required and prior warning of intended visits is considered courteous.

Informing building occupants of the purpose of the survey is a major time factor in undertaking survey work and it is often overlooked. Explaining to the occupant of each office, area or facility what is going on can easily double the time it takes to survey an area. Prior warning, through line management where appropriate, can save a lot of time.

It will often be necessary to obtain information on equipment operation or occupation periods from operators or local management. There may well be a conflict between the information provided and judgement calls will often be necessary. For example, management may say that the lights are turned off in a particular building at 5:00 at the end of the shift. The occupants may say the lights are left on for the cleaners until 7:00. In these cases the source closer to the building is more likely to be right.

5.4 - Survey Timing

Ideally heating systems should be surveyed during the heating season but not necessarily under full load conditions. The performance of a heating system under part load may highlight inadequacies in control systems (see EMS No. 16). Similar considerations apply to cooling systems.

It is generally beneficial to survey facilities under normal operation although some of the tasks may be more easily undertaken outside of occupied hours. For example, surveying lecture theatres or classrooms is only practical when they are empty. When time is limited it may often be possible to survey non-occupied areas (eg. plant rooms) during the time when access to other areas is inconvenient.

5.5 - Equipment

For all survey work the following items are considered basic:

- Clipboard and pencil.
- A compact pocket lamp.
- Tape measure.
- Screwdriver with a variety of drives, eg. slot, Robertson.

Further discussion on instrumentation can be found in Appendix E.

6.0 - THE AUDIT SURVEY

6.1 - Walk-through Energy Audits

The purpose of the walk-through is to obtain sufficient information to be able to sort all potential EMOs into the following categories.

- EMOs that should be implemented without further evaluation.
- EMOs that appear to offer some economic benefit but which require further evaluation (eg. diagnostic audit). These EMOS should be sub-divided into three groups, those with 'high', 'average' and 'low' potential.
- EMOs that are not applicable or desirable.
- EMOs relating to energy systems not encountered at the audit site.

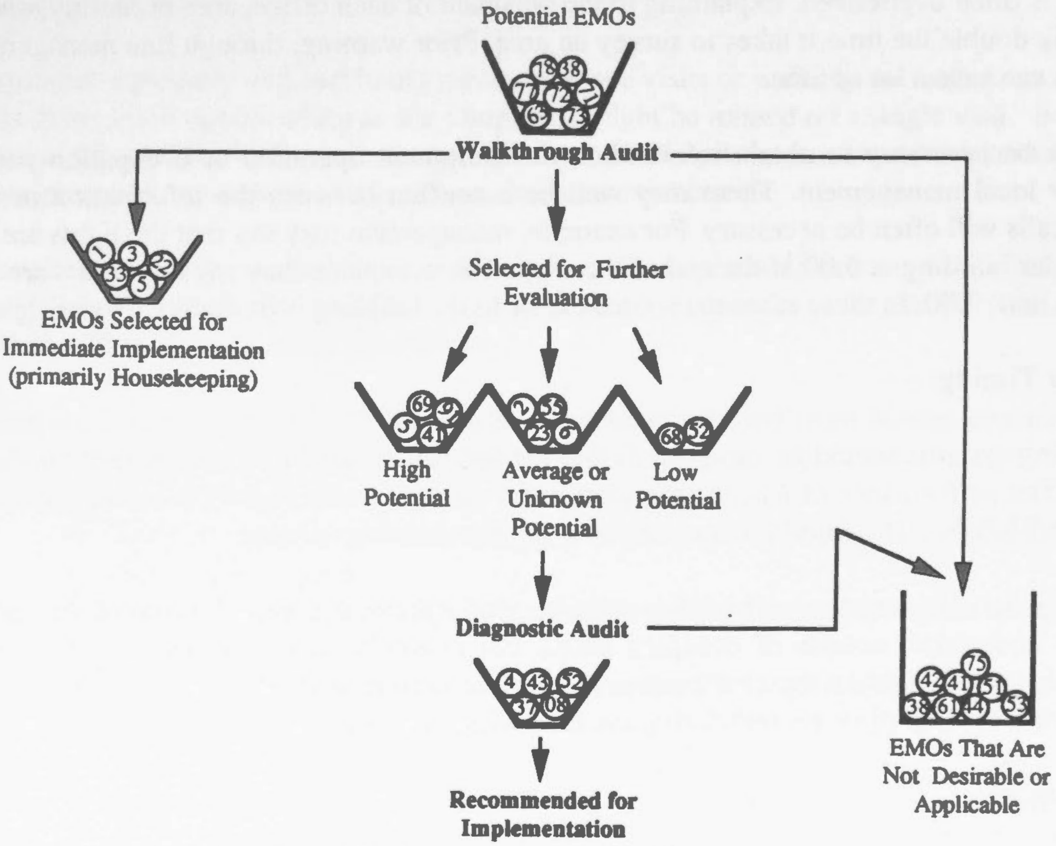


Figure 6.1 The EMO Evaluation Process

The need to implement sub-metering and special data collection requirements to facilitate further detailed evaluations should also be identified during the walk-through.

The process, with the subsequent diagnostic audit, is illustrated in Figure 6.1. The basis of the technique is to evaluate EMOs with as low a level of detail and cost as possible.

6.2 - Walk-through Audit Checklists

In Appendix D, Walk-through Audit checklists are provided to assist in this initial survey work. An example sheet is provided as Figure 6.2 to illustrate how these might be filled in. The potential EMOs

Steam and Condensate Systems
Walkthrough Audit Checklist No. 11

Facility: Factory No. 1

Survey date: 5th March 89

Surveyed by: N.J.D

Other comments: Area # 1 = Main plant room, Area # 2 = Service Corridor Area # 3 = Roof top mechanical room, Area # 4 = Basement mechanical room.

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5	Area No. 6
System condition	Good	V-Good	Poor	V-Good		
Steam leaks	No	No	2 Found	No		
Plumes from vents	Yes	N/A	Yes	Not Visible		
Trap operation	OK	OK	Passing	Passing		
Redundant steam mains	–	1" feed to old mech. room.	–	–		
Condition of insulation	Good	Good	Wet	Good		
Condensate return temperature	90°c	——	N/A	——		
Underground steam mains condition	——	——	N/A	——		

Figure 6.2 Sample Walk-through Audit Checklist

appropriate to the system being examined are listed on the appropriate EMO checklist to assist in site survey work.

6.3 - Diagnostic Energy Audits

Diagnostic audits should follow the walk-through audit and subsequent data evaluation (see Section 7). Additional sub-metering may be necessary to aid the evaluation process and this should have been identified during or following the walk-through.

Diagnostic surveys will involve detailed examination of installed plant and equipment in order to obtain very specific measurements and data for analysis. The calculation of the costs and savings from individual EMOs should be undertaken using the appropriate Energy Management Series Manuals.These are listed in the preface to this manual and are repeated below for convenience.

Energy Management/Employee Participation
Financial Analysis
Energy Accounting
Waste Heat Recovery

EMS	No.	1	Process Insulation
EMS	No.	2	Lighting
EMS.	No.	3	Electrical
EMS	No.	4	Energy Efficient Electric Motors
EMS	NO.	5	Combustion
EMS	NO.	6	Boiler Plant Systems
EMS	No.	7	Process Furnaces, Dryer and Kilns
EMS	No.	8	Steam and Condensate Systems
EMS	No.	9	Heating and Cooling Equipment (Steam and Water)
EMS	No.	10	Heating,Ventilating and Air Conditioning
EMS	No.	11	Refrigeration and Heat Pumps
EMS.	No.	12	Water and Compressed Air Systems
EMS	No.	13	Fans and Pumps
EMS	No.	14	Compressors and Turbines
EMS	No.	15	Measuring, Metering and Monitoring
EMS	No.	16	Automatic Controls
EMS	No.	17	Materials Handling and On-Site Transportation Equip.
EMS	No.	18	Architectural Considerations
EMS	No.	19	Thermal Storage
EMS	No.	20	Planning & Managing Guide

Detailed worksheets and worked examples are provided in these Manuals to allow calculation of costs and savings for EMOs. The manuals also indicate where specialist help is appropriate (See Section 1.7)

7.- EVALUATION OF ENERGY MANAGEMENT OPPORTUNITIES

7.1 - Introduction

Using the information collected during the walk-through, the 'EMO checklist', previously completed during the planning stage, should be updated based on the new information available. The information provided on the EMO descriptions contained in Sections 9 to 18 should assist the process of EMO evaluations.

For convenience, EMOs have been pre-arranged as "Housekeeping", "Low Cost" and "Retrofit" on the checklist and in subsequent sections.

Housekeeping EMOs are those which require no special funding or capital investment to be implemented. These measures may often become part of on-going regular maintenance or be undertaken by building occupants. The benefits of these measures often disappear if the measure is not regularly checked.

The definition of low cost EMOs will depend on the size of the organization. They are normally defined as those measures which may be funded from existing revenue budgets and will pay for themselves within the same financial year. Usually additional capital is not required

Retrofit EMOs are normally capital intensive because of the higher implementation cost, and can have longer pay back periods. Depending upon the financial policies of the organization, the dividing line between low cost and retrofit will vary considerably.

In order to quantify predicted energy swings, where this is necessary, accurate costs of energy will be required and it is important to make sure the correct energy units are being used; the following text provides some guidance in this regard. Note that for no cost and clearly favorable low cost items, there is no real need to estimate energy savings.

7.2 - Energy Conversion System Efficiencies

Consumption data from utility billings or financial records will be 'gross', i.e they will not take account of fuel conversion efficiency. Electricity, when used for heating, is used 'directly' and has no conversion loss. For most other fuels, which have to be ignited and burned to produce heat, there is a conversion loss and useful heat energy obtained is less than that available in the fuel. It is important to understand what the true cost of energy is in order to evaluate EMOs. Worksheets provided in the other EMS Manuals require the auditor to be aware of the concept of the **cost of useful energy.**

7.3 - Cost of Gross and Useful Energy

When the efficiency of energy conversion is known it is possible to calculate the cost of useful energy. This is the figure which should be used to calculate the actual amount that would be saved by any EMO (which does not affect the conversion efficiency). This is simply:

$$\text{Useful Cost} = \frac{\text{Gross Cost} \times 100\%}{\text{Conversion Efficiency}}$$

For example, natural gas delivered to site at a cost of 25 cents per cu. m or 0.67 cents per MJ and burned at a 78% furnace efficiency would have a useful cost of 0.86 cents per MJ.

The above example is straightforward, however, it becomes more complicated when other system efficiencies are considered as illustrated in Figure 7.1 and discussed below.

The thermal efficiency of a steam boiler would normally be around 80%. The energy lost would be primarily due to flue gas loss, radiation loss and blowdown loss. Taking the boilerhouse as a whole there are other losses that will reduce efficiency, for instance standby boiler heating (if the second boiler is kept at pressure in case of failure), make-up water heating or oil tank heating. Such losses might typically reduce the boiler house overall efficiency to 70%.

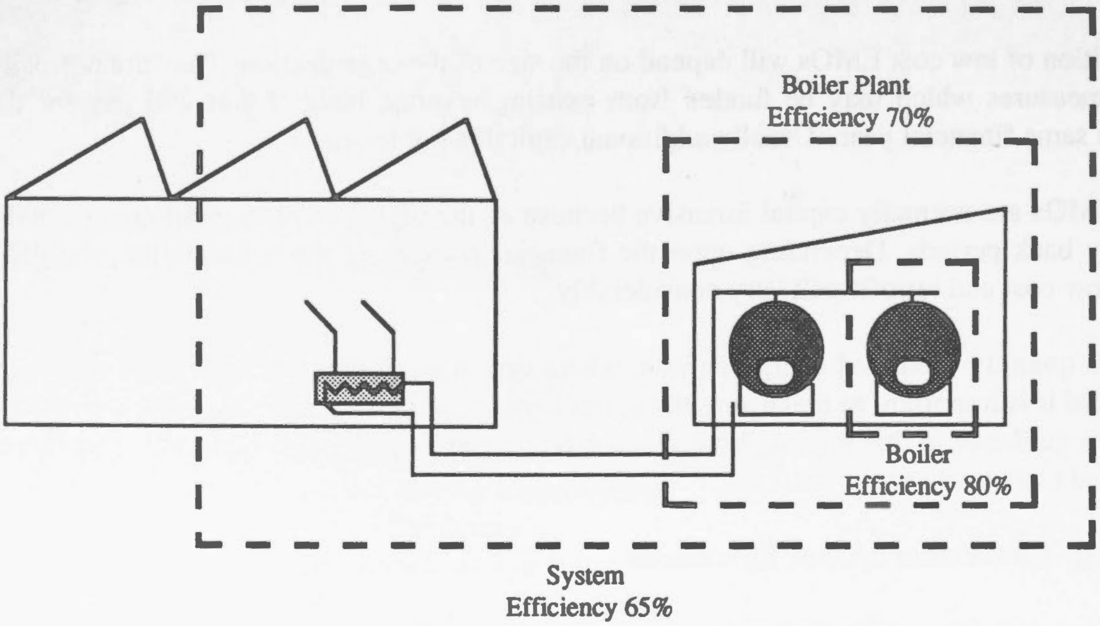


Figure 7.1 Boiler, Boilerplant and System Efficiency

Further heat loss will occur in the distribution system and as flash condensate loss at the heat exchanger. Considering these losses the overall system efficiency could drop to 65%. This would mean that for every 1 MJ of heat provided to the building, 1.54 MJ of fuel will have to be used.

The efficiency of a system will also change depending on the imposed load. This is termed Seasonal Efficiency which will normally drop in the summer as the system losses represent a larger proportion of the total load. These efficiencies are discussed in more length in EMS Nos. 5, 6, 8 and 9.

7.4 - Use of Worksheets from the EMS Manuals

Worksheets provided in the EMS manuals provide calculated energy savings which must then be multiplied by a unit cost of energy to establish financial savings.

Three main unit costs of energy are used, \$/GJ, \$/1000 kg and \$/kWh, i.e. the energy units used are not consistent in the series and must be converted to a common consistent system.

When using \$/GJ (1 GJ = 1000 MJ) the energy that is saved by a measure will normally be in the form of fuel that would be consumed by a boiler or furnace. Therefore, the cost of energy used should be the cost of useful energy produced by the boiler, i.e the purchased cost divided by the efficiency of conversion (boiler efficiency). This is based on the assumption that the boilerhouse and distribution losses will remain unaffected by the EMO.

$$\text{Cost of useful energy (\$/GJ)} = \frac{\text{Purchase cost (GJ)} \times 100}{\text{Boiler efficiency}}$$

If steam is delivered by a utility then this cost will be readily available although there will normally be on-site distribution losses which will increase the cost of useful heat delivered to the point of use.

For on-site produced steam, the cost used should normally be the cost of steam leaving the boilerhouse. This cost should take account of the boilerhouse efficiency which can include boiler efficiency, tank heating, make-up water heating, water costs, standby boiler heating and blowdown losses. Whilst a boiler operates at 80% thermal efficiency, this may translate into a boiler house efficiency of 70-75%.

The cost of useful energy may be established by taking the steam output per month and dividing it by boilerhouse fuel and water costs for the same month.

For electrical savings \$/kWh are easily obtained from utility billings. In its simple form the total unit consumption may be divided by total cost to provide overall average unit costs (\$/kWh). This will be adequate for first approximations or for small sites where there are no charges for electrical peak demand and no sliding scale of energy changes.

Where demand charges are levied judgement is required as to whether the EMO proposed will affect peak demand recorded as well as unit consumption. If peak consumption is not likely to be affected, then the cost per kWh provided on the billing should be used.

On many rate structures costs per kWh normally reduce on a sliding scale for increasing amounts of electricity used. Cost savings are therefore normally made at the lowest rate for which charges apply.
It is important to use the correct unit cost as the rate can vary by over 25% which will significantly affect savings from an EMO.

7.5 - Declining Balances

When calculating energy savings from multiple EMOs it is important to consider the effect of each EMO on any subsequent measure introduced.

This is easiest to illustrate by example. For an office building, two EMOs are being considered; the installation of new high efficiency boilers and the draughtproofing of windows.

If the current (pre-boiler conversion) cost of useful energy is used, the simple pay back period for draughtproofing may be 2.4 years but if new boilers are installed and the cost of useful energy reduced, then the pay back for draughtproofing may be extended to 3.1 years (possibly outside the criteria for

EMOs to be financed).

When analyzed separately, each successive saving must be based on calculated consumption levels after the previous measure is carried out.

Perhaps the chosen EMOs represent the other extreme; they are truly independent, and savings from each can be added. In some instances super-additive conditions may be present; for example, sealing air leaks under insulation not only reduces air infiltration, but can increase the thermal resistance. If there is a degree of overlap between different EMOs, reference to past history of similar retrofit actions will help make sound judgements.

Often it is advantageous to group a set of complementary EMOs into an **"EMO package"** which has been demonstrated to provide energy savings. Examples of such packaging include insulation upgrade with window EMOs, and heating system furnace efficiency improvements with enhanced controls.

EMO Checklist No. 11

EMO No.	Description	Implementation Recommended	Further Evaluation of Potential Required			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
HOUSEKEEPING							
11.1	Repair leaks		✓				Roof top mechanical room
11.2	Maintain steam traps		✓				Mechanical Room
11.3	Maintain chemical treatment program			✓			
LOW COST							
11.4	Repair/upgrade insulation on pipes and tanks			✓			
11.5	Rationalise pipework		✓				
RETROFIT							
11.6	Heat recovery from condensate				✓		
11.7	Separate flash steam from condensate			✓			

Figure 7.2 Sample Completed EMO Checklist

7.6 - EMO Checklists

A sample completed EMO checklist for the steam and condensate section of an audit is given in Figure 7.2 for purposes of illustration. The checklist has been completed based on the information collected and detailed on the sample Walk-through Audit Checklist (Figure 6.2) included in Section 6.

7.7 Detailed Evaluations

Following the preliminary sorting of EMOs made possible by the walk-through, the auditors next task is to evaluate those EMOs selected for further consideration, and to do so in an economical manner consistent with the desired degree of accuracy. The evaluation process will involve either detailed on-site investigation, or analysis, or both.

The final output should be a recommended list of EMOs for implementation and an overall implementation plan giving details of cash flows. One should consider, for example, the plans for the building and budget limitations, the choice of EMOs where alternatives may be viable, and the effects of combinations and interactions between EMOs. Senior Management has a choice of options for implementation of the evaluated EMOs which include:

* A sequence of EMOs to effect changes in the following order: loads, terminal equipment, distribution systems, and finally the central plant. This is a logical sequence; for example, any boiler derating should only be carried out once all other loads have been minimized.
* Implementing in order of ascending pay back or capital cost.
* Using savings from low cost or housekeeping measures to fund retrofit work.
* Combining EMOs with other maintenance or refurbishment.
* Implementing housekeeping or low cost measures and instigating further studies to evaluate retrofit potential in more depth.

7.8 - Factors Affecting the Value of an EMO

7 8.1 - Cost Benefit

The reasons for making investment decisions will vary, and may include benefits difficult to value, such as improved appearance. Consequently, an auditor should not make cost benefit decisions in isolation of senior management.

7.8.2 - Retrofit Longevity and Cost Effectiveness

Total annual operating costs should be considered; ideally lifetime and maintenance costs should be parameters in any EMO evaluation although this may not prove to be a simple matter. The durability of retrofit may be largely unknown. An example is the increased corrosion of heat exchangers of high performance condensing furnaces and boilers. If corrosion significantly reduces equipment lifetime, or increases maintenance costs, the cost effectiveness is greatly reduced. Obviously, two retrofits of equal capital cost and energy savings are not equal investments if one has twice the expected life of the other.

7.8.3 - Side Effects, Comfort Allowance, and Interactions

Focusing only on direct energy savings and cost in EMO choices may prove to be shortsighted. Side effects may prove highly beneficial or, conversely, there may be detrimental effects suggesting that the EMO be avoided.

One example of beneficial side effects is the elimination of convective loop air flows (penetrations of cold air into the building envelope during the heating season). The appropriate EMO choice will allow interior surfaces to reach proper temperatures, add to the comfort of the occupants, and solve possible condensation problems. There may even be an additional energy saving potential, since cold radiation may be reduced, allowing for lower temperature set points. On the other hand, marginally ventilated attic spaces may experience moisture damage when additional insulation is added to the ceiling; the moisture release from the interior may remain unchanged, but the cooler attic space may now be prone to moisture condensation and roof damage.

When considering changes, it is important that appropriate environmental qualities, such as air temperatures and ventilation rates, are maintained. Without such control the retrofit measures may even result in additional energy consumed; for example, adding insulation may worse apartment overheating, causing additional window openings and energy losses.

In some instances, lack of comfort has motivated an energy audit. Where possible, ways of improving comfort and minimizing energy use should be sought. EMO choices adding to human comfort may not only mean extra energy savings, but can win the confidence of the occupants, which is essential to an effective energy management program. Energy management effort should not compromise comfort, and the auditor should aim to provide normally acceptable comfort conditions. Where the audit uncovers unacceptable conditions, these should not be ignored, even if to improve such conditions requires the expenditure of some additional energy.

Indirect effects in the form of tangible energy consequences must not be overlooked, especially where the implementation of an EMO in one area impacts upon the use of energy or an EMO in another area. For example, reducing lighting loads will directly reduce electricity use, but may also indirectly reduce cooling consumption and increase heating consumption. Similarly, in a terminal reheat system where the supply air volume or temperature is not changed, the full benefit of reduced heating and cooling would not be realized.

7.8.4 - Choice of Alternative EMOs and Coupled Opportunities for EMOs

In some cases, alternative EMOs or general strategies need to be evaluated. For instance, there are two very different envelope strategies associated with windows; one a defensive strategy, pursuing such options as replacing glazing with insulated panels; the alternative being to capitalize on the potential benefits associated with daylighting and winter solar gains.

In the lifetime of any building there are critical times for major repairs and replacements. Combining such extensive repairs with EMOs may be a logical way to justify a particular EMO. For example, it is often hard to justify roof insulation where this would require removal of the roofing material; coupling insulation with a needed roof replacement can, however, make this EMO a high energy saver because of the small incremental cost - a cost freed from the roofing cost which was already inevitable.

7.8.5 - Group Opportunities

Where many similar buildings are being considered for auditing, there is a possibility for economy and effectiveness by auditing in detail one or more representative buildings with a view to applying the results to other buildings. Furthermore, the capital costs should also be reduced as the same EMOs can be implemented in a number of similar buildings. One must take into account that the opportunities for cost reductions due to group discounts can change the priorities of different EMOs as the investment cost is modified. This can lead to EMO combinations, which are optimal, not for energy conservation, but from the point of view of cost efficiency for a given budget. The Energy Accounting & Financial Analysis Manuals in this series provide detailed guidance on evaluation of EMOs.

On a smaller scale, co-operation between building owners, so that major purchases of energy saving items can be arranged, offers the opportunity for cost reductions and improved cost benefit ratios. For example, changing to high efficiency lamps, if proved successful in one of the buildings, might also be employed in other buildings, thereby permitting a major purchase with a bulk discount.

7.9 - Who Benefits?

Whether or not an energy saving retrofit activity takes place in a building often depends on who benefits. For instance, in the multi-family building sector owners, operators and tenants may have different motivations regarding energy and expense.

If the owner can pass energy expenses directly to the tenant, there is little interest in implementing any EMOs. Only when energy costs make it difficult to find new tenants, may the owner be sufficiently interested to trim energy costs.

Frequently, since individual tenants are not directly responsible for heating energy costs, they may operate apartments at higher than necessary temperatures and open windows beyond that reasonable for ventilation purposes. Since they have no ownership, they generally have little concern in adopting energy saving behavior or interest in energy saving investment.

Finally, building operators may be primarily interested in minimizing tenant complaints, in order to simplify their jobs, and give concern for energy savings only second priority.

7.10 - Grants, Subsidies and Tax Write-offs

Energy conservation programs, with associated tax allowances or subsidies from governments or utilities on specific EMO items, should make the energy auditor sensitive to an EMO which can move from being a marginal choice to one which is highly attractive. Viewing such programs as unique opportunities to achieve specific energy saving goals is an important EMO implementation strategy. Such opportunities are often available for limited periods, a fact that should be considered when developing an EMO implementation strategy.

7.11 - Presentation of Recommendations

Presentation of the EMOs selected may not be an issue if funding is available and no higher approval is required. However in most cases there will be a need to present survey findings. A preliminary assessment of EMOs should be made immediately after the walk-through audit and the findings presented to management for their review and comments. This should eliminate the risk of pursuing EMOs which management may want to reject.

The initial or first stage assessment would not necessarily include any quantitive data but would indicate where energy management potential exists. For example, a walk-through audit may identify that steam traps are in need of replacement but that pipe insulation is in good condition. This may be enough information to get management approval for a steam trap maintenance program.

A more detailed second stage report including detailed costing, energy savings and pay back periods may be necessary at a later date to justify the cost of the survey or to obtain approval of, or support for, capital intensive proposals. At this stage it will be advantageous to have a complete and concise list of EMOs with individual and total costs and savings summarized.

A short but descriptive title for each EMO will be required together with assessed costs and savings. The EMOs should be grouped into the three categories and listed in descending order of pay-back or desirability. The sub-totals of costs and savings for each category plus the overall totals should also be shown.

A sample format presentation is provided in Figure 7.3. A blank copy for reproduction may be found in Appendix D.

A management summary can also be produced indicating the level of savings expressed as a percentage of annual energy costs. An outline of the planned implementation program should be provided in order that the timetable for savings can be established. This limits the problem of results being expected too soon.

7.12 - Implementation

At this stage of the audit process EMOs should have been identified, analyzed and recommendations made to management. Upon receipt of management approval the measures should be implemented. The implementation process requires careful planning to ensure that EMOs are undertaken in the correct order (i.e. duct leaks rectified before rebalancing or insulation improvement made prior to controls resetting). In addition certain EMOs may have to be programed ahead; for example, it would be preferable to carry out major alterations to a heating system in the summer months.

As an integral part of an energy management program, monitoring of the effectiveness of EMOs should commence immediately after implementation.

Summary of Recommendations

Item	Description	Capital Costs	Savings		Payback
			$	GJ	
	HOUSEKEEPING				
1	Repair steam leaks.	$600	$950	210	0.6 yrs
2	Maintain steam traps.	$1500	$1650	365	0.9 yrs
	LOW COST				
3	Repair insulation in roof top mechanical room.	$850	$510	113	1.7 yrs
4	Remove redundant pipework to old mechanical room.	$1100	$390	86	2.8 yrs
	RETROFIT				
5	install flash steam recovery to preheat	$4500	$1150	254	3.9 yrs
6	D. H. W. in basement mechanical room				
	Totals	8550	4650	1028	1.8 yrs

Figure 7.3 Summary of Recommendations

8.- AUDITING, MONITORING AND TARGETING

8.1 - Introduction.

Any Energy Management Program should include some monitoring of energy performance in order to assess the effectiveness of EMOs implemented. The basis for comparison would be the pre-implementation level of performance. However, this can be taken a step further with the introduction of a structured monitoring and targeting system to provide information and motivation to maintain the benefits of housekeeping EMOs.

Targeting of future energy use represents an extension to a program of monitoring. Targeting gives an immediate cross check of energy use per period (day, week, month) and as such can be used as a motivator for building occupants and operators to implement housekeeping EMOs.

8.2 - Energy Accountability

Central to the success of monitoring and targeting is the establishment of a chain of managerial responsibility that can motivate improvements in energy efficiency throughout the organization. The first step, therefore, in installing a monitoring and targeting system, is to identify along the energy flow paths within the company a series of 'energy-accountable centers' that will provide the requisite breakdown and framework necessary both for monitoring energy performance and for achieving targets. An energy-accountable centre might consist of an individual machine, the whole building or even an entire site.

Recording and reporting procedures for these centers should be set up at appropriate levels within the company to allow wider control (by senior management) at less frequent intervals. Each centre must relate to a nominated individual responsible for operational achievement in that area. Tying resource consumption to those responsible for operational achievement is a key factor in a monitoring and targeting system since it focuses attention on those with authority to effect improvements in performance.

It is, moreover, essential that all those held accountable for energy performance should also be able to assess that performance and have the pertinent information on which to base judgements, decisions and actions to bring about improvements.

Co-ordination is a vital component of an energy management program. Effective energy management within any company depends on the full commitment and continuing support of senior management, who must participate in the development of corporate energy policy, in the establishment of targets and in the monitoring of progress. To this end, particularly for larger companies, it is important to consider setting up - in conjunction with the monitoring and targeting system - a multi-disciplinary, inter-departmental 'Energy Executive' manned by senior staff - not only those with the knowledge and ability to effect energy improvement measures but also managers who are primarily concerned with finance and investment.

8.3 - Monitoring

A monitoring system should be a well defined energy management activity. The procedures to be followed, including exact times and dates for monitoring should be precisely laid out. It is important to take readings at the same time each period of the day/week/month to maintain the validity of any monitoring system.

These functions extend the benefits beyond simple checking of the effectiveness of an EMO or of grouped EMOs.

Monitoring would normally be undertaken using existing metering devices unless the measure is a large retrofit which may justify the cost of extra metering. Often it will not be possible to directly measure the effect of one specific EMO as it may not have an independent meter.

To maximize the benefits of post-EMO monitoring it is preferable to have pre-EMO data for energy usage in the same format, (i.e. taken at the same time, level of detail and accuracy). This ensures that pre and post figures are directly comparable. For example if daily electricity readings are to be taken to monitor the effect of a lighting upgrade, then it is advantageous to take daily readings on the same basis before the measure is implemented. Otherwise the only data for comparison may be monthly electricity bills.

Other factors may influence the pre or post EMO energy performance such as changes in occupancy schedule or new loads added to the system. The effect of changes in the monitored energy use should be examined and if they can be accurately quantified they may be allowed for when calculating the savings from an EMO.

8.4 - Targeting

In its simplest form, targeting may be undertaken by subtracting the calculated benefits of an EMO from existing or pre-implementation consumption levels and using this figure as an immediate check of improved performance. Performance targets can be further reduced to provide an incentive for occupants to reduce energy consumption.

Performance targets based on calculated future energy performance must be used with caution and may require adjustment in use. For example, if targeting monthly heating fuel use based on average monthly weather conditions then the actual weather conditions (normally in degree days) must be used to adjust the target appropriately.

8.5 - Motivation and Accountability

Setting inaccurate or unachievable targets can be a significant demotivating factor and can bring into question the validity of the entire monitoring and targeting system. To guard against such a situation the system should be 'dry run' for a period prior to 'publishing' figures to ensure the system is suitable.

Presentation of monitored energy consumption in either tabulated or graphical form for building occupants or operators can provide benefits by involving the occupants in energy management. Direct feedback on the effectiveness of EMOs, particularly housekeeping measures can serve to motivate staff to repeat or better this performance.

9 BOILER PLANT SYSTEMS

9.1 - Introduction

Boilers are frequently used for the generation of steam and hot water in industrial, commercial and institutional facilities. This section deals with the most common types of boilers in use and identifies EMOs that may to maximize the efficiency of heat generation.

9.2 - Fundamentals

9.2.1 - Classification

Boilers may be classified by the temperature or pressure of the heated fluid; by the fuel burned; and by the boiler design as follows :

- Temperature/Pressure Classification
  - Low temperature hot water (LTHW): Up to 120°C.
  - Medium temperature hot water (MTHW): Between 120°C and 150°C.
  - High temperature hot water (HTHW): Above 150°C.
  - Low pressure steam: Up to 100 kPa.
  - High pressure steam: Above 100 kPa.
- Fuels Classification :
  - Oil
  - Gas
  - Coal
- Design types:
  - Fire tube
  - Water tube
  - Coiled tube

Further details of boiler types may be found in EMS No. 6, Boiler Plant Systems.

9.2.2 - Combustion

All boilers utilize a burner to fire the fuel and provide heat. The exact construction of the burner will depend on the fuel being used, however all burners share a common function, that is to provide a mixture of air and fuel into the combustion chamber maintaining the correct air-fuel ratio for optimum combustion.

The combustion process involves the rapid burning of carbon and hydrogen based fuels in oxygen. In order to ensure complete conversion of all carbon in the fuel into carbon dioxide sufficient air must be supplied and be fully mixed with the fuel when burning. Air contains 21% oxygen and the remaining constituent gases (primarily nitrogen) take no part in the combustion process but are heated as they pass through the boiler and form the largest loss from the boiler termed "dry gas loss" via the flue.

The minimum quantity of air required for complete combustion is called the stoichiometric air supply. This is the minimum amount of air that, in theory, is required to convert all the carbon in the fuel into carbon dioxide. In practice additional or "excess air" has to be supplied to ensure complete combustion.

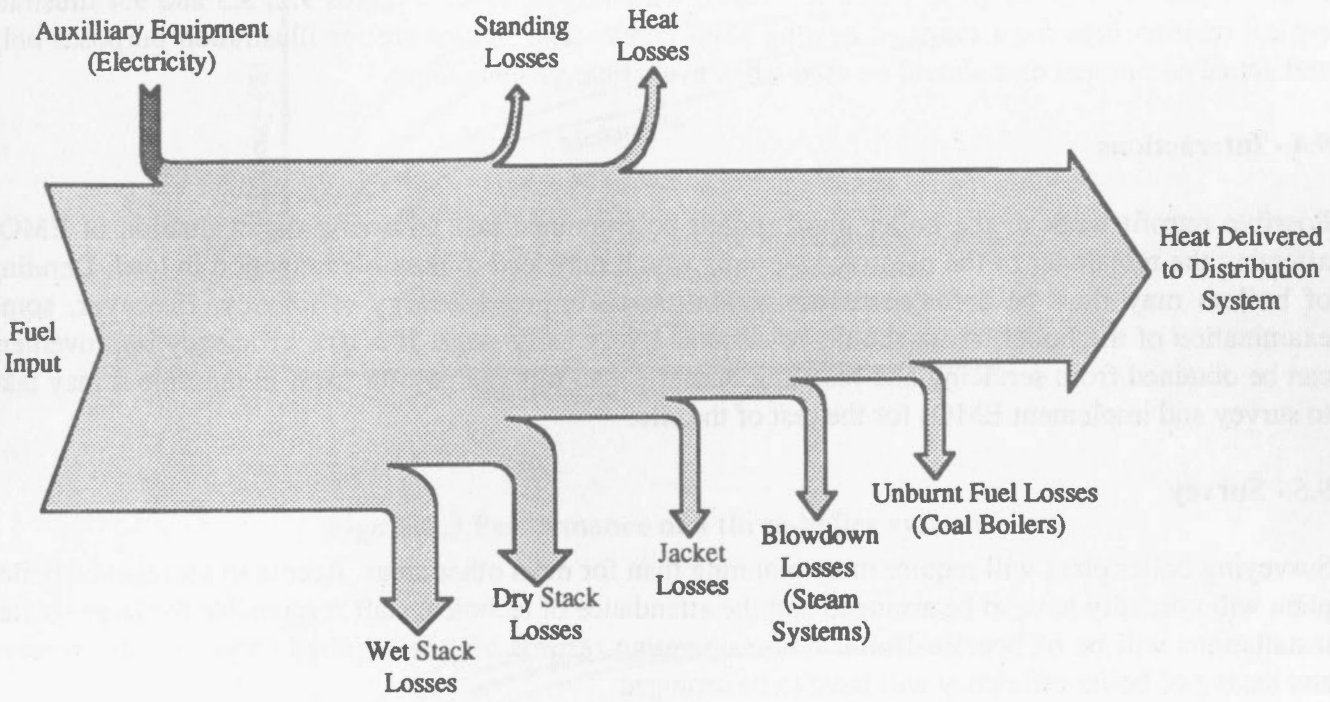


Figure 9.1 Sankey Diagram of Boiler Energy Losses

Jacket losses are the heat losses from the boiler casing.
The amount of excess air required varies with fuel type; gas requires the least and coal the most. Insufficient excess air results in carbon monoxide being present in the flue gases.

Further details on the combustion process may be found in EMS No. 5, Combustion.

9.3 - Energy Losses

Identification of energy management opportunities for boiler plant involves examining the sources of inefficiency or loss in the combustion process and the boilerhouse.

Energy losses from boiler plant are illustrated in Figure 9.1.

Dry stack losses are described in Section 9.2.3.
Wet gas losses are due to moisture formed by the combustion process (hydrogen from the hydro-carbon fuel combining with oxygen from the air) being exhausted through the flue.
Blowdown losses occur on steam boilers when water at boiler pressure is discharged to drain to remove solids and excess chemicals from the system.
Burner purging losses are stack losses that occur on start or stop of a forced draught burner when air is blown through the boiler to vent volatile gas and liquids prior to or after firing.

Additional losses within the boilerhouse must also be considered. These may include; Standby boiler heating, hot well heating (steam boilers) and oil tank heating. Losses due to combustion inefficiencies are discussed in depth in EMS No. 5, Combustion; losses from the boilerplant are examined in EMS No. 6, Boiler Plant Systems.

Since boiler plant will operate over most of its life at part load efficiency it is important for the auditor to understand how boiler plant efficiency varies with varying load. Figures 9.2, 9.3 and 9.4 illustrate typical relationships for a range of heating plant types. The figures are for illustration purposes only and actual equipment data should be used when evaluating plant changes.

9.4 - Interactions

Possible retrofit work to the boiler plant should be examined last following the evaluation of EMOs affecting the remainder of the plant and systems which may lead to possible reduction in load. Derating of boilers may then be a major recommendation to improve energy efficiency. However, some examination of the boiler house should be done at a very early stage. If a 10% efficiency improvement can be obtained from servicing and resetting burners, than this can pay for itself in the time it may take to survey and implement EMOs for the rest of the site.

9.5 - Survey

Surveying boiler plant will require more planning than for most other areas. Access to un-manned boiler plant will normally have to be arranged and the attendance of technical staff responsible for larger boiler installations will be of benefit. Boiler house operating records will be required for diagnostic surveys and testing of boiler efficiency will have to be arranged.

It is important to allocate sufficient time for surveying the boiler plant. This is often where most of the energy is used on a site and efficient operation is essential for good energy management.

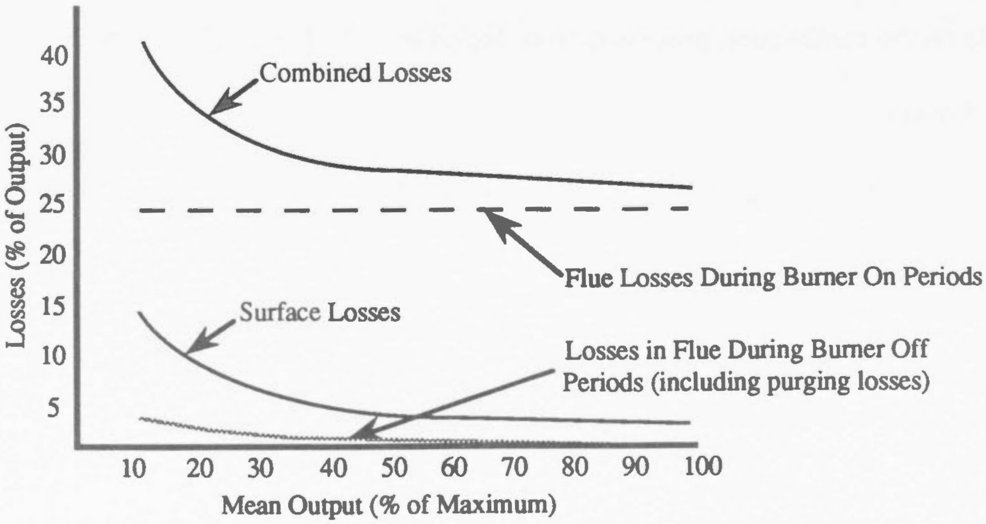


Figure 9.2 Losses in a sectional boiler

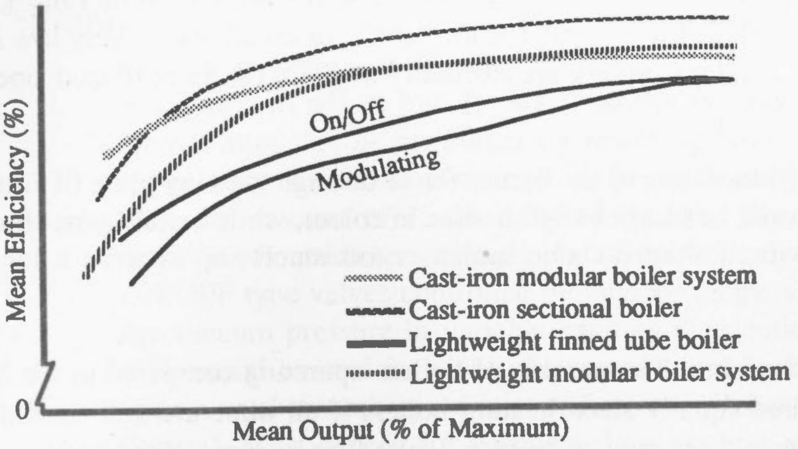


Figure 9.3 Performance of a three-boiler system

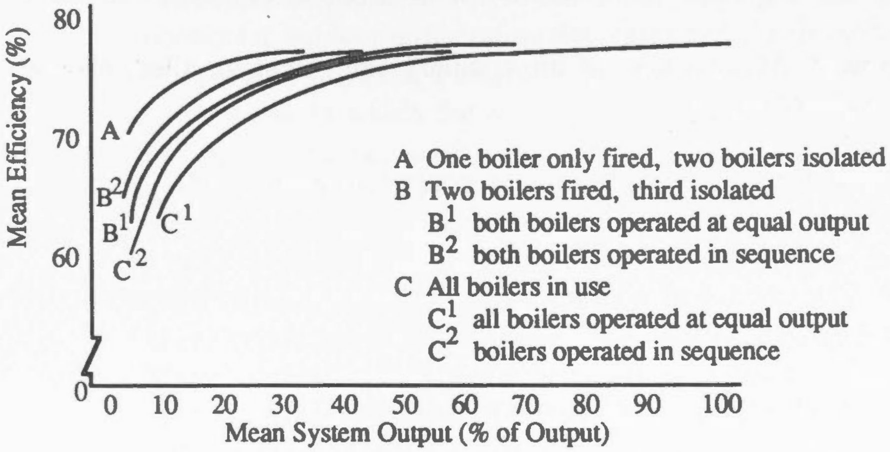


Figure 9.4 Efficiency curves for various boiler systems

The overall condition of the boiler house provides a good indication of the level of maintenance. An untidy, dirty or dilapidated installation is unlikely to be a well maintained installation. Boilers will not remain at peak efficiency without maintenance and a good maintenance program will normally include maintaining the boiler room/house in good order.

9.5.1 - Walk-through Audit Procedure

During a walk-through the following items should be checked:

Condition of boiler house Note the cleanliness, state of repair of the boilers, building and auxiliary equipment.

Details of boiler(s) Note the fuel, burner type, age, rating etc..

Water or Smoke Leaks Look for evidence of smoke leaks on boilers, floor, breaching or stack.

Instrumentation Readings Note readings on fixed instrumentation. Flue gas temperatures of approximately 190 to 210°C. for gas and 220 to 240°C. for oil are ideal. Very low flue gas temperatures on standard (non-condensing) boilers are normally attributable to part load operation or downrated burners.

Burner Flame Condition Observe the burner flame through viewing glass (if fitted). In general terms a natural gas flame should be clear or slightly blue in colour, while an oil flame should be light brown or yellow. A short blowtorch shaped flame indicates too much air, whereas a long lazy smoky flame indicates too little air.

Number of Boilers On-Line The number of boilers operating compared to the load should be noted. eg. In a plant with three equally sized heating boilers if all three are still operating when the outside temperature is 12°C. then there may be scope to isolate one or more of the boilers.

Boiler Cycling Time Time how often are boilers cycling on/off. Operating periods of only a few minutes will reduce boiler life and also operating efficiency. Although an atmospheric gas boiler efficiency may actually be improved by short cycling, unless the boiler is designed to handle the additional flue gas condensation that will result, boiler life will be reduced substantially.

Ancillary equipment Make a note of the ancillary equipment installed; economizers, flue dampers, blowdown heat recovery etc..

Blowdown Control The method of blowdown control on steam boilers should be established; Manual, continuous, timed, based on total dissolved solids etc..

Output Control The method of controlling boiler heat output should be confirmed; Aquastat, boiler sequencer, manual etc..

9.6 - Annotated List of Energy Management Opportunities

9.6.1 - Housekeeping

EMO 9.1 REDUCE NUMBER OF ON-LINE BOILERS AS LOAD REDUCES

DESCRIPTION:	Manually turn off the boilers as load reduces and isolate them hydraulically to avoid the standby losses.
APPLICATION:	Heating plants with more than one boiler.
SIDE BENEFITS:	Improved lifetime of components.
CAUTIONS:	Avoid starts of additional boilers just for very short periods, i.e., in the morning, after temperature reduction during night.
COST FACTORS:	Negligible cost if done manually. Higher costs for automatic operation based on outside temperature for instance.
INTERACTIONS:	Low cost alternative to EMO No. 9.24 Install Boiler Sequencing Control
EVALUATION:	Energy saving equates to the reduction of the standby losses of the boilers.
COMMENTS:	With many oversized heating plants, additional boilers can be shut off semi-permanently.

EMO 9.2 REDUCE BOILER FLOW TEMPERATURE/PRESSURE WITH HEAT DEMAND

DESCRIPTION: Reduce boiler aquastat set-point as demand for heat drops (can be automated to adjust for climactic variations). For water systems water temperature can be regulated by resetting boiler aquastat. For steam systems the same kind of control can be obtained by: "heat timers" which vary the amount of steam allowed into the distribution system as a function of outside temperature; "zone control valves". These are usually ON/OFF type valves controlled by outdoor temperature sensors; varying the vacuum pressure in variable vacuum distribution systems; pressure differential control in which the steam supply pressure is varied. This system need properly sized inlet orifices at each heating unit.

APPLICATION: General. Most benefit for perimeter heat systems with no other form of control.

SIDE BENEFITS: Reduced distribution losses (in addition to a very small improvement in boiler efficiency). Possibility of improved control of space temperatures (terminal control valves allowed to perform in more fully open positions).

CAUTIONS: Possibility of condensation in the boiler leading to corrosion. May affect comfort if outdoor temperature decreases and the increase of the set-point is executed too late. Possibility of condensation will limit the lowest temperature to which the aquastat might be set. Temperature should not be below dew-point of water, minimum 47°C for cast iron oil fired boilers, 57°C for oil fired welded boilers, 35 - 60°C for natural gas. DHW generation may be affected.

COST FACTORS: Negligible cost if done manually. Higher cost if automatic, but preferred method of control.

INTERACTIONS: May be combined with EMO No. 9.24, Boiler Sequencing Control.

EVALUATION: Most benefit if this is the only means of space temperature control, but may improve control and reduce heat losses if other forms of room control provided, e.g. in induction systems, fan coils and unit ventilators, reheat coils and convectors.

REFERENCES: Johnson Controls Ltd., 1982, Bloor 1983.

EMO 9.3 MAINTAIN CORRECT SYSTEM PRESSURIZATION

DESCRIPTION: Adjust and maintain system fill pressurization to prevent boiling of fluid within the distribution and the subsequent loss of heated water through pressure relief devices.

APPLICATION: All boilers.

CAUTIONS: Balance of the system is dynamic and therefore typical cycles of heating water is lost.

COST FACTORS: Provided original equipment is properly sized to adjust for system dynamics, not cost is involved.

COMMENTS: Low system pressurization can allow air to enter the system resulting in air traps and accelerated pipe scaling.

EMO 9.4 SERVICE BURNER AND ADJUST AIR-FUEL RATIO

DESCRIPTION: Service burner and adjust air-to-fuel ratio in oil or gas burners to achieve the highest combustion efficiency. Ensure proper atomization of oil by providing air turbulence and possibly preheating oil.(Heavy Oils).

APPLICATION: Gas and oil boilers.

SIDE BENEFITS: Decreased air pollution and soot production.

CAUTIONS: Condensation in the chimney may cause damage. This occurs if the flue gas temperature is too low or if the running time is too short.

COST FACTORS Normal maintenance of the burner.

INTERACTIONS: Carry out after EMO No. 9.5 Remove Scale and Soot.

EVALUATION; Part of normal maintenance; carry out at same time as measuring combustion efficiency.

EMO 9.5 REMOVE SCALE AND SOOT

DESCRIPTION: Removal of scale and soot to increase the heat transfer from combustion gases to the heating fluid

APPLICATION: Fuel fired boilers.

SIDE BENEFITS: Prolonged plant life.

COST FACTORS: Part of normal maintenance.

COMMENTS: When the fuel used is heavy oil or coal, soot formation can be minimized by correctly adjusted air-fuel ratio. Consider installation of soot blowers. Proper water treatment will minimize build-up on the water side.

EMO 9.6 RECALIBRATE MONITORING AND CONTROL EQUIPMENT

DESCRIPTION: Poor or low boiler efficiency is often caused by high levels of excess air due to incorrectly operating, combustion control systems. The accuracy of fixed instrumentation reduces with time and can mislead the boiler operator as to operating conditions.

APPLICATION: Boilers with fixed monitoring equipment or automated combustion controls.

COST FACTORS: Periodic maintenance item.

EVALUATION: By measurement of boiler efficiency (indirect method).

REFERENCES: EMS No. 6. Boiler Plant Systems.

EMO 9.7 MAINTAIN CHEMICAL TREATMENT PROGRAM

DESCRIPTION: Recommended water treatment procedures must be consistently followed to avoid scale build-up and ensure cleanliness of the heat transfer surfaces.

APPLICATION: All hot water and steam boilerhouses.

SIDE BENEFITS: Increased boiler and ancillary equipment life. Improved performance of distribution and end use systems.

CAUTIONS: Specialist advise on chemical treatment programme should be sought.

COST FACTORS: Moderate but ongoing cost. Capital costs may be high if new automatic dosing equipment required.

EVALUATION: Essential for steam and large boiler plant.

COMMENTS: Direct energy savings, difficult to quantify unless pre and post

	implementation efficiency testing of boiler carried out (using direct method).
REFERENCES	EMS No. 5 Combustion, EMS No. 6 Boiler Plant Systems Neff, C.H., 1986.

EMO 9.8 MINIMIZE LOAD SWINGS

DESCRIPTION:	Rescheduling of steam or hot water consumption can eliminate inefficient load swings where a boiler may operate at low load or an additional boiler be brought on line for a short period.
APPLICATION:	Generally only applicable where process steam energy use may be rescheduled or system start up times varied.
SIDE BENEFITS:	May permit shutdown of a boiler for maintenance purposes.
CAUTIONS:	Must be considered in light of production costs if process operation costs are varied.
COST BENEFITS:	Negligible if scheduling done manually.
EVALUATION:	Examine boiler operating hours and daily load profile.
REFERENCES:	EMS No. 5 Combustion, EMS No. 6 Boiler Plant Systems

EMO 9.9 MONITOR PLANT OPERATIONAL LOGS

DESCRIPTION:	Regularly check operational log books to compare present and past performance and look for trends or patterns in fuel use or maintenance costs.
APPLICATION:	All large boiler plants subject to regular inspection.
SIDE BENEFITS:	Ensures that maintenance checks are being carried out. May give advance warning of impending failures. Permits assessment of optimum maintenance frequencies.
COST FACTORS:	Negligible. Part of energy management program/duty of staff responsible for boiler plant.
EVALUATION:	Difficult to directly measure. Sustained high operating efficiencies resulting may be compared to previously recorded efficiencies.
REFERENCES:	EMS No. 5 Combustion, EMS No. 6 Boiler Plant Systems

EMO 9.10 MAINTAIN AIR TIGHTNESS OF BOILER SYSTEM GAS SIDE

DESCRIPTION:	Check for and correct air and flue gas leaks on air ducting, gas breaching, regenerative air heaters, observation doors, and boiler doors.
APPLICATION:	All types of boilers.
SIDE BENEFITS:	Improved safety condition in boiler house.
CAUTIONS:	Ensure all materials are suitable for duty and are approved for use with boiler/ancillaries.
COST FACTORS:	Normally low cost but depends on severity and source of leaks.
COMMENTS:	Direct measurement of savings difficult.
REFERENCES:	EMS No. 5 Combustion, EMS No. 6 Boiler Plant Systems

EMO 9.11 REDUCE OIL STORAGE TEMPERATURE

DESCRIPTION:	Heavy fuel oils (No. 6) require heating to 80 - 105º C to atomise effectively at the burner. However, oil may be stored at a lower temperature and final heating done at the tank outflow or burner.
APPLICATION:	Heavy fuel oil burning installations.
CAUTIONS:	Minimum recommended oil temperatures must be maintained.
COST FACTORS:	Low cost if no additional reheat installation required.
EVALUATION:	Base on difference in heat loss from tank shell.
REFERENCES	EMS No. 1 Process Insulation.

9.6.2 Low Cost

EMO 9.12 REDUCE BLOWDOWN LOSSES

DESCRIPTION:	Minimize blowdown losses by replacing regular (periodic) blowdown practices by: blowing down only when monitored suspended solids levels increase beyond that desirable and/or recovering heat from blowdown to preheat make-up water.
APPLICATION:	Steam boilers.
SIDE BENEFITS:	Reduced water treatment costs if time between blowdowns increased.
CAUTIONS:	Ensure adequate total dissolved solids removal maintained.
COST FACTORS:	Automatic blowdown system based on solids monitoring must be weighed against time spent by maintenance personnel and costs involved with treating boiler water to reduce solids formation.
COMMENTS:	Normally viable on larger boiler systems.
REFERENCES:	EMS No. 6. Boiler Plant Systems, Oven, M., 1983.

EMO 9.13 REPAIR OR UPGRADE INSULATION ON BOILER/FURNACE

DESCRIPTION:	Repair existing insulation of boiler, furnace and piping to reduce radiation and convection heat losses.
SIDE BENEFITS:	Reduced boiler room temperature.
CAUTIONS:	Do not block up the entrance for combustion air. Do not use inflammable insulation material.
COST FACTORS:	Low cost.
INTERACTIONS:	Consider EMO 9.25 Replace Obsolete Plant first.
EVALUATION:	Energy saving effectiveness increases with oversized boilers and high service temperature.
REFERENCES:	EMS No. 1. Process Insulation.

EMO 9.14 REPAIR REFRACTORY

DESCRIPTION:	Repair or replace refractory in the boiler.
APPLICATION:	All fossil fuel fired boilers with refractory lining.
SIDE BENEFITS:	Improve combustion efficiency, reduce soot formation, prolong boiler life.
COST FACTORS	Low if minor repairs are required. Replacement can be very expensive.
INTERACTIONS:	Consider EMO 9.25 Replace Obsolete Plant first.

EVALUATION: Measure combustion efficiency.
COMMENTS: Boiler inner chamber may benefit from size reduction by adding additional refractory where the burner has been derated.

EMO 9.15 INSTALL FLUE DAMPERS

DESCRIPTION: Install flue dampers to limit off cycle heat loss up the chimney, subject to compliance with regulatory codes.
APPLICATION: All boiler plants without power burners or with uncontrolled draught. Particularly beneficial on multi-unit plant where boilers are kept warm. Less benefit with furnaces since retained furnace heat less than retained heat in the water system.
SIDE BENEFITS: Reduced air infiltration (closed flue decreases stack induced infiltration).
CAUTIONS: May be less effective if burner has automatic air damper.
INTERACTIONS: Consider also EMO 9.22 Flue Gas Heat Exchanger.
EVALUATION: Evaluation must involve running time of boiler/furnace.
COMMENTS: Energy savings range from 1-2% to almost 10% in the ideal application.

EMO 9.16 DECREASE FIRING RATE OF THE BURNER OR FIT SMALLER BURNER

DESCRIPTION: Change burner nozzles or orifices, adjust secondary flow fuel restrictor, or replace burner with a smaller one.
APPLICATION: Oversized combustion equipment.
SIDE BENEFITS: Improved control and longer equipment life (less cycling).
CAUTIONS: Flue gas temperature must be high enough to avoid condensation. Large reductions in firing rate may require fire box size reductions.
COST FACTORS: Low, if existing burner can be derated, otherwise high cost.
EVALUATION: Potential benefit proportional to amount by which flue gas temperature exceeds 230°C. Short cycling indicative of oversized burner.
REFERENCES: Marcriss, 1985.

EMO 9.17 INSTALL MONITORING EQUIPMENT

DESCRIPTION: Install instrumentation to permit checking of boiler efficiency, fuel use, fuel meters or electricity meters for each boiler and for larger plant flue gas temperature and CO and O_2 monitoring and heat/steam metering.
APPLICATION: Fuel meters for all boilers, other equipment depending on size of boilers.
CAUTIONS: Calibration of fixed instrumentation should be checked regularly.
COST FACTORS: Depends on equipment installed flue gas monitoring can be costly.
INTERACTIONS: EMO 9.6 Recalibrate Monitoring Equipment.
REFERENCES: EMS No. 5 Combustion, EMS No. 6 Boiler Plant Systems

EMO 9.18 RELOCATE COMBUSTION AIR INTAKE

DESCRIPTION: Locating the boiler or furnace air intake in a hot spot such as at high level in the boiler house will preheat the combustion air resulting in higher efficiency.
APPLICATION: Any burner except atmospheric gas burners.
SIDE BENEFITS: Lower temperatures in boiler house.

CAUTIONS: Ensure pressure drop of intake duct does not alter fuel/air ratio.

COST FACTORS: Low cost normally but depends on size of boiler and height of boiler house.

EVALUATION: Savings may be calculated based on temperature difference.

REFERENCES: EMS No. 6. Boiler Plant systems.

9.6.3 - Retrofit

EMO 9.19 INSTALL MORE EFFICIENT BURNER

DESCRIPTION: Install multi-stage burner or modulating burner. Electronic ignition.

APPLICATION: All boilers except modular boiler systems or atmospheric burners.

INTERACTIONS: Consider as alternative to EMO 9.16 Downrate Burner.

EVALUATION: Estimate of improved seasonal efficiency will be required.

EMO 9.20 INSTALL DUAL FUEL BURNER

DESCRIPTION: Install burner for both oil and gas combustion, or solid-liquid solid-gas combination.

APPLICATION: Where better fuel costs are available with interruptible supply clause.

SIDE BENEFITS: More secure energy supply.

CAUTIONS: Does not normally result in energy saving unless more efficient burner is selected.

EVALUATION: Savings can be estimated based on differences in the fuel tariff cost.

EMO 9.21 INSTALL SUMMER DOMESTIC HOT WATER BOILER

DESCRIPTION: Install separate heater for DHW, for year round or summer only use.

APPLICATION: Combined space heat and DHW systems (EMO eliminates high summer stand-by losses), primarily large systems.

CAUTIONS: May not be cost effective, depending on individual system. Shutting off boiler plant when not required may be more efficient, i.e., if local DHW storage exists.

COST FACTORS: Effectiveness of summer use only increases with: oversizing of system with respect to summer demands, decreasing distribution efficiency, length of nonheating season and increasing DHW consumption.

EVALUATION: Cost-effectiveness based on estimation of differences in stand-by losses for heating plant and separate DHW heater required.

EMO 9.22 INSTALL FLUE GAS HEAT EXCHANGER

DESCRIPTION: Install flue gas heat exchanger (economizer).

APPLICATION: Subject to a need for the recovered heat boilers with high flue gas temperature. Heating systems with low temperature return flow. Steam boilers where recovered heat can be used to pre-heat boiler feed water.

CAUTIONS: Condensation in chimney.

INTERACTIONS: May be alternate to EMO 9.15 Flue Dampers.

EVALUATION: Generally worthwhile if flue gas temperature cannot be brought lower than 230°C, by other means.

EMO 9.23 INSTALL AUTOMATIC OXYGEN TRIM CONTROLLER

DESCRIPTION: Install automatic oxygen trim controller (combustion optimization system) to maintain minimum safe excess air level over varying load and fuel conditions.

APPLICATION: Commercial and institutional size boilers burning fossil fuels with jack-shaft or pneumatic controls.

CAUTION: Check calibration frequently.

COST FACTORS: Paybacks of the order of less than one year have been claimed for large boiler applications.

COMMENTS: Can reduce need for regular testing of efficiency.

REFERENCES: Hafeman, L.

EMO 9.24 INSTALL SEQUENCE FIRING OF MULTI-UNIT BOILER PLANT

DESCRIPTION: Fire no more boilers at any one time than are required to meet the heating load. Sequencing could be achieved by setting aquastats at different temperatures in each boiler but sensor drift and the inability to deal effectively with system time lags makes this method least effective.

APPLICATION: Multi-unit boiler plant.

CAUTION: The sequence should be verified through field measurements or monitoring.

INTERACTIONS: Alternative to EMO 9.1 Reduce On-Line boilers.

EVALUATION: Measure running time and starting frequency of individual boilers for different loads.

COMMENTS: The most efficient boiler should be used as the lead boiler. If all boilers are similar, running hours should be equalized.

EMO 9.25 REPLACE OBSOLETE HEATING PLANT

DESCRIPTION: Replace obsolete and oversized heating plant with new high efficiency correctly sized units or heat pumps.

APPLICATION: General. Most cost effective where existing boiler plant nearing the end of its useful life.

COST FACTORS: High cost.

EVALUATION: Desirability of retrofit influenced by boiler and burner age, combustion efficiency, extent of improvements required.

COMMENTS: Consider when other high cost EMOs under evaluation.

EMO 9.26 INSTALL WASTE HEAT BOILER

DESCRIPTION: Install a waste heat boiler or heat recovery incinerator to burn garbage or waste oil.

APPLICATION: Normally large facilities with continuous (all year) process loads and significant on site waste production.

SIDE BENEFITS: Reduction in waste disposal costs.
CAUTIONS: Exhaust gas emissions from waste burning should be considered.
COST FACTORS: High cost.
REFERENCES: Waste Heat Recovery manual.

EMO 9.27 REPLACE STEAM FEED PUMPS

DESCRIPTION: Steam operated boiler feed pumps are less efficient than electric feed pumps. Normally an electric feed pump is installed to facilitate start-up.
APPLICATION: Steam boiler installations with steam feed pumps.
COST FACTORS: Low cost if existing electric feed pumps installed. However, each site should be subjected to a financial analysis.
EVALUATION: Requires measurement of steam use and calculation electricity use .

10 - PROCESS FURNACES, DRYERS AND KILNS

10.1 - Introduction

Process furnaces, dryers, and kilns are used extensively in many industries for a wide variety of applications involving the addition of heat. Major uses include:

- **Heating or melting of metals**
- **Manufacture of bricks and ceramics**
- **Drying of wood and farm products**
- **Evaporation of solvents in paint or chemical products.**

10.2 - Fundamentals

The basic components of a fuel fired furnace are shown in figure 10.1

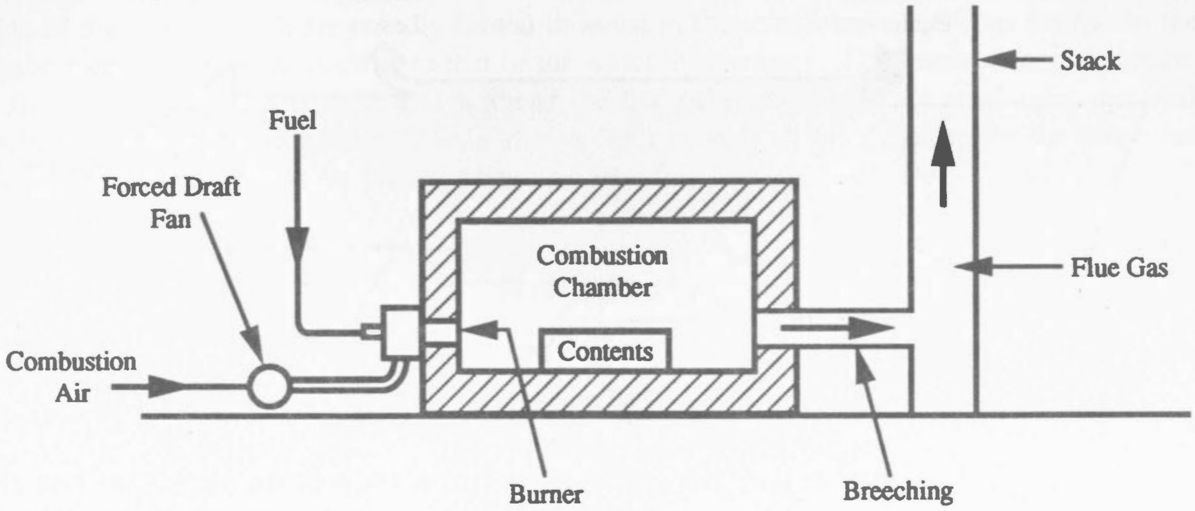


Figure 10.1 Fuel Fired Furnace

10.2.1 - Fuel System

In all applications of furnaces, dryers, and kilns, heat is produced from the combustion of fuel or by the use of electrical energy.

If heat is produced by the combustion of fuel, the furnace, dryer or kiln will have a combustion chamber where the fuel is burned. The product may be exposed directly to the heat generated in the combustion chamber, or indirectly through a heat exchanger so that the product is not directly exposed to the combustion gas.

10.2.2 - Combustion Air System

Combustion air can be supplied to the equipment by natural or forced draft systems. Natural draft uses the negative pressure (draft) produced by the furnace stack to draw combustion air into the furnace and the resulting flue furnaces with less than about one GJ/h heat input.

10.2.3 Excess Air

Information on the actual percentage of excess air supplied to the furnace is of importance to the furnace operator. The most accurate way of determining this is to analyze the flue gas leaving the furnace.

10.3 Energy Losses

10.3.1 Flue Gas heat Loss

The largest single source of heat loss in a fuel fired furnace is normally the heat in the flue gas leaving the furnace. The heat loss to the flue gas has two main components. The first is the heat in the dry gas, and the second is the heat in the water vapour leaving the furnace.

The water vapour loss includes the heat required to evaporate the moisture in the flue gas. It is not normally possible to recover the heat of evaporation since this would require lowering the temperature of the flue gas below the point where the moisture will condense. Other losses are mainly from convection and radiation and apply to all furnaces. The losses are shown diagrammatically in the Sankey diagram in Figure 10.2.

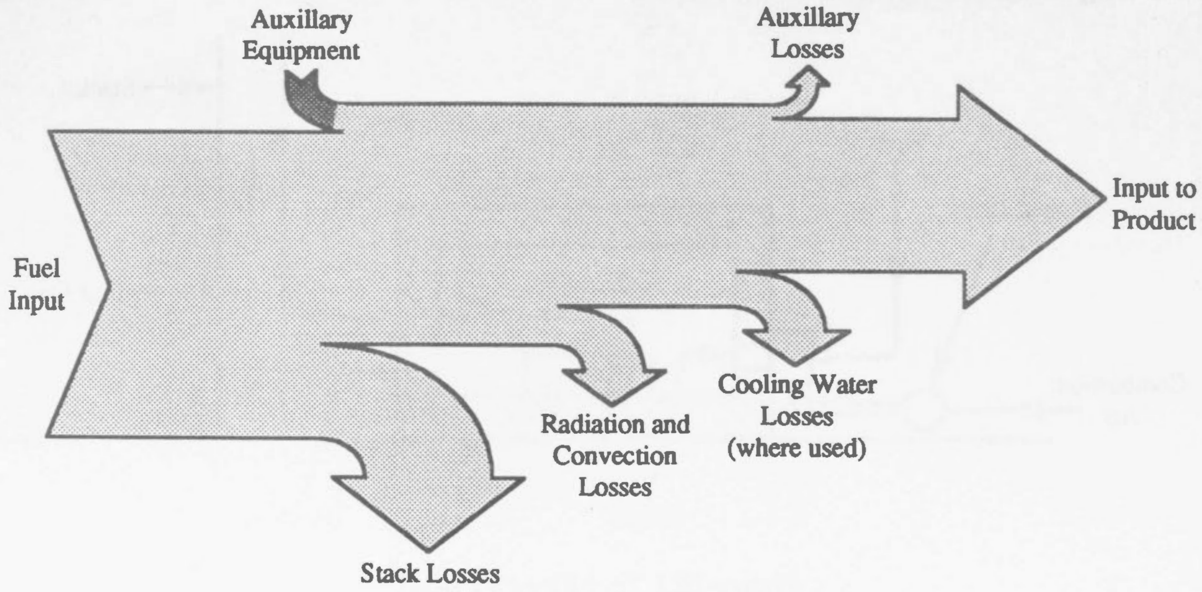


Figure 10.2 Furnace Energy Losses

10.3.2 - Heat Exchangers

Since most of the heat losses from a fuel fired furnace appear as heat in the flue gas, the recovery of this heat can result in substantial energy savings.A common method is to install a heat exchanger at the furnace exit. A heat exchanger can be used to transfer heat from the hot flue gas to the incoming combustion air, or to heat water used elsewhere in the plant. The rate of heat transfer is proportional to the surface area of the heat exchanger, and to the mean temperature differential between the flue gas and the combustion
air.

There are three main types of heat exchangers used.

1) **Recuperators**

Heat exchangers, which transfer heat from hot flue gas to combustion air, are sometimes called recuperators. The hot gas passes inside tubes arranged in bundles. The combustion air is directed over the outside of the tubes by means of a series of baffle plates.

Another form of gas to air heat exchanger is a regenerative air heater which has two separate sets of refractory bricks. These are alternately heated by the hot flue gas and cooled by the incoming combustion air. At regular intervals dampers automatically divert the hot has and cold air from one set of bricks to the other. Thus, one set fo bricks is being heated by the hot gas while the other set is heating the combustion air. The advantage of the regenerative air heater is that very high temperature gas can be handled without the need for expensive thin wall tubing made from stainless steel or other heat resistant materials.

2) Economizers

Economizers are heat exchangers which use hot flue gas to heat water. Economizers can be considered where hot water is required whenever the furnace is operating. If the use of hot water and the operation of the furnace does not always occur simultaneously, it may be practical to install an insulated hot water storage tank. This would level out the effect of variations in the hot water supply and demand.

The heated water passes inside metal tubes arranged in bundles. The hot flue gas passes over the outside of the tubes, which are usually finned to assist in the transfer of heat from the gas to the water. The tube metal temperature is close to that of the water temperature. Economizers can therefore extract heat from very high temperature gas without the use of expensive alloy steel tube material. It is important to ensure that the water flow is always high enough to avoid boiling of the water inside the tubes. If this happens, the tubes will overheat and way fail.

There is a counterflow arrangement in the economizer so that the gas leaving the economizer will be cooled to the lowest possible temperature by the cold water entering the economizer. This provides the most effective use of the flue gas heat.

3) Waste Heat Boilers

Waste heat boilers use hot flue gas heat to produce steam. In most instances there is a common steam header into which the waste heat and fuel fired boilers are connected. The fuel fired boilers will then supply the difference between the steam demand and the steam supplied by the waste heat boiler.

Economizers are often used with waste heat boilers to preheat the feed water to the boiler. That flue gas passes through the boiler before going to the economizer.

10.3.3 - Product Temperature Control

Control of product temperature is important in heat treating furnaces and similar applications. High temperatures may cause oxidizing or burning of the furnace contents, while low temperatures result in improper hardening or annealing. Location of the point of temperature measurement is important. The measuring element should not be exposed to radiation from the flame, nor should it be close to the furnace wall. Usually, the rate of energy input is varied in order to maintain a suitable furnace gas temperature. In large furnaces it is important to maintain an even temperature across the furnace. Continuous furnaces may require multiple heating zones each with banks of burners and a temperature controller. The ratio fo fuel to combustion air should be monitored carefully to keep the excess air as low as is practical.

10.3.4 - Safety

Safety implications must be evaluated when implementing energy management opportunities. The addition of a heat exchanger to recover flue gas heat by preheating combustion air, means that the air ducting to the burner may be at 400° C. The maximum temperature to which operating staff should be exposed is 50° C. Thus, protection for the operating personnel should be provided by insulating the air ducting. The protective insulation will also effect some heat savings; so it is worthwhile to consider insulating all hot ducting.

10.3.5 - Energy Management Potential

One of the first steps to be taken in a program of improved energy management is to become aware of the potential savings. It is helpful to compare the actual energy input with the energy usefully applied to the product.

Oil or gas energy input can be read directly if there is a meter which measures the fuel consumed by specific equipment. If a meter is not installed, arrangements for the installation a temporary positive displacement type meter should be made. Care should be taken to choose a meter which provides sufficient accuracy for this purpose. It should be possible to measure within one percent of the fuel use.

10.4 - Interactions

Improvements made to furnaces, dryers or kilns can have a large impact on other operations within a facility. Often the furnace may have contributed a large part or all of the space heating on the area. Replacement of covers, re-insulation or changes in operating periods can dramatically effect the space temperature in the furnace or foundry room.

Any changes to the operating regime of the furnace can impact on production or process schedules and this should be examined to determine if production rates will be adversely effected.

Utility rate structures can also be effected by changes in operating patterns. Supply agreements may have maximum hourly consumption limits which may prevent multiple operation of large items of equipment.

Energy input to an electric furnace should be measured by a wattmeter, which requires a measurement of voltage and current in two phases of a three phase power supply. If heating is provided by a resistance element and the voltage does not fluctuate it is possible to use a clamp-on ammeter to give an instantaneous indication of the energy input.

Electrical demand charges must be considered for electric furnaces. The demand charges can be reduced by automatically shutting down non-essential electrical loads whenever a new peak in electrical load is approached. It may also be possible to reduce load on some furnaces to reduce the peak demand. Substantial savings in electricity costs can be achieved with the use of a "peak-load" control system.

10.5 - Survey

Many energy management opportunities in the operation fo furnaces, dryers, and kilns can be recognized by performing and audit. It is often helpful to engage someone for this task who is not normally associated with the plant operation. A fresh viewpoint will often pick up items which have been overlooked in the past. Typical energy wasting items which can be identified in this manner are open or missing furnace doors, deteriorating insulation, and under-loaded or over-loaded equipment.

10.5.1 - Walk-through Audit

During the walk-through, the following items should be checked.

Type of Equipment Note the type of furnace, drier and kiln under investigation.

Rating/Size The capacity or maximum fuel load of the equipment should be recorded.

Fuel Type The type of fuel burned should be recorded.

Flame Appearance In general terms a natural gas flame should be clear or slightly blue in colour, while an oil flame should be light brown or yellow. A short blowtorch shaped flame indicates too much air, whereas a long lazy smoky flame indicates too little air.

Missing or Damaged Insulation Look for damaged, missing or inadequate insulation and covers on the furnace enclosure.

Operating Schedule Take note of the hours which the equipment is kept hot and compare this with its actual use.

Evidence of Inefficient Operating Procedures Observe the operation of the equipment to establish if it is left empty or if the doors are left open unnecessarily.

While some EMOs can be identified during the walkthrough most potential measures for furnaces, dryers and kilns are difficult to analyze. It may have been observed, for instance, that the temperature of the flue gas leaving a furnace is very high at 500° C. The economics of recovering this energy are not immediately obvious and must be thoroughly investigated. A number of key questions must be answered.

* What quantity of energy is available in the gas stream?
* Can this energy be used?
* What is the capital cost for the equipment needed to recover the energy?
* What are the energy savings and will the resulting cost reductions pay for the equipment needed?

A diagnostic audit will answer the above questions and lead to a determination of the financial feasibility of the Energy Management Opportunity. Detailed information on conducting diagnostic audits is provided in the EMS modules referenced following in section 10.6 below.

10.6 - Annotated List of Energy Management Opportunities

10.6.1 - Housekeeping

EMO 10.1 SERVICE BURNER AND ADJUST AIR-FUEL RATIO

DESCRIPTION:	Service burner and adjust air-to-fuel ratio in oil or gas burners to achieve the highest combustion efficiency.

APPLICATION: Gas and oil furnaces and boilers.

SIDE BENEFITS: Decreased air pollution and soot production.

CAUTIONS: Condensation in the chimney may cause damage. This occurs if the flue gas temperature is too low.

COST FACTORS: Normal maintenance of the burner.

INTERACTIONS: Carry out EMO 10.2 as alternative. (Remove scale and soot) before servicing, evaluate EMO 10.12 as alternative. Also consider EMO 10.13 Oxygen trim and EMO 10.10 Flue gas heat recovery.

EVALUATION: Part of normal maintenance; carry out at same time as measuring combustion efficiency.

EMO 10.2 REMOVE SCALE AND SOOT

DESCRIPTION: Remove of scale and soot to increase the heat transfer from combustion gases to the heating fluid.

APPLICATION: Fuel fired furnaces.

COST FACTORS: Part of normal maintenance.

INTERACTIONS: Carry out before EMO 10.1 Service Burner

EVALUATION: Test efficiency before and after cleaning.

COMMENT: When heavy oil or coal are used as fuel, soot formation can be minimized by correctly adjusted air-fuel ratio. Consider installation of soot blowers.

10.6.2 - Low Cost

EMO 10.3 REPAIR OR UPGRADE INSULATION ON FURNACE

DESCRIPTION: Repair of existing insulation of furnace and piping to reduce radiation and convection heat losses.

SIDE BENEFITS: Reduced furnace room temperature.

CAUTIONS: Do not block up the entrance for combustion air. Do not use inflammable insulation material.

COST FACTORS: Low cost.

INTERACTIONS: Upgrade is alternative to EMO 10.11 Re-insulate furnace enclosure.

EVALUATION: Energy saving effectiveness increases with oversized boilers and high service temperature.

EMO 10.4 REPAIR REFRACTORY

DESCRIPTION: Repair or replace refractory.

APPLICATION: All fossil fuel fired furnaces with refractory lining.

SIDE BENEFITS: Improved combustion efficiency, reduced soot formation, prolonged furnace life.

COST FACTORS: Low if minor repairs are required. Replacement can be very expensive.

INTERACTIONS: Consider in conjunction with EMO 10.11 Re-insulate furnace enclosure.

EVALUATION: Measure combustion efficiency.

COMMENTS: Furnace inner chamber may benefit from size reduction by adding additional refractory where the burner has been derated.

EMO 10.5 REINSTALL DOORS OR COVERS

DESCRIPTION: Access or inspection doors to fire side or product side should be in good order and keep closed.

APPLICATIONS: All dryers, furnaces and kilns.

SIDE BENEFITS: Improved comfort for operators, closer control of product temperatures.

COST BENEFITS: Low if straight replacement required.

INTERACTIONS: Carry out prior to other EMOs.

REFERENCES: EMS No. 7 Process Furnaces, Dryers and Kilns.

EMO 10.6 MINIMIZE LOAD SWINGS

DESCRIPTION: Rescheduling of production can eliminate inefficient load swings where a furnace or kiln may operate for only an hour each day.

APPLICATION: Generally only applicable where production may be rescheduled or system start-up times vary.

SIDE BENEFITS: May permit shutdown of a furnace for maintenance purposes.

CAUTIONS: Must be considered in light of production costs if process operation costs are varied.

COST BENEFITS: Negligible if scheduling done manually.

EVALUATION: Examine furnace operating hours and daily load profile.

REFERENCES: EMS No. 5 Combustion, EMS No. 6 Boiler Plant Systems.

EMO 10.7 MAINTAIN AIR TIGHTNESS OF PRODUCT SIDE AND GAS SIDE

DESCRIPTION: Check for air or flue gas leaks on air ducting, gas breaching, regenerative air heaters, observation doors or furnace doors.

APPLICATION: All types of furnaces.

SIDE BENEFITS: Improved safety condition for operators.

CAUTIONS: Ensure all materials are suitable for duty and are approved for use with furnace/ancillaries.

COST FACTORS: Normally low cost but depends on severity and source of leaks.

INTERACTIONS: See EMO 10.5 Re-install doors or covers.

COMMENTS: Direct measurement of savings difficult.

REFERENCES: EMS No. 5 Combustion, EMS No 6 Boiler Plant Systems..

10.6.3 - Retrofit

EMO 10.8 INSTALL MONITORING EQUIPMENT

DESCRIPTION: Install instrumentation to permit checking of furnace efficiency and fuel use, fuel meters or electricity meters for each furnace and for larger plant flue gas temperature and oxygen monitoring and heat/steam metering.

APPLICATION: Fuel meters for all furnaces, other equipment depending on size of furnaces.

CAUTIONS: Calibration of fixed instrumentation should be checked regularly.

COST FACTORS: Depends on equipment installed flue gas monitoring can be costly.

INTERACTIONS: Consider as alternative to EMO 10.13 Install oxygen trim.

REFERENCES: EMS No. 5 Combustion, EMS No. 6 Boiler Plant Systems.

EMO 10.9 INSTALL HEAT RECOVERY OF PROCESS COOLING WATER

DESCRIPTION: Install heat exchangers to recover heat from cooling water to preheat furnace air or domestic hot water.

APPLICATION: Water or liquid cooled processes.

CAUTIONS: If contaminated water is produced, care should be taken to avoid fouling or corroding of heat exchanger.

INTERACTIONS: Consider in tandem with EMO 10.10 Install flue gas heat exchanger.

EVALUATION: Depends on a consistent requirement for recovered heat.

REFERENCES: EMS No. 7 Process Furnaces, Dryers and Kilns.

EMO 10.10 INSTALL FLUE GAS HEAT EXCHANGER

DESCRIPTION: Install flue gas heat exchanger (economizer).

APPLICATION: Subject to the need for the heat recovered, furnaces with high flue gas temperature. Heating systems with low temperature return flow. Steam boilers where recovered heat can be used to pre-heat boiler feed water.

CAUTIONS: Condensation in chimney.

INTERACTIONS: Consider in tandem with EMO 10.9 Heat recovery from process cooling water and EMO 10.1 Adjust air-fuel ratio.

EVALUATION: Generally worthwhile if flue gas temperature cannot be brought lower than 230^{o}C. by other means.

EMO 10.11 REINSULATE FURNACE ENCLOSURE

DESCRIPTION: Older furnaces may use refractory brick linings. When rebuilding it is often economic to use ceramic fibre blanket insulation.

APPLICATION: Furnaces, dryers or kilns with poor insulation and in need of repair.

SIDE BENEFITS: Improved comfort and safety for operators.

CAUTIONS: If lining has to withstand rough handling then an outer layer of ceramic fibre insulation could be used. Danger of overheating inner refractory.

INTERACTIONS: Consider as an alternative to EMO 10.3 Upgrade Insulation.

REFERENCES: EMS No. 7 Process Furnaces, Dryers and Kilns.

EMO 10.12 REPLACE BURNER

DESCRIPTION Install higher efficiency burner or regenerative burner.

APPLICATION: Fuel fired furnaces, dryers and kilns.

SIDE BENEFITS: Can provide automated start and stop and closer product temperature control.

COST FACTORS: Normally high cost.

INTERACTIONS: Consider if EMO 10.1 does not provide satisfactory results.

REFERENCES: EMS No. 7 Process Furnaces, Dryers and Kilns

EMO 10.13 INSTALL AUTOMATIC OXYGEN TRIM CONTROLLER

DESCRIPTION	Install automatic oxygen trim controller (combustion optimization system) to maintain minimum safe excess air level over varying load and fuel conditions.
APPLICATION:	Furnaces burning fossil fuels with jack-shaft or pneumatic controls.
CAUTION:	Periodic checking of calibration essential.
COST FACTORS:	Paybacks of the order of less than one year have been claimed for large applications.
INTERACTIONS:	Reduces frequency of burner servicing EMO 10.1.

11 - STEAM DISTRIBUTION AND CONDENSATE RETURN SYSTEMS

11.1 - Introduction

Steam is one of the most commonly used mediums for the transfer of energy in the form of heat, particularly in large industrial buildings. This sub-section deals with the major system types to be found and focuses on potential EMOs and methodologies for surveying steam and condensate pipe work systems.

11.2 - Fundamentals

In any steam system, steam is generated in a boiler and distributed to the energy consuming equipment. Where steam is used via a heat exchanger **(indirect use)** only the latent heat in the steam is used and the unused portion (condensate) is returned to the boiler or discharged as waste. Steam may also be injected straight into a product or process **(direct use)** in which case there is no condensate to return (see Figure 11.1).

In normal terminology the piping carrying the steam between the boiler and the equipment is called the Steam Distribution System and the piping returning the condensate is called the Condensate Return System.

Piping systems vary in size, but the basic concepts are the same. Steam can be used for space heating, or as a heat source for process equipment, where it is put to use through heat exchangers, steam coils, jacketed vessels, laundry equipment and kitchen equipment. Steam can also be used as an energy source in certain cooling systems.

Steam and condensate piping systems are classified under three separate categories.

- Piping arrangement.
- Pressure ranges.
- Method of condensate return.

11.2.1 - Piping Arrangement

Under this classification the systems are further subdivided as follows.

One-pipe systems in which a single main is used to deliver the steam to and return the condensate from the terminal unit. This type of system does not have steam traps to separate the condensate from the steam.

Two-pipe systems in which the steam and condensate flow in separate pipes. The steam system is separated from the condensate system by steam traps which allow the passage of condensate but not steam.

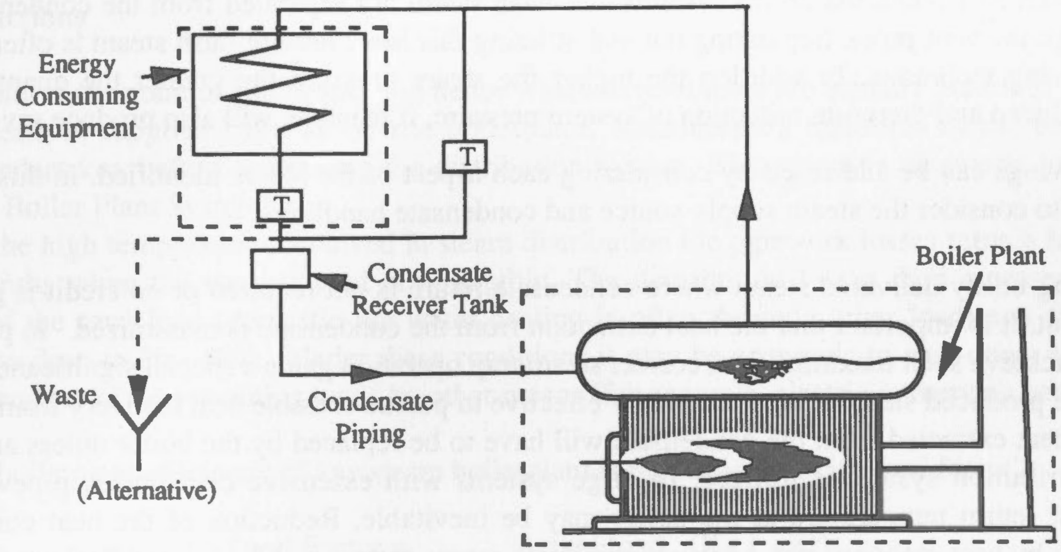


Figure 11.1 Steam and Condensate Cycle

11.2.2. - Pressure Ranges

Systems are subdivided as follows.
High pressure system- with operating pressures of 690 to 2400 kPa(gauge).
Medium pressure system- with operating pressures of 103 to 690 kPa(gauge).
Low pressure system- with operating pressures of 0 to 103 kPa(gauge).
A vacuum system- operates at less than 0 kPa (gauge).
A vapour system- operates under the same conditions as a vacuum system but without use of a vacuum pump.

Where steam is required at differing pressures it will normally be generated at the highest pressure required and pressure reduced locally to the required levels using pressure regulating valves.

11.3 - Method of Condensate Return

Systems are subdivided as follows.

Gravity return systems-where condensate is returned to the boiler or condensate receiver by gravity.
Mechanical return systems-where steam traps, condensate pumps or vacuum pumps are used to return condensate.

These systems and associated equipment are fully described in EMS No. 8 Steam and Condensate Systems

11.4 - Energy Losses

Losses in a steam distribution system occur in two principal areas, heat loss from the piping system components and fluid losses. Losses are shown pictorially in the Sankey diagram Figure 11.2. Steam pipework heat losses are potentially higher than in similar water pipework systems because of the higher operating temperatures.

For open vented condensate return systems any flash steam not separated from the condensate will be lost through the vent pipes. Separating out and utilizing this low pressure flash steam is often a valuable energy saving technique. In addition the higher the steam pressure the greater the quantity of flash steam produced and therefore reduction of system pressure, if feasible, will also produce savings.

Energy savings can be addressed by considering each aspect of the losses identified. In this regard it is important to consider the steam supply source and condensate handling.

When using utility delivered steam where condensate return is not required or no credit is given for its heat content, it is important that the heat extraction from the condensate is maximized. In pursuance of EMOs to achieve such maximization, correct steam trap operation gains a special significance.

For on-site produced steam it is not normally effective to pursue sensible heat recovery from condensate since the heat extracted from the condensate will have to be replaced by the boiler unless an open-loop steam distribution system is utilized. In large systems with extensive distribution pipework, a low condensate return temperature at the boiler may be inevitable. Reduction of the heat content of the condensate by heat recovery can, however, minimize return system heat losses and flash steam losses.

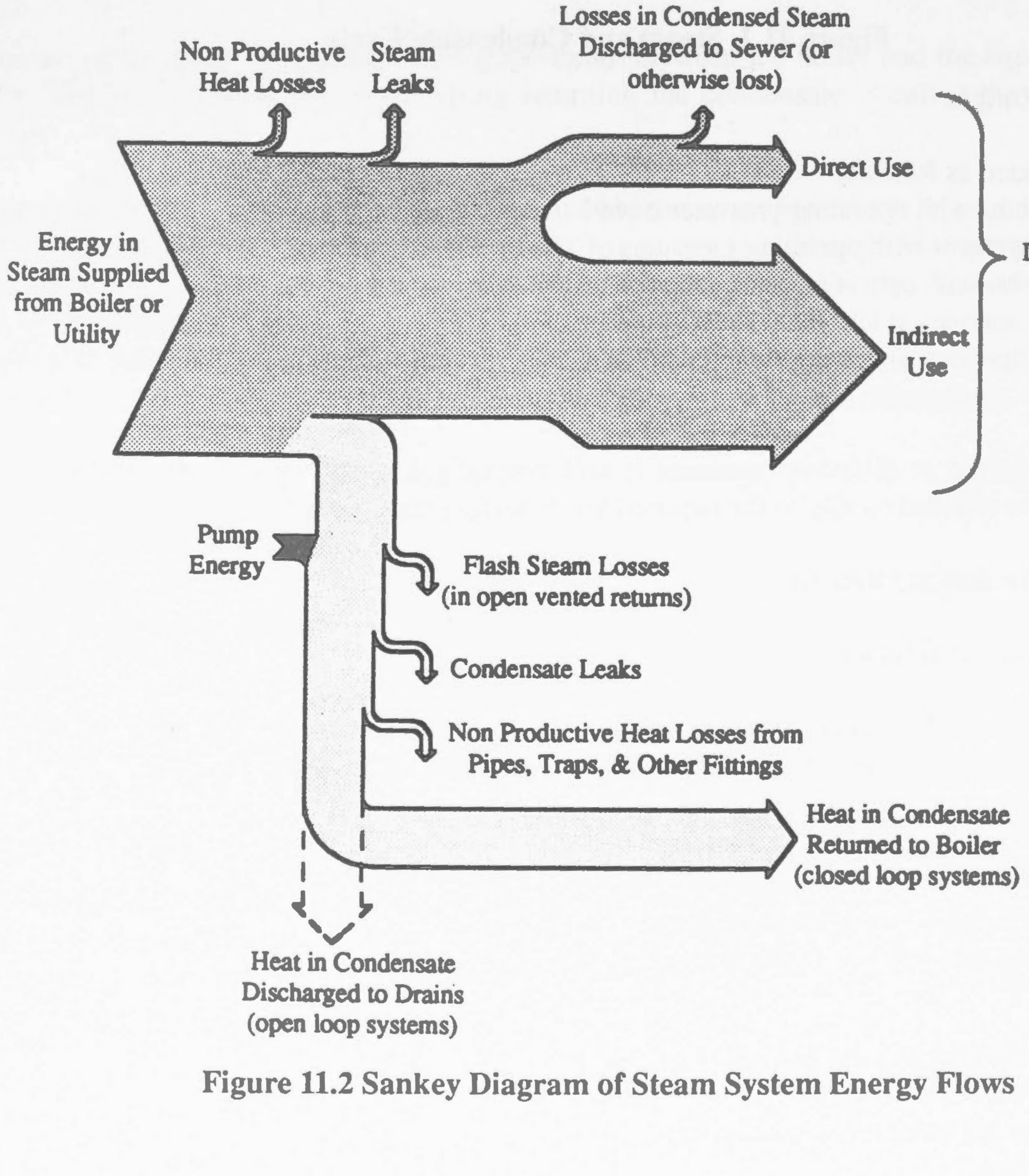


Figure 11.2 Sankey Diagram of Steam System Energy Flows

11.5 - Interactions

The boilerplant is the point of use of fuel and hence where expenditures are actually incurred. Therefore wherever steam is supplied from an on-site boilerplant, housekeeping measures in the boilerhouse should be undertaken before examining the distribution system. Boilerplant is discussed in detail in EMS No.6 - Boiler Plant Systems.
Because of the high temperatures involved in steam distribution the pipework losses remain high in the summer months when the heating load is negligible. The distribution losses then represent a large proportion of the total load (domestic hot water heating is often the only other load) and the system efficiency can drop to 30 - 40%. Under these conditions it may be economic to shut-down the central boiler plant and serve the remaining loads by other means (for example, electric immersion heaters).

The overall boilerplant efficiency of any steam boilerplant is proportional to its 'load factor'.

$$\text{Load Factor} = \frac{\text{Actual load (Kg / year)}}{\text{Plant Capacity(Kg/hour)x8760}}$$

That is, in general the nearer the boilerplant operates to full load the better the efficiency. The thermal efficiency of a given boiler may be higher at part load than full load but boiler radiant losses and standby boiler operation normally reduce the boilerplant efficiency at part load. Therefore a reduced distribution loss will have a slightly detrimental effect on boilerplant efficiency unless, of course, the boilers were previously unable to meet the peak load.

Any reduction in loads due to EMOs undertaken will affect boilerplant efficiency and, when these measures represent more than 10-15% of total load, the boilerhouse should be examined to assess if it would be appropriate to implement further modifications, such as downrating the boilers.

11.6 - Survey

When inspecting a steam distribution system a systematic approach will assist in ensuring that no areas are missed or overlooked. Starting at the boilerhouse or audit boundary for the survey, follow the main distribution lines noting where branches are taken off. Do not get sidetracked examining individual branches initially. Trace the main pipe runs to their furthest point before backtracking and examining individual feeds to buildings or areas.

11.6.1 - Walk-through Audit Procedure

During a walk-through audit the following items should be noted:

System Condition: The condition (state of repair) of pipework, valves, traps, etc. should be recorded.

Steam leaks: Note where steam leaks are occurring and their size (plume length)

Plumes from Vents: Some steam loss is inevitable but if it appears to be discharging under pressure i.e. with some velocity, a problem is indicated.

Trap Operation: Listen for operation of traps. A trap opening and closing can normally be heard. If the trap is continuously noisy or completely silent, a problem is indicated. A cold discharge pipe may indicate a trap fixed in the closed position.

Redundant Steam Mains: Note if there are any live steam mains serving loads that are no longer in operation.

Condition of Insulation: Look for missing or damaged insulation. The surface temperature of insulation should be checked. High jacket temperatures may indicate wet or missing insulation. Wet insulation may be indicative of leaks or failure of the weatherproofing membrane.

Condensate Return Temperature: Where steam is supplied from an on-site boiler facility, the boilerhouse provides useful evidence of the condition of the distribution system. The proportion of make-up water to steam produced should be calculated. The lower the proportion of make-up, the better. Normally 15 - 20% make-up may be expected in a primarily indirect system. If the return condensate temperature is very low (less than 60° C.), then insulation may be inadequate. If the temperature is very high (greater than 85°C.) then this may indicate traps passing steam.

Underground Steam Mains Condition: Faults in underground external steam pipework may often be indicated in the winter by excessive or rapid snow melt, early development of plant growth or by premature browning of grass during the summer months.

11.7 - Annotated List of Energy Management Opportunities

11.7.1 - Housekeeping

EMO 11. 1 REPAIR LEAKS

DESCRIPTION:	Check for leaks in pipes, tanks, or other pipework components. This EMO will prevent deterioration and loss of thermal resistance of insulants.
APPLICATION:	Applies to all the components that are likely to leak (unions, flanges, valves and pump packing/glands).
SIDE BENEFITS:	Will reduce water consumption and water treatment costs, building damage, mould formation, etc. May reduce system cycling improving occupant comfort.
COST FACTORS:	Depends on type of failure. May be very expensive if site is not accessible. Best pay-back for large control valves and where pipes outside or heat loss not contributing to space heating.
INTERACTIONS:	Carry out prior to EMO. 11.4 Repair/Upgrade Insulation. Consider EMO 11.5 Rationalize Pipework before repairing minor leaks.
EVALUATION:	For steam leaks use Table 5 or 7 in EMS No.8.
REFERENCES:	EMS No.8. Steam and Condensate Systems.

EMO 11.2 MAINTAIN STEAM TRAPS

DESCRIPTION:	Check that steam traps passing condensate, venting gases and restricting steam passage. Also check that bypass around traps are not passing steam.
APPLICATION:	Non gravity return type steam systems.
SIDE BENEFITS:	A reduction of steam loss at traps can make more steam available for useful

purposes.

CAUTIONS: Condensate left in the system can cause noise (water hammer), coil freeze up in extreme climates or damage as a plug of water is carried along in the pipework. Air in the system tends to reduce heat transfer; carbon dioxide forms carbonic acid which causes corrosion.

COST FACTORS: Negligible. Maintain all faulty traps as part of required maintenance.

EVALUATION: Most benefit obtained in open loop systems where condensate is discharged to drain or lost, or where steam is purchased and discharged with little or no account given for the condensate heat content. EMS No. 8 describes methods by which faulty steam trap operation can be identified.

COMMENTS: Steam issuing from open vents usually indicates that one or more traps in the installation is passing steam.

REFERENCES: EMS No.8. Steam and Condensate Systems, Spirax Sarco -Design of Fluid Systems, Steam Utilization, 1985.

EMO 11.3 MAINTAIN CHEMICAL TREATMENT PROGRAM

DESCRIPTION: Maintain chemical treatment programme to ensure cleanliness of steam and condensate system and maximize efficiency.

APPLICATION: All closed loop steam and condensate systems.

SIDE BENEFITS: Increased life of pipework and equipment. Improved heat transfer in heat exchangers.

COST FACTORS: Moderate but ongoing cost if manual testing and dosing carried out. Higher cost if automated monitoring and dosing. Professional advice should be sought on implementation.

INTERACTIONS: Chemical treatment programme must be developed to protect boiler as well as distribution system.

EVALUATION: Should be considered as part of maintenance programme.

COMMENTS: Direct energy savings may be small and difficult to quantify depending on the condition of plant and systems prior to implementation.

REFERENCES: EMS No.8.Steam and Condensate Systems.

11.7..2 - Low Cost

EMO 11.4 REPAIR/UPGRADE INSULATION ON PIPES AND TANKS

DESCRIPTION: Repair, upgrade or install insulation of pipes and tanks.

APPLICATION: Applies to all equipment (pipes, tanks, heat exchangers, etc.) containing heated fluids, especially to larger, higher temperature difference equipment; where heating temperatures do not vary with demand; and where heat losses do not contribute to space conditioning.

SIDE BENEFITS: Increases the distribution efficiency.

CAUTIONS: Do not exceed optimal thickness. Boilerhouse efficiency may be reduced slightly. Often not economic to insulate condensate lines between trap and vented condensate receiver.

COST FACTORS: Depends on labor cost and material cost.

INTERACTIONS: EMO 11.1 Repair Leaks should be carried out first.

EVALUATION: Use Table 6 in EMS No.8 or Tables 4 to 6 in EMS No.9.

REFERENCES: EMS No.8 Steam and Condensate Systems and EMS No. 9 Heating and

Cooling Systems.

EMO 11.5 RATIONALIZE PIPEWORK

DESCRIPTION: Rationalize pipework systems to optimize pipe lengths and eliminate unnecessary or disused branches.
APPLICATIONS: Any system that has been modified or was inefficiently installed.
SIDE BENEFITS: Additional space 'freed up' for other services.
COST FACTORS: Entirely dependant upon amount of pipework to be removed.
INTERACTIONS: Carry out before EMO 11.4 Repair/Upgrade Insulation or EMO 11.1 Repair leaks.
EVALUATION: May be easily calculated from the heat lost from the piping to be removed.
COMMENTS: Normally cost effective unless removals hampered by out-side factors (i.e. asbestos insulation).
REFERENCES: EMS No.8 Steam and Condensate Systems.

11.7.3 - Retrofit

EMO 11.6 HEAT RECOVERY FROM CONDENSATE

DESCRIPTION: Use flash steam generator or heat exchanger to extract heat from condensate.
APPLICATION: In open loop systems (or parts of system) and where steam is purchased and little or no account is made of condensate heat content, or where condensate return system is lengthy.
INTERACTIONS: Installation of a condensate return system would be an alternative in open loop systems or sub-systems. The recovered heat could be utilized for domestic hot water heating.
EVALUATION: Calculation of useful heat content of condensate should be carried out using steam tables.
COMMENTS: Recovered heat should ideally be used for non-critical heating applications and storage type heating duties (for example, service hot water storage type heaters).
REFERENCES: ASHRAE Systems, Ch. 13, 1984;

EMO 11.7 SEPARATE FLASH STEAM FROM CONDENSATE

DESCRIPTION: Ensure that sufficient heat is removed from the condensate to prevent flash steam escaping from open vents by using Flash Steam generators to produce low pressure steam and by equalizing pressure between pressure powered pumps and the equipment they drain.
APPLICATION: Open vented return systems.
SIDE BENEFITS: Generation of low pressure steam.
INTERACTIONS: Ensure correct steam trap operation before considering this EMO. See also EMO 11.6 Heat recovery from condensate.
EVALUATION: This EMO should be considered where system vents are discharging steam and all steam traps have been checked for correct operation and maintained or replaced as found necessary and where the steam can be effectively utilized.
REFERENCES: Spriax Sarco - 1985.

12 - DOMESTIC AND PROCESS HOT AND COLD WATER

12.1 - Introduction

This section examines the generation, storage, distribution and end use of domestic hot and cold water and process water. Domestic water is defined as potable water where as process water may or may not be potable.

12.2 - Fundamentals

DHW systems usually fall into one of the following two categories.

- **Individual systems** designed for service water heating, using electricity, oil or gas as the primary energy source, either with or without storage.

  In the latter case, water is heated as soon as a tap is opened, while in the former the water storage mass is maintained at a given temperature.

- **Central systems**, normally oil- or gas-fired, or electrically heated, either instantaneous units in which water is heated by means of a coiled tube built into the boiler, or in a separate heat exchanger; or storage systems in which the storage tank may be either incorporated in the boiler or may be separate. Central units are often part of combined space heating and DHW production units.

12.3 - Energy Losses

Typical energy flows associated with domestic hot water are illustrated in the Sankey diagram Figure 12.1.

The relative magnitude of the various energy flows depends on several factors, namely:

- **Type of primary energy source,** eg. electricity (resistive heating), electricity (heat pump), fossil fuel, solar.
- **Type of boiler,** eg. combined space heating/DHW production, separate DHW production.
- **Type of DHW delivery,** eg. instantaneous, storage type.
- **Type of distribution,** eg. local production of DHW at each tap, distribution to taps from a central boiler, circulation loop with return of unused water, dead-leg distribution (no return).

12.3.1 - Production Losses

In DHW plants using conventional combustion heat generators, energy losses are of the same origin (i.e. incomplete combustion, stack losses, etc.) as in boiler plant. See section 9.0.

For electric resistive boilers the production losses are virtually nil, since the input electric energy is totally converted into heat, which is transferred to the water. Since the heating element is immersed into the water, losses to the environment are negligible.

Some ambiguity exists in the definition of production losses for those systems, such as heat pumps and solar systems, in which the input energy (fossil fuel or electricity) is smaller than the heat transferred to the water. In this case it seems more appropriate to evaluate the system performance in terms of a Coefficient of Performance (COP) defined as the ratio of delivered energy to input energy, rather than in terms of production losses.

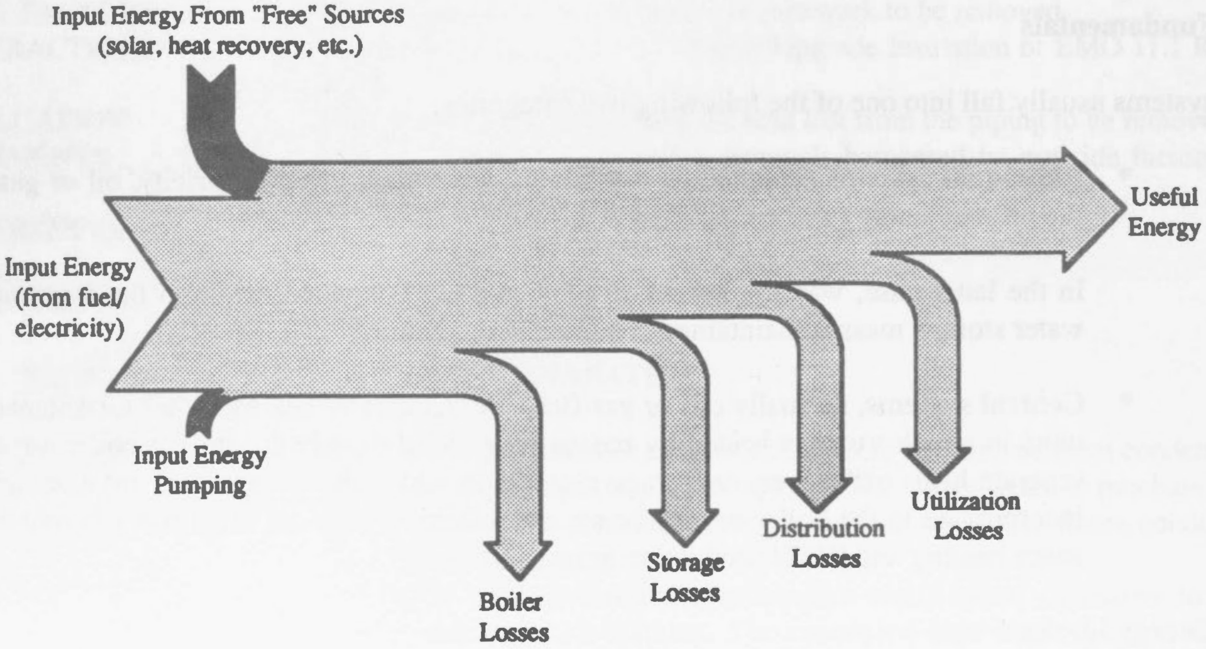


Figure 12.1 Energy Flows in a DHW System

12.3.2 - Storage Losses

The thermal power lost by conduction through a tank jacket can be easily estimated. See EMS No.1 Process Insulation. In addition, the following effects contribute to the storage losses:

- pipe connections to a tank, especially if not insulated,
- poor stratification in a tank due to high flow velocity or mixing induced by the recirculated water,
- ventilated airspace between tank and insulation, and
- high output heating element inducing strong convective currents.

Storage losses can be reduced by increasing the thermal resistance (i.e. the insulation thickness), reducing the size of storage or reducing the temperature of the stored water.

12.3.3 - Distribution Losses

In the distribution sub-system, two energy flows must be considered: heat transfer through the pipe wall, and pumping energy. The latter is obviously zero if no circulation pump is provided, or if the pump is turned off. Distribution losses can be particularly significant in central systems in which the circulation pump maintains a constant hot water flow in the distribution loop (this is done in order to guarantee a constant delivery temperature). Savings are possible if a lower water temperature can be accepted. If the user can accept some delay in hot water delivery, the pump can be turned off with a resulting decrease in distribution losses. (The user will first have to drain the pipe of the cool water.)

An intermediate solution is to cycle the circulation pump operation based on the minimum acceptable return water temperature, or to schedule pump operation with occupied hours.

12.3.4 - Utilization Losses

These losses can be attributed to excessive DHW use and operation at higher than necessary temperatures. Lower supply temperatures, mixing faucets and changes to personal habits can all contribute in limiting excessive use. It should be observed that the sensible enthalpy of waste DHW is usually quite high: a heat exchanger could therefore be employed to recover some of the waste heat for cold water preheating.

12.4 - Interactions

Hot water supply, both domestic and process, is often affected by other building services. Heating boilers may often provide domestic or process hot water through shell and tube or plate heat exchangers. Any EMOs affecting central boiler plant operating hours or temperatures may impact on hot water generation.

Reductions in flow temperatures or pressures on large distribution systems can reduce the capacity of local hot water generators.

DHW storage temperatures should not be reduced to such an extent that bacteriological growth becomes a problem.

The occupancy of a facility should always be considered when evaluating DHW systems. For example, schools (i.e. showers) or batch process loads represent periodic high peak demands with little or no load in between. Large storage capacities are required to economically meet these loads. Public washrooms may have frequent but low volume use which could be provided by instantaneous hot water generation.

12.5 - Survey

It is recommended that the occupants or process requirements are considered before commencing site survey work. The anticipated pattern of usage can be useful in establishing whether storage capacities are adequate or excessive.

It is often difficult to determine the routing of water pipework or from where loads are served. Any installation drawings available should be reviewed as they may assist in establishing how and if the distribution system is zoned and the location of the points of use and generation.

Water supply bills should be examined to assess if any monthly pattern of use exists.
The audit should commence at the point of generation and then follow the distribution system (where

possible) to the point of use.

12.5.1 - Walk-through Audit Procedure

During a walk-through audit of a facility the following points should be noted:

Domestic Hot Water -

Type of hot water generation Note whether storage or non-storage systems are used and whether centralized or local systems are installed.

Heating Source Note if electric, oil, gas or coal is used to produce hot water.

Circulation pump Check if a secondary circulation pump is installed and the hours of operation and method of control (timed or temperature control).

Storage tank size Where applicable note the size of the storage vessel(s) installed.

Temperature of stored water Record the temperature of the hot water in the tank. It should normally be between 55 and 65°C.

Delay Time at faucet Measure the delay time between turning on tap and hot water delivery (Take point distant from generation point)

Water Temperature at Faucet Measure the temperature of hot water at tap. Comparing this with the storage temperature will give an indication of the heat losses in the distribution system.

Flow and Return Temperatures On pumped systems measurement of the flow and return temperatures will also give an indication of the distribution system losses.

Domestic Cold Water -

Water Pressure Measure the water pressure available at tap.

WC Flush System Note the type of flush systems on WC and urinals (Tank or valve)

Faucet type Note the type of faucets installed i.e. Push top, mixing etc.

Process Water Use -

Process Description Record the temperature required and use to which the water is put e.g. cooling, rinsing , and whether or not it is a continuous or batch process.

Consumption Establish if possible the volume of water consumed by the process and whether the spent water is discharged to drain or evaporated

Discharge Temperature Measure the temperature at which the water is discharged to drain and if the spent water is contaminated in any way.

Schedule of Use The operating period of the process should be established.

12.6 - Annotated List of Energy Management Opportunities

12.6.1 - Housekeeping

EMO 12.1 REDUCE WATER TEMPERATURE

DESCRIPTION: Reduce storage or hot water supply temperature (if provided) to reduce associated distribution and storage heat losses.
APPLICATION: All units.
SIDE BENEFITS: Temperature regulation enhanced (reduced mixing problems).
CAUTIONS: The lower temperature will effectively reduce the amount of useable hot water available if storage temperature is reduced.Verify that supply temperature to all users is still above minimum. Health problems may arise due to possible bacteria and virus proliferation at low temperatures. Maintain minimum temperature of 55° C.
COST FACTORS: No cost.
REFERENCES: Dubin, 1974; Gatts, 1974.

EMO 12.2 REDUCE USE OF CIRCULATION PUMPS

DESCRIPTION: Turn off circulating pump during periods of no demand to save electricity and pipe heat losses.
APPLICATION: All systems using circulating pumps.
SIDE BENEFITS: Less time between pump maintenance and replacement.
CAUTIONS: Causes delay in hot water supply at taps when pump switched off, i.e. more cool water must be run off before water becomes hot.
COST FACTORS: Negligible.
EVALUATION: Check occupancy schedule and pump running time. Evaluate reduction of pumps running time; measure flow/return temperatures to evaluate energy saving potential.

EMO 12.3 INSTALL OR IMPROVE WATER TEMPERATURE REGULATION

DESCRIPTION: Install flow mixers in place of existing taps. If applicable, adopt modulating rather than on-off burner. Install a mixing valve to obtain stable supply temperature for varying boiler temperatures and supply demand. Fit storage tank thermostat.
APPLICATION: All units with improper temperature control.
SIDE BENEFITS: Improved temperature regulation prevents scalding accidents.
CAUTIONS: Make sure mixers are compatible with supply water pressure. Make sure mixer can be installed on existing sinks, showers,etc.
COST FACTORS: More convenient if taps or sinks must be replaced when installing flow mixers.

INTERACTIONS: See also EMO 12.1 Reduce Water Temperature.
EVALUATION: Check mixing problems in individual and central systems.

EMO 12.4 USE DHW IN APPLIANCES

DESCRIPTION: Consider using service hot water instead of cold water in domestic appliances.
APPLICATION: Laundry and dish washing machines that can be fed with DHW.Only applicable if central DHW system uses cheaper fuel source.
SIDE BENEFITS: Shorter cycle time.
CAUTIONS: Make sure appliance is equipped for accepting DHW input, or if it can be modified.
COST FACTORS: Negligible if appliances are equipped to accept DHW.
EVALUATION: Check average duty cycle water consumption.

EMO 12.5 SHUT OFF WATER HEATING WHEN NOT REQUIRED

DESCRIPTION: Shut off water heating when not required, e.g. when building not occupied. Control heater operation (boiler or resistive heater) to match DHW demand, thereby saving on standby losses.
CAUTIONS: Ensure adequate pre-heat time.
COST FACTORS: Moderate.
INTERACTIONS: Alternative to EMO 12.2 Reduce use of Circulation Pumps.
EVALUATION: Inspect water usage profiles and look for high and low usage periods. Evaluate standby losses and estimate energy savings associated with heating time reduction.
REFERENCES: Dubin, 1976.

12.6.2 - Low Cost

EMO 12.6 INSTALL HEAT PUMP WATER HEATER

DESCRIPTION: Install heat pump for heating of DHW. Also investigate possibility of using heat pump for heating or cooling.
APPLICATION: Installations producing DHW.
CAUTIONS: Large tanks will increase heat losses.
COST FACTORS: Using several small storage tanks can sometimes reduce installation costs and improve stratification.Adding insulation is fairly cheap. Connecting heat pump to a heating system (if only hot water is produced) is normally not very expensive and is mostly cost effective. Addition of a hot gas cooler is fairly expensive.
EVALUATION: See EMS No.11. Refrigeration and Heat Pumps.
COMMENTS: Large volumes and correct positioning of aquastats will give longer running times and fewer starts, thus improving life expectancy, which is also improved by keeping condensing temperatures low.

EMO 12.7 HEAT RECOVERY FROM WASTE DHW

DESCRIPTION: If the waste DHW is collected in a suitably insulated tank, the heat content of the water may be recovered passively using, for example, a coil heat exchanger or a heat pump. The heat exchanger can be used to preheat incoming cold water.

APPLICATION: Where large quantities of hot water are discharged to waste.

SIDE BENEFITS: Reduced sewer discharge temperatures.

CAUTIONS: Leakage between water systems must not occur.

EVALUATION: Approximately 25% of the useful heat content of the water is recoverable. Applying a factor of 0.25 to the useful DHW energy demand provides a measurement of the prospective energy saving. Check that distance between heat exchanger and heater compatible with supply pressure.

EMO 12.8 INSTALL FLOW RESTRICTORS

DESCRIPTION: Install flow restrictors in suitable points of piping, low-flow shower heads, aerated faucets, etc., to conserve use of hot and cold water.

APPLICATION: General.

SIDE BENEFITS: Reduced city water costs.

CAUTIONS: Make sure supply flow rate is not reduced below minimum accepted by occupants.

COST FACTORS: Low cost but can result in substantial savings.

EVALUATION: Use manufacturers data for reduction in consumption.

REFERENCES: Dubin, 1974.

EMO 12.9 INSTALL CONTROLS TO REDUCE PUMP USE

DESCRIPTION: Similar to EMO 12.2 (reduce use of circulating pumps) but automated. Automatic valves may be desirable to stop gravity circulation.

APPLICATION: All systems using pumps for water circulation.

CAUTIONS: Make sure EMO is compatible with water use patterns (increased time lag in DHW delivery).

COST FACTORS: Variable, highly dependent upon installation.

INTERACTIONS: See EMO 12.2 (Reduce use of circulating pumps.)

EVALUATION: Estimate distribution losses from flow and return temperature. Calculate energy savings from pump operating time reduction (two benefits: reduced distribution losses and pumping energy consumption).

REFERENCES: Dubin, 1976; Harrje, 1983.

EMO 12.10 INSTALL WATER SOFTENER

DESCRIPTION: Install water softener on cold water service to limit water hardness or condition for acidity (reduces build-up of scale on fuel-fired water heaters maintaining heat transfer efficiency).

APPLICATION: Hard water areas.

SIDE BENEFITS: Reduces water circulation problems. Increases life of system components.

CAUTIONS: May be objected to by local water utility.

COST FACTORS: Can prove very effective in saving on soaps and detergents.

EVALUATION: Look for chalky deposits on pipes and taps; if necessary perform a water quality analysis.

EMO 12.11 REPLACE PILOTS WITH ELECTRIC IGNITION

DESCRIPTION: Replace standing pilot flame with automatic electronic ignition system.

APPLICATION: Gas units.

SIDE BENEFITS: Possibly safer operation.

COST FACTORS: Moderate.

INTERACTIONS: Consider particularly if DHW system replacement is advisable.

EVALUATION: Base on pilot light fuel use.

REFERENCES: Dubin, 1976.

EMO 12.12 INSTALL PRESSURE REDUCING VALVES

DESCRIPTION: Install pressure reducing valves in hot and cold water piping.

APPLICATION: This can be done where there are problems of high pressure (e.g. high rise apartment blocks) and/or where standard sized pipework is to be used and flow is to be regulated by the valve.

SIDE BENEFITS: Can reduce water consumption in showers etc. Can produce a fairly uniform discharge rate over a range of pressures which can help at times of simultaneous demand.

CAUTIONS: Do not use to compensate for an oversized pump. Will increase the resistance to flow in the system.

COST FACTORS: Moderate.

INTERACTIONS: May be alternative to EMO 12.8 Install Flow Restrictors.

EVALUATION: Measure flow rate from outlet and compare with the recommended value. Estimate saving due to reduced consumption.

COMMENTS: This EMO will not reduce the amount of energy used to heat the water to "fill" baths etc.

EMO 12.13 INSTALL TRACE HEATING ON DEAD LEGS

DESCRIPTION: Use trace heating to keep hot water at temperature in pipework rather than circulating pumps. This reduces pumping losses and pumping energy, also less pipe (no return pipe required) reduces distribution losses.

APPLICATION: DHW systems with long pipe run and/or high pumping energy and losses and/or high distribution losses.

SIDE BENEFITS: Eliminates pump maintenance.

CAUTIONS: Water may be in dead legs for long periods if use is infrequent.

COST FACTORS: High for existing buildings, consider if other work is being carried out. Often cost effective on new buildings.

INTERACTIONS: Complimentary to EMOs 12.2 and 12.9 Reduced use of Circulating Pumps.

EVALUATION: Saving in distribution losses and pumping energy should be compared against trace heating energy.

COMMENTS: Modern trace heating cable is available that is self (temperature) regulating.

12.6.3 - Retrofit

EMO 12.14 OPTIMIZE SIZE OF DHW STORAGE TANK

DESCRIPTION: Modify size of storage tank to adjust to storage needs.

APPLICATION: Large oversized storage systems.

CAUTIONS: Check compatibility with DHW demand.

COST FACTORS: Comparable with replacement costs.

EVALUATION: Compare actual storage size with optimal value. Estimate savings due to standby loss reduction.

EMO 12.15 CONSIDER AUTOMATIC DHW TAPS

DESCRIPTION: Substitute ordinary taps with taps automatically operated by photocells, infrared sensors, or mechanical means to minimize water use.

APPLICATION: Primarily systems such as public washrooms.

SIDE BENEFITS: Advisable for hygienic reasons also. Particularly suitable for community buildings, offices, factories, sporting facilities, etc.

EVALUATION: Calculate energy savings based on estimated water savings (from Manufacturers data).

COST FACTORS: Moderate cost.

EMO 12.16 ADD INSTANTANEOUS BOOSTER TO STORAGE SYSTEM

DESCRIPTION: Add an instantaneous booster heater to raise water temperature from storage to desired level. Installation permits smaller storage tank or lower storage temperature for reduced storage losses.

APPLICATION: Central storage systems.

SIDE BENEFITS: Reduced tank and distribution losses.

EVALUATION: Estimate energy savings based on annual DHW requirements and storage loss reduction.

COMMENTS: May be used where one load with higher temperature requirement than rest of system. For example commercial dishwashers.

EMO 12.17 INSTALL METERING DEVICES

DESCRIPTION: Install DHW metering devices at apartment or building level to heighten energy awareness.

APPLICATION: Buildings where additional metering is practicable (check plant layout).

SIDE BENEFITS: Occupants are informed about actual DHW consumption, which may be a very effective action for energy conservation.

CAUTIONS: Verify flow sensor does not introduce excessive pressure losses.

COST FACTORS: Costs may be significant. Reductions from 20 to 40% common.

EVALUATION: Should be applied if water consumption is high.

EMO 12.18 INSTALL SOLAR WATER HEATING

DESCRIPTION: Possible combinations that may be used to lower heating DHW costs are solar only and solar-assisted heat pump.

APPLICATION: Especially electrical DHW system.

CAUTIONS: All features of systems must be evaluated such as corrosion, weather effects, etc.

COST FACTORS: Highly variable, realistic lifetime for equipment must be factored in.

EVALUATION: Evaluate solar energy availability and daily DHW production. Calculate DHW energy demand before the retrofit and estimate the savings based on system performance figures.

REFERENCES: Dubin, 1976.

EMO 12.19 SWITCH FROM STORAGE TO INSTANTANEOUS DHW SYSTEM

DESCRIPTION: Replace existing storage system with instantaneous systems.

APPLICATION: Most applicable to highly intermittent use and/or widely distributed points of use.

CAUTIONS: May adversely affect maximum demand in electrical systems.

SIDE BENEFITS: DHW supply not constrained by storage size.

COST FACTORS: Particularly effective if existing system needs replacement. The convenience of this EMO will increase with decreasing distribution efficiency of the storage system, and decreasing average amount of water drawn at one time.

EVALUATION: Estimate storage losses. Calculate energy savings associated with reduced distribution/storage losses and (possibly) increased production efficiency.

COMMENTS: Instantaneous systems are mostly indicated when there is infrequent and light use of DHW.

EMO 12.20 DECENTRALIZE DHW PRODUCTION

DESCRIPTION: Replace single central system with a number of small distributed units to minimize distribution losses.

APPLICATION: Typically intermittent use, widely distributed points of use.

SIDE BENEFITS: May permit summer shutdown of central boiler plant.

COST FACTORS: Mostly effective if existing system has low distribution efficiency.

EVALUATION: Evaluate feasibility of this EMO by inspecting plant layout. Estimate potential savings by calculating distribution efficiency. May be viable for summer months, with shutdown of central plant.

13 - PROCESS AND AIR CONDITIONING REFRIGERATION

13.1 - Introduction

This section examines the use of refrigeration equipment in process and comfort cooling applications. Equipment discussed includes condensers, evaporators, chillers, liquid coolers, cooling towers and associated auxiliary equipment. Heat pumps and equipment that contains some cooling processes that are strictly comfort cooling applications, such as roof top air conditioners, are discussed in Section 17, Heating Ventilating and Air Conditioning.

13.2 - Fundamentals

They are examined in detail in EMS No. 11, Refrigeration and Heat Pumps. There are two types of refrigeration process which may be used, Vapour compression and Absorption. Each has different thermodynamic cycles.

13.2.1 - Vapour Compression Cycle

Four basic steps are required to complete the refrigeration cycle:

- Evaporation,
- Compression,
- Condensing, and
- Expansion of a refrigerant fluid.

These are illustrated in Figure 13.1.

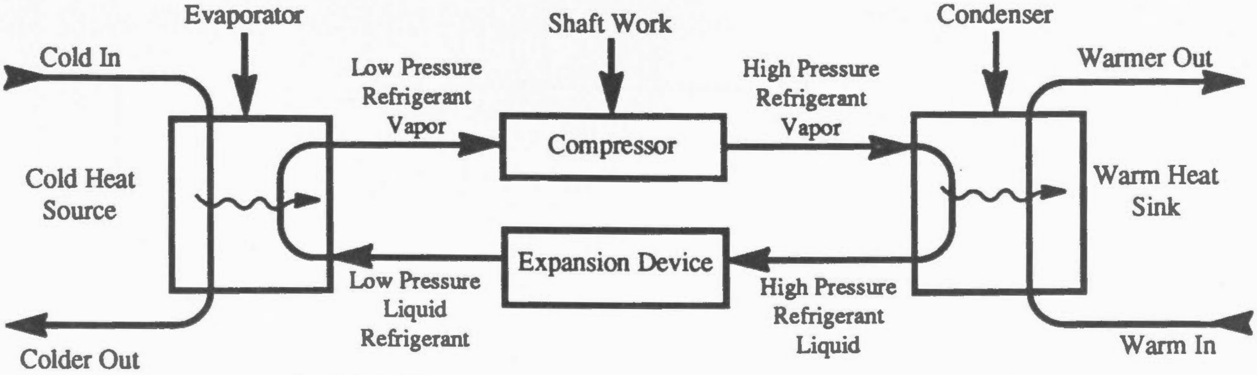


Fig. 13.1 Basic Vapour Pressure Refrigeration Process

Evaporation: A cool, liquid refrigerant at low pressure is brought into contact with the heat source (the medium to be cooled). The refrigerant, being at low pressure, absorbs heat and boils, producing a low-pressure vapor. The heat exchanger used for this process is called the evaporator.

Compression: The addition of shaft work by a compressor raises the pressure of the refrigerant vapor. Heat may also be used to raise the pressure. Increasing the gas pressure raises the boiling and condensing temperature of the refrigerant. Once the refrigerant gas has been sufficiently compressed, its boiling point will be above the temperature of the heat sink, (the higher temperature medium).

Condensing: The high-pressure refrigerant gas now carrying the heat energy absorbed at the evaporator, and the work energy from the compressor, is pumped to a second heat exchanger called the **condenser**. Because the refrigerant's condensing temperature is higher than that of the heat sink, heat transfer will take place, condensing the refrigerant from a high-pressure vapor to a high-pressure saturated liquid.

Expansion: The condensed liquid is returned to the beginning of the next cycle. Its pressure must be reduced to prevent the high-pressure liquid from entering the low pressure evaporator, and to reduce the boiling temperature of the refrigerant to below the temperature of the heat source. A throttling device such as a **valve, orifice plate or capillary** is generally used for this purpose. Energy lost through this reduction of pressure must be offset by additional energy input at the pressurization stage.

13.2.2 - Absorption Cycle

The absorption cycle is similar to the vapour compression cycle. However, instead of using a compressor, to increase the pressure and hence condensing temperature of the fluid, heat is added to a refrigerant solution.

The basic process is shown on Figure 13.2

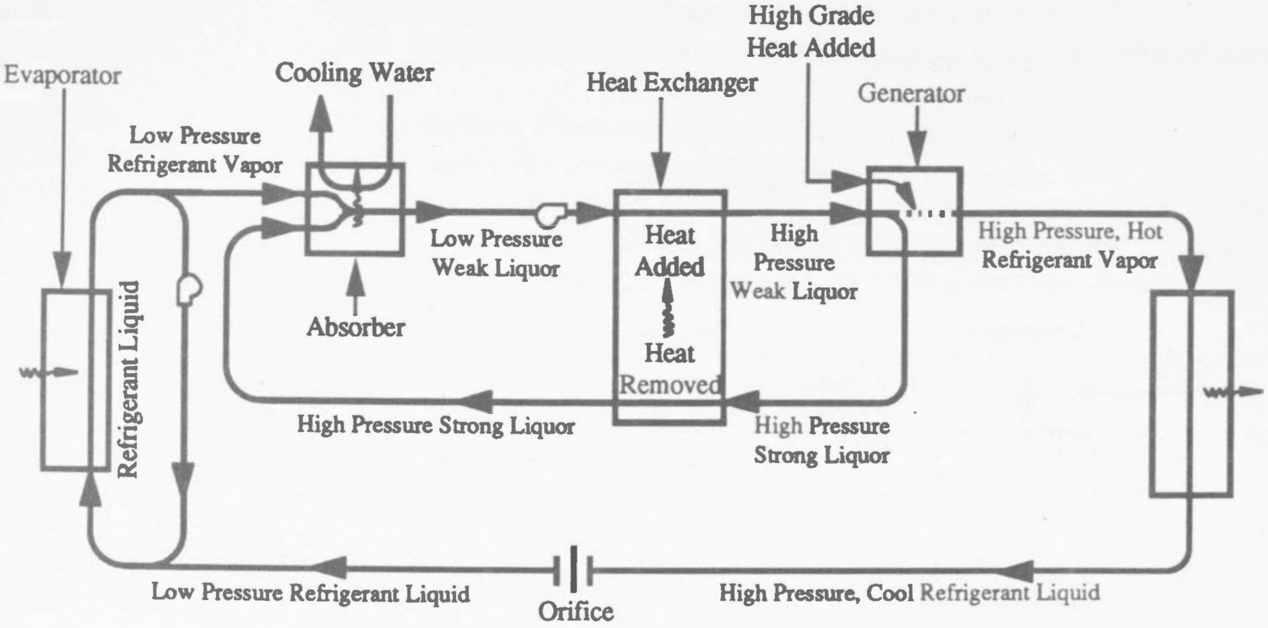


Fig. 13.2 Absorption Refrigeration Cycle

These basic cycles plus theoretical and practical refrigeration cycles are examined in EMS No. 11. Refrigeration and Heat Pumps.

13.2.3 - Coefficient of Performance

It is important to understand the principle of Coefficient of Performance (C.O.P.) to allow evaluation of refrigeration EMOs.
The C.O.P. is the ratio of the cooling or refrigeration effect, to the work required to produce the effect.

As a refrigeration cycle extracts heat energy from 'free sources' (i.e. one that does not cost dollars) they will normally have theoretical C.O.P.s as high as 7.0. In practice limitations on refrigerants available, temperatures of heat sources and heat sinks and power consumption of ancillary equipment all reduce the actual C.O.P. achieved, normally to between 2.0 and 4.0.

13.2.4 - Equipment

Compressors used in refrigeration systems are normally either displacement type or dynamic type.

The displacement type includes reciprocating, rotary (vane), and screw (helical rotary) compressors. The dynamic type of compressor includes centrifugal and turbo types. Refrigeration compressors are also categorized as hermetic, semi-hermetic or open. Hermetic compressors have all components including the motor in a sealed welded casing. Semi-hermetic compressors are similar to hermetic but the motor and compressor are accessible through bolted covers. Open compressors have the motor outside of the compressor casing. Compressors are discussed in more detail in EMS No. 11, Compressors and Turbines.

Evaporators: Two types of evaporators are commonly used:

- Direct expansion (DX) coils, and
- Liquid coolers.

DX coils are mainly used for gas or air cooling and the refrigerant is evaporated in a coil directly exposed to the fluid to be chilled. Liquid coolers are normally shell and tube heat exchangers where a secondary fluid (water, brine) is chilled and this fluid then cools the product or process. This is inherently safer as there is less risk of refrigerant gas leaking into the product and is therefore used in many food or process industries.

Condensers: Three types of condensers are normally used:

- Shell and Tube,
- Air cooled, and
- Evaporative.

Shell and tube heat exchangers require a supply of cooling (condenser) water which may be a once through system or a closed system with a cooling tower.

Air cooled condensers are often used in packaged or unitary equipment and require a cooling air fan.

In Evaporative condensers water is sprayed over a refrigerant coil and the heat is extracted through evaporation of the water; a fan then exhausts the moist air to atmosphere.

More detailed descriptions of types and cooling tower configurations are provided in EMS No. 11, Refrigeration and Heat Pumps.

13.3 - Energy Losses

Energy flows for a cooling plant are shown in Fig. 13.3.

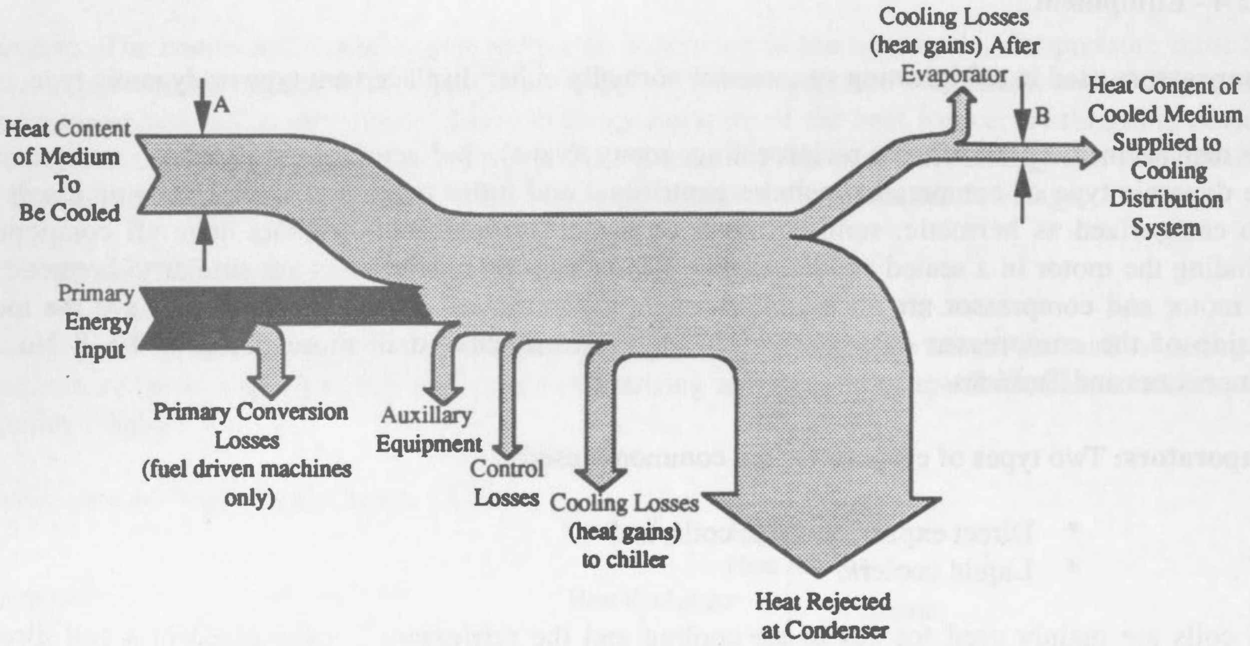


Fig. 13.3 Cooling plant energy flows. Note that the net cooling delivered to the cooling distribution system is the difference between A and B above.

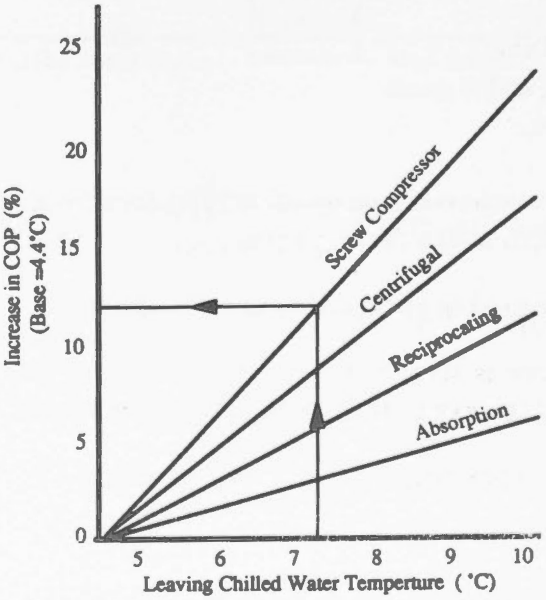


Figure 13.4 Increase in chiller C.O.P with increasing chilled water temperature

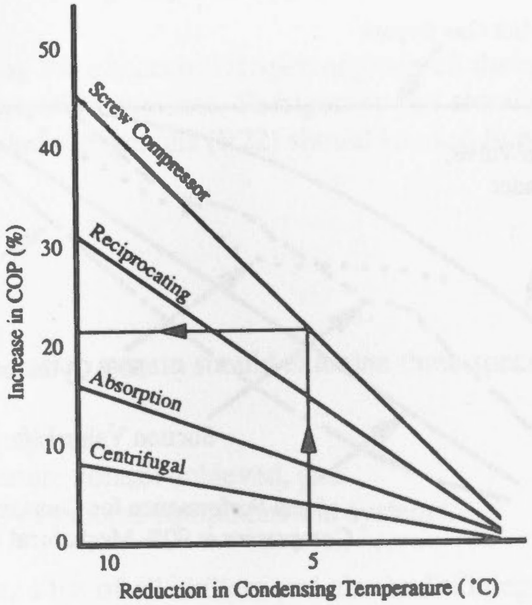


Figure 13.5 Increase in chiller C.O.P. with decreasing condensing temperature

Primary conversion losses Absorption cooling plants burning fossil fuels will lose energy through stack losses and burner inefficiency. Chillers using motor driven compressors will lose energy through motor inefficiency.

The thermodynamic efficiency of the actual cooling process will greatly depend on evaporating and condensing temperatures as illustrated by Figures 13.4 and 13.5. Compressor efficiencies such as friction losses, dead spaces and leakages will also reduce the theoretical cycle efficiency. Strategies aimed at lowering the condensing temperature and increasing the evaporating temperature will improve process efficiency. A number of such strategies are discussed in Section 13.6.

Cooling losses. As long as there is a temperature difference between the cooling plant and its surroundings, cooling losses will occur by radiation, conduction, and convection. Losses will occur in the chiller itself and between the evaporator and the point of the cooled medium. When a cooling unit has both a cold part (e.g. evaporator) and a hot part (e.g. condenser), these losses can take place both externally and internally through casings or leakage of refrigerant from the high to the low pressure side.

Since these losses occur all the time they will have a greater percentage effect for a system operating intermittently than for a continuously working system. In particular losses from storage systems can be considerable, thereby discarding any gains in generation efficiency.

Axillary Equipment losses. These include energy expended on control equipment, crank case heaters, pumps or fans. Even though small, these losses can be important if left on continuously and actual cooling running times are short. Cooling towers and spray coolers lose energy through circulation losses and replacement of evaporated water.

Control losses. Depending on the manner in which capacity control is achieved chiller C.O.P. will either improve or deteriorate at part load. Figures 13.6 and 13.7 give typical performance data. It is very clearly in the auditors interest to review the type of capacity control employed.

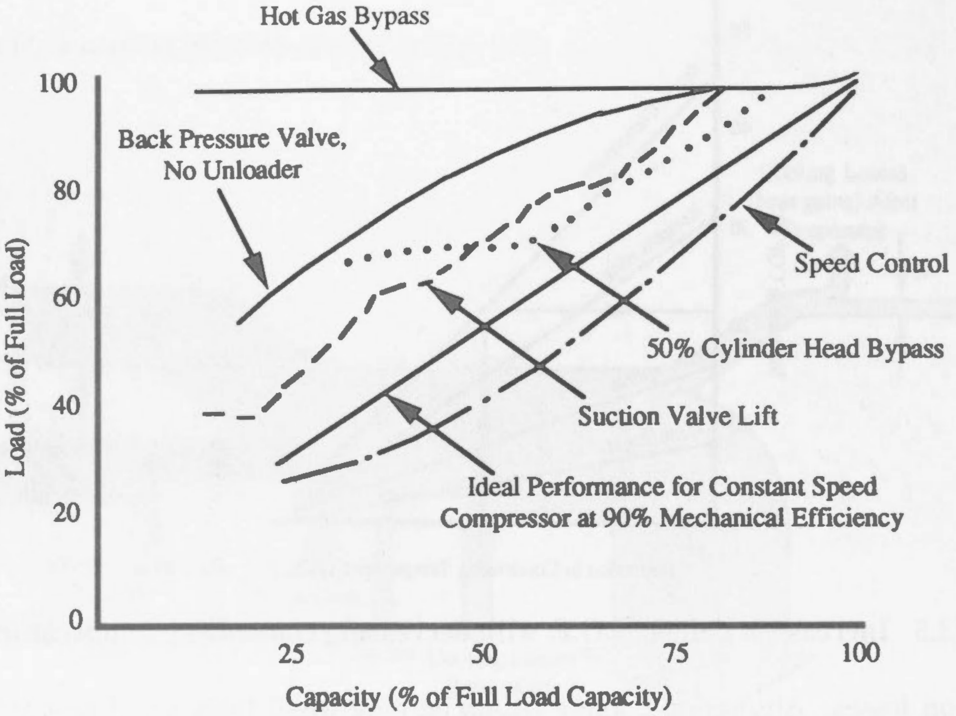


Figure 13.6 Part load performance of reciprocating chillers

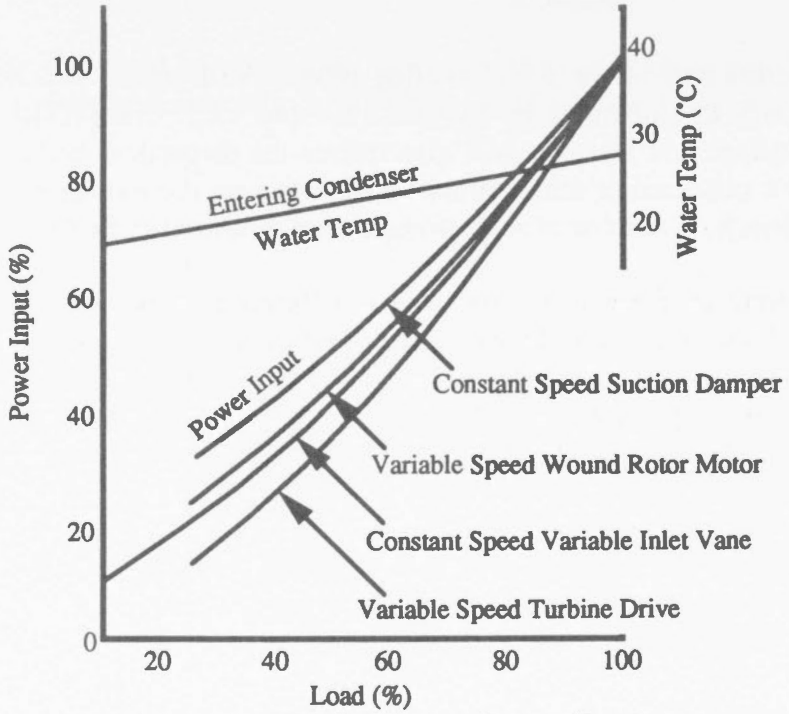


Figure 13.7 Part load performance of centrifugal compressors

13.4 - Interactions

Refrigeration equipment can represent a large electrical load. EMOs carried out on refrigeration plant can often produce additional savings in demand charges which can sometimes outweigh the calculated unit cost savings.

Environmental concerns involving the effects of refrigerant gases on the ozone layer should be considered when making changes to refrigeration systems. Refrigerant gas should not be discharged to drain or atmosphere. Non fully halogenated refrigerants (R22) should be used in preference to R11, R12.

13.5 - Survey

13.5.1 - Walk-through Audit

A walk-through audit of a refrigeration system should examine three specific areas:

- condition of equipment,
- level of temperature control achieved, and
- operating hours of process equipment and systems.

Prior to the actual walk-through, a list of all chillers and air conditioning equipment should be developed and the areas served established. This can be done by reviewing drawings where available. Where drawings are not available, system coverage will have to be established on site. Organize the actual walk-through on a system by system basis. For a large chilling plant, it will be useful to review the chilled and condensing sides separately.

Ideally the site should be visited during the peak operating periods (peaks may be different for process and comfort cooling applications) with subsequent visits during a lightly loaded period to establish part load operating conditions.

For process cooling applications it will be necessary to liaise with those responsible for the refrigeration equipment or processes to find the required operational conditions.

Area and Processes Served Identify the area(s) fan plants and processes served by the system.

System Description Note type of system, eg. chiller with cooling tower, "split system", "packaged water cooler". Record whether there are any water or ice storage systems or heat recovery systems. Describe controls.

Equipment Description Record age and type of equipment (eg. reciprocating centrifugal) and type of fuel/motive power. Note also types of heat rejection equipment (eg. cooling tower, evaporative condenser).

Cooling Requirements Determine the time of day/month/year that cooling is required and compare with actual operating hours (check operating logs where kept). Note where there is reason to believe there is excess capacity, for example as indicated by multiple equipment not being used or short cycling of equipment on 'design days'. Indications of possible under capacity should also be noted.

Operation and Sequencing of Multiple Chillers Note whether chillers are piped in 'series' or 'parallel' and how and when individual chillers are started and stopped. Note if manual or automatic control. Inspection should cover all system auxillaries such as oil heaters, cooling tower pumps, pan and trace heaters. Note where chillers are operated when facility has a need for heating.

Evaporating and Condensing Temperatures Check system set points and actual temperatures where equipment has built-in gauges. Check to see if control systems are provided to allow resetting of control points with load variations. Determine maximum allowable and desirable process cooling temperature requirements and ensure these are being maintained.

Heat Rejection Equipment Check general condition of cooling tower, look for dirty heat exchangers, louvres, pans. Check water quality and chemical dosing plant; if water quality is a problem, review need for condenser tube cleaning. Check if pan heaters or other frost protection systems are working correctly and only as required. Check location of exhaust air duct and temperature of exhaust to see if suitable for discharging through/over tower or condenser.

Refrigerant Level Check level of refrigerant in sight glass. If refrigerant loss is a problem correct leak rather than continual topping up.

Capacity Control Note method of capacity control used for all cooling equipment. This will generally require a review of relevent Operation and Maintenance manuals.

City Water Usage Review city water consumption to see if water could be used for cooling. (This should be done prior to the audit). Where potential exists, check location of city water mains relative to required cooling load.

Size/Rating (Normally obtained from equipment rating plates). Condenser and compressor may each have rating plates when mounted in one unit. The manufacturer may have to confirm capacity from rating plate information.

The amount and complexity of data required for most low cost and retrofit EMOs will be beyond the scope of many auditors. Specialist assistance from equipment manufacturers, service companies or consultants will often be required.

13.6 - Annotated List of Energy Management Opportunities

13.6.1 - Housekeeping

EMO 13.1 RAISE CHILLED WATER TEMPERATURE AND SUCTION GAS PRESSURE

DESCRIPTION:	Raise chilled water temperature setpoint (chillers) and suction gas pressure (direct expansion equipment) to highest value consistent with satisfying cooling and dehumidifying requirements. Consider changing setpoint manually or automatically as load varies.
APPLICATION:	General.
SIDE BENEFITS:	Reduced pressure lift on compressors prolongs their life.
CAUTIONS:	In comfort cooling applications raising chilled water temperature lowers capacity for latent cooling causing space humidity levels to rise. Too

high an evaporator temperature may compromize proper functioning of expansion devices.

COST FACTORS: No cost unless automatic water reset controls are added.

EMO 13.2 LOWER CONDENSING WATER TEMPERATURE AND HEAD PRESSURES

DESCRIPTION: Lower condensing cooling water setpoint (chillers) and head pressures (direct expansion equipment) consistent with the cooling capabilities of the heat rejection equipment. Consider changing setpoint manually or automatically as load and outside air conditions vary. Lower temperatures can be achieved by: increasing tower or air cooled condenser fan volumes; increasing tower water flow rate;where installation operates at constant condenser water temperature, modify controls for more continuous tower/condenser operation and; move condenser closer to the compressor to minimize pumping energy.

APPLICATION: Air conditioning chillers and direct expansion (DX) equipment and industrial refrigeration systems except where condenser heat is reclaimed, unless lower temperature heating fluid can be tolerated.

SIDE BENEFITS: Increased compressor life (lower load and pressures).

CAUTIONS: Increased overall energy use may occur if increased tower energy use is greater than savings from COP improvements. Under-compression in screw compressors will reduce the energy saving. Low head pressures may upset liquid refrigerant flows in large industrial systems. Low pressures may affect defrost operation in industrial systems.

REFERENCES: Cole, 1985; Dubin, 1975.

EMO 13.3 SHUT OFF AUXILIARIES WHEN NOT REQUIRED

DESCRIPTION: Shut off all auxiliaries where plant is not required. Equipment would include chilled and condenser cooling water pumps, oil heaters and cooling tower pan heaters and trace heating (to cooling tower).

APPLICATION: Chillers and refrigeration units with non-continuous operation.

CAUTIONS: Caution is needed to remove risk of freezing when pan and trace heating is removed.

COST FACTORS: No cost if done manually but more effective if automated.

EMO 13.4 SEQUENCE OPERATION OF MULTIPLE UNITS

DESCRIPTION: Sequence operation of multiple chillers and refrigeration compressors with load variations to achieve optimum overall plant performance. Isolate off line equipment when not required and reduce water flow rate and pumping costs.

APPLICATION: Multiple plant installations.

SIDE BENEFITS: Return of chilled water through the standby chiller(s) will be eliminated (bypass water has the effect of increasing the temperature of chilled water delivered by the cooling plant). Starting currents are reduced.

COST FACTORS: Isolation of off-line chillers is low cost if carried out manually using existing valves; more expensive if automatically operated valves are required to be installed. Control of water flow rate may be expensive if multiple pumps are not installed.

EVALUATION: The sequencing should ideally be verified through field measurements and/or monitoring since catalogue data are not always valid or applicable at part loads. Measure the running time and starting frequency for individual compressors as a function of load. Measure supply or temperatures and compare with values required by cooling system. A difference will result in decreased compressor performance which can be estimated from compressor diagrams.

REFERENCES: Dubin, 1975. EMS No. 11, Refrigeration & Heat Pumps.

EMO 13.5 CLEAN AND MAINTAIN COOLING TOWER CIRCUITS AND HEAT EXCHANGER SURFACES

DESCRIPTION: Clean and repair cooling tower fill and heat exchanger surfaces, clean pans and air louvres and, if applicable, provide water treatment to maintain water quality and limit algae growth.

APPLICATION: All systems with cooling towers or heat exchangers.

SIDE BENEFITS: Less potential for growth of harmful bacteria (Legionella virus) in water circuits. Diminished risk of undue stops because of clogging or early shutdown of safety equipment. Enhanced heat transfer.

CAUTIONS: Use of chemicals for cleaning should be exercised with care.

COST FACTORS: In air systems cleaning is inexpensive. Liquid systems will normally have to be shut down. Essential part of regular maintenance.

COMMENTS: Compare cost of manual and automatic cleaning.

REFERENCES: Burger, 1980. EMS No. 11 Refrigeration & Heat Pumps.

EMO 13.6 MAINTAIN FULL CHARGE OF REFRIGERANT

DESCRIPTION: Locate and correct leaks and add refrigerant as necessary.

SIDE BENEFITS: Improved service life of the compressor.

CAUTIONS: Loss of refrigerant has potentially adverse environmental effects. Overcharging can cause liquid refrigerant to enter compressor which can damage compressors and affect performance of all compressor types.

COST FACTORS: Elimination of leaks will remove cost of refrigerant recharging although cost of repairing leaks can be costly.

REFERENCES: Stamm, 1978. EMS No. 11 Refrigeration & Heat Pumps.

13.6.2 - Low Cost

EMO 13.7 CLEAN CONDENSER TUBES

DESCRIPTION: Clean condenser tubes when required or install automatic tube cleaning system (Leitner, 1980).

APPLICATION: Water cooled condensers, generally on larger units.

SIDE BENEFITS: Reduced dependence on chemical water treatment which lessens corrosive and ecologically undesirable side effects.

COST FACTORS: Two years claimed payback on large well utilized units.

REFERENCES: Leitner, 1980.

EMO 13.8 REPIPE/OPERATE CHILLERS OR COMPRESSORS IN SERIES OR PARALLEL

DESCRIPTION: Repipe/operate chillers, compressors, evaporators and condensers in series or parallel according to optimum arrangement balancing compressor power savings with pumping costs.

APPLICATION: Central cooling systems with multiple units.

SIDE BENEFITS: Reduced starting currents.

CAUTIONS: Caution required in Direct Expansion systems.

COST FACTORS: A check on operating conditions is straight forward and inexpensive. Changes in strategy are normally inexpensive unless pipe work is needed.

EVALUATION: It is necessary to evaluate both C.O.P and pumping differences between the two options. Failure to do so can lead to erroneous conclusions. Series piping systems are normally preferable where there is a low chilled water flow rate or high temperature difference (i.e. supply-return temperature).

REFERENCES: Tao, 1985.

EMO 13.9 REPLACE INTERNAL COLD CABINET LIGHTS WITH EXTERNAL ONES

DESCRIPTION: Replace cold cabinet internal lights with external ones. Reposition existing lights outside cabinets or install new lighting to shine into the cabinet.

APPLICATION: Refrigerated food displays with internal lighting; primarily associated with restaurants and stores.

CAUTIONS: May reduce display effectiveness.

INTERACTIONS: EMO 13.10, Provide Covers and 13.11, Reduce Losses can be considered complimentary.

EVALUATION: Refrigeration savings can be considered as being directly proportional to the wattage of the removed lamps unless compressor heat is reclaimed for heating.

REFERENCES: Dubin, 1975.

EMO 13.10 PROVIDE NIGHT COVERS FOR COLD CABINETS

DESCRIPTION: Provide temporary night covers to close off open cold cabinets during the unoccupied hours.

APPLICATION: Open refrigerated food cabinets, particularly applicable in supermarkets. Greater savings with vertical than horizontal cabinets because of greater air spillage from vertical units.

INTERACTIONS: EMO 13.9, Remove Cabinet Lights can be considered complimentary. Alternative is to replace with closed cabinets (EMO 13.11).

EVALUATION: In addition to refrigeration savings, effects of <u>reduced</u> space heating and possibly <u>increased</u> space cooling should be taken into account. Air temperature measurements and simple tests in the area of the cabinets can give an indication of the extent of the air spillage.

REFERENCES: Dubin, 1975.

EMO 13.11 REDUCE COOLING LOSSES FROM OPEN REFRIGERATED DISPLAY CABINETS

DESCRIPTION: Replace open cold cabinets with closed type of retrofit with doors or strip covers.
APPLICATION: Refrigerated food display units with open front. Primarily applicable to stores and restaurants.
CAUTIONS: Some retailers view such action to have an adverse effect on sales of products from the cabinet.
COST FACTORS: Replacement of cabinets can only be justified when existing equipment is ready for replacement. Retrofit can be considered worthwhile, particularly the strip curtain type.
INTERACTIONS: Lower cost (and lower savings) can be achieved using night covers (EMO 13.10).
EVALUATION: Evaluation can be complex if heat from refrigeration compressors is reclaimed for space heating.
REFERENCES: Dubin, 1975.

13.6.3 - Retrofit

EMO 13.12 HEAT RECOVERY OF CONDENSER HEAT

DESCRIPTION: Install heat exchangers on condenser cooling water or hot refrigerant lines (Stamm, 1978) or install double bundle condenser to reclaim heat.
APPLICATION: Facilities with air conditioning or process cooling. This EMO is attractive where there is year round need for cooling operation and a co-incident need for space or DHW heating.
SIDE BENEFITS: Less use of water.
EVALUATION: Measure flow and temperature of cooling water to calculate possible heat recovery.
COMMENTS: Heat storage can increase savings.
REFERENCES: Stamm, 1978, EMS No. 11, Refrigeration and Heat Pumps.

EMO 13.13 ATMOSPHERIC COOLING

DESCRIPTION: Obtain free chilled water by cooling with outside air using the existing cooling tower, an auxiliary heat exchanger located outside or using an existing air handling unit coil.
APPLICATION: Installation requiring year round cooling with cold (cool) winters where it is not practical to use outdoor air directly (i.e. economizer cycle).
CAUTIONS: Risk of freezing.
COST FACTORS: Can be a relatively low cost item compared with other means of generating winter chilled water.
INTERACTIONS: Free cooling chillers are an alternative strategy (EMO 13.19).
EVALUATION: Hourly analysis normally required to estimate savings.

COMMENTS: Filtration systems are available to allow condenser water to be circulated directly through chilled water pipework.

REFERENCES: Winger, 1983; Albern 1984.

EMO 13.14 EXHAUST (COOL) CONDITIONED AIR OVER CONDENSERS AND THROUGH COOLING TOWERS

DESCRIPTION: Modify exhaust ductwork so that when exhaust air is of a lower temperature or enthalpy content than outside air, it can be used to provide more efficient cooling of the heat rejection equipment.

APPLICATION: Where exhaust is close to cooling tower or condenser. Most benefit where outside air temperatures are consistently much higher than maintained internal conditions.

COST FACTORS: Capital costs depend on the extent to which ductwork modifications are required. Estimates of improved COP with lower condensing temperatures can be made using exhaust temperatures local weather conditions as a minimum and a bin method type of analysis.

EMO 13.15 USE CITY WATER FOR COOLING

DESCRIPTION: Install cooling coil using city water to provide free cooling.

APPLICATION: Facilities with large and consistent cold water demand such as laundries and other buildings using water for sanitation or processes.

SIDE BENEFITS: Heat gain to water may be of benefit if the process water requires heating.

CAUTIONS: It is generally not economical, and in many instances not permitted by water supply agencies, to use city water for cooling unless it is also being used for some other purpose.

COST FACTIONS: Can be quite low.

COMMENTS: This EMO is not to be confused with the common practice of using city water for cooling condensers.

EMO 13.16 CENTRAL CHILLER/REFRIGERATION CONTROL

DESCRIPTION: Install central controller to optimize the operation of all cooling system components including compressor sequencing, condenser and chilled water reset and auxiliaries operation.

APPLICATION: Most applicable for large installations.

SIDE BENEFITS: Unattended operation allows the staff to be used elsewhere.

CAUTIONS: Operators must be appropriately instructed. Hardware used to provide feedback information to the central controller are essential but can be expensive.

EVALUATION: Small percentage savings can often justify the cost of the central controller. Hourly analysis is desirable.

REFERENCES: Stoecher, 1980; Baillie, 1985; and Thielman, 1983, EMS No. 11, Refrigeration and Heat Pumps.

EMO 13.17 USE NATURAL WATER SOURCES FOR CONDENSING

DESCRIPTION: Use rivers, lakes and other natural water bodies for condenser cooling.

APPLICATION: Installations primarily with existing water cooled equipment close to natural water sources, most favourable in larger installations.

SIDE BENEFITS Increased oxygen content of return water can improve conditions in rivers and lakes (spray cooling).

CAUTIONS: Use of natural water source may cause fouling of heat transfer equipment resulting in loss of performance and requiring additional maintenance. Increased temperature, due to rejected heat, in small nonflowing water bodies can upset water ecological system.

EMO 13.18 MINIMIZE ADVERSE EXTERNAL INFLUENCES ON COOLING TOWER AND AIR COOLED CONDENSERS

DESCRIPTION: Provide shading from solar and wind, correct recirculation of hot damp discharge air, remove any air flow restrictions.

APPLICATION: General

SIDE BENEFITS Prolonged equipment life.

COST FACTORS: General low cost except where relocation is required.

REFERENCES: Hensley, 1983.

EMO 13.19 FREE COOLING CHILLERS

DESCRIPTION: Modify existing chillers or install new chillers to make use of refrigerant migration for generating chilled water.

APPLICATION: Facilities requiring winter, spring or fall cooling which are located in climates which have an appreciable number of days below 7.5^{o} C and more than 2,000 (heating) degree-days (C) per year, and which have low outdoor wet bulb temperatures.

CAUTIONS: In comfort cooling applications space humidity may rise because chillers in free cooling mode cannot produce chilled water temperatures as low as when compressors are operating.

COST FACTORS: Cooling tower may have to be winterized.

EVALUATION: Electric power requirements of pumps and cooling tower need to be taken into account.

COMMENTS: Free cooling chillers should only be considered when it is not feasible to "free cool" with outside air (EMO 13.33).

REFERENCES: Welsh, 1984 and Kallen, 1982.

EMO 13.20 USE OF DESICCANT FOR DE-HUMIDIFICATION

DESCRIPTION: A desiccant such as silica gel can be used to reduce the moisture content of an airstream, thereby reducing the overall cooling load. The remaining sensible load can be taken care of in the normal way using a cooling coil and a cooling medium. Because the latent load is handled by the desiccant, the cooling medium can be at a higher temperature than required if it were to handle the latent load: consequently higher temperature cooling mediums such as tower or well water can be considered.

APPLICATION: Locations with long periods of high wet bulb temperatures, high internal latent loads or high fresh air loads.

EVALUATION: Process is adiabatic and air dry bulb temperature increases in proportion to the amount of water removed. The desiccant eventually becomes fully charged and must be regenerated by driving off the moisture by heating the desiccant. The energy required to do this must be taken into account.

REFERENCES: Dubin, 1975.

EMO 13.21 USE "PIGGY BACK" ABSORPTION SYSTEM

DESCRIPTION: Make use of exhaust steam from turbines to generate chilled water using absorption chiller(s).

APPLICATION: Buildings with steam driven centrifugal chillers, or other steam driven equipment particularly in buildings using steam where the condensate is not returned to the supplier.

COST FACTORS: High cost item although it can yield good paybacks (5 yrs. or less in favourable situations).

COMMENTS: Under part load conditions, it is desirable to generate as much of the load as possible with the absorption machine and modulate the turbine drive equipment to meet the remaining load. Absorption equipment may require larger cooling towers and condenser water piping. Air cooled condensers are usually not appropriate with absorption machines.

REFERENCES: Dubin, 1975.

EMO 13.22 CHILLED WATER AND ICE STORAGE SYSTEMS

DESCRIPTION: Use water storage or ice making to store cooling. Storage may be short term (e.g. hourly/daily) or long term (e.g. seasonal).

APPLICATION: Seasonal storage systems (Klassen, 1981 and Francis, 1985) are appropriate in locations with continental type climates where cooling store can be generated during winter months without mechanical refrigeration. Short term systems (Baltimore Air Coil, 1984; Tamblyn, 1977 and Landman, 1976) are applicable where electrical demand costs for cooling are significant.

COST FACTORS: Capital cost of providing short term storage with small chiller can often be less than or comparable with cost of larger machines without storage providing equivalent cooling. Consequently storage should generally be considered when considering replacing existing equipment.

EVALUATION: Detailed hourly evaluations are almost always required.

COMMENTS: May be attractive if limited electrical capacity available.

REFERENCES: Baltimore Air Coil, 1984; Tamblyn, 1977; Landman, 1976; Klassen, 1981; and Francis, 1985.

EMO 13.23 IMPROVE CAPACITY CONTROL

DESCRIPTION: Improve part load efficiency by more efficient capacity controls, i.e. variable speed control, cylinder unloading, solution control for absorption machines, and vane angle control (large centrifugal units).

SIDE BENEFITS: Prolonged equipment life.

CAUTIONS: Capacity control should also include associated circulation pumps or fans to avoid unnecessarily high power consumption in these systems.

COST FACTORS: Variable speed control through gearboxes is expensive and requires long changeover times. Slipping devices inherently have lower efficiencies as the speed reduces. Power inverters are expensive but have high efficiencies. Variable number of motor windings is efficient and inexpensive.

INTERACTIONS: See EMO 13.4 Sequence Operation of Chillers.

EVALUATION: Figures 13.6, 13.7 give comparative performance of various types of capacity control for reciprocating and centrifugal machines. Hourly analysis methods may be required to justify capital expenditures.

COMMENTS: Centrifugal machines normally operate most efficiently between 40 and 70% loaded. For reciprocating machines maximum savings are obtained when cylinder unloading (which in itself is often inefficient) is in steps of one cylinder at a time. For multiple compressor applications, only one compressor should be unloaded at a time; all others should be used at full capacity or shutdown.

REFERENCES: Erth, 1980; Garland, 1980.

EMO 13.24 REDUCE COMPRESSOR CAPACITY OR FIT A SMALLER COMPRESSOR

DESCRIPTION: Reduce compressor capacity where equipment is oversized by reducing speed of motor, fitting a smaller compressor or reducing the size of the impeller in centrifugal machines. Reduce motor size to match reduced load and retain the (now oversized) heat exchangers.

APPLICATION: Where existing equipment is oversized, particularly where energy intensive capacity controls are used, and where it is possible to replace the compressor only.

SIDE BENEFITS: Improved life expectancy.

EVALUATION: Measure running time and number of starts under most extreme conditions. Short frequent cycles indicative of oversized equipment.

EMO 13.25 REPLACE OR UPGRADE COOLING EQUIPMENT

DESCRIPTION: Replace old and inefficient equipment (condensers, cooling towers, compressors etc.) with new more efficient types.

APPLICATION: Prime targets are change of: air cooled condensers to cooling towers (particularly in locations with fewer than 15000 wet bulb degree hours); single unit to multiple plant, upgrade fill of tower; absorption chillers to two stage, hermetic with open compressors (Stamm, 1984); and high lift single stage compressors with two stage with flash intercooling (Prasad, 1981; Klinger, 1980).

CAUTIONS: There is some concern that (wet) cooling towers, if not properly maintained can be a cause of Legionaires disease. Their choice over air cooled condensers in critical situations such as hospitals should be reviewed carefully.

EVALUATION: For check of oversizing measure running time and number of starts and electric consumption. If running times are short, unit is probably oversized. Compare estimated output from unit to estimated demand.

REFERENCES: Stamm, 1984; Prasad, 1981; Baltimore Air Coil, 1984; Klinger, 1980; and Hill, 1984.

14 - PRODUCTION AND PROCESS EQUIPMENT

14.1 - Introduction

This section examines energy consuming equipment utilized in production and process environments. Topics covered include:

* Compressors & Turbines
* Compressed air systems
* Materials handling

There are a large number of different process and production techniques in use in manufacturing and resource industries. It would not be possible to discuss specific examples or provide energy auditing strategies for individual processes, therefore the basic components that make up most processes are examined and the auditor must adapt the information provided to suit the particular circumstance.

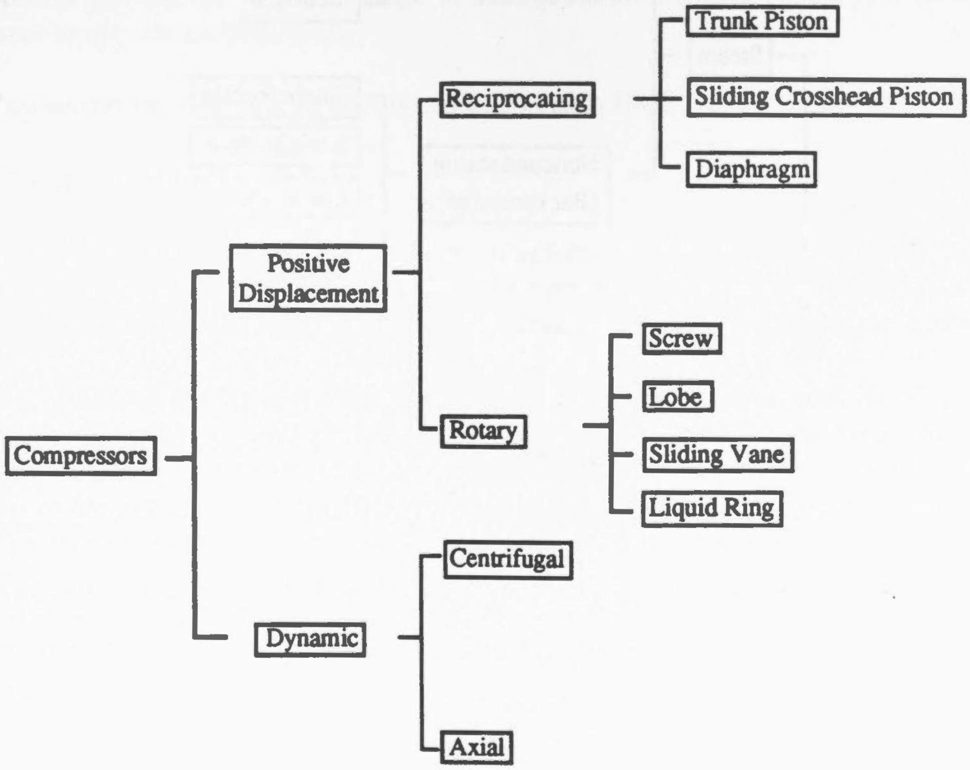


Figure 14.1 Classification of Compressors

14.2 - Fundamentals

14.2.1 - Compressors

Compressors are devices which draw in air and discharge it at a higher pressure, usually into a piping system or tank. These machines can be used to compress room air into a high pressure distribution system or to draw the air from a tank and discharge it into the atmosphere thereby causing a vacuum in the tank. Positive displacement compressors use pistons or rotors to compress the gas, and dynamic compressors use impellers or blades for compression.

There are a number of different types of compressor commonly used which fall into two main classifications, positive displacement and dynamic. See Figure 14.1.

The differences between compressor types are discussed in more detail in EMS No. 14. Compressors and Turbines.

14.2.2 - Turbines

Turbines are rotary machines that convert expanding hot gas or vapor into shaft power. Figure 14.2 is a classification of the various types of turbines that are operated in Industrial, Commercial and Institutional facilities. The two major classifications are steam and gas turbines.

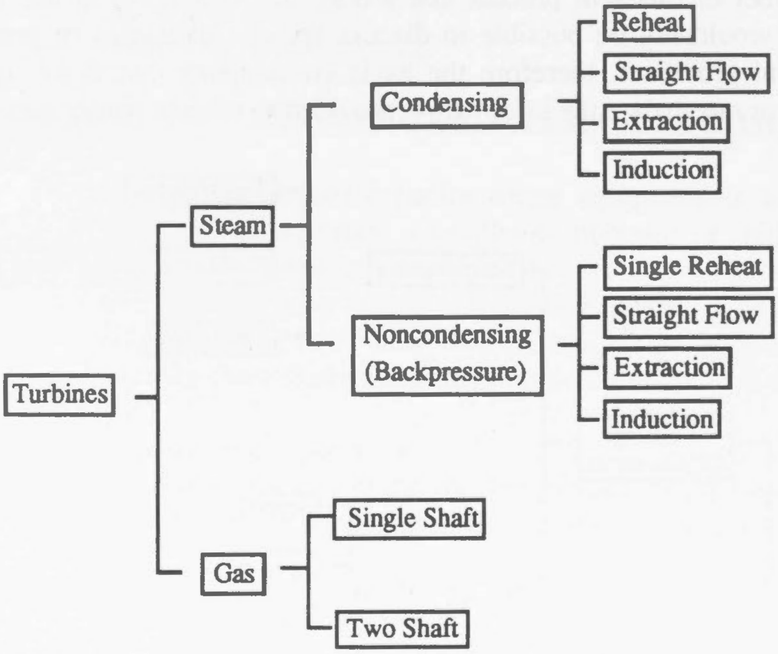


Figure 14.2 Classification of Turbines

Steam Turbines: Steam turbines are classified by the condition of the exhaust steam as condensing and non-condensing.

Condensing turbines usually utilize superheated steam, to minimize condensation within the turbine, and operate with exhaust steam below atmospheric pressure. The low exhaust steam pressure is created by an external heat exchanger that uses exterior cooling to condense the steam as it leaves the turbine.

Non-condensing turbines sometimes called **back pressure turbines,** operate with the exhaust steam at or above atmospheric pressure. They often utilize inlet steam at saturation pressure and temperature resulting in a mixture of steam and condensate, or **wet**, exhaust steam.

Gas turbines: A gas turbine compresses combustion air, burns fuel in a combustor and directs the resulting hot gases through a series of turbine blades. The compressor is usually of the centrifugal or axial type, and is driven by the turbine. Gas turbines are classified as single shaft or two shaft.

14.2.3 - Compressed Air Systems

A compressed air system consists of pipes, valves and fittings used to transport compressed air from the compressor air receiver to the tool or device requiring air for operation.

Compressed air systems can be divided into two types:

- Plant air, which is normally used to supply air operated tools and equipment.
- Instrument air, which is used to supply pneumatically operated instrumentation and controls.

In most installations plant air and instrument air are generated and disributed separately because the moisture content and cleanliness of instrument air is more critical than that of plant air. A refrigerated or chilled water dryer is often employed to remove moisture from the air and limit waterlogging of system pipework. The dryer also removes any compressor oil carried over from the compressor.

Air receivers provide air system storage to accommodate demand surges and eliminate the need for the compressor to operate continuously.

More detailed discussions on air systems can be found in EMS No. 12 Compressed air systems.

14.2.4 - Materials Handling

Materials handling and on-site transportation equipment play a vital role in making Industrial, Commercial and Institutional facilities operate efficiently. The operating costs associated with materials handling and on-site transportation equipment are significant. However, this equipment is seldom evaluated in energy audits.

Materials handling and on-site transportation can be defined as the methods of moving material from the yard or receiving facility, through the various stages of production to storage, and finally, to the shipping area for distribution. In recent years great emphasis has been placed on the use of mechanization. This has led to the widespread use of various types of materials handling and on-site transportation equipment ranging from simple gravity conveyors to computer controlled systems.

The predominant use of this type of equipment is in the Industrial sector, however Commercial and Institutional facilities also use materials handling equipment on a regular basis.

In common usage the term "materials handling" is used to denote the handling of a solid product such as boxes or bags of sugar, dry powders, cereal grain, tires or other such objects. The movement of liquids and gases is normally considered as part of a liquid or gas piping system and is not covered in this module. For information on steam and condensate piping, reference should be made to EMS No. 8, Steam and Condensate Systems. For water and compressed air piping, reference should be made to EMS No. 1 Water and Compressed Air Systems.

The use of materials handling and on-site transportation equipment is not limited to goods or products. People are moved vertically by elevators, horizontally by moving sidewalks, or on an incline by escalators.

The most commonly used transportation and conveying systems are described in EMS No. 17, Materials Handling and On-Site Transportation equipment . These include:

- Overhead, trolley and chain conveyors
- In-floor and overhead towline systems
- Pneumatic conveyors
- Bulk handling conveyors
- Live roller conveyors
- Package handling powered conveyors
- Non-powered conveyors
- Chutes
- Lift trucks
- Freight and passenger elevators.

14.3 - Energy Losses

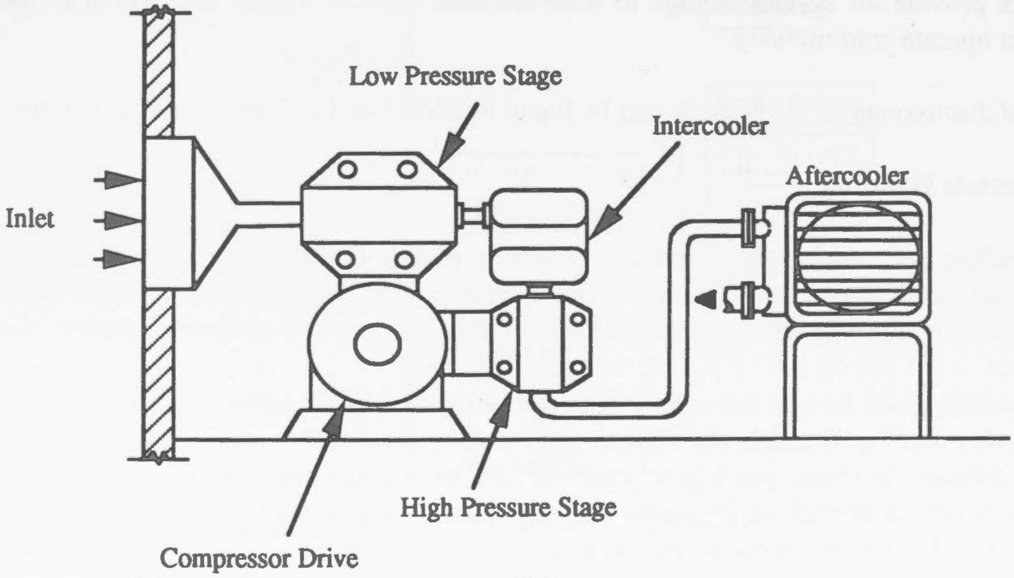


Figure 14.3 Arrangement of Compressor Components

14.3.1 - Compressors

Energy losses in a compressor appear as heat either in the compressor components and/or in the discharge air. Some form of cooling system is required to dissipate this heat. Small compressors may use heat dissipating fins on the compressor casing. In multiple staged compressors the air is normally cooled between stages in an intercooler (Figure 14.3), and in many installations the air is also cooled after the final stage by an aftercooler.

Cooling the compressed air reduces the specific volume which may allow the use of smaller pipe and/or reduce the friction losses. Most of the energy losses expended in compressing the air is recoverable by utilizing the intercooler and aftercooler as heat sources for other useful purposes.

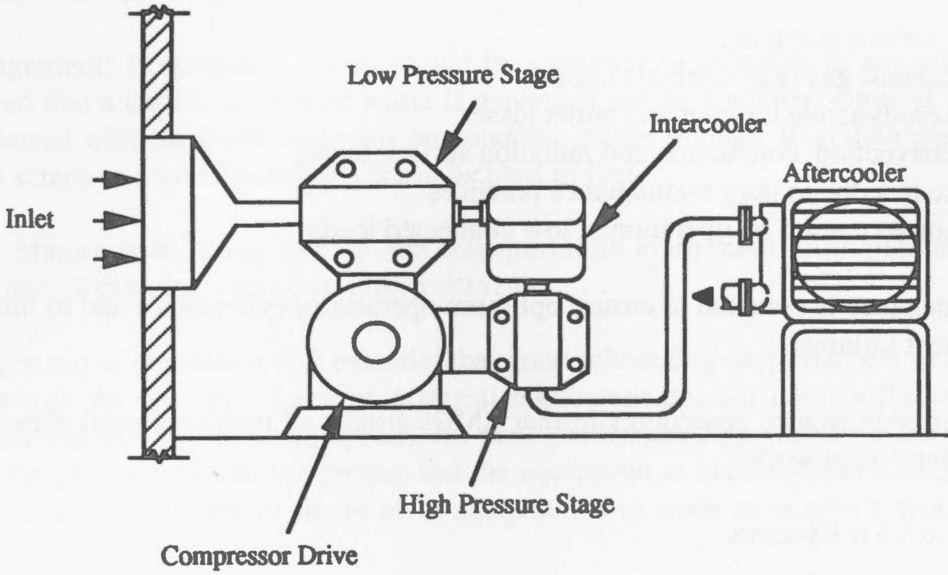


Figure 14.3 Arrangement of Compressor Components

Typical Portion of Input Energy
Released by Compressor Components
Table 14.1

	Heat Exchange Efficiencies (Portion of energy available for recovery)	
Component	**Cooling Media**	
	Air	**Water**
Electric motor	8%	---
Intercooler	45%	44%
Aftercooler	45%	44%
Air cooled compressor	5%	---
Water cooled compressor	1%	4%
Air cooled compressor and water cooled intercooler	3%	44%
Air cooled compressor and intercooler	5%	---

Table 14.1, reproduced from EMS No. 14, lists the components of an air compressor that have potential for energy recovery. The values listed represent the maximum portion of input energy that is recoverable as heat from the cooling air and water. The values are referred to as the **heat exchange efficiencies**

Calculations of the potential benefits that may be obtained from energy recovery are provided in EMS No. 14.

14.3.2 - Turbines

Energy losses in a turbine occur as:

- Exhaust gas (gas turbines) losses
- Aerodynamic air inlet and outlet losses
- Convection, conduction and radiation surface losses
- Losses due to poor maintenance practices
- Losses caused by operation at low connected loads

Preventative maintenance is essential to ensure optimum operational efficiencies and to limit potentially expensive equipment failures.

Aside from correct maintenance procedures further EMOs almost all involve capital expenditures often requiring significant design work.

14.3.3 - Compressed Air Systems

Energy losses within compressed air systems fall into three categories:

- Production losses - see compressors
- Distribution losses
- Utilization losses

Distribution losses often represent a significant part of the total load and include:

- **Air leakage:** Air leaks from hoses and couplings is a major source of air leakage. Copper or brass fittings have high air leakage potential because of possible cross threading.
- **Filter pressure drops:** The degree of filtration should be related to the specific application, because the finer the pore size of the filter, the more dirt will be collected, increasing the pressure drop and ultimately choking the air supply.

Utilization losses are primarily under the control of the process or equipment operator. Proper education and training on the cost of compressed air and its wise use is the best procedure to minimize wastage.

14.3.4 - Materials Handling

Minimising energy losses in materials handling environments generally results in improved production or process efficiency and therefore, many non-energy related side benefits may occur.

Plant Layout: Efficient use of facilities is most important and a review of the overall facility layout should be done on a regular basis. This review may also indicate "bottleneck" locations in material flow through a plant because of limitations or constraints caused by production equipment layout. Revising the plant layout and adding or modifying the materials handling or on-site transportation equipment may relieve this condition.

Many older plants are operating in multi-storied buildings and opportunities may be available for improved energy management. Chutes can be used to transfer product downwards from floor to floor as long as the manufacturing or assembly operations are arranged to allow this type of flow to take place.

Waste Management: Reduction of waste should be a continuing objective in any plant operation. It is also recognized that a certain amount of waste is generated and its handling, removal or reuse should be carefully reviewed with particular emphasis on potential energy savings. In certain cases, waste material such as wood scraps or used lubricating oils can be used as fuel.

Scheduling: Materials handling and on-site transportation equipment knits purchasing, production, warehousing and distribution into a cost effective system.

To make proper use of equipment it is essential that good scheduling be carried out to control the flow of materials through the facility. Lack of material movement control creates fluctuations in facility throughput and requires additional equipment for peak production times. Under these circumstances, the capital costs for plant equipment are greater and the equipment is underutilized during off peak periods. Controlled flow allows full use of the in-plant equipment and tends to eliminate fluctuations in facility throughput.

Scheduling of incoming and outgoing material, in-process material and finished product is also very important since these items all have an impact on the utilization of equipment and storage space requirements.

Production Operation Analysis and Automation: In many applications, the addition of modern material handling methods, equipment and microprocessor or computer control may be used to advantage. Levelling the flow of materials to production operations, and co-ordinating the starting and stopping of materials handling and production equipment can lead to improved plant operation and better energy management.

Reviewing individual production operations with the intent of combining one or more into a sequenced production operation may allow the reduction of floor space required for in-process material storage. This could reduce handling costs associated with moving the material to and from the production areas.

Shipping and Receiving Facilities: Shipping and receiving facilities range from simple manual systems, to highly mechanized and automated operations. Air infiltration and building fabric losses are major energy losses associated with these facilities. These are described in Section 18.0 Building Envelope and EMS No. 17, Materials Handling and On Site Transportation Equipment.

14.4 - Interactions

Most production processes carried out indoors will have an effect on the building HVAC systems. Large machinery or plant can produce heat loads that negate the need for space heating of the building. Where heated buildings include plant producing heat it is important that the heating system controls be capable of compensating for this.

Ventilation equipment may often be provided to vent heat or fumes from a building. The operating hours of this equipment should be co-ordinated with the production of heat or fumes. Transportation of materials or products into or out of a building can result in doors being left open. Where these doors are large (for example: aircraft hangers) the heating systems should be interloaded with the door opening.

To summarize, production processes will impact on other energy consuming equipment and fuel supply rate structures and therefore, can rarely be examined in isolation.

14.5 - Survey

A walk-through audit of production or process facilities can be a very complex undertaking. It may often be necessary to enlist the support of operators or plant supervisors if the auditor is unfamiliar with the process under examination. This will normally help to visualize the audit boundary for the process.

A number of different processes may be combined within a facility and may interact with each other. In these cases the audit boundary can be extended to include all interdependant plant, equipment or processes.

14.5.1 - Walk-through Audit

During a walk-through audit, the following items should be noted:

Compressed Air Leaks Look and listen for evidence of compressed air leakage.

Air Compressors Idling Examine the air compressors at lunch time or after hours; air compressors running with no load is a good indication that either equipment is being left on or that there are significant air leaks.

Condition of Auxiliaries Filters, dryers and lubricators on air systems should be examined for evidence of neglect.

Equipment operating Unnecessarily Production/Process equipment running when not required, for example during lunch, should be noted.

Condition, cleanliness of aisles and production areas Make note of these items especially where they appear to be affecting the flow of products or materials.

Raw material/Product stockpiles maintained outside This should be of concern where materials are to be heated or melted in a process or brought into heated areas.

14.6 - Annotated List of Energy Management Opportunities

14.6.1 - Housekeeping

EMO 14.1 MAINTAIN SYSTEM FREE FROM AIR

DESCRIPTION:	Repair all leaks on air distribution systems. Flexible hoses and couplings, brass or copper fittings at joints and elbows can all represent sources of loss. These should be eliminated whenever possible.
APPLICATION:	All compressed air pipework systems.
SIDE BENEFITS:	Additional compressed air will be available for other uses.

COST FACTORS: Part of normal maintenance.
EVALUATION: See EMS No. 12 worked example. Or measure compressor power consumption when all connected loads are off.
REFERENCES: EMS No. 12 Water and Compressed Air Systems.

EMO 14.2 MINIMIZE/ELIMINATE AIR WASTAGE

DESCRIPTION: Misuse or careless use of compressed air by equipment operators can be minimized or reduced by education or training; often equipment can be switched off at lunch times or between batch loads to reduce air use.
APPLICATION: All compressed air end users.
COST FACTORS: No capital costs but staff time will be required for training.
EVALUATION: Monitor compressor operation during periods of very low usage.
COMMENTS: Ongoing supervision will be required to ensure benefits are attained and maintained.
REFERENCES: EMS No. 12, Water and Compressed Air Systems.

EMO 14.3 MAINTAIN AIR FILTERS AND DRYERS REGULARLY

DESCRIPTION: Ensure that inline filters and dryers are changed regularly to ensure that blocked filters and dryers are not causing increased pipeline pressure losses.
APPLICATION: All compressed air systems.
SIDE BENEFITS: Better quality compressed air to tools or equipment.
COST FACTORS: Part of regular maintenance.
REFERENCES: EMS No. 12, Water and Compressed Air Systems.

EMO 14.4 MAINTAIN AIR LINE LUBRICATORS

DESCRIPTION: Ensure that automatic lubricators are working properly to reduce friction on air operated equipment.
APPLICATION: Compressed air systems with oil lubricators.
SIDE BENEFITS: Longer life of air seals and improved operation of air cylinders.
COST FACTORS: Part of regular maintenance.
REFERENCES: EMS No. 12, Water and Compressed Air Systems.

EMO 14.5 MAINTAIN GAS TURBINE INLET FILTERS

DESCRIPTION: Clean and efficient intake air filters are essential to reduce dust and other impurities which can foul compressor blades and increase wear. Dirty filters restrict air flow and reduce efficiency and output.
APPLICATION: Stationary gas turbines.
SIDE BENEFITS: Improved reliability.
COST FACTORS: Part of regular maintenance.
REFERENCES: EMS No.14, Compressors and Turbines.

EMO 14.6 OPERATE TURBINES AT OPTIMUM INLET AND OUTLET CONDITIONS

DESCRIPTION: Gas turbines should be operated with the least inlet suction loss and the lowest exhaust back pressure practical. Periodic checks should be carried out to ensure that inlet and exhaust passages are kept free of obstructions. Steam should be supplied at the maximum possible enthalpy and exhausted at the lowest possible enthalpy. The greater the difference, the greater the output. On non-condensing turbines the exhaust pressure should be kept at the lowest pressure acceptable to the low pressure steam system.

APPLICATION: Steam and gas turbines.

CAUTIONS: Turbines should always be operated within manufacturers recommended conditions.

COST FACTORS: Operational item.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.7 ENSURE AISLES ARE MARKED AND KEPT CLEAR

DESCRIPTION: Unless aisles are clearly marked, there is a tendency for material to be temporarily stored in areas which are intended to be used as passageways. When this occurs, inplant vehicular traffic must either wait until the aisle is cleared or find alternative and possibly longer routes resulting in additional energy use and cost.

APPLICATION: Mainly industrial and commercial facilities using mechanical transportation equipment.

SIDE BENEFITS: Improved staff productivity.

COST FACTORS: Low cost to implement, regular checking required to avoid aisles becoming blocked.

EVALUATION: See EMS No. 17.

COMMENTS: It is important to keep all manufacturing areas clear to minimize travel/time required for equipment tranportation.

REFERENCES: EMS No. 17, Materials and On Site Transportation Equipment.

EMO 14.8 MINIMIZE OPERATING HOURS OF POWERED TRANSPORTATION EQUIPMENT

DESCRIPTION: Conveying and other fixed material transportation equipment may often be switched off between shifts or during breaks in production.

APPLICATION: Mechanized product or material transportation equipment.

SIDE BENEFITS: Extended conveyor life, reduced maintenance.

COST FACTORS: Low cost if manual but can be high cost if automated.

EVALUATION: Base on reduced operating hours of motor(s).

COMMENTS: Ultrasonic or infra red sensing of material flow can maximize savings from this EMO

REFERENCES: EMS No. 17, Materials and On Site Transportation Equipment.

EMO 14.9 MINIMIZE MATERIALS OUTDOOR STORAGE TIMES

DESCRIPTION: Materials left outside the plant in cold weather can represent a substantial heating load when brought into a heated building. Materials that are to be heated as part of a process will require more energy to reach the desired temperature.

APPLICATION: Production processes utilizing large quantities of raw materials.

SIDE BENEFITS: Improved comfort when handling material.

COST FACTORS: Low cost if delivery can be scheduled to limit stockpiling indoors.

EVALUATION: See EMS No. 17.

REFERENCES: EMS No. 17, Materials and On Site Transportation Equipment.

EMO 14.10 REVIEW PRODUCTION SCHEDULES TO OPTIMIZE ENERGY USE

DESCRIPTION: Review production schedules to avoid peaks and troughs in energy use. Furnaces or kilns may be operated continuously for reduced periods rather than frequently heating & cooling the furnace/kiln which can be wasteful in energy.

APPLICATION: Manufacturing facilities.

SIDE BENEFITS: Can provide savings in reduced overtime working.

COST FACTORS: Low or no cost.

REFERENCES: EMS No. 17, Materials and On Site Transportation Equipment.

14.6.2 - Low Cost

EMO 14.11 MODIFY TURBINE AIR INTAKE

DESCRIPTION: Modify gas turbine intake to reduce the inlet pressure drop.

APPLICATION: Gas turbine installations where inlet conditions may be modified (i.e. with internal air intake).

SIDE BENEFITS: Increased output of turbine.

COST FACTORS: Normally moderate cost.

EVALUATION: See EMS No 14.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.12 INSTALL HEAT RECOVERY FROM GAS TURBINE OIL COOLER

DESCRIPTION: In many instances the cooling water from turbine oil coolers may be discharged to waste or the heat dissipated through a radiator or cooling tower. This heat may be used to preheat hot water or air.

APPLICATIONS: Gas turbines using water cooled oil coolers.

SIDE BENEFITS: If water recirculation is introduced potential savings in water costs may be available.

CAUTIONS: Water quality should be checked before installing heat exchange equipment.

EVALUATION: See EMS No. 14.

COMMENTS: The availability of a useful need for heat, such as preheating water, will have a large effect on the viability of this measure.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.13 INSTALL ADDITIONAL INSULATION

DESCRIPTION: Application of insulation around machines such as steam or gas turbines reduces casing loss. Steam turbines benfit from insulation on all components which carry steam. The condensers on condensing turbines may be insulated to reduce the required amount of space cooling. The compressor and air ducts of gas turbines can be insulated to retain the heat gained by the air during compression. Regenerators and secondary combustion chambers can also be insulated to retain the heat in the gases and combustion air.

APPLICATION: All steam and gas turbines.

SIDE BENEFITS: Improved safety conditions for operators.

EVALUATION: See EMS No. 14, EMS No. 1.

REFERENCES: EMS No. 14, Compressors and Turbines and EMS No. 1, Process Insulation.

EMO 14.14 UPGRADE CONTROL COMPONENTS

DESCRIPTION: The location and quality of control components such as temperature and pressure sensors, flow meters and flow detectors may not be ideal in an existing installation.

APPLICATION: Potential may exist on any turbine installation.

CAUTIONS: The removal, relocation or addition of a control device must be performed by personnel experienced with turbines and controls. Prior to performing any work on a turbine the manufacturer should be consulted for discussion of the envisaged change.

COMMENTS: The manufacturer may provide information on optimizing the changes, proper procedures to follow, measurements to verify the value of the changes, and any detrimental effects to the turbine and auxiliaries.

REFERENCES: EMS No. 14, Compressors and Turbines.

14.6.3 - Retrofit

EMO 14.15 INSTALL HEAT RECOVERY FROM WASTE STREAMS

DESCRIPTION: Waste water streams leaving a facility may contain useful heat that may be recovered and put to use.

APPLICATION: Process systems where cooling or rinsing fluids are discharged to sewers.

SIDE BENEFITS: Reduced sewer temperatures. If heat used to pre-heat products or fluids the process cycle time may be shortened.

CAUTIONS: Waste streams may be poluted or contaminated, careful selection of filtration and heat exchanger required.

COST FACTORS: High cost.

COMMENTS: Collection and use of recovered heat in the same process often maximizes utilization effectiveness. Batch processes may require the installation of buffer vessels to optimize the size of the heat exchanger.

REFERENCES: EMS Waste Heat Recovery Manual.

EMO 14.16 INSTALL COOLING TOWER MIST ELIMINATORS

DESCRIPTION: A mist or draft eliminator can reduce the water losses from a cooling tower which reduces costs for make up water.
APPLICATION: Closed loop process cooling towers of the direct evaporation type.
CAUTIONS: Manufacturers should be consulted when modifying cooling towers.
REFERENCES: EMS No. 12, Water and Compressed Air Systems.

EMO 14.17 INSTALL COMPRESSED AIR DRYERS

DESCRIPTION: Reduction in the water content of compressed air reduces corrosion of pipes, fittings and equipment which in turn reduces pressure drop and compressor power consumption.
APPLICATION: All large compressed air systems without dryers.
SIDE BENENFITS: Improved quality compressed air can improve finished products (eg. if used for paint spraying).
COST FACTORS: High cost.
REFERENCES: EMS No. 12, Water and Compressed Air Systems.

EMO 14.18 REPLACE PIPEWORK WITH LOWER FRICTION COEFFICIENT EQUIVALENT

DESCRIPTION: Corroded pipework and fittings may be replaced with pipe which has less resistance to air flow, therefore reducing the pressure loss in the system.
APPLICATION: Compressed air distribution systems.
COST FACTORS: Generally only applicable if pipework has to be replaced due to deterioration.
REFERENCES: EMS No. 12, Water and Compressed Air Systems.

EMO 14.19 RECIRCULATE WATER IN COOLING, FLUSHING,WASHDOWN PROCESS SYSTEMS

DESCRIPTION: When cooling water is not contaminated, it may be possible to install a cooling tower or evaporative cooling device to re-use water. Filtering or screening of water may permit re-use of contaminated cooling or wash down water.
APPLICATION: Generally applicable to large systems flowrates.
SIDE BENEFITS: Reduced water consumption. Reduced process and cycle time if water contains useful heat.
CAUTIONS: Chemical or particulate contamination of water may cause high maintenance of re-circulating systems.
COST FACTORS: High cost but good potential cost savings.
REFERENCES: EMS No. 12, Water and Compressed Air Systems.

EMO 14.20 REDUCE FLUID SYSTEM OPERATING PRESSURES

DESCRIPTION: Install local booster pumps to serve individual high pressure loads to permit lower operating pressure on remainder of system. Install low pressure loss filtering equipment or valves.

APPLICATION: Pumped process water fluid pipework systems, open or closed loop.

SIDE BENEFITS: Reduced risk of leakage.

CAUTIONS: Pump derating required to prevent overpumping due to reduced head.

REFERENCES: EMS No. 12, Water and Compressed Air Systems.

EMO14.21 REPLACE AIR COMPRESSORS WITH NEW HIGHER EFFICIENCY UNITS

DESCRIPTION: Modern multistage compressors offer higher operating efficiencies than single stage units. Differing types of compressors should be considered to provide most efficient unit for the application.

APPLICATION: Single and multiple air compressors generally where loads vary.

SIDE BENEFITS: Lower noise, higher quality air.

COST FACTORS: Normally economic when equipment replacement under consideration.

EVALUATION: See EMS No. 14.

REFERNECES: EMS No. 14, Compressors and Turbines.

EMO 14.22 INSTALL HEAT RECOVERY EQUIPMENT IN COMPRESSOR COOLING WATER SYSTEM

DESCRIPTION: Install a heat recovery system to extract heat from compressor cooling water for re-use elsewhere in the facility.

APPLICATION: Larger water cooled air compressors.

COST FACTORS: Depends on locality of suitable heat requirement.

INTERACTIONS: Examine in conjunction with other compressor EMOs.

EVALUATION: See EMS No. 14.

REFERENCES: EMS No. 14, Compressors & Turbines.

EMO 14.23 SEGREGATE COMPRESSOR FROM MAIN BUILDING

DESCRIPTION: Install enclosures around compressors to trap and exhaust unwanted hot or moist air directly outdoors. Relocate compressors to isolated areas having individual cooling systems.

APPLICATION: Locations where compressor heat does not contribute to space heating load or creates a cooling load.

CAUTIONS: Ensure adequate air circulation for compressor cooling.

INTERACTIONS: Consider in conjuction with EMO 14.25 Replace Compressors with Blowers.

EVALUATION: See EMS No. 14.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.24 UTILIZE COMPRESSOR WASTE HEAT FOR BUILDING HEATING

DESCRIPTION: A compressor may directly contribute to the space heating in an open plan building. Alternatively waste heat can be ducted to areas such as external doors to act as an air curtain.

APPLICATION: Large compressors primarily older units or air cooled units.

INTERACTIONS: Consider in conjunction with EMO 14.23, Segregation of Compressors.

EVALUATION: See EMS No. 14.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.25 REPLACE LOW PRESSURE COMPRESSORS WITH BLOWERS

DESCRIPTION: In some applications compressed air may be generated at high pressure and locally pressure reduced to serve individual items of equipment. In these cases a local high pressure blower may be a higher efficiency alternative.

CAUTIONS: If air compressor (as opposed to using system air generated by a compressor) also serves high pressure loads then this EMO may be uneconomic.

EVALUATION: See EMS No. 14.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.26 INSTALL AIR COOLED COMPRESSED AIR AFTER COOLERS

DESCRIPTION: Install air-cooled compressed air after coolers in series with water-cooled units to assist the plant heating system and reduce cooling water consumption.

APPLICATION: Large air compressors with water cooled after coolers located in or near to heated areas of a facility.

SIDE BNENFITS: Reduced cooling water consumption.

EVALUATION: See EMS No. 14.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.27 INSTALL VARIABLE SPEED COMPRESSOR DRIVE

DESCRIPTION: Install variable speed control on compressor motor to minimize energy consumption during periods of low air demand.

APPLICATION: Compressed air systems subject to varying loads utilizing single stage or single speed compressors.

CAUTIONS: Consult manufacturers for suitability to specific compressors involved.

INTERACTIONS: Alternative to EMO 14.28 Install Multiple Compressors.

EVALUATION: See EMS No. 14.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.28 REPLACE CENTRAL COMPRESSORS WITH MULTIPLE UNITS

DESCRIPTION:	Large central compressed air stations with low efficiency and considerable maintenance should be compared with smaller high efficiency compressors sized for individual loads and located near the point of use. Large central compressors that are sized for the peak load of the entire plant and the highest pressures will not operate at peak efficiency when the full air flow rate is not required. Multiple compressors can operate at the peak efficiency for longer periods of time when sized for individual loads.
APPLICATION:	Large complex or distributed compressed air systems utilizing single or multiple units.
COST FACTORS:	Should be considered when large plant is in need of replacement.
INTERACTIONS:	Possible alternative to EMO 14.27 Install Variable Speed Drive.
COMMENTS:	To provide backup in the event of failure individual compressors may be cross connected.
REFERENCES:	EMS No 14 Compressors and Turbines.

EMO 14.29 INSTALL MICROPROCESSOR ENERGY MANAGEMENT SYSTEM

DESCRIPTION:	A microprocessor compressor management system can accomplish energy cost savings over and above the savings from individual actions by monitoring and integrating various control functions.
APPLICATION:	Larger multiple compressor installations with varying load patterns.
SIDE BENEFITS:	Additional maintenance advantages through continuous compressor monitoring.
COMMENTS:	The analysis and selection of such equipment should be based on a professional review of the requirements for the particular facility. In a process setting, compressor control is often integrated into a larger control network.
REFERENCES:	EMS No. 14, Compressors and Turbines.

EMO 14.30 INSTALL AN AIR RECEIVER

DESCRIPTION:	Install an air receiver to provide a buffer to cope with peak demands and permit intermittent operation of air compressors.
APPLICATION:	Installations where compressors operate continuously to meet varying demands.
SIDE BENEFITS:	Longer compressor life due to reduced running hours.
EVALUATION:	See EMS No. 14.
REFERENCES:	EMS No. 14, Compressors and Turbines.

EMO 14.31 PREHEAT GAS TURBINE COMBUSTION AIR WITH EXHAUST GAS

DESCRIPTION:	Utilization of hot gas turbine exhaust gas to preheat the intake air can reduce fuel consumption considerably. Air generators are commonly used for this purpose.
APPLCIATION:	Fuel fired turbines providing output as shaft horsepower, as opposed to air movement.
CAUTIONS:	Manufacturers must be consulted prior to undertaking this type of measure.

INTERACTIONS: Possible alternative to EMO 14.32

EVALUATION: See EMS No. 14.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.32 UTILIZE HEAT FROM GAS TURBINE EXHAUST

DESCRIPTION: Heat available in gas turbine exhausts may be utilized directly e.g for product drying, or indirectly via a heat exchanger e.g. for space heating.

CAUTIONS: Any measure which introduces additional air flow resistance through the turbine should be discussed with manufacturers.

INTERACTIONS: Possible alternative to EMO 14.31

EVALUATION: See EMS No. 14.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.33 MODIFY TURBINE INLET AND EXHAUST TRACTS

DESCRIPTION: The piping and ducts connected to turbines are usually sized to optimize the various constraints of economy, weight, friction loss, space and materials. In many cases friction loss is not the principal constraint. Opportunities may be found to save operating cost by enlarging pipes, ducts, valves, filters, instrumentation fittings, heat exchangers and passageways.

SIDE BENEFITS: Reduction in noise generation.

CAUTIONS The manufacturer should be consulted to ensure that any modification will not adversely affect the turbine operation.

INTERACTIONS: Should be evaluated when considering heat recovery of exhaust gases.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.34 UTILIZE SURFACE HEAT FROM TURBINES

DESCRIPTION: Turbines are designed to have some external cooling surfaces because of the high internal temperatures to which they are subjected. The heat emitted from the surfaces may be utilized for space heating, drying processes or preheating process air. The quantity of energy available is best determined by temperature and air flow measurements. Utilization of the heat can yield savings by replacing energy generated by more costly methods.

APPLICATION: Turbines located adjacent to other heat loads. i.e. Space heating or drying processes.

SIDE BENEFITS: Improved comfort conditions for occupants.

REFERENCES: EMS No 14, Compressors and Turbines.

EMO 14.35 UPGRADE TURBINE COMPONENTS

DESCRIPTION: Replacement of worn or corroded turbine blades or other components can reduce blade surface friction and improve balance which will improve operating efficiency. Installation of low friction coatings may produce further savings.

APPLICATION: Steam turbines subject to varying load conditions.

CAUTIONS: Obtain specialist or manufacturers advice prior to implementation.

REFERENCES: EMS No 14, Compressors and Turbines.

EMO 14.36 IMPROVE STEAM TURBINE CONTROL

DESCRIPTION: Automatic auxiliary valves that effectively regulate the number of operating nozzles will significantly improve the efficiency of a steam turbine that operates under varying load conditions. The application of such devices requires expert assistance.

APPLICATION: Steam turbines subject to varying load conditions.

CAUTIONS: Obtain specialist or manufacturers advice prior to implementation.

REFERENCES: EMS No 14, Compressors and Turbines.

EMO 14.37 INSTALL BACK PRESSURE TURBINE TO SERVE AS PRESSURE REDUCING DEVICE

DESCRIPTION: Where pressure reduction of steam is required this may be achieved using a back pressure turbine to produce shaft power (possibly for electircal generation) instead of throttling valves or devices.

APPLICATION: Large scale pressure reduction systems.

COMMENTS: Will probably only be viable on very large systems due to high cost of equipment required.

REFERENCES: EMS No 14, Compressors and Turbines.

EMO 14.38 OPTIMIZE STEAM TURBINE OPERATING CONDITIONS

DESCRIPTION: Ensure that steam turbines operate at design conditions; fouled condensors, incorrect steam pressures and worn process pumps can all contribute to inefficient operation.

APPLICATION: All steam turbines.

COST FACTORS: Part of major maintenance routines.

EVALUATION: See EMS No. 14.

REFERENCES: EMS No. 14, Compressors and Turbines.

EMO 14.39 REVISE TOTAL MATERIAL HANDLING OPERATIONS

DESCRIPTION: Materials handling equipment is often installed to move the product through the facility with little or no consideration given to its energy utilization. Based on the escalating costs of energy today, consideration should be given to total plant layout and material flow with the objective of reducing or at least controlling energy costs.

SIDE BENEFITS: Relocation of certain pieces of production equipment can result in both energy and maintenance savings, as well as freeing up equipment for possible use elsewhere in the facility.

INTERACTIONS: Consider when evaluating minor housekeeping or low cost alterations to materials handling systems.

COMMENTS: If the entire facility is looked at in the global sense, many other opportunities of this type may become apparent. Each opportunity will have to be investigated individually to ensure that the implementation of the opportunity does not have a detrimental effect on the total facility operation.

REFERENCES: EMS No. 17, Materials Handling and On Site Transportation Equipment.

EMO 14.40 INSTALL MICROPROCESSOR BASED CONTROL SYSTEMS

DESCRIPTION: In numerous installations controls can be installed to operate transportation and handling equipment only when needed i.e. conveyors can be stopped when no product is actually being transported. Elevators power consumption can be greatly reduced by replacing control systems.

SIDE BENEFITS: Longer equipment life.

COMMENTS: Elevators may often be switched to 'local control' by night security staff which may cause them to idle rather than switch off overnight when not in use.

EVALUATION: See EMS No. 17.

REFERENCES: EMS No. 16, Automatic Controls, EMS No. 17, Materials Handling and On Site Transportation Equipment.

EMO 14.41 REDUCE FREQUENCY OF DELIVERIES

DESCRIPTION: Frequently, warehouse operations are set up on the basis that orders are filled as soon as they are received. In many instances, a powered vehicle circulates through the warehouse each time an order is placed. Consider rescheduling warehouse operations in order to fill multiple orders during one warehouse circuit. Further, if the frequency of product delivery to customers can be reduced, fuel saving both from the warehouse and delivery vehicles would result.

CAUTIONS: Care must be taken prior to the implementation of any scheme of this type to ensure that a reduction in delivery frequency does not adversely affect customer satisfaction.

INTERACTIONS: Examine this option when reviewing total site materials handling options.

REFERENCES: EMS No. 17, Materials Handling and On Site Transportation Equipment.

EMO 14.42 IMPROVE MATERIALS FLOW MONITORING

DESCRIPTION: In many instances, difficult to reach equipment or transfer points in materials handling systems can be monitored, for example by the use of closed circuit TV. Jams, blockages or lack of transfer can be noted and equipment can be shutdown until the problem is cleared. This would eliminate hazardous operating conditions from both an equipment and product point of view.

APPLICATION: Automated materials handling systems.

REFERENCES: EMS No. 17, Materials Handling and On Site Transportation Equipment.

EMO 14.43 CONSOLIDATE WAREHOUSE OPERATIONS

DESCRIPTION: If multiple warehouses within close geographic vicinity are being operated by a company, it may be advantageous to consider combining some or all of the warhouses into a single central unit. Although transportation costs from the centralized warehouse to the customer may increase, offsets could occur through a reduction in building energy requirements, staffing and possible fleet delivery vehicles.

APPLICATION: Large distribution operations.

REFERENCES: EMS No. 17, Materials Handling and On Site Transportation Equipment.

15. LIGHTING

15.1 - Introduction

Lighting is invariably a large energy user in most commercial institutional and industrial buildings and there are often opportunities to produce significant energy savings. The auditor, however, should be careful not to compromise visual performance in making lighting system changes which may reduce worker performance and in turn negate or outweigh any savings in energy costs.

15.2 - Fundamentals

Technicians and engineers with a mechanical background, who have been designated the task of managing energy use, may find themselves unfamiliar with the lighting disciplines. For this reason, more so than the other disciplines discussed in this manual, it is extremely important that they review and gain an understanding of the principles of lighting design before embarking on the audit.

Fundamentals are discussed in this section in the context of energy losses in lighting installations (section 15.3 following). It is also recommended that EMS No. 2, Lighting, be read in conjunction with this section.

15.3 - Energy Losses

The efficiency of a lighting system can be improved by following two basic strategies, reducing the installed (electric) lighting load and reducing the actual usage of the lights. Losses are illustrated in Fig. 15.1 below.

Electric power to light conversion losses occur at the actual point of conversion. Because the energy sources electricity and light are not measured in the same units, it is not possible to speak in terms of efficiency of light sources, instead the term "luminous efficacy" is used and is defined as the ratio of the light flux emitted by a light source to the power input. The common unit is the lumen/watt (or lux).

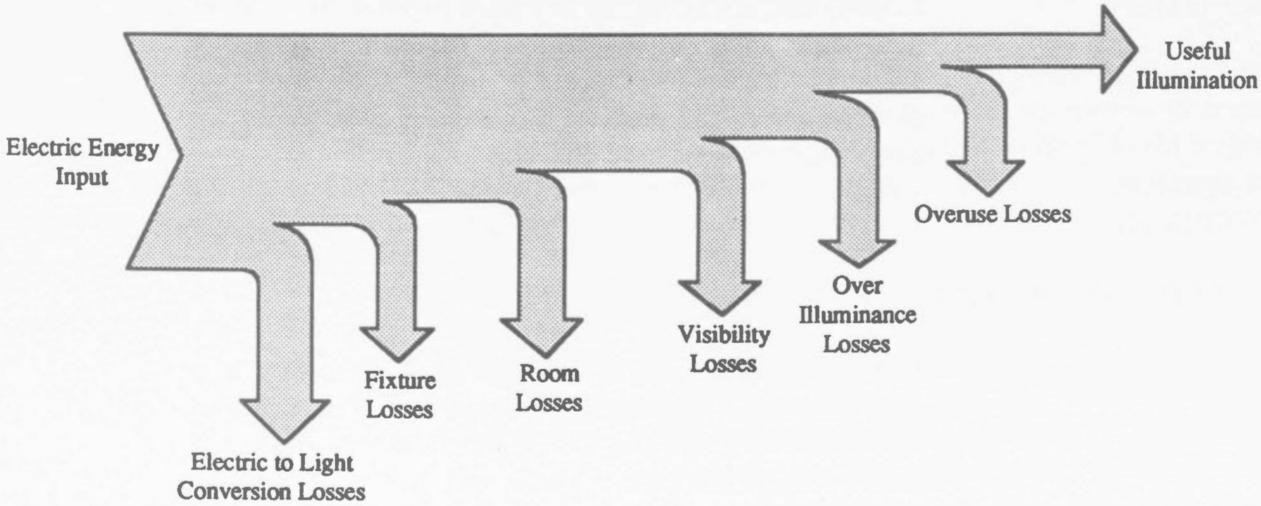
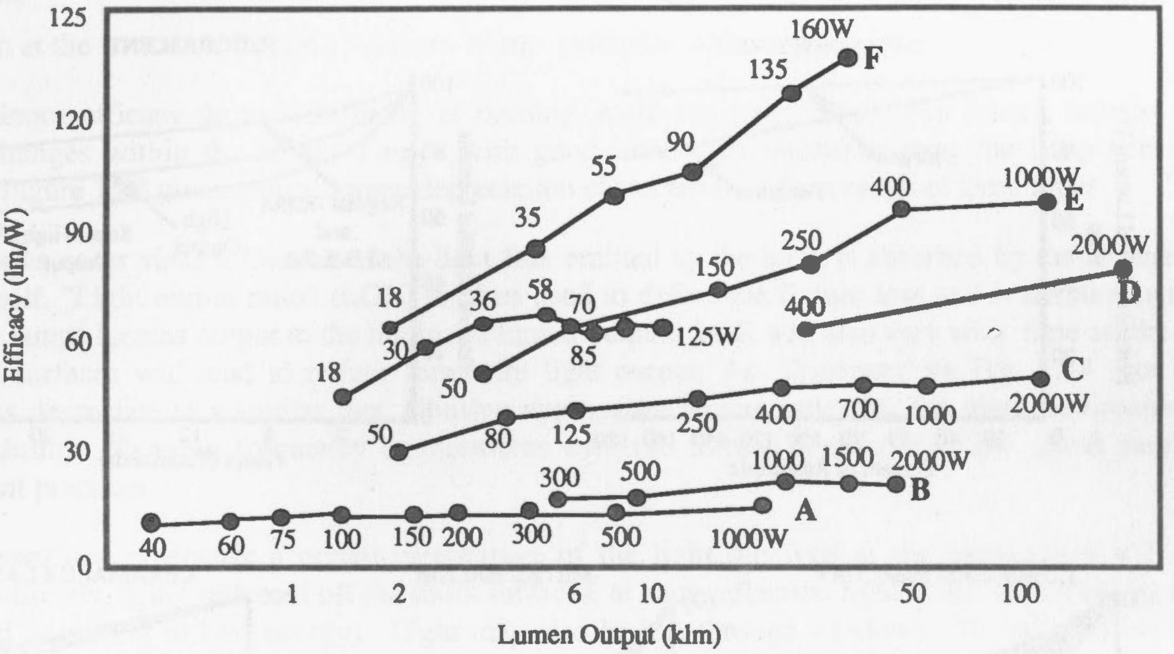


Figure 15.1 Losses in Lighting Systems



Lamp Type	Ra-Index
A Incandescent (Inert Filling)	100
B Incandescent (Halogen)	100
C High Pressure Mercury Fluorescent (HPL-N)	47 - 96
D High Pressure Mercury + Metal Halide (HPI)	67 - 86
E High Pressure Sodium (SON)	25
F Low Pressure Sodium (SOX)	5

CIE General Colour Rendering Index (Ra)	Typical Application
80 < Ra < 90	Wherever accurate colour matching is required. e.g. colour printing inspection. Wherever accurate colour judgements are necessary and/or good colour rendering is required for reasons of appearance, e.g. shops and other commercial premises.
60 < Ra < 80	Wherever moderate colour rendering is required.
40 < Ra < 60	Wherever colour rendering is of little significance but marked distortion of colour is unacceptable.
20 < Ra < 40	Wherever colour rendering is of no importance and marked distortion of colour is acceptable.

Fig. 15.2 **Efficacy versus Lumen output and colour rendering characteristics for different lamp types (after Philips, Eindhoven, The Netherlands).**

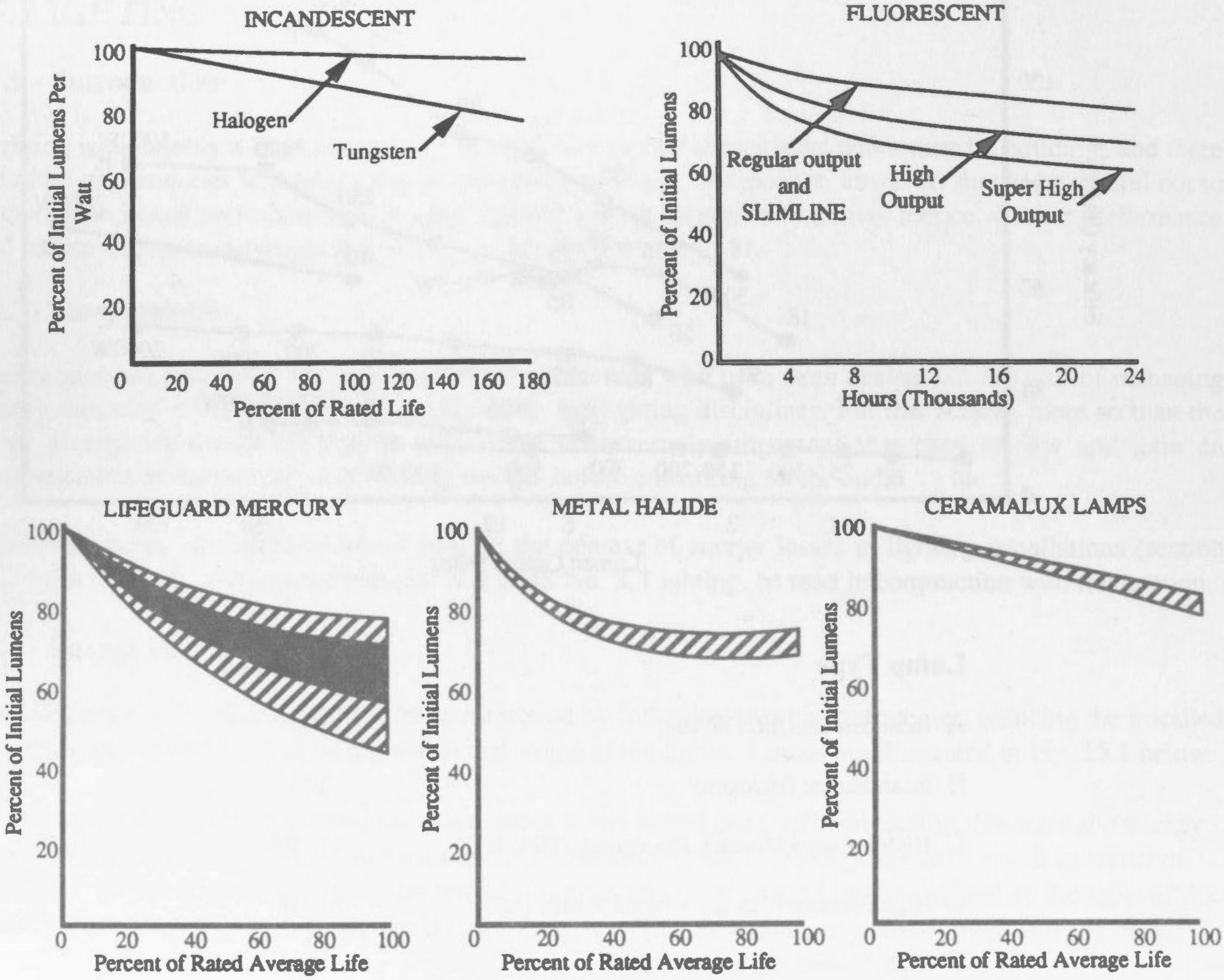


Fig. 15.3 Lumen Depreciation Curves for Various Types of Lamps

Lamps used for interior lighting fall into one of two major groups,'incandescent' or 'discharge'. With incandescent lamps, light is emitted by a tungsten filament heated to incandescence by an electric current, while with discharge lamps it is the vapor filling in the tube or bulb that emits light by electric discharge when power is supplied. Fluorescent lamps are basically discharge lamps in which light is absorbed and re-emitted at a different wavelength by a fluorescent coating of the glass envelope. Discharge lamps other than the common "Fluorescent tubes" and new "compact fluorescent lamps" are normally referred to as high intensity discharge lamps (HID), and may or may not have fluorescent coating. In order to operate correctly, discharge lamps require auxiliary circuitry including a starting device and a current stabilizing device (ballast). When comparing the luminous efficacy of light sources, it is important not to forget the auxiliary circuit losses.

HID lamps usually have a higher efficiency than incandescent and fluorescent lamps. Typical values of luminous efficacy for a range of lamp types are given in Figure 15.2. On the other hand, HID lamps modify the color appearance of objects more (in other words, they have a lower "color rendering index"). Chosing a lamp with the highest efficacy is an obvious conservation strategy but may not always be compatible with the color rendering requirements of the space. The supplementary information at the bottom of Figure 15.2 gives some guidance in this regard.

Lamp luminous efficacy drops with hours of burning, more for some lamps than others, because of physical changes within the lamp. Lamps with good lumen maintenance over the lamp life are desirable. Figure 15.3 gives typical lumen depreciation characteristics for a range of lamp types.

Fixture losses occur since a fraction of the light flux emitted by the lamp is absorbed by the luminaire (fixture) itself. "Light output ratio" (LOR) is often used to define the fixture loss and is defined as the ratio of the lamps lumens output to the luminaire lumen output. LOR will also vary with time as dirt on the fixture surfaces will tend to reduce luminaire light output. As illustrated by Fig. 15.4 not all installations depreciate at a similar rate. Chosing appropriate fixture types for the given environment and scheduling cleaning frequency concomitant with the fixture depreciation are good energy management practices.

Room Losses occur because a certain percentage of the light received at the work space will be received indirectly, being reflected off the room surfaces; at each reflection light is lost (absorbed by the surface and degrading to heat energy). Light may also be lost through windows. To account for the actual contribution of illuminance from a particular fitting in a particular room, the lighting engineer uses the term Utilisation Factor (or coefficient of utilisation). The utilisation factor, (UF), is defined as the ratio of the total lamp flux received by the working plane to the total lamp flux of the installation. The value will depend on the actual light distribution from the fixtures, the space geometry and surface reflectance.

Generally large and light surfaced rooms are more efficient then small and dark colored rooms because there is less light absorption. Similarly, fixtures that concentrate most of their light on the area to be illuminated will be more efficient than fixtures that spread the light around more uniformly.

Reducing room losses, or making any improvement to the efficiency of the lighting installation will not directly affect the energy consumption, but rather increase the lighting quantity: energy savings are only achieved if other actions aimed at reducing installed power or time of operation, e.g. delamping, are carried out.

Visibility losses result from glare and veiling reflections; to offset such effects higher illuminance levels are sometimes provided.

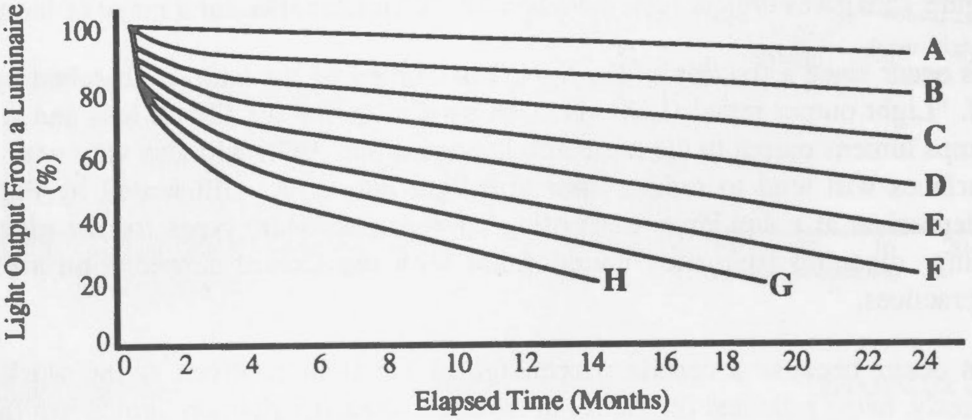
Over-illuminance losses occur because more than the required illuminance is supplied at the task. This may result from the need:

- To meet certain architectural grid layouts,
- To provide an overall high level of illuminance to cover the most critical task leaving much of the area with less critical task over illuminated, or
- To provide sufficient illuminance to allow for dirt collected in the fixtures and lumen depreciation of the lamps.

Over-use losses occur when lighting is left on when not required. Significant savings can often be made by controlling light usage, often without compromising visual performance, the major strategies possible include:

- Use of daylight to replace or complement artificial lighting,

- The use of automatic dimming systems, and
- The use of devices (switches) to permit lights to be switched off when not required or to adjust illuminance levels to changing visual tasks or changing light output from fixtures.



Fixture Type	All Air Conditioned Buildings	Clean Country Area	City or Town Outskirts	City or Town Center	Dirty Industrial Area
Bare lamp	A	A/B	B	B/C	C
Open ventilated reflector	A	A/B	B	B/C	C
Dust-tight, dust-proof or reflector lamp	A	A/B	B	B/C	B/C
Open non-ventilated reflector, enclosed diffuser/controller	A/B	B	C	C/D	D
Open base diffuser or louver	A/B	B	B/C	C	C/D
Recessed diffuser or louver, diffusing or louvered luminous ceiling	A	A/B	B	B/C	C
Indirect cornice	B	C/D	E	F/G	G

Fig. 15.4 Light output from a luminaire versus elapsed time for different luminaire, activity & location categories.

15.4 - Interactions

The electric energy used by the lighting system is eventually transferred through combined heat transfer mechanisms to the ambient air. During the heating season, this positive heat gain reduces the HVAC thermal load, while the opposite occurs when cooling is needed. (Lighting energy savings are therefore particularly important in those buildings which require cooling.) The way in which HVAC control systems respond to the variation in space heat gain will also affect the overall savings realized from lighting load and usage reductions. In some instances, such as terminal re-heat systems, little if any overall energy savings may be realized if loss of light heat gain is compensated for by additional reheat. Additional discussion is provided on this topic in Section 17 (HVAC Systems).

Pursuing daylighting strategies also interacts strongly with possible envelope conservation strategies; for example the improved thermal performance of the envelope achievable by replacing windows with opaque insulated panels must be considered against the possible loss of daylight.

Some fluorescent lights installed before 1978-79 may contain Poly Chlorinated Byphenols (PCBs). It is illegal to dispose of these ballasts when removed, and they must be stored by the owner until the PCBs can be safely destroyed.

15.5 - Survey

The walk-through survey should have two principal focuses; one to identify where the installed lighting load is considered too high, because of over-illuminance or low efficiency fixtures and/or poor layout; the other to identify where lighting use (hours of operation) can be reduced.

A useful energy indicator in the preliminary assessment of the potential for lighting power reduction is the unit power density (UPD) of the building, which is defined as the ratio of the installed electric power to the gross floor area of the building; the UPD is commonly expressed in units of watt/sq. m (see the IES LEM-1, 1982-1983 and LEM-4, 1984, for reference and target values of UPD for the main building categories). For general lighting systems, the UPD can also be defined as the ratio of the average illuminance on the working plane (lumen/sq. m) to the installed efficacy of the lighting system (lumen/watt): if the UPD is too high for a given building, this can be attributed either to an excessive illuminance level, or to poor efficacy of the lighting system.

For the most part, the audit can make use of a visual inspection of the electrical lighting layout drawings and facility.

Making selected illuminance measurements at the time of the walk-through is, however, recommended as this is a relatively quick process and yields reliable information by which an assessment of the potential for energy management can be made.

The order in which the facility is surveyed is not too critical; ideally one should work on an area at a time, each area being selected on the basis of its type of installation, visual tasks and/or partitioning arrangement. The time of the audit is perhaps more critical and ideally should be divided into a number of visits to get a complete picture of the lighting usage pattern. Making visits at the start of the work-day, during lunch breaks, at the end of the work-day and through cleaning and security activities will enable the auditor to determine the potential for energy savings through lighting controls. Questioning building occupants about how they use lighting controls rarely provides reliable information about actual switching patterns and should not be relied upon as a basis for evaluating potential EMOs.

15.5.1 - Walk-through Audit Procedure

During the initial review of plans and specifications and during the walk-through, the following information should be collected.

Lighting controls For each representative space note the kind of lighting control, eg. "individual offices have own manual switch".

Unnecessary lighting usage Note where lights are left on when not required. Prime examples include lights left on during daylight hours (outside lights), in unoccupied rooms, in spaces with adequate daylight, after the normal work-day and during cleaning and security operations. Identify areas where daylight or different switching strategies might be utilized more effectively.

Lighting levels Measure working plane illuminance in a number of representative areas; measurements should be taken to coincide with the range of visual tasks being performed; note type of task against measured illuminance complete with recommended levels. Note that it is not necessary to do a detailed measurement survey at this time. Record situations where task lighting or better placement of work station might be considered.

Note where installation appears glaring or where veiling reflections are causing visual performance difficulties. (Take a sample of text printed on shiny surfaced paper to check out for possible veiling reflections in key areas). Note glare source, i.e. fixture or window.

Installed lighting load From drawings or survey, record installed lighting load; an approximate figure is good enough for a preliminary assessment of EMOs.

Luminaire types Record fixtures and lamp types on an area by area basis.
Note age of fixture in general term, eg. "original equipment", "recently installed".

Luminaire maintenance Note where lamps are burnt out or nearing the end of their life (blackened incandescent lamps, lack of light at ends of fluorescent tubes, lamps duller than other similar lamps in the area). Check for dirty fixtures, missing, broken or yellowed lenses.

Room finishes Note any dark or dirty surfaces that may have an adverse effect on the amount of reflected light reaching the working place.

15.6 - Annotated List of Energy Management Opportunities

15.6.1 - Housekeeping

EMO 15.1 SWITCH OFF UNNECESSARY LIGHTS

DESCRIPTION:	Switch off lights in unoccupied areas.
APPLICATION:	All buildings.
SIDE BENEFITS:	Reduced cooling loads. For incandescent lamps, longer time between lamp changes.
CAUTIONS:	Make sure lighting sufficient for safety. Frequent switching of

fluorescent or discharge lights shortens life-time.
COST FACTORS: Negligible.
INTERACTIONS: EMOs dealing with lighting control.
EVALUATION: Check lighting use during non-working periods: estimate possible reductions in operating time.

EMO 15.2 LIMIT LIGHTING NEEDS DURING CLEANING PERIODS

DESCRIPTION: Organize cleaning schedules so that lighting needs are minimized (e.g. by cleaning fewer spaces at the same time).
APPLICATION: Commercial and institutional buildings.
CAUTIONS: Respect minimum safety illumination levels in other spaces.
COST FACTORS: Negligible.
INTERACTIONS: EMO 15.15 (add switches), EMO 15.19 (central light operation)
EVALUATION: Examine cleaning schedules and building layout.
REFERENCES: IES, 1981.

EMO 15.3 USE LOW LEVEL LIGHTING FOR SECURITY PERIODS

DESCRIPTION: Use low level lighting during security operations.
APPLICATION: All buildings which require security checks.
CAUTIONS: Care must be taken so that safety is not compromized.
COST FACTORS: Negligible.
INTERACTIONS: EMO 15.15 (add switches), EMO 15.19 (central light operation).
REFERENCES: IES, 1981.

EMO 15.4 REARRANGE WORK SPACE TO MAKE BEST USE OF DAYLIGHT

DESCRIPTION: Rearrange work space to make best use of daylight, e.g. make use of the space close to windows.
APPLICATION: Generally spaces up to about 7 m from window.
SIDE BENEFITS: Natural light preferable from psychological standpoint.
CAUTIONS: Shading maybe needed to avoid glare and direct solar radiation.
COST FACTORS: Negligible
INTERACTIONS: EMOs related to lighting control. (EMOs 15.16, 15.17, 15.19). EMO 15.5 (Delamping.) EMO 15.19 Improve fixtures arrangement. See also ENVELOPE EMOs dealing with fenestration.

EMO 15.5 REMOVE LAMPS

DESCRIPTION: If lighting is above required level, consider removing some of the lamps from fixtures. If luminaires are provided with two low efficacy lamps, consider replacing by a single high efficacy lamp.
APPLICATION: All buildings.
SIDE BENEFITS: Reduced cooling loads.
CAUTIONS: Removing lamps from fluorescent fixtures may leave ballast connected and consuming energy. Some fixtures (e.g. two lamp) may require both

lamps to be installed for operation. If applied to two lamp luminaires, be aware of possible stroboscopic affects in areas where rotating machinery exists. Avoid worsening of the power factor.

COST FACTORS: Negligible.

INTERACTIONS: Removing lamps may increase heating load. See also HVAC system interactions. Could be applied in conjunction with EMOs increasing the lighting level.

EVALUATION: Check illuminance levels on working plane.

EMO 15.6 LUMINAIRE MAINTENANCE

DESCRIPTION: Set up a regular maintenance procedure including cleaning and checking of all luminaire components. Replace lamps when they reach life limit (as specified by manufacturer, i.e. when light output 70% of rated value). Consider reducing lamp wattage if feasible. Consider repainting diffuse reflector surfaces with lighter color. Do not repaint mirrors.

APPLICATION: All buildings.

SIDE BENEFITS: Improved lighting quality.

COST FACTORS: Should be part of ordinary maintenance.

INTERACTIONS: This EMO does not save energy unless coupled with actions aimed at lighting power reduction (e.g. delamping, permanent power reduction, automatic voltage control, etc.). Consider coupling with component replacement.

COMMENTS: Cleaning required after approximately 1000 operating hours (bulbs) or 2500 hours (tubes).

REFERENCES: IES, 1981 EMS No. 2 Lighting.

EMO 15.7 CLEAN INTERIOR WALL SURFACES. REPAINT WITH LIGHTER COLORS

DESCRIPTION: In order to make better use of emitted light flux, use high reflectance matte paints for walls and ceilings.

APPLICATION: Generally applicable, especially so where reflected light is a significant part of the overall lighting level; e.g. indirect lighting, small rooms, luminaires with wide angle distribution.

CAUTIONS: Avoid excessive reflectances which may cause veiling reflections and glare.

COST FACTORS: May be part of ordinary maintenance.

INTERACTIONS: This EMO does not save energy unless coupled with actions aimed at lighting power reduction (e.g. delamping, permanent power reduction, etc.).

15.6.2 - Low Cost

EMO 15.8 REDUCE EXTERIOR, GROUNDS, SIGN, DISPLAY LIGHTING

DESCRIPTION: Reduce lighting of exterior spaces, grounds, signs, display, etc. to a minimum. Install an astronomic clock to automatically turn off lights at proper times all year round.

APPLICATION: Buildings with outside lighting systems.

CAUTIONS: Respect minimum safety illumination levels.

COST FACTORS: Negligible to low.

INTERACTIONS: EMOs dealing with lighting control (EMOs 15.16, 15.17, 15.19).

EMO 15.9 IMPROVE GEOMETRIC ARRANGEMENT OF LUMINAIRES

DESCRIPTION: Modify position of lighting fixtures, according to work station location, and/or lower luminaire mounting height.

APPLICATION: All buildings.

CAUTIONS: Control veiling reflections and glare.

COST FACTORS: EMO most approriate where lighting renovation work is needed.

INTERACTIONS: Should be coupled with delamping or power reduction to achieve energy savings. Alternatively consider task lighting (EMO 15.10).

EVALUATION: Auditor should first check if it is possible to rearrange the space layout.

EMO 15.10 USE TASK LIGHTING

DESCRIPTION: Locate work stations and provide required illuminances, while maintaining lower values in surrounding non-critical areas.

SIDE BENEFITS: Better lighting for activities which require high concentration.

CAUTIONS: Lowering of the overall lighting level required in order to achieve any energy savings.

INTERACTIONS: Should be coupled with delamping to achieve energy savings. Alternatively consider improving luminaire arrangement (EMO 15.9).

EVALUATION: Auditor should identify spaces in which a high, uniform illuminance level is maintained to perform visually critical tasks in small areas. Estimate reduction in overall lighting power to calculate energy savings.

REFERENCES: IES, 1981.

EMO 15.11 USE EFFICIENT BALLASTS

DESCRIPTION: Substitute existing ballasts with more efficient ones: install multi-level ballasts if lighting level control is desirable; install high frequency ballasts.

APPLICATION: Fluorescent systems.

COST FACTORS: Ballast replacement only may not be cost-effective. Consider also complete luminaire replacement.

INTERACTIONS: Luminaire maintenance (EMO 15.6). Multi-level ballasts may be an alternative to other lighting control (EMOs 15.16, 15.17, 15.19). Alternatively, consider lighting replacement (EMO 15.13, 15.18).

EVALUATION: Usually a simple visual inspection of the ballast type is sufficient to assess replacement; high ballast temperature is an indicator of poor performance.

EMO 15.12 REPLACE LOW WATTAGE LAMPS WITH FEWER HIGH WATTAGE LAMPS

DESCRIPTION: For most types of source, lamp efficacy increases with size. Use fewer but larger lamps.
APPLICATION: Only effective for incandescent and low-wattage fluorescent lamps.
CAUTIONS: Verify that the spatial distribution of light flux is still satisfactory.
COST FACTORS: Will often require new lighting fixture or ballast.
INTERACTIONS: Luminaire maintenance (EMO 15.6). Alternatively, consider lighting replacement (EMO 15.13, 15.18).

EMO 15.13 INSTALL MORE EFFICIENT LIGHT SOURCE

DESCRIPTION: Substitute lamps with more efficient ones (e.g. fluorescent in place of incandescent).
APPLICATION: Older lighting systems and components. In areas where color rendering is not a critical requirement, high intensity discharge lights (or other high efficiency lamps) may be used.
CAUTIONS: Respect color rendering requirements. Most fixtures have limited lamp possibilities: this EMO may imply substituting the whole fixture. Also note that not all lamps have equal dimming capability.
COST FACTORS: Moderate.
INTERACTIONS: Consider as a complement/alternative to component or lighting system replacement.
COMMENTS: Miniature fluorescent lamps with built-in ballast are available as a direct replacement for incandescent lamps.
REFERENCES: IES, 1981, Zackrison, H., 1985, EC&M, 1983.

EMO 15.14 INSTALL MORE EFFICIENT REFLECTORS AND LENSES IN LUMINAIRES

DESCRIPTION: Install reflectors and lenses achieving the desired light distribution with minimum light loss.
APPLICATION: Older lighting systems and components.
CAUTIONS: Make sure no discomfort glare is produced. No energy savings unless coupled with delamping.
COST FACTORS: Mostly effective if existing luminaires need replacement.
INTERACTIONS: Consider as an alternative to component or lighting system replacement. May be coupled to power reduction by delamping (EMO 15.5, 15.6).
COMMENTS: Many older type lenses were subject to yellowing with age and consequent reduction in light transmission.

EMO 15.15 ADD SWITCHES, TIMERS, PRESENCE SENSORS, DIMMERS FOR BETTER CONTROL

DESCRIPTION: Add switches to enable better local lighting control; install time clocks to reduce lighting in public spaces during unoccupied periods; install photo-electric cells to control outdoor lighting; install timer switches on local circuits in intermittently occupied areas; install movement-sensitive switches to turn out lights in intermittently occupied areas; install dimmers for adjusting illuminance level; install pull switches in offices.

COST FACTORS: May be cost effective only when major interior renovation or rewiring is planned.

INTERACTIONS: All EMOs related to lighting control and occupancy. Consider multi-level ballasts as an alternative control technique (EMO 15.11). Consider switching functions along with other EMS functions (EMO 15.16, 15.19).

EVALUATION: Evaluation requires knowledge of occupancy habits.

REFERENCES: Dulanski, G., 1987, EMS No. 2, Lighting.

15.6.3 - Retrofit

EMO 15.16 INSTALL AUTOMATIC CONTROL SYSTEM TO MAINTAIN CONSTANT ILLUMINANCE

DESCRIPTION: Install a control system which adjusts the luminaire light output to maintain a constant illuminance.

APPLICATION: Only for lighting systems that allow dimming.

INTERACTIONS: EMO 15.6 (luminaire maintenance); EMO 15.7 (wall repainting).

COMMENTS: Illuminance is kept at a constant level over the entire maintenance period. Energy savings are achieved by avoiding over-illuminance when lamps are new and fixtures clean.

EMO 15.17 INSTALL CONTROL TO ENABLE BETTER USE OF DAYLIGHTING

DESCRIPTION: Install controls which automatically reduce artificial lighting when daylight is available; install separate switches for inner and perimeter areas.

APPLICATION: Spaces within about 7 m from windows.

CAUTIONS: Can create lighting balance problems in deep plan buildings (windows appear too bright compared to surrounding luminance).

COST FACTORS: Consider when either major interior renovation or complete wiring renovation is planned.

INTERACTIONS: Switch off lights (EMO 15.1).

EVALUATION: Estimation of daylight potential required.

REFERENCES: EC&M 1987.

EMO 15.18 SWITCH TO A MORE EFFICIENT LIGHTING SYSTEM

DESCRIPTION: Replace existing lighting system with one using more efficient light sources and/or more efficient luminaires.

APPLICATION: Older systems and buildings.

CAUTIONS: Respect color rendering requirements.

COST FACTORS: Consider if major renovation work is planned.

INTERACTIONS: Consider as an alternative to delamping (EMO 15.5), luminaire maintenance (EMO 15.6) or components replacement (EMO 15.11, 15.12, 15.13, 15.14).

COMMENTS: Typically fluorescent, sodium or mercury vapor metal halide lamps installed in place of incandescent.

EMO 15.19 INSTALL CENTRAL LIGHT CONTROL

DESCRIPTION: Install a central, computer based lighting management system.
SIDE BENEFITS: System may perform other control tasks (e.g. HVAC, security, fire safety).
COST FACTORS: High: cost-effective only if full capability of management system is actually needed.
INTERACTIONS: Occupancy related EMOs.
REFERENCES: Knisley, J.R., 1986.

16 - ELECTRICAL SYSTEMS

16.1 - Introduction

Although electrical energy bills may be the only energy expense or represent a significant part of the total energy expense, most electrical energy savings will occur as a direct result of retrofit actions described under other categories such as Lighting and HVAC Systems. There are, however, a few instances that can be considered as uniquely or more closely related to the electrical system and these are discussed in this section.

16.2 - Fundamentals

Before commencing on an audit of the building electrical systems, either as a separate audit activity or part of an audit of other sub-systems, it is extremely important that the auditor has an understanding of basic electrical principals. EMS No. 3 "Electrical Systems" and EMS No. 4 "Energy Efficient Motors" give good introductions to the subject and are recommended reading for auditors.

16.3 - Energy Losses

Losses in electrical systems are most often a function of inefficient operation of other sub-systems; for example an exhaust fan left operating when not required not only wastes heating or cooling energy by virtue of the outside air it induces into the building, but also wastes the electrical energy required to drive the motor. These options for saving energy are discussed in other sections of this manual.

Losses which can be considered uniquely electrical in nature include:

- Distribution system losses.
- Electrical equipment losses.
- Rate structure losses.

Distribution system losses can normally be discounted as having neglible effect on the overall energy consumption of the facility.

Electrical equipment losses include losses from the conversion from either one voltage level to another (i.e. in transformers) or more significantly from the conversion of electrical power to mechancial power (i.e. in motors).

Rate structure losses are normally dollars lost rather than energy losses and result from not using electricity in a manner consistent with obtaining the lowest overall unit cost of electricity through such strategies as demand limiting or power factor correction.

16.3.1 - Electric Equipment

Because of the relative magnitude of energy consumed by electric motors in building systems, it is worthwhile for the auditor to gain some appreciation of the performance of electric motors and to be knowledgeable of those parameters that affect their performance.

The most influential parameter to full load motor efficiency is motor size, with typical efficiencies ranging from 30%, or less, for fractional horse power motors; up to 90% or more for large (100 kW) motors (see Figure 16.1). The type, method of construction, and condition of the motor can be considered secondary but nevertheless an influencing parameter on full load motor efficiency. The motor transmission, i.e. the connection to the driven piece of equipment, is also a source of energy loss.

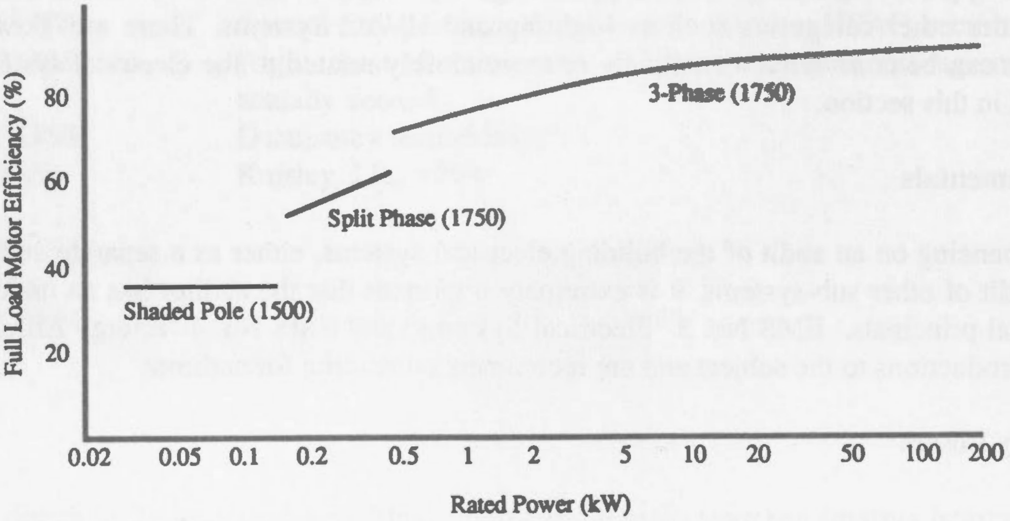


Figure 16.1 Typical variation of efficiency with motor size. Numbers in brackets give the nominal rpm.

Motor efficiency drops at part load, but only significantly at loads less than 25% of the rated motor power. In fact motor efficiency may rise slightly with decreasing load before dropping sharply at very low loads (see Figure 16.2). Power factor, however, drops off more dramatically and consistently with load reduction as shown in Figure 16.3.

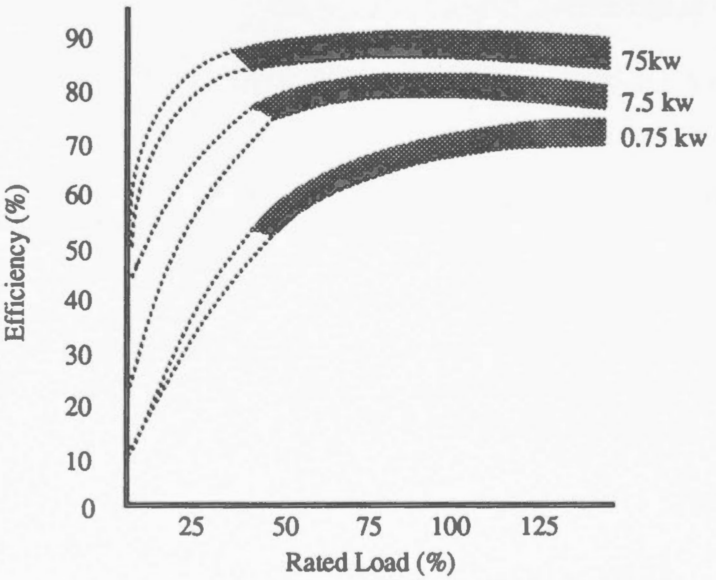


Figure 16.2 Typical variation of motor efficiency with load for three motor sizes.

Power kW	Full Load (rpm)	Power Factor		
		Full Load	Three Quarter Load	Half Load
2	1160	79.0	70.0	57.0
7	3515	86.0	83.0	74.0
	1740	86.0	82.0	72.0
	1160	80.5	74.5	61.5
33	3555	88.0	85.0	79.0
	1770	83.0	79.0	70.0
75	3560	91.5	90.5	90.5
	1780	85.5	83.5	76.5

Figure 16.3 Typical variation of motor efficiency with load for three motor sizes.

Opportunities for energy conservation in motors are varied and can be considered in the context of those parameters affecting motor performance. Examples are given below and additional information on these and other motor related EMOs are given at the end of the section.

* **Motor Size** Motors can be correctly sized to match the loads they are expected to drive. This normally means reducing the motor frame size and is generally only relevant when the size of the driven equipment is reduced. Significant size reductions are however required to make this worthwhile unless savings can be justified on the basis of power factor savings. Sometimes motors need to be oversized to provide sufficient torque to overcome inertia of large equipment (e.g. large diameter fans) and care must be taken in replacing motors.

Large numbers of small motor driven equipment, e.g. small exhaust fans, can in some instances be replaced by a common system utilising a single larger and more efficient motor. In such instances a more efficient motor is being traded against duct friction losses.

* **Motor Construction** High efficiency motors, typically having improved efficiency ratings of up to 10% and improved power factors of up to 8%, can be substituted for

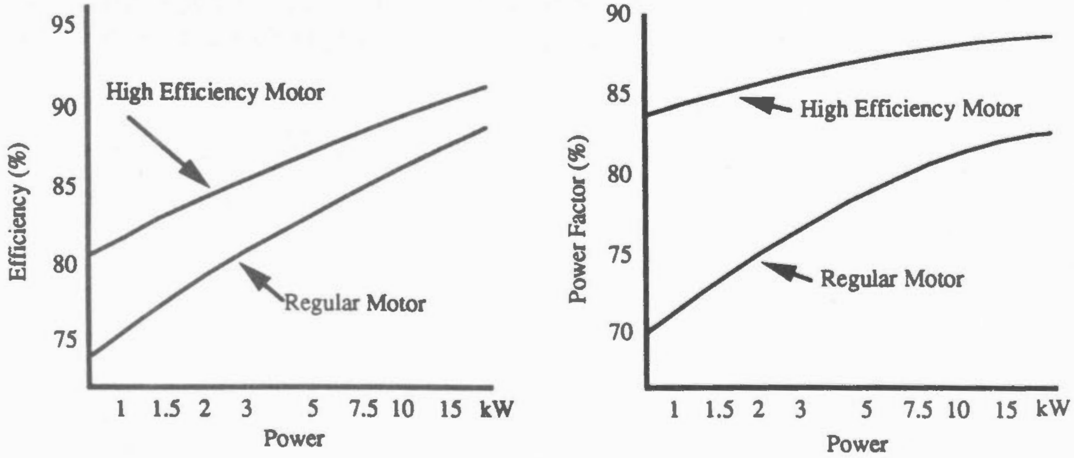


Figure 16.4 Typical efficiency and power factor differences for small size range of high and normal efficiency motors.

standard construction motors. Typical efficiency and power factor improvements are shown in Figure 16.4. Further discussion on High Efficiency Motors can be found in EMS No. 4 "Energy Efficient Motors".

- **Power Factor Correction** This is normally justifiable where motors are running at part load and at low power factor and where the utility rate structure includes a penalty for power factor. As power factor drops, the current will increase and although this will not increase the real power consumed by the motor it will increase the power losses in the feeder cables - power loss being proportional to the product of the current squared and the cable resistance. In reality this increase can be considered to be negligible.

- **Part Load Performance** Where the driven equipment does not have to meet a constant demand, opportunity can be exercized to provide speed control to the motor. This gives both a means of providing the desired reduced capacity as well as improving the part load performance of the motor. An example might be to provide volume control of a variable air volume fan by motor speed control as opposed to controlling volume by means of a throttling device in the air supply. Typical performance of speed control devices are given in Figures 16.5, 16.6 and 16.7.

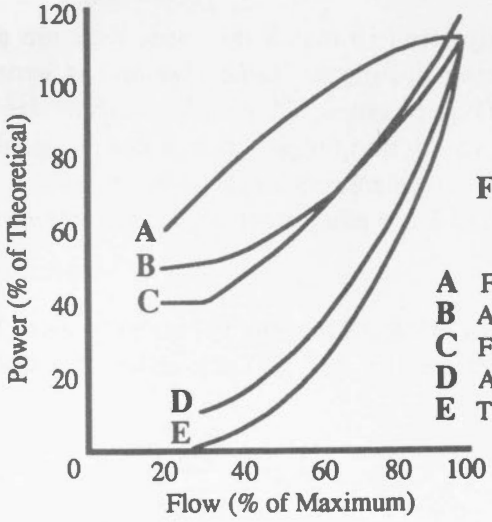


Fig. 16.5 Fan energy consumption

A Forward Curved Fans and Discharge Dampers
B Airfoil Fans/Variable Inlet Vanes
C Fan Control/Eddy Current Clutch
D Adjustable Frequency AC Motor Control
E Theoretical Fan Curve

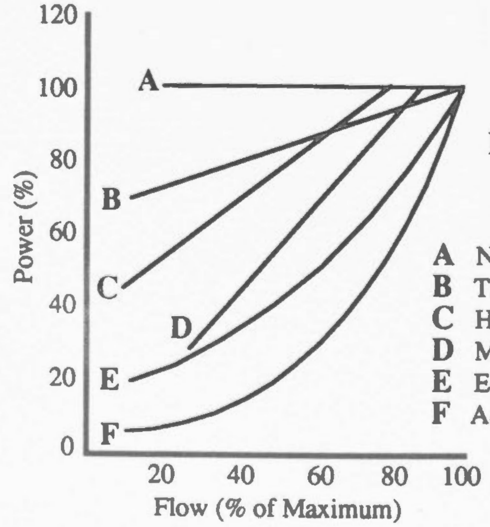


Fig. 16.6 Centrifugal pump

A No-Flow Control Valve
B Throttling Control Valve
C Hydrostatic Control
D Mechanical Control
E Eddy-Current Control
F Adjustable Frequency AC Motor Control

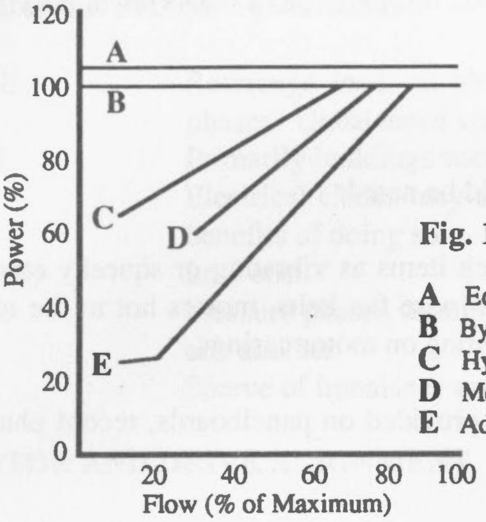


Fig. 16.7 Positive displacement pump

16.4 - Interactions

As previously mentioned, the interaction of other sub-systems with electrical systems is stronger than between any other two systems and the effect on electrical systems of EMOs carried out on, for instance, cooling and lighting systems should always be carefully evaluated.

In some situations saving energy might actually result in an increase in the utility cost. This may be the case for instance where demand costs for electric heating at the start of a setback period are higher than the cost of energy savings resulting from reduced heat losses over the setback period.

Further discussion on rate structures is given in section 19 of this manual.

16.5 - Survey

Before starting the actual survey it is essential to have gathered and reviewed historical electrical consumption and demand data and to have formulated a clear picture of the utility rate structure eg. what are the unit costs of electricity?, is there a demand charge levied? and if so what is the billing basis; similary are there charges for poor power factor? and if so what has been the historical power factor.

Electrical layout plans should also be reviewed, if available, as should the electrical distribution schematic.

Maintenance records should be collected and briefly reviewed (if available) and general trends, such as voltage regulation, overloads, frequent motor replacements, should be noted.

Conducting the audit starting at the main distribution panel and working along feeders to the sub-distribution panels, on to panelboards and finally to actual equipment is a good way to proceed with an inspection if an electrical distribution schematic is available. Mark any changes that have occured in the facility on the schematic. If the schematic is not available, and the auditor is not familiar with the installation, it is often better to start with the main panel and proceed on an area by area basis to ensure complete coverage of the facility. Whilst carrying out this exercise, it is worthwhile trying to sketch out the layout of the distribution system.

16.5.1 - Walk-through Audit Procedure

During the walk-through, the following items should be noted:

General condition of motors and drives. Note such items as vibrating or squeeky conditions, oil and grease leaks, painted over grease nipples, worn or loose fan belts, motors hot to the touch, obviously misaligned motors and drives and signs of overheating on motor casings.

Meter Readings If voltmeters and ammeters are provided on panelboards, record phase currents and voltages. Check if panels feel hot to touch.

Maximum Demand Limiters If charges are made for demand in the facility, check to see if any demand control is provided; note sizes and fuel type of any installed emergency generating equipment. Note any obvious loads that could be 'shed' at time of peak demand.

Power Factor Correction If charges are made for power factor (either directly or by kVA as opposed to kW demand changes) check to see if any power factor correction equipment has been installed.

Motor PF Correction Note if any motors have power factor controllers.

Motor Speed Controllers Note if any speed control devices are employed and look for obvious operations where speed control might prove practical.

High Efficiency Motors Note where high efficiency motors are installed.

16.6 - Annotated List of Energy Management Opportunities

16.6.1 - Housekeeping

EMO 16.1 MOTOR AND DRIVE MAINTENANCE

DESCRIPTION:	Carry out preventive maintenance procedures including: cleaning, especially around ventilation openings; lubrication, (do not overgrease); tightening of terminals; inspection of drives for signs of wear and belt tension.
APPLICATION:	All motors.
SIDE BENEFITS:	Greater reliability, longer life.
INTERACTIONS:	See also EMO 16.3 (Motor and Motor Drive Alignment).
EVALUATION:	Should be part of scheduled maintenance.
COMMENTS:	Should reduce motor load.
REFERENCES:	CMHC, 1982; Dalrymple, 1984; Feldman, 1983; Tedrow, 1984.

EMO 16.2 BALANCE PHASE VOLTAGES

DESCRIPTION: Rearrange loads to obtain a balanced load and equal voltages on all 3 phases. Unbalanced voltages can affect motor efficiency.

APPLICATION: Primarily buildings with large motor loads.

CAUTIONS: Electrical Codes may demand that loads be balanced irrespective of cost benefits of doing so.

COST FACTORS: Low cost.

EVALUATION: Measure phases voltages. Rebalance if voltages differ by more than 1% of one another.

COMMENTS: Source of imbalance could result from building load or from the utility.

EMO 16.3 MOTOR AND DRIVE ALIGNMENT

DESCRIPTION: Align motor and motor drive.

APPLICATION: Belt driven and close coupled equipment.

SIDE BENEFITS: Longer bearing and belt life.

EVALUATION: Check alignment as part of regular maintenance program, correct misalignment as required; no further evaluation required.

COMMENTS: Should reduce motor load.

REFERENCES: CMHC, 1982.

EMO 16.4 REDUCE ELEVATOR AND ESCALATOR USE

DESCRIPTION: Convince people to make less use of elevators and escalators.

COMMENTS: Escalators must have a switch-off feature if energy is to be saved.

REFERENCES: Dubin, 1976.

16.6.2 - Low Cost

EMO 16.5 LOAD DEMAND CONTROL

DESCRIPTION: Provide means of reducing peak demand in a building by either turning off non-essential loads over periods of peak demand or by installing storage systems to shift demands of electric heating and cooling systems or rescheduling activities and processes to avoid peak demand periods.

APPLICATION: Buildings in which electricity rate structure includes maximum demand or time of day charges.

CAUTIONS: Be careful not to remove essential loads or create undesirable conditions. Cycling of motors can affect life expectancy (Berutti, 1984).

COST FACTORS: Where load is predictable and non-essential, equipment can be disconnected at time(s) of peak, a simple time clock and maximum demand alarm can prove most effective. Stand alone load demand monitor and load shedding system can be used where loads are not predictable. Also, most energy management systems (EMS) have facility for load monitoring and shedding and load demand control should be considered where an EMS system is being considered.

INTERACTIONS:	See corresponding EMO under Other Categories, particularly Energy Management Systems. Note that improving power factor (EMO 16.9) can reduce kVA demand. See also EMO 16.7 (peak shaving using on site generation).
EVALUATION:	Potential savings generally increase with lower Load Factors and large Secondary Loads (i.e. loads that can be switched off at times of peak loads).
REFERENCES:	NECA, 1975; Spethmann, 1981; Berutti, 1984. EMS No. 19. Thermal Storage; EMS No. 3, Electrical.

EMO 16.6 CORRECT MATCHING OF DRIVEN LOAD AND MOTOR

DESCRIPTION:	Replace motors that are significantly oversized with units closer matching the driven load.
APPLICATION:	Motor driven equipment utilising standard motor drives.
CAUTIONS:	Ensure smaller motors have sufficient torque to accelerate the piece of equipment being driven. This can be a problem with large fans.
COST FACTORS:	Most potential benefit where driven loads are a fraction(less than one half) of motor size, - and/or where rate structure includes penalty for poor power factor. In carrying out significant retrofitting in large buildings with many different motors the possibility of switching motors offers major cost advantages over motor replacement.
INTERACTIONS:	Where an oversized motor is required to provide sufficient torque, consider the installation of a power factor controller (EMO 16.8), replace the motor to a high efficiency type (EMO16.11) to improve part load performance, or alternatively consider power factor correction (EMO 16.9) although this last measure will not improve efficiency.

EMO 16.7 PEAK SHAVING USING ON SITE GENERATION

DESCRIPTION:	Reduce the maximum demand of a system by supplying part of the required load during the time(s) of peak demand from an on site fuel driven generator(s).
APPLICATION:	Buildings in which electricity rate structure includes demand component and primarily buildings with existing emergency generation equipment.
SIDE BENEFITS:	Emergency generating equipment needs to be "exercized" regularly to ensure that it will start when required.
COST FACTORS:	The installation of generating equipment solely for peak shaving purposes is generally not economically justifiable but the use of existing emergency generation equipment may be very cost effective. Those parts of the electrical installation connected to the emergency power source can readily be switched to the emergency generator at times of peak demand.
INTERACTIONS:	Consider in parallel with EMO 16.5 (Load demand control).
EVALUATION:	Compare additional cost of site generated electricity (higher kilowatt hour cost and depreciation of emergency generating equipment) against utility demand savings. Some estimate of the total time that the emergency generating equipment must run is required.

REFERENCES: Choi, 1982; PME, 1984 EMS No. 3, Electrical.

EMO 16.8 POWER FACTOR CONTROLLERS

DESCRIPTION: Install power factor controller (PFC) to electric motors. These devices differ from simple capacitors that can be installed for the purpose of power factor correction, in that they improve the part load efficiency of motors.

APPLICATION: Primarily any motor that is lightly loaded, less than 50%, and especially those instances where the motor idles between duty cycles, e.g. compressors, (where motors run idle once pressure is reduced) hoists, elevators and escalators.

SIDE BENEFITS: For new installations or replacement motor starters, PFC function can be economically combined within solid state motor starter.

CAUTIONS: These are relatively new devices and should be selected with care, many early devices proved to be unsatisfactory.

INTERACTIONS: Alternative to the installation of high efficiency motors (EMO16.11) matching of motor and driven load (EMO 16.6) and power factor correction (EMO 16.9).

REFERENCES: Freund, 1981.

16.6.3 - Retrofit

EMO 16.9 POWER FACTOR CORRECTION

DESCRIPTION: Install power factor (PF) correction equipment (capacitors, synchronous motors or synchronous condensers) at individual equipment with poor power factor or in groups or banks to collectively correct poor power factor. For most installations the installation of capacitors will be the most suitable form of correction device.

APPLICATION: Primarily in those situations with low power factor and where the rate structure penalizes poor power factor. Typically buildings with transformers and motors, particularly where the motor load is a significant part of the total load and the motors are lightly loaded, can be expected to have low power factors.

SIDE BENEFITS: Small savings in energy losses in the electrical distribution system, better voltage regulation; lower currents permitting additional load to be added to the system (if required). This last side benefit is only realized if power factor correction is made at the source of poor power factor since the capacitor only affects the electrical circuit to the supply (not load) side of the electrical distribution system.

CAUTIONS: For grouped capacitors, amount of power factor correction may need to be varied if system power factor varies to prevent over-compensation of power factor which can create leading but equally costly power factors.

COST FACTORS: Relatively high cost item - Capacitors can take up valuable floor space and require ventilation. Above about 7 kW (10 hp) it is normally cheaper to install the PF capacitor directly at the motor. For a larger number of low power motors group correction becomes more attractive. Per unit kvar cost is normally lower at higher rated kvar and at higher voltages.

INTERACTIONS: Power factor can also be improved with high efficiency motor upgrade (EMO 16.11), correct matching of motor and drive load (EMO 16.6) and installing a power factor controller, (EMO 16.8).

EVALUATION: Most potential at low power factor since a capacitor added at low power factor will improve the power factor by a greater amount than the same capacitor added at a higher power factor; e.g. improvement of PF from 0.6 to 0.9 requires 0.85 kvar/kW of load whilst to raise PF from 0.7 to 1.0, the same increase, requires 1.02 kvar/kW. A knowledge of the type of electrical equipment would permit calculation but site measurement is invariably cheaper and more reliable.

COMMENTS: Check Wiring Regulations for requirements concerning the installation of capacitors and synchronous motors/condensers.

REFERENCES: Freeborn, 1980; Bell and Hester, 1980 EMS No. 3, Electrical.

EMO 16.10 MOTOR SPEED CONTROL

DESCRIPTION: Provide speed control for motor. Speed control may be achieved by either controlling motor speed directly or through variable speed drives.

APPLICATION: Those instances where the driven load need not be a constant load. Typical applications include variable air volume fans and variable speed pumping.

SIDE BENEFITS: Increased motor and driven equipment life, low noise levels.

COST FACTORS: Usually a relatively high cost item, desirability of the retrofit improves with the variability of the driven load.

INTERACTIONS: See those EMOs in other categories requiring variable speed drives.

EVALUATION: Refer to EMOs listed above to determine the potential for speed control.

REFERENCES: ECM, 1983.

EMO 16.11 HIGH EFFICIENCY MOTORS

DESCRIPTION: Replace "standard" motors with "high efficiency type".

APPLICATION: Motor driven equipment utilising standard motor drives.

SIDE BENEFITS: Quieter operation, longer life, greater stall capacity.

COST FACTORS: Most potential when motor nearing the end of its useful life or is showing signs of deterioration and/or where motor runs continuously or for long hours. Additional cost advantage if tariff includes penalty for poor power factor.

INTERACTIONS: Consider when existing motor is oversized for driven load.

REFERENCES: ECM, 1984; Dautovich, 1980, EMS No. 4, Energy Efficient Motors.

17.0 - HEATING, VENTILATING AND AIR CONDITIONING

17.1 - Introduction

With the exception of boilers, steam systems, and refrigeration equipment which have been previously described in Sections 9, 11 and 13, this section examines systems and equipment that provide and regulate heating, cooling and ventilation within a building or space.

For the sake of convenience, since the subject matter is both extensive and varied, the section is broken down into a discussion of four sub-systems namely :

* Environmental Control Systems
* Pipework Systems
* Ductwork Systems
* Heat Pumps

17.2 - Fundamentals

Before proceeding to modify HVAC systems, it is important to remember that HVAC systems are provided to produce a comfortable environment in which to work, reside or socialize. A basic understanding of the factors that influence environmental comfort and how these factors can be manipulated to advantage is necessary both to maximize savings and to avoid or minimize occupant dissatisfaction.

17.2.1 - Environmental Quality

Thermal comfort is an expression of the thermal sensation of the interaction between the body and the environment. The heat balance of this interaction will depend on a combination of six major parameters :

* air temperature
* mean radiant temperature
* air velocity
* humidity
* activity level
* clothing thermal resistance

With the exception of activity level, these factors can be manipulated to minimize energy consumption, for example :

* Temperature set points can be varied between winter and summer; lighter summer dress allows higher temperatures to be maintained in summer thereby minimizing air conditioning load. Whilst long term and predictable space temperature variations can be compensated for by adjusting dress, short term variations (hour to hour or day to day) or variations between adjacent spaces often cannot, and such variation of air temperature should be avoided.
* Increasing the mean radiant temperature in a space will provide the same thermal comfort with a lower air temperature. The mean radiant temperature can be

increased by improving the building envelope (higher U values, smaller and better windows) or by utilising radiant heating systems. In heavy buildings, cold surfaces following night set back can often create an uncomfortably low radiant temperature adversely affecting thermal comfort.

* Low humidity levels increase evaporative losses from the skin, thereby requiring generally higher air temperatures to maintain thermal comfort. Higher humidities are therefore desirable in the winter whilst lower ones are desirable in summer. The energy required to control humidity must, however, be balanced against any possible benefit from a lower air temperature. Humidity should not be allowed to vary beyond normally accepted ranges. Low humidities tend to increase the generation of static electricity, high humidity can have an adverse effect on envelope deterioration (condensation spoiling and mould growth).

* Air velocities should be carefully controlled within the space to avoid occupants being subjected to draughts, particularly cold draughts. Sources of adverse air velocities include down draughts from large areas of glazing; infiltration; and improperly designed room air diffusion systems. However higher air velocities can be beneficial during the summer season to provide comfort at higher air temperatures but such systems need to be carefully designed to avoid occupants being subjected to the discomfort.

17.2.2 - Air Quality

Significant variations in concentration and make-up of the ambient air will affect comfort (e.g. bad smells) and health. Substances that are not present in normal, clean air are called air contaminants and may be particulate or gaseous; organic or inorganic; visible or invisible; submicroscopic, microscopic or macroscopic; toxic or harmless.Air quality is a qualitative term describing the state and composition of ambient air.

Air quality will generally depend on the production, rate and type of contaminants and on the removal rate of contaminants. It should, however, be noted that for some contaminants contained in the building fabric or the supply air, the production rate may be proportional to the removal rate. In this case contaminants cannot readily be removed from the air by increasing the ventilation rate. A fuller discussion of air quality is provided in ASHRAE Standard 62-1981.

Air quality is a particularly important aspect that must not be overlooked by the energy auditor; indeed much of the negative reaction to energy management programs has been a direct result of ignoring this most important of environmental quality concerns.

In dealing with conventional spaces such as offices, guidelines published by such bodies as ASHRAE should be followed. In industrial situations with more specific ventilation problems, production rates of contaminants should be studied prior to changing ventilation systems. Contaminants should be treated at source by eliminating the cause. If this is not possible, removal of contaminants should start as close to the source as possible by introducing point exhausts to avoid excessive ventilation of entire buildings.

If contamination or occupancy is intermittent, ventilation systems can operate intermittently. General ventilation should be adjusted according to the needs of individual rooms. A ventilation system should first try to minimize the time a contaminant spends in a building rather than trying to dilute it.

17.3 - Energy Losses

To minimize energy usage with an HVAC system, it is necessary :

- to produce heating and cooling fluids as efficiently as possible,
- to distribute these heating and cooling fluids around the building with as little loss of energy as possible,
- to utilize this heating and cooling in the spaces as efficiently as possible and
- to avoid over-heating, over-cooling or over-ventilating the spaces.

The last two items are discussed below under the heading Environmental Regulation Systems; the remaining items are discussed in:

- Section 9.0 (Boilers)
- Section 13 (Process and Air Conditioning Refrigeration)
- Section 17.3.2 (Pipework Systems)
- Section 17.3.3 (Ductwork Systems)
- Section 17.3.4 (Heat Pumps)

17.3.1 - Environmental Regulation Systems

Two principal groups of factors affect energy use of environmental control systems; one is related to the quality of the environment being provided, the other to the efficiency with which the systems maintain this environment. Typical energy flows are illustrated in Fig. 17.1.

17.3.1.1 - Control Of The Space Environment

For greatest efficiency of energy usage, it is desirable to tailor the standard of the environment to that of the building occupancy. Such tailoring of conditions is normally achieved through system scheduling control. Control can be manual or automatic and based on time schedules, occupancy density or measured internal environmental conditions. Examples of simple time scheduling opportunities include:

- Shutting off ventilation and humidification equipment when the building is unoccupied, and
- Setback and setup where the space temperature setpoint during unoccupied periods is reduced in the heating season and increased in the cooling season.

Measures involving space monitoring include varying the ventilation rate based on measured carbon dioxide levels, humidistat control of swimming pool hall ventilation rate and carbon monoxide control of parking garage ventilation. There are also some compound control strategies such as optimal start of heating and cooling plant relying on two or more inputs. In the case of optimal start, in which outside temperature and occupancy period are considered, the start of the heating or cooling plant is delayed until there is just sufficient time to bring the space to comfort conditions. This means that as outside conditions become less extreme, the preconditioning period is shortened.

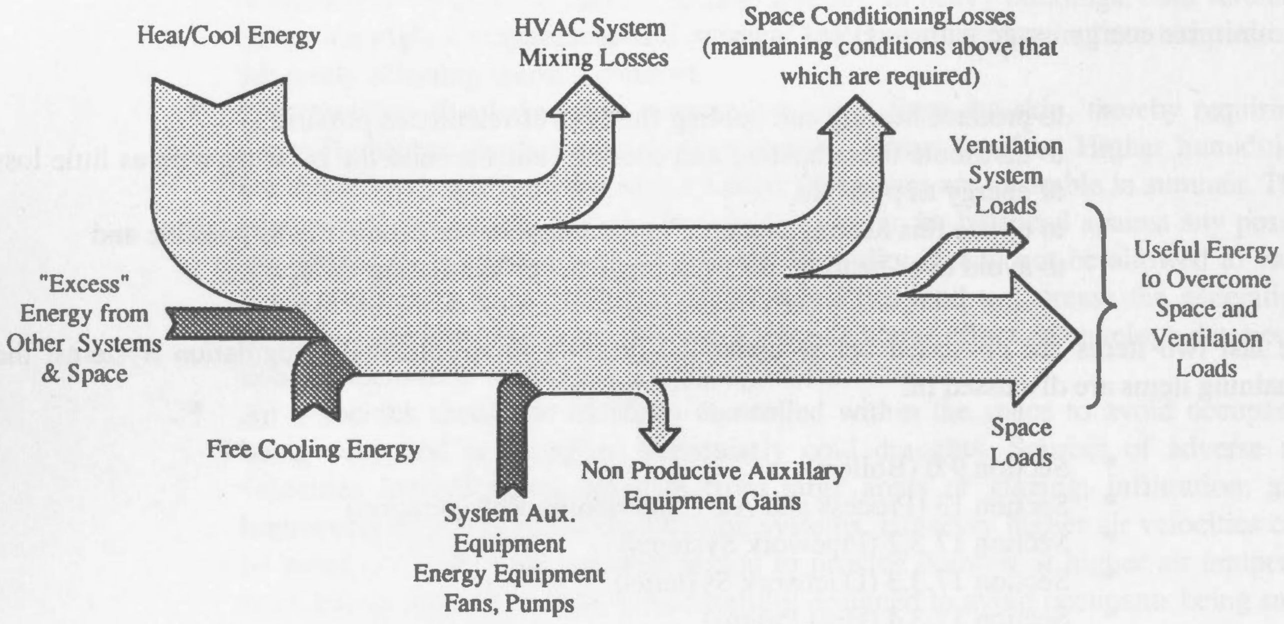


Fig. 17.1 Examples of energy flows in an environmental control system.

In some cases it may not be possible to obtain the desired conditions with the installed environmental systems. Besides undersized equipment which cannot meet loads, system design often limits the ability to provide the required conditions in all zones at all times. Often areas of a building are overheated or overcooled in order to satisfy the requirements of some other areas resulting in energy wastage. An illustration of this is where occupants respond to overheating by opening windows. The most common cause of such problems is poor zoning and the use of open loop, as opposed to closed loop or feedback control strategies.

In open loop control systems there is no information feedback to the heating or cooling system controller from the space being conditioned. Thus it is not possible to directly correct space conditions deviating from those desired. With such systems control, heating or cooling to the space is controlled according to some measurement value external to the conditioned space; typically this is outside temperature although some systems allow compensation for solar radiation and wind speed.

Open loop control systems can be replaced by closed loop systems for improved control and generally improved efficiency. In a closed loop system the heat supply to the space is controlled by a device installed in the space.

Zoning may be improved in a variety of ways; by simple measures such as correcting balancing deficiencies; through the installation of additional terminal control devices; or by complete system replacement.

Losses also occur as a result of inadequacies in the system or component response. Some examples of such control losses are :

- losses due to the building thermal inertia during temperature setback,
- losses due to the building thermal inertia during the start-up after a temperature setback, and
- losses due to heat exchange between spaces having different temperature setpoints.

17.3.1.2 - System and Equipment Inefficiencies

Major system and equipment inefficiencies and opportunities can be broken down into the following categories :

- use of "free" cooling,
- minimisation of HVAC system "mixing losses",
- re-use strategies,
- equipment related opportunities, and
- minimisation of auxiliary equipment, consumption (primarily transportation energy).

Free Cooling: Evaporative cooling and cooling by outdoor air can be considered as **free cooling** sources. Outdoor air for cooling is almost universally utilisable and in most cases can provide an economic benefit while evaporative cooling is particularly attractive in those locations with large wet bulb depressions (i.e. where the outdoor wet bulb temperature is considerably lower than the coincident dry bulb value).

Cooling by outdoor air can be achieved through the sensible use of operable windows, through separate ventilation systems or by the integration of an air economizer into the HVAC system. An air economizer in addition to providing a minimum amount of air for ventilation purposes, allows outside air to be used in place of mechanically cooled air when outside air conditions are appropriate. A simple conventional temperature controlled system is shown in Fig. 17.2. Such a system has 4 basic stages.

- Heating: where the outside air is at a minimum to satisfy ventilation requirements.
- The free cooling stage in which the control dampers are modulated to maintain the desired supply air temperature.
- Mechanical cooling when outside air is still of a lower enthalpy than space air and is consequently supplied to the space in preference to recirculating large percentages of space air. The air, however, does require mechanical cooling to maintain design space conditioning.
- Mechanical cooling when the outside air volume is reduced to a minimum (to satisfy ventilation requirements) at an outdoor temperature representative of the condition at which the heat content of the outdoor air is greater than that of the space air.

The temperature T2 (see Fig. 17.2) selected for returning to minimum outside air is normally set a few degrees below the estimated return air temperature to make allowances for the possible higher enthalpy of the (more moist) outside air. This temperature difference should be selected based on design outside conditions and can be expected to be different for different types of climate. To avoid this somewhat arbitrary selection and avoid the problem of non-coincident relationships between dry bulb and enthalphy, enthalphy sensors can be used in place of temperature sensors.

However, temperature-controlled systems are still commonly used. Night-time ventilation using cool outside air can also be integrated into combined ventilation and mechanical cooling systems where it can be of benefit.

Mixing losses: Mixing losses are common in practically all types of HVAC systems and their elimination or minimisation provides opportunities for energy savings. Mixing losses occur when a hot fluid mixes with a cold one within the system. Often mixing losses are an inherent part of the design, for example in reheat systems; or result from component deterioration (e.g. air leakage through dampers in double duct system mixing boxes). A terminal reheat is an example of engineered mixing losses in which the central system supply air is cooled down sufficiently to handle the most severe zone cooling load at design conditions; at all other times and from zone to zone, this air is reheated to prevent overcooling.

Mixing losses can be minimized by sequencing heating, cooling and latent heat transfer processes; by resetting system setpoints according to zone demands; and by minimizing leakage between hot and cold fluids by maintaining valves and dampers.

The basic philosophy for sequential operation is that for any fluid undergoing a process of heating, cooling or mixing or for any air stream undergoing humidification or dehumidification, the various stages should be sequenced so that energy in one stage is not wasted thereby offsetting economies achieved in a previous stage. Deadband thermostats can be considered a form of sequencing which minimizes mixing losses either occurring in the occupied space as a result of cycling between heating and cooling; or between adjacent spaces, one of which requires cooling while the other requires heating. In theory sequencing may be obtainable using separate controllers but in practice wide control throttling ranges and loss of calibration (sensor drift) may make such a solution unworkable. Sequence control is in most cases preferable under the action of a single controller and should be considered along with reset strategies.

In reheat-type systems, sequencing alone cannot achieve low mixing losses and "reset strategies" are appropriate, otherwise the system must be changed, for example, to a variable air volume system which is substantially mixing loss free. Reset strategies are possible in some form in most systems with the exception of single zone, fan coil and unit ventilator systems. The philosphy behind reset control is to reset central system deck temperature(s) based on the actual zone demand. For example, in the terminal reheat system, which is a good application for this kind of control, the deck temperature is reset as high as possible such that the zone with the greatest cooling load is satisfied without the addition of any reheat.

The type of reset control should not be confused with the resetting of heating fluid with variation of outside air temperature which is normally provided to give closer space temperature control.

Re-use strategies: Re-use strategies involve the collection and re-use of surplus heat and cooling sources within or being discharged from the building. Re-use within the building requires the redistribution of surplus heat through indirect heat recovery systems such as heat recovery chillers and water loop heat pump systems, or through simpler direct approaches such as the transfer of air from one space to another. Examples of simpler systems include destratification devices moving warm air from the upper to lower levels of a space or fans moving warm air from an attached sunspace to the occupied area. Direct mixing strategies involving common return air from zones with different load profiles, also offer limited benefits. Depending on the building thermal characteristics, thermal mixing can offer

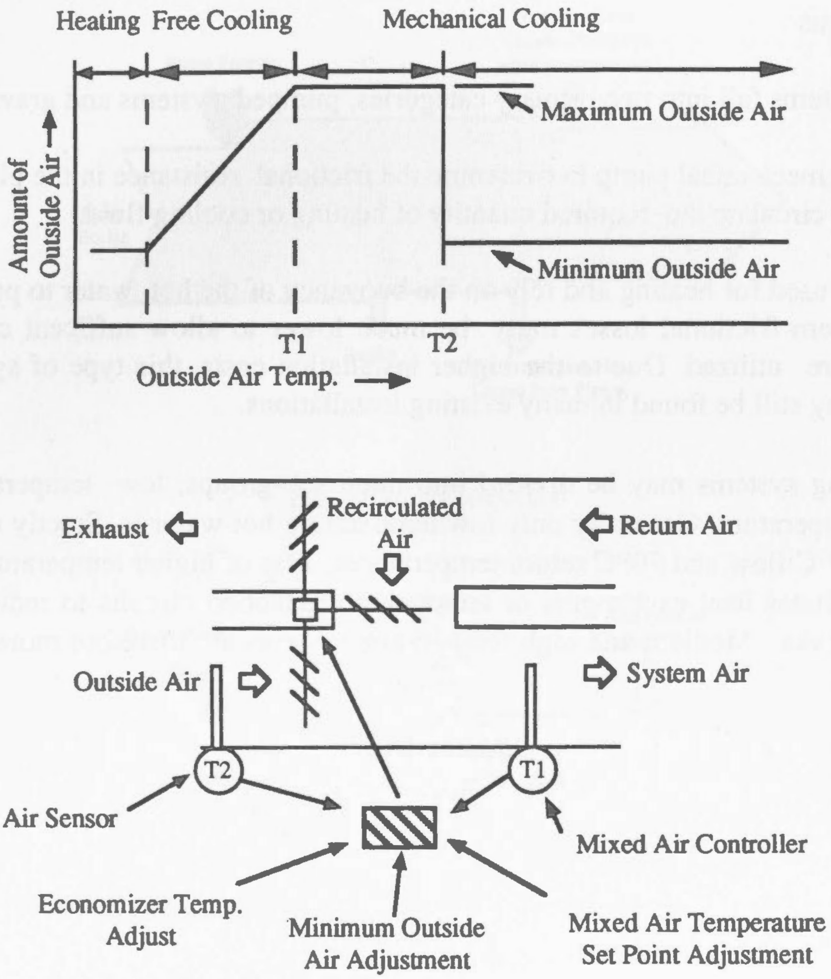


Fig. 17.2 Temperature controlled economizer cycle.

significant savings (Jones, 1985).

Re-use of heat being discharged from the space involves either the direct reuse of air to heat or cool a secondary space with lesser environmental requirements, such as a parking garage; the re-use of the air in the space after filtering, e.g. using activated carbon; or the indirect use of the air via heat transfer devices e.g. the use of air to air heat exchangers, both with and without indirect evaporative cooling, and the discharging of cool inside air over refrigeration condensing equipment.

With all these re-use strategies, the load profiles of the potential sources and sinks of the "surplus heat" should be considered with a view to establishing the need or desirability of providing thermal storage.

Equipment Related Opportunities: Energy management opportunities not classifiable in the above groups are primarily **equipment related opportunities**, that is, energy savings are brought about by substituting existing equipment with new, thermodynamically more efficient units. Examples of such system changes include the use of direct gas fired heaters in place of indirect; replacing VAV bypass boxes with throttle type to reduce fan energy consumption; and using mechanical dehumidification for humidity control in swimming pool hall ventilation systems.

17.3.2 - Pipework Systems

Pipework distribution systems fall into two primary categories; pumped systems and gravity systems.

Pumped systems utilize a mechanical pump to overcome the frictional resistance in the pipework and to provide sufficient flow to circulate the required quantity of heating or cooling fluid.

Gravity systems are only used for heating and rely on the buoyancy of the hot water to provide circulation. In this type of system frictional losses must be much lower to allow sufficent circulation and hence larger pipe sizes are utilized. Due to the higher installation costs, this type of system is used infrequently today but may still be found in many existing installations.

Pumped hot water heating systems may be divided into three sub-groups; low temperature, medium temperature and high temperature. Generally only low temperature hot water is directly used for space heating normally with 80°C flow and 70°C return temperatures. Use of higher temperature distribution systems normally necessitates heat exchangers or temperature reduction circuits to reduce the risk of scalding or flash steam leaks. Medium and high temperature systems are therefore more often used in 'district heating' schemes.

Energy losses in pipework systems occur from pumping losses; losses caused by leaks; and from heat losses and gains from and to the pipework system. These losses are illustrated in Fig. 17.3.

High temperature differentials between fluid and ambient air are common particularly in heating systems. Piping system heat gains and losses are often high enough to warrant their consideration on an equal footing with pumping costs.

Pumping losses in water systems pumping energy can often be significant. Pumping power consumption is given by $\Delta p * q_v * t/(N_f * N_t * N_m)$

where Δp = pipework pressure drop (N/m^2)
q_v = volumetric flow rate (m^3 /s)
$N_f \, N_t \, N_m$ = efficiency of pump, transmission and motor, respectively
t = time of operation (seconds)

The auditor should look at each parameter in the equation for possible energy savings.

Note that for heating systems, part of the pump energy often contributes to the heating of the building although this is counter productive if it causes overheating and reduces the level of control available. Energy will be wasted all the time that the pump is operating when heating is not required. Also, pump transmission and motor losses not transferred to the pipework system would normally be considered a complete energy loss. For chilled water systems, all the pump energy can be considered to be an energy loss.

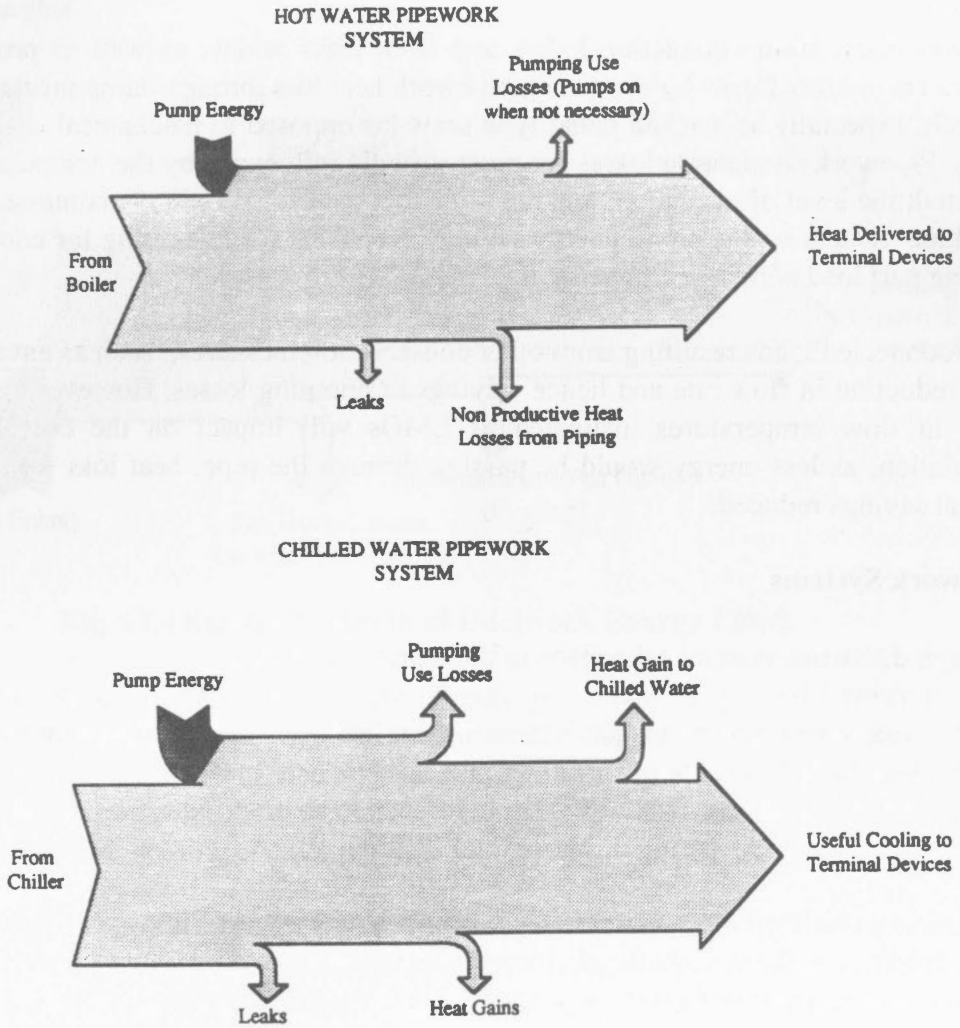


Figure 17.3 Energy flows in pipework systems.

Pumping energy losses can be reduced by:

Reducing Pressure Losses: Any reduction in pressure drop in the circuit will create an increase in the flow rate and hence the amount of power consumed. This is not to say reducing pipe losses should not be looked at, merely that if ways to reduce pressure drops are found then the pump speed should be lowered, the pump impeller reduced in size, or a smaller pump installed. It is desirable to look primarily at the pipework index run; that is the part of the system which has the highest pressure drop, often the longest run.

Reducing Flow Rate: Reducing flow rate is often a particularly attractive EMO since systems are invariably oversized, especially where efforts to reduce space loads have been implemented. Flow rate may be reduced even where the system is not oversized if a higher than design temperature drop can be accepted. Flow rate reductions could be considered using multi-stage pumping or variable speed drives which can reduce flow-rates at part load conditions. Throttling by adding resistance to the system is an inexpensive but less efficient measure.

Reducing Operating Hours: This is a particularly attractive and often cost effective action and efforts should be directed towards scheduling operations with the need for heating or cooling.

Pipework losses occur from conduction losses and from leaks which, as well as producing obvious direct losses, cause indirect losses by increasing pipework heat loss through damp insulation. Leakage at pump shaft seals, especially at packed gland type seals (as opposed to mechanical seals) is a common source of loss. Pipework conduction losses are most strongly influenced by the temperature of the fluid being transported; the level of insulation; and the time that the heated fluid is maintained hot - reducing any of these three factors will result in energy savings. Reducing (or increasing for cooling) flow temperatures during part load conditions can effectively reduce heat losses.

Reductions in connected loads resulting from other conservation measures, such as envelope insulation, may permit a reduction in flow rate and hence savings in pumping losses. However, reduced flow rate or reductions in flow temperatures instigated as EMOs will impact on the cost effectiveness of pipework insulation; as less energy would be passing through the pipe, heat loss would be lower and hence, potential savings reduced.

17.3.3 - Ductwork Systems

Energy losses in ductwork systems take place in three principal areas:

- loss of heat energy by conduction and air leakage from the ductwork into the building.
- energy lost in pushing air through the system, and
- loss incurred as a result of either cold outside air entering the ductwork system or warm air leaving the ductwork system and building.

The first loss can be minimized by reducing air leakage and improving ductwork insulation; the second by improving fresh air and exhaust damper sealing; but generally far greater benefits are possible by looking for ways to minimize the third type of loss, that of fan energy.

Fan energy consumption equals $\Delta P^{*}.q_v{}^{*}\ t/(N_f{}^{*}\ N_t{}^{*} N_m)$

where Δp = ductwork pressure drop (n/m^2)
q_v = volumetric flow rate(m^3/s)

$(N_f N_t N_m)$ = efficiency of fan, transmission and motor, respectively
t = operating time (seconds)

These losses are shown schematically in Fig. 17.4. The auditor should look to each parameter in the equation for possible energy savings.

"Fanning" energy losses can be minimized by:

Reducing air flow rates: Overall air volume flow rate reductions are possible where air conditioning or space heating loads are reduced, where room supply air temperature differentials can be increased, or where ventilation rates can be relaxed. Reductions in overall air flow may affect room air diffusion and will limit the amount of free cooling capacity. Increasing the room supply air temperature differentials (ie. the difference between the room air and the supply air) can create discomfort through draughts.

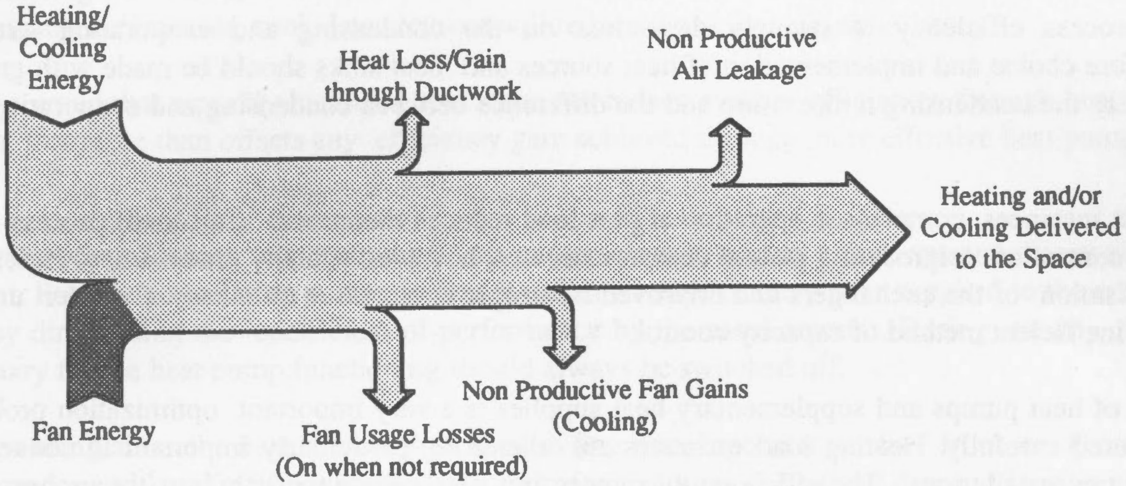


Fig. 17.4 Sankey Diagram of Ductwork Energy Flows

Air flow rates can be reduced by throttling the air supply, ie. increasing the ductwork resistance for moderate energy savings or by reducing fan speed for much improved performance.
Advantage can also be taken of reduced volume requirements at part loads by converting to a variable air volume HVAC or ventilation system. Variable volume changes also have the added advantage of reducing heating, cooling and dehumidification needs.

Reducing ductwork resistance: This may be achieved by identifying and correcting excessive pressure drops across components of the ductwork system. Particular attention should be paid to the index run (the run with the greatest pressure drop, often but not necessarily the longest run) since other runs will require throttling to maintain air balance. It is very important to remember, however, that reducing resistance alone will increase the flow rate and thereby the fan power and energy requirement. In the case of forward curved centrifugal fans this can seriously overload the fan motor. All reductions of ductwork resistance must be accompanied by a change of fan speed or a change of the fan itself for any benefit to be derived.

Reducing operating hours This is normally a particularly attractive strategy, more so than for pumps since total building fan horse power is normally much higher than that for pumps.

Improve fan and drive efficiency: More efficient fans can be considered but this is rarely a cost effective strategy unless the fan has to be replaced for other reasons. Reduction in fan power requirements may also permit savings in electrical demand or a smaller motor to be fitted. Generally, no benefits are derived from replacement unless the motor is substantially oversized. Caution must also be exercized not to reduce the motor size to such an extent that it fails to provide sufficient torque to accelerate the fan wheel.

17.3.4 -Heat Pumps

Heat pumps can operate according to a number of different refrigeration cycles and can be powered by different types of primary energy supplies and prime movers. The most common types in use are the electric motor driven vapor compression heat pumps and the heat powered absorption systems. Energy flows are illustrated in Figure 17.5.

The process efficiency is strongly dependent on the condensing and evaporating temperatures. Therefore choice and implementation of heat sources and heat sinks should be made with great care to minimize the condensing temperature and the difference between condensing and evaporating temperatures.

In most instances, compressor operation at part load reduces theoretical (full load) process efficiency. Speed control of reciprocating piston compressors can, however, actually render improvements by better utilisation of the exchangers and improved isentropic compressor efficiency. Cylinder unloading is a very inefficient method of capacity control.

Sizing of heat pumps and supplementary heat supplies is a very important optimization problem to be considered carefully. Heating load estimates are therefore, particularly important in connection with heat pump installations. The efficiency of motors and gearboxes directly affects the process efficiency and this should encourage use of high performance components.

Using solenoid valves and pump down operation will reduce cyclic losses by preventing the refrigerant charge transfer to the evaporator side during standby periods. If subcooling of the warm refrigerant condensate can be used to preheat incoming fresh air or cold tap water, the losses from adiabatic expansion can be reduced, thus improving the process efficiency.

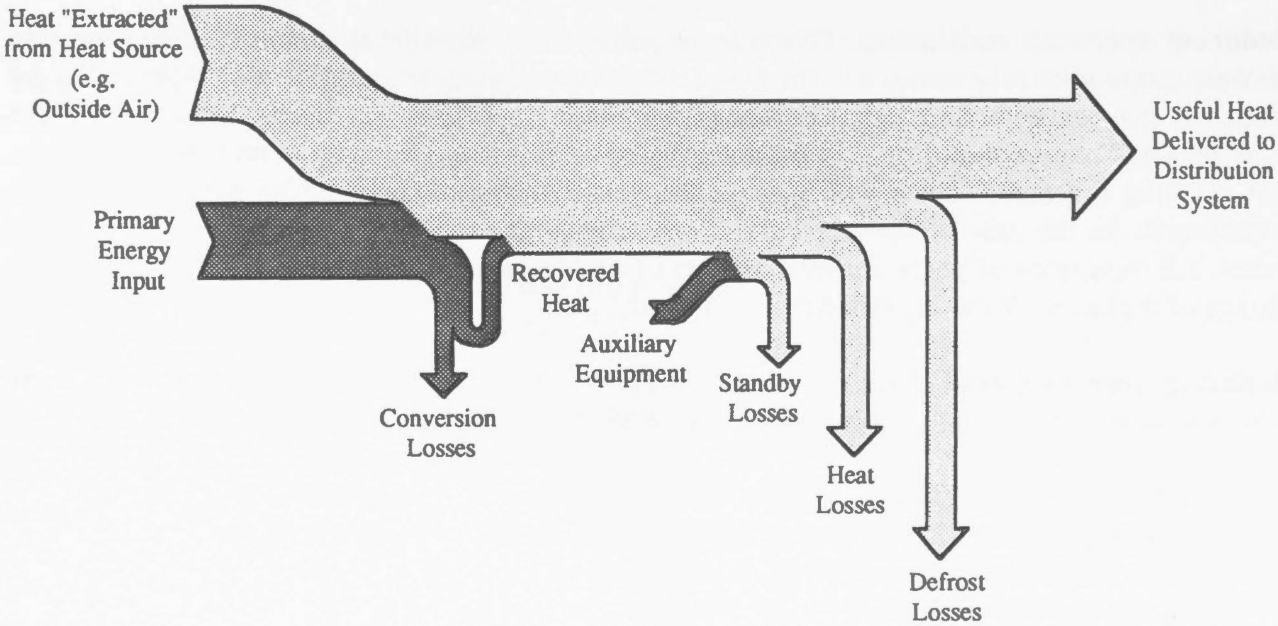


Figure 17.5 Heat pump energy flows.

Heat exchange with the surroundings (ambient losses) occurs in a similar fashion to the combustion boiler. Heat pumps differ, however, in that they have both hot and cold parts. Therefore they can lose heat not only to spaces not intended to be heated, but they can also remove heat from heated spaces.

In particular compressors and condensors placed outdoors are exposed to significant temperature differentials. Heat can also leak internally between the hot and cold parts of the heat pump. Air cabinets placed indoors can contribute to heat losses not only through heat exchange but even more through air leakage. Drawing warm air into air heated evaporators will increase the energy demand for the building and losing warm air from air cooled condensors will reduce the delivered useful heat.

It should be noted that a poorly insulated heat store can reduce system efficiency, through heat losses, to an extent that more than offsets any efficiency gain achieved through more effective heat pump operation.

Heat pump auxiliary devices such as pumps, fans and crank case heaters affect system efficiencies to a large extent. Power to circulating pumps or fans is often 10-20% of the power supplied to the compressor, thereby diminishing the coefficient of performance by the same amount. During standby, devices not necessary for the heat pump functioning should always be switched off.

Heat pumps using air as the heat source often need to free the evaporator surface from ice. Using optimized demand control and efficient methods of defrosting reduces the energy demand for this process. During periods of continuous operation it is particularly important to minimize the defrosting time, since no heat can normally be produced during defrosting periods.

17.4 - Interactions

The important interactions to consider between this group and other sub-systems are:

- Changes to loads either as a result of envelope or lighting changes which will influence HVAC systems operations. Reducing loads uniformly across a building, or zone, will result in the systems operating at part load. Given that part load operation may be operating at less than peak efficiency, HVAC part load operation should be reviewed following such load reductions for possible inefficiencies. Often system and equipment changes can provide additional savings. If load changes are not uniform zone control problems may result and re-balancing may be necessary. Reductions in loads should permit secondary savings in HVAC distribution by reducing air and water volumes.

- Improvements of Environmental Control Systems operation will likewise reduce the loads on boilers, chillers and air conditioning equipment and distribution systems. Part load operation of these systems should also be reviewed for additional savings following Environmental Controls System improvements.

- Shutting off systems, reducing ventilation rates of modifying controls may adversely affect thermal comfort and air quality.

- Scheduling of equipment will normally reduce electricity consumption and electrical demand but adverse effects are possible. Examples of adverse effects include set-back with electric heat systems which may increase demand charges and the overall cost of electricity; scheduling all equipment to start simultaneously may create undesirable power surges and voltage dips; vastly reduced loads on electric motors will reduce the power factor and power factor correction equipment may be necessary for maximum savings.

There are many other interactions associated with EMOs in this category and the reader is referred to the "INTERACTION" sub-headings for each individual EMO described in Section 17.6.

17.5 - Survey

Surveys of heating, ventilating and air conditioning systems can become very complex and lengthy undertakings. Walkthrough audit procedures are provided below separated into five areas.

- Environmental Control Systems
- Pipework Systems
- Ductwork Systems
- Chillers
- Heat Pumps

17.5.1 - Walk-through Audit Procedure - Environmental Control Systems

The auditing of environmental control systems involves both the audit of the actual space conditions and the equipment. Auditing of the space conditions is generally easier to carry out than auditing systems and equipment and often provides valuable clues to system deficiencies.

Auditing of equipment and systems involves the inspection of existing controls and systems and checking to see if energy is being wasted by one or more of the various mechanisms previously discussed. Difficulties are encountered, however, in that:

- What is documented as being the installed control system may not in fact be what is presently installed; site inspection is therefore recommended and should involvev-erification of control action.

- What is installed may work in theory but may not work in practice. To spot such difficulties often demands considerable experience and the use of specialist advice may be worthwhile for the inexperienced. Specific problems are raised in Section 17.6.

During the walk-through and during the walk-through planning stages, the following information should be collected.

Space Temperature Controls It is important to establish how interior temperatures are controlled; determine the location of control sensors and thermostats and identify which areas they control. Poor positioning of controls is a common cause of temperature regulation problems.

Heating and Cooling System Controls Examination of the actual heating and cooling equipment concialist advice should be sought. Measurement or recording of the controlled conditions (system temperatures) may be appropriate.

Time Control Matching of heating and cooling set point temperatures to the occupancy pattern of the facility often produces valuable energy management potential. In many cases a physical examination of time controls may be difficult due to inaccessibility. The installation of temperature recording instruments can avoid this problem. In addition, a recording thermometer provides evidence of control malfunction which may not be apparent from a physical inspection.

Space Temperatures Measurement of space temperatures should be undertaken using calibrated portable equipment (see Appendix E). Temperature measurements made during peak heating or cooling loads will indicate if adequate capacity exists. Occupants will seldom tolerate underheating and will often use supplementary heating. If local heaters are noted during a it is indicative that heating problems exist even if measured temperatures are satisfactory.

Open windows during the heating season are an indication of overheating problems.

Heating or cooling systems which adequately and efficiently maintain temperatures under peak conditions may often perform poorly under part load conditions; spring and fall are therefore ideal times to undertake walk-through audits.

Space Humidity This is only of interest (in energy terms) in buildings incorporating humidity control. Many 'air conditioned' buildings do not include humidity control and this should be established prior to the audit.

Heating Distribution Examine the zoning of heating distribution systems either by examining plant rooms or from drawings. Note the control type and location and the devices installed to regulate the heating system.

Space Heating Control Check controls for each zone and record set points and actual controlled temperatures. Determine performance of controls under peak and partial load conditions and throughout the working day. Note the types of thermostat and if time controls or setback controls are installed.

Space Cooling Control Examine the zoning of cooling systems, set point and maintained temperatures. Note where and when comfort problems exist. Note the type of control thermostat.

Mechanical Ventilation and Exhaust Systems Document the type of system installed, note the percentage fresh air in recirculating air systems. Washroom exhausts should be identified together with design or recorded volume flow rates (if available). The current operation for each system should be noted and reviewed against what is desirable for minimum energy consumption. The type of control should be checked and its operation verified.

Swimming Pool Halls Record the pool size (length x width), water temperature, air temperature and humidity.

Humidity Control Humidity control is an important factor in pool running costs. The type of humidity control (ventilation, dehumidification) should be recorded. It should be noted whether a pool cover is installed and being used.

Indoor Garages Indoor garages are normally mechanically ventilated to remove fumes. The method of control of these ventilation systems, along with air volumes should be determined. Note both exhaust and make up air systems.

High Spaces Heated areas such as warehouses or factories should be inspected to assess if heat stratification is a problem. The space height, type of heating system and internal temperature should be recorded. Note if destratification devices have been installed and are operating.

Induction Systems Where perimeter induction heating and cooling systems are installed, the nozzles should be examined for blockages and general condition. The primary air control system should also be inspected to see if the flow temperature is scheduled with the outside temperature.

Dual Duct, Multizone and Reheat Systems A audit of these types of air conditioning systems should include examination of controls to establish if load reset control is installed. A physical examination of air handling equipment should be undertaken to identify if individual coils are installed for zone recool and if stratification splitters are installed on dual duct or multizone systems.

Rooftop Packaged Air Handling Units Rooftop units should be examined to assess the condition of coils, filters, fan belts, casing insulation, seals/gaskets, access doors and covers. It should be recorded if the condensor is exposed to direct sunlight. Air passing through condensate traps should also be noted. It should be established if an economizer is installed on the unit. It may be necessary to contact equipment suppliers and quote the unit serial number to determine this.

Fume Hoods and Cabinets An examination of this equipment should establish whether a retrofit to multi-speed or variable speed operation is desirable. The method of supplying make-up air to the hood or room should be also recorded. The operating practices used with fume hoods can play a large part in energy usage. Establish if sashes are closed or switched to lower speed (or off) when not in use. Hoods may be left running only because chemicals are stored in the space.

17.5.2 - Walk-through Audit Procedure - Pipework Systems

Prior to proceeding with the audit, a review of available pipework drawings should be made; use the drawings to help plan the audit, identifing those systems and sub-systems that should be addressed separately. Whilst the drawings may not represent exactly what has been installed it is often easier to trace piping routes on drawings than on site where pipes may disappear into a wall or ceiling space and not emerge again for some distance. The following information should be collected.

General The function of the pipe, or system, should be classified for each (eg. chilled water supply, heating return). Where a problem or potential for upgrade is noted in the piping system, it is useful to record the size of the pipe at this location; this can be done under this general space or where the particular problem is identified, eg. under insulation if there is an insulation deficiency.

Fluid Leaks Actual leaks or signs of stained insulation, marks on floors, etc. should be recorded. Excessive use of chemicals for any water treatment equipment is indicative of leaks which may not be readily visible. Check around overflows, drain valves and pressure temperature relief valves of signs of leakage. Check leakage from pump seals, note that an occasional drip from packed glands is normal.

Insulation Record thickness, type and condition of insulation, be especially careful to note areas of wet insulation and establish whether it is caused by a pipework leak or by condensation on a cold pipe; note any areas of insulation suspected of containing asbestos. Wet insulation around valves and fittings is often a problem as these components are costly to insulate effectively. High jacket temperatures on aluminum jackets may indicate missing or wet insulation. Faults in underground external heating pipework may often be indicated in the winter by excessive or rapid snow melt, early development of plant growth or in summer by premature 'browning' of grass. Make a note of any factors contributing to unusual heat losses, eg. pipes installed in unheated areas.

Potential for Flow Reductions This would normally be determined during audits of the environmental control systems; a note should be made on the pipework walkthrough check list to remind the auditor where such reductions can be made.

Pump Motor Type and Loading If an audit of the electrical system has not been carried out, the size and condition of the motor, and whether or not it is a high efficiency type, should be recorded. Taking current measurements and comparing them with the motors full rated load current will permit the extent to which the motor is loaded to be established.

Condition of Pump Drives Check for wear and correct tensions on belts, for wear and misalignment of drives; listen or feel for excessive noise and vibration from the pump and motor bearings.

Air in System Check for air locks in pipework and terminals (usually indicated by cold sections). Check the type of expansion tank (open or sealed) and for its correct placement; look for evidence of system fluid releases through the temperature pressure relief valve.

Redundant Pipework Look for un-used sections of pipework and equipment that can be eliminated or simplified. Such piping should be removed or at least isolated from the remaining active pipework.

Pump Operating Schedule Record the current pump operating schedule, note whether automated or manual.

Potential for Zone Pumping Be on the look out for large pipework systems with a common pump in which there are loops of dissimilar resistance or loops that require heated or cooled fluid at different periods.

Potential for Variable Volume Pumping Record factors that favour the use of variable volume or staged pumping strategies, i.e., large systems, highly variable loads, and constant temperature variable flow control systems (eg. diverting or throttling as opposed to mixing valve control).

Balancing Problems If an audit of the environmental control systems has not already been undertaken, temperatures within separate areas should be measured; lack of consistency indicates poor balancing or poor zoning. Complaints from occupants, either solicited during the audit or previously received should be recorded.

17.5.3 - Walk-through Audit Procedure - Ductwork Systems

As with pipework, a review of the ductwork drawings, if available, should preceed the audit. Use the drawings to help plan the audit, identifing those systems and sub-systems that should be addressed separately. The following items should be addressed.

General For each area record the function of the duct or system (eg. "heating", "exhaust", "supply" or "outside air"). Where a particular problem or potential for upgrade is noted in the ductwork system, it is useful to record the size of the ductwork or fitting at the location. This can be done in this general space or where the particular problem is identified.

Dirty Filters Check all filters to see if they require changing; where pressure drop gauges are installed record reading. Typical pressure drops and filter life for a range of filter types are given below.

Filter type	Cleanable 5 cm thick	Throw-away 5 cm thick	Automatic Roll	Pleated, 5 cm thick
Life (hours)	600	480	3750	2000
Initial Pressure Drop (Pa)	20	25	100	35
Final Pressure Drop (Pa)	100	75	100	150
Average Pressure Drop (Pa)	60	50	100	92

Excessive Ductwork Resistance While this inspection is often hampered by inaccessability or concealment, it is often possible to identify sources of unnecessary pressure drops either from inspection doors in the ductwork or fan plant. (It is also a good idea to inspect components for cleanliness whilst carrying out these checks). A review of the design or "as-built" drawings is also useful. Note that it is most important to concentrate on the "index run" since all other branches will require throttling to maintain system balance. Examples of high pressure losses include:

- sharp bends.
- lack of turning vanes
- abrupt inlet and outlets,
- dirty coils,
- damaged coils (fins required combing)
- long lengths of flexible ductwork,
- unnecessary coils, eg. pre-heat
- control dampers not fully open on "index run",
- non-aerodynamic louvres (look for lips used to prevent rain carry over)
- closed or partially closed fire dampers.

Excessive noise from ductwork, if not accompanied by leaks, is normally evidence of a high pressure loss. The source of duct noise should be investigated further.

Air Leaks Use visual, audible or touch test to identify sources of leakage. A smoke puffer is an inexpensive and very reliable way of identifying leaks. Make a value judgement on the size of the leak either by area and/or velocity of the smoke jet and record this information on the audit checklist. The exact cause of air leaks should be established (ie. whether a flange is not sealing or a seam leaking). Damper shafts or sensor pockets are often sources of leaks.

leakage. Check leakage from pump seals, note that an occasional drip from packed glands is normal.

Insulation Record the thickness, type and condition of insulation; be especially careful to identify any areas of wet insulation. Insulation of a possible flammable nature or possible asbestos content should also be noted during this check. In most cases return air ductwork will be uninsulated. Similarly exhaust air ductwork will normally only be insulated close to the point of the external discharge. Record any factor contributing to unusual heat losses, eg. ducts installed in unheated areas or where duct heat loss does not contribute to space conditioning.

Potential for Air Volume Reductions This will normally be determined during audits of the environmental control systems. A note should be made on the ductwork checklist to remind the auditor where such reductions can be made.

Fan Motor Type and Loading If an audit of the electrical system has not already been carried out, the size and condition of the motor and whether or not it is a high efficiency type should be recorded. Taking current measurements and comparing them with full rated load current of the motors will also permit the establishment of the extent to which the motor is loaded.

Condition of Fan Drives Check for wear and correct tensions on belts; check for wear and misalignment of drives; listen or feel for noise and vibration from fan and motor bearings.

Condition of Fans On large fans, check for dirt build-up on the fan blades. Check for vibration, usually low frequency, as indication of fan imbalance.

Backdraft Dampers Check that backdraft, pressure operated or motorized dampers on outside air intakes and air exhausts have been installed and are operating correctly. Note the lack of, or damaged, seals.

Balancing Problems If an audit of the environmental control systems has not already been undertaken, temperatures within separate spaces on the same control zone should be measured; lack of consistency indicates poor balancing or poor zoning. Complaints from occupants, either solicited during the or previously received should be recorded.

17.5.4 - Heat Pumps

Auditing should focus on heat source and heat sink temperatures and flowrates. It is important to understand the functioning of control equipment and this can be both intriguing and time consuming. An understanding of how the system is intended to function is essential. The heat pump can be checked by measuring electric power consumption, evaporating and condensing pressures and a few temperatures. This can only be done with good results if the heat pump can run for sufficiently long periods to reach a steady state.

Unlike chillers, heat pumps may often be examined under part load conditions. Heat performance under changing loads, when switching between heating and cooling can be informative.

Area Served Identify the area served by the system.

System Description Note the type of system, eg. heat source and sinks, secondary heat exchangers, pumps and auxiliary equipment installed.

Equipment Description Record age and type of equipment and note any servicing records.

Energy Loads Note if equipment is short cycling under peak load conditions. This may be indicative of over sizing.

Heat Rejection Equipment On water loop heat pumps check the condition of cooling towers, evaporative coolers or other heat rejection devices.

Refrigerant Level Check level of refrigerant in sight glass. If refrigerant loss is a problem, correct leaks.

17.6 - Annotated List of Energy Management Opportunities

17.6.1 - Environmental Control Systems

17.6.1.1 - Housekeeping

EMO 17.1 MAINTAIN PROPER SPACE SETPOINTS

DESCRIPTION: Check setting and calibration of all space thermostats and humidistats. Adjust anticipator setting where thermostats have such devices.

APPLICATIONS: Buildings with individual space or zone control devices.

SIDE BENEFITS: Improved comfort.

COST FACTORS: Negligible cost unless sensors or controls need replacing.

INTERACTIONS: EMO 17.2 Setup/back Space Temperatures.

EVALUATION: If thermostat setpoints or measured values (occupied period) are not equal to design values, reset to correct setting. If thermostat setpoint acceptable but measured values not, re-calibrate controls. If temperature overshoot, adjust anticipator (on-off thermostats only).

COMMENTS: If complaints of discomfort when maintaining design setpoints, a more thorough analysis of the thermal environment may be necessary.

REFERENCES: ASHRAE STANDARD, 1981 and Berglund, L.G., et al, 1978. EMS No. 10 HVAC.

EMO 17.2 SET-BACK, SET-UP SPACE TEMPERATURES

DESCRIPTION: Adjust space thermostats or other space temperature controllers for energy saving set-points during unoccupied periods or for unoccupied spaces. Consider cycling heat and cool plant and auxiliaries to minimize power costs. Consider earlier shutdown or setback (i.e. before occupants leave). Plant may be turned off in mild conditions when there is no danger of freezing. Auxiliaries should also be turned off where possible.

APPLICATIONS: Buildings not continuously occupied or occupancy conditions are altered; e.g. working, relaxing, sleeping.

SIDE BENEFITS: Reduced operation and longer life of system auxiliaries, e.g. pumps, fans.

CAUTIONS: Extreme swings can result in condensation in winter, and mildew in summer. Shut down of steam systems can create problems caused by expansion and contraction cycles, boiler stress, water carryover (wet steam), slow pressure build-up (not normally a problem in sub-atmospheric systems) and high condensate rate causing water hammer. This last problem can be minimized by using liquid expansion type steam traps and/or providing smaller control valves to limit flow of steam, and hence condensate forming during system warm-up (Spirax Sarco, 1985). Unoccupied rooms with relaxed temperatures may affect comfort in adjacent spaces. Setting back electric heating systems can increase cost in certain cases if maximum demand incurred at pre-heat costs more than cost of additional units. Frequent cycling equipment can reduce its life.

COST FACTORS: Negligible cost if done manually but in most cases automatic means (time clocks, energy management systems) provide more reliable and potentially greater savings, particulary if optimum start (variable preconditioning period) is adopted. Can be expensive if large number of thermostats need to be changed to night setback type.

EVALUATION: Check if equipment already installed or monitor temperatures. Energy savings proportional to overall heat loss, ratio of occupied to unoccupied hours and building preconditioning period; building preconditioning period proportional to building and system thermal inertia and plant load ratio. Desirability of EMO often most influenced by cost of necessary control modifications.

COMMENTS: Night setback savings for air source heat pumps can be less than one would expect for an electric or fuel fixed system since the early morning warm up period is typically occurring at the coldest part of the day (thus lowering the COP).

REFERENCES: Levine, M.M., 1981; Johnson Controls Ltd., 1982; Berglund 1978; Spirax Sarco, 1985; Ellison, R.D., 1977; Backus, 1982; Bullock, 1978. EMS No. 11, Refrigeration and Heat Pumps.

EMO 17.3 SHUT OFF HUMIDIFICATION AND VENTILATION EQUIPMENT

DESCRIPTION: Shutdown ventilation and humidification equipment when building or space is unoccupied. Close off outside air dampers in HVAC systems.

APPLICATION: Buildings with mechanical ventilation systems and/or humidification equipment that are not continuously occupied.

CAUTIONS: Not appropriate where ventilation required for safety or cooling, or where humidity needs to be controlled, e.g. museums.

COST FACTORS: No cost if manual, wide range of costs for automatic operation.

INTERACTIONS: Complimentary to EMO 17.5 Shut Off Circulators.

EVALUATION: Where applicable, shut off manually. Energy savings proportional to fresh air volumes climatic severity, and the ratio of occupied to unoccupied hours. Savings in most cases justifiable without further evaluation.

EMO 17.4 NIGHT FLUSHING

DESCRIPTION: Use cool outside night air to pre-cool the building.

APPLICATIONS: Most beneficial in heavy mass buildings and where nightime temperatures are much lower than daytime setpoint.

SIDE BENEFITS: Improved comfort if mechanical cooling is not possible.

CAUTIONS: Be careful not to overcool the space and create discomfort or a need for heating.

COST FACTORS: Low cost if ventilation equipment already installed.

EVALUATION: Fan power requirements need to be evaluated against mechanical cooling requirements.

COMMENTS: High pressure fan systems can end up using more power than if fans run for shorter periods with mechanical cooling.

EMO 17.5 SHUT OFF COIL CIRCULATORS WHEN NOT REQUIRED

DESCRIPTION: Schedule heating & cooling coil circulators off when no demand for heat or cool.

APPLICATIONS: Coils controlled by three-way mixing valve with circulator.

COST FACTORS: Most benefit where or when a system operates with full coil flow and intermittant fan operation. Pump energy savings small but payback can be achieved where natural convection losses from coils are eliminated.

INTERACTIONS: Complimentary to 17.3 Shut Off Ventilation.

COMMENTS: Avoid turning off where danger of freezing. Auxiliary contacts on mixing valves may be utilized to shut off pumps.

EMO 17.6 MAINTAIN PROPER SYSTEM CONTROL SET-POINTS

DESCRIPTION: Ensure correct set-points, calibration and location of control sensors and operators; correct control operations, i.e. check controls are capable of doing what they are supposed to do. Examples include: a) Throttling Range. (On many commercial controllers the adjustment of throttling range is a simple field adjustment). Too small a range can cause control instability, too wide can waste energy; for example reducing the throttling range on dual duct and multizone air temperature controllers effectively reduces mixing losses; going below 2%, however, can cause control instability. b) For two pipe induction systems check correct settings for primary air reset schedule (winter operation) and fixed summer air temperature. The aim is in winter to have the air temperature as high as possible while still satisfying the zone with the greatest cooling load (in winter the systems act like a reheat system and so doing minimizes reheat energy). In summer, to minimize re-cool energy when the system functions as a recool system, the primary air temperature should be set as low as possible, consistent with not overcooling space with the least cooling demand (there may be some trade-off required in summer with a free-cooling cycle). c) For four pipe systems it might be worthwhile to re-evaluate the primary air setpoint temperature if this is to remain fixed.

APPLICATION: All systems with automatic controls, particularly those with heating and cooling.

COST FACTORS: Minor.

EVALUATION: Check of control sequences can normally be made by adjusting system setpoints and control switches temporarily to force the controls through their sequence. Note that a thorough understanding of the system should be achieved before attempting such changes. Check correct position/operation of all control valves, dampers etc. Accuracy of reset water schedule in systems with such a control system can be checked by analysing the results of coincident inside, outside and heating flow water temperatures.

COMMENTS: Unlike room thermostats, which when out of calibration will be adjusted by the occupants to provide comfort irrespective of what the set-point indicates, system controls can go unnoticed and can waste considerable amounts of energy. This is especially relevant where separate controllers are utilized to sequence heating, cooling, mixing.

REFERENCES: Johnson Controls Ltd., 1982; Kao, 1983, 1985; EMS No. 10 HVAC.

EMO 17.7 REPLACE WORN NOZZLES IN INDUCTION SYSTEMS

DESCRIPTION: Replace worn primary indication nozzles in cabinets.

SIDE BENEFITS: Improve induction of room air.

CAUTIONS: Ensure system balance maintained.

EVALUATION: Cost savings based on reduced fan power resulting from a reduction in primary air volume and reduce costs of conditioning primary air. Hourly evaluation method normally required to predict savings, the cost of which is normally not justifiable.

EMO 17.8 SPECIAL CONSIDERATIONS, ROOF TOP AIR CONDITIONING UNITS

DESCRIPTION: The following list contains a number of maintenance and minor improvements specific to roof top units:

- Clean air sides and straighten damaged fins of condenser and evaporator.
- Adjust fan belts.
- Caulk leaking seams.
  Repair and replace gaskets on inspection covers.
- Secure loose covers, replace screw fixings with hinges and marine catches
- Repair or upgrade insulation.
- Erect shade to keep direct sunlight off condenser.
- Add additional water trap if existing drain from evaporator is blown out by fan pressure.
- Replace gas train and install electronic ignition.
- Clean and/or repair/replace filters, (filters not working correctly will pass dirt onto evaporator coil).

APPLICATION: Self-contained (roof top) heating, ventilating and air conditioning systems.

SIDE BENEFITS:	Improved reliability, longer equipment life.
COST FACTORS:	With exception of gas train replacement, all items are low to medium cost maintenance items.
EVALUATION:	No further evaluation required on maintenance items. Base gas train evaluation on current state of repair and measured combustion efficiency.
REFERENCES:	Korte, B. 1976. EMS No. 10 HVAC.

EMO 17.9 SHUT DOWN HOT OR COLD DUCT IN DUAL DUCT SYSTEM OR MINIMIZE TEMPERATURE DIFFERENCE

DESCRIPTION:	Close off hot duct when no zones require heating and close off cold duct when no zones require cooling or operate both ducts with only heat or cool coils opened as required, or set the hot deck temperature as low as possible and the cold deck as high as possible.
APPLICATION:	Buildings with dual duct or multizone HVAC systems.
CAUTIONS:	Ensure comfort not compromized in some zones. Check for suitability of fan operating point when air volumes significantly changed.
EVALUATION:	Operation in such a manner will eliminate mixing losses (mixing between hot and cold ducts) and reduce fan power.
REFERENCES:	WECS, (undated).

EMO 17.10 CYCLE AIR CONDITIONING

DESCRIPTION:	Cycle compressor operation 10-15 min. and run fan after compressor stops to re-evaporate condensation formed on the coil (benefit from evaporative cooling effect).
APPLICATIONS:	Small central air conditioning installations with fan forced air circulation.
CAUTIONS:	Increased space humidity value depending on cycle frequency.
EVALUATION:	See Reference.
REFERENCES:	Kinsey, B.A., 1979.

17.6.1.2 - Low Cost

EMO 17.11 PREOCCUPANCY CYCLE

DESCRIPTION:	Carry out pre-heating and pre-cooling without introducing outside air where this would impose an additional load.
APPLICATIONS:	All buildings with HVAC systems with economizers or separate ventilation systems.
SIDE BENEFITS:	Can reduce peak demand on heat and cool plant for quicker warm up and/or can reduce peak load electrical demand charges.
CAUTIONS:	Care must be taken to avoid internal air quality problems when occupancy commences.
INTERACTIONS:	Evaluate in conjunction with EMO 17.2-17.5 Night Operation Strategies.
COMMENTS:	Note some controllers have self learning capability (e.g. pre-heat time automatically adjusts to system and building).

REFERENCES: Johnson Controls, 1982.

EMO 17.12 INSTALL AUTOMATIC VENTILATION CONTROL

DESCRIPTION: Vary ventilation rate by means of: Adjustment to outside air and mixing dampers; Throttle fan flow; Motor speed control; Mechanical speed control; Variable pitch blades (vane axia fans); Inlet guide vanes (centrifugal fans).

APPLICATION: Most potential in buildings with highly intermittent and variable occupancy, e.g. shops, theatres, auditoria.

COST FACTORS: Most benefit if automatic using CO_2 sensor. Time clock can be considered where the occupancy density pattern is predictable.

EVALUATION: ASHRAE gives recommended ventilation rates for building occupants. Simple degree-day methods may be used when occupancy is uniform in time. Hour by hour methods are required when occupancy is skewed, e.g. a greater use in evenings.

COMMENTS: Be sure acceptable conditions are maintained. Cycling equipment will reduce life.

REFERENCES: Liptak, 1979; Woods, 1982; Ogaswari, 1979. EMS No. 10 HVAC.

EMO 17.13 SEQUENCE HEATING & COOLING

DESCRIPTION: In any air system with mixing, heating or cooling, ensure that the desired final air condition is obtained first by trying to obtain the desired temperature through mixing and then adding only sufficient heat or cooling.

APPLICATION: Most common application is sequencing economizer cycle with deck temperature control. Other possibilities where sequencing is important include systems with preheat or those utilising evaporative cooling.

CAUTIONS: Overlapping throttling ranges of controllers and loss of calibration can cause loss of sequencing when individual controllers are utilized.

COST FACTORS: Low cost if only system set point adjustment required. Sequencing by common controller more expensive but generally more satisfactory.

EVALUATION: An indication of mixing losses can be obtained by comparing cooling demands of those days when the heating is turned on and those days when it has been purposely turned off. Make the comparison days with similar outside conditions. Check and correct without further evaluation. Sequence should maintain suitable deadbands between control steps so that heating and cooling are not opposing one another.

COMMENTS: The installation of temperature sensors before, between and following the various heating and cooling processes can be used to sound an alarm when heating and cooling mixing starts to occur.

REFERENCES: Dubin, F.S., 1975; Haines, R.W., 1984; Albern, W.F., 1983. EMS No. 10 HVAC.

EMO 17.14 MIXING DAMPER REPLACEMENT

DESCRIPTION: Ensure minimum practical leakage when hot or cold air supply 'shut-off' by maintaining and adjusting damper control mechanisms, replacing damaged seals, or replacing dampers with low leakage types.

APPLICATIONS: Can be particularly effective when applied to dual duct mixing boxes. Applicable to air economizers, multizone & dual duct systems. Dampers on older type roof-top air conditioning units are prime examples for retrofit.

SIDE BENEFITS: Reduction of peak loads.

EMO 17.15 INSTALL RADIATOR THERMOSTATIC VALVES

DESCRIPTION: Replace radiator valves by radiator thermostatic valves.

APPLICATION: Buildings with hydronic heat distribution systems, except series loop systems.

SIDE BENEFITS: Improved comfort.

CAUTIONS: Effect strongly dependent on positioning of sensors, equipment where sensor separate from thermostatic valve is preferred. Avoid placing sensors close to windows or where sensor may be subjected to draughts or solar radiation. The quality of thermostatic radiator valves can vary widely. Ensure correct type utilized for one pipe or two pipe system.

COST FACTORS: Large variations in experienced savings, from slightly increased energy consumption to large savings. Cost effectiveness dependent on building and status of heat distribution system.

INTERACTIONS: Alternative to other local space temperature control EMOs.

COMMENTS: Post-adjustment of system may be required.

EMO 17.16 HUMIDISTAT CONTROL OF SWIMMING POOL HALL VENTILATION

DESCRIPTION: Use humidistat to maintain maximum acceptable humidity by varying the ventilation rate.

APPLICATION: Indoor pools with ventilation systems relying on outside air for humidity control.

SIDE BENEFITS: Improved comfort level because of less evaporation from the skin during those periods that would otherwise be at lower humidities.

CAUTIONS: On average more humid conditions are maintained in the pool hall which may exacerbate material and surface deterioration.

COST FACTORS: Nominal.

INTERACTIONS: Low cost, less effective alternative to EMO 17.35 Dehumification.

EVALUATION: Consider alternatives before deciding to implement this EMO.

REFERENCES: EMS No. 10 HVAC, EMS No. 11 Refrigeration and Heat Pumps.

EMO 17.17 CO CONTROL OF PARKING GARAGE VENTILATION

DESCRIPTION: Use carbon monoxide sensor to turn on garage ventilation equipment only when safe limits of CO concentration have been exceeded.

APPLICATIONS: Primarily mechanically heated and ventilated garages.

SIDE BENEFITS: Reduced noise levels when fans off.

CAUTIONS: Check that variable ventilation can satisfy safe limits of CO concentration. Garage should be maintained under negative pressure at all times to minimize air flow to occupied zones.

COST FACTORS: Moderate cost.

EVALUATION: As much as 90% cost saving as compared to continuous fan operation can be anticipated depending on vehicle use. Best paybacks with heated garages.

COMMENTS: Ventilation rates may be regulated by municipal or provincial governments.

REFERENCES: EMS No. 10 HVAC.

EMO 17.18 MINIMIZE STRATIFICATION DURING HEATING SEASON

DESCRIPTION: Eliminate high temperatures at upper levels by use of fans, tubes, entrainment by air jets or drawing return air from high level. Makeup air can sometimes be introduced in this manner without the need for pre-heating.

APPLICATION: Large open and high spaces (generally higher than 5 meters). Useful in boiler rooms where high level hot air can be directed to burners.

SIDE BENEFITS: Improved air movement. Improved comfort to occupants.

CAUTIONS: Destratifying in summer could increase cooling load.

COST FACTORS: Moderate cost.

COMMENTS: The effect of stratification can in general be neglected, but for buildings with forced warm air convective heating and cross flow at low level the energy consumption may increase by 5 to 15% for a height of the heated space between 5 and 10m and by 15 to 30% for a height of more than 10m. The corresponding numbers for forced air downward from high level are 5 to 10% and 10 to 20%, respectively.

REFERENCES: Fizzel, 1977. EMS No. 10 HVAC.

EMO 17.19 INSTALL AIR ECONOMIZER

DESCRIPTION: Use air for free cooling by employing air economizer cycle.

APPLICATION: Air handling systems capable of handling 100% fresh air.

SIDE BENEFITS: Enhanced air quality (as opposed to fixed minimum air system) during free cooling.

COST FACTORS: Temperature controlled system less costly than enthalpy but theoretically less efficient. (Shavit, 1984)

EVALUATION: Evaluation of savings normally requires the use of an hourly calculation technique or bin method. Where only control changes are required, cost most often justifies the change.

COMMENTS: Enthalpy economizer sensors are considered somewhat unreliable by some engineers. Careful selection of air temperature set-points can supply savings nearing those theoretically possible with enthalpy control. Since the economizer cycle is basically a cooling energy saver, its direct application to multizone and dual duct systems can in cases not provide an optimum solution. Ideally the mixed air control should be able to decide if it is better to mix the desired hot duct temperature, to the desired cold deck temperature or somewhere in between. This decision must be made based on the relative overall energy costs between heating and cooling fuels and on the relative flow quantities in each deck. Special consideration also required for VAV systems with "Reset Control".

REFERENCES: Haines, 1981; Shavit, 1974; EMS No. 10 HVAC.

EMO 17.20 PROVIDE EVAPORATIVE COOLING

DESCRIPTION: Replace or supplement mechanical cooling with evaporative cooler. Some degree of evaporative cooling possible by spraying existing cooling coils.

APPLICATION: Most applicable in low humidity climates with adequate water supplies. Requires careful analysis to justify costs.

CAUTIONS: Appropriate chemical treatment procedures should be rigourously followed when using evaporative cooling equipment due to risk of bacteriological growth.

COMMENTS: Will need to be sequenced carefully with deck temperature and economizer control.

REFERENCES: Eskra, 1980; Supple, 1982; Meyer, 1983; Pearson, 1982; and Dombroski, 1984. EMS No. 11 Refrigeration and Heat Pumps.

EMO 17.21 INSTALL DEADBAND THERMOSTATS

DESCRIPTION: Replace existing space thermostats with deadband type or set existing heat and cool setpoints with deadband. NOTE: This is a specific form of sequencing.

APPLICATIONS: Not desirable on dual duct or multizone systems because of control instability (leaves mixing damper in neutral position) unless complex strategies adopted. Only applicable to those systems capable of supplying both heating and cooling in same period, e.g. not applicable to 2 pipe induction systems.

CAUTIONS: Wide deadband can compromise comfort.

COST FACTORS: Negligible cost if setpoint adjustment is all that is required.

EVALUATION: Reliable estimation of savings normally requires the use of an hourly energy analysis program.

REFERENCES: Fullman, 1981; Paoluccio, 1981; Haines, 1984. EMS No. 10 HVAC.

EMO 17.22 DISCONTINUE OR RELOCATE PRE-HEAT COILS

DESCRIPTION: Remove pre-heat coils or relocate after mixing box.

APPLICATIONS: Fan plant with pre-heat coils, particularly those plants that were designed for 100% or large percentages of outside air and that have or are being considered to be converted to handle larger volumes of return air.

SIDE BENEFITS: Reduction in the risk of freeze up associated with the pre-heat coil.

CAUTIONS: Ensure danger of freeze up to downstream coils is not increased.

INTERACTIONS: Should be considered in conjunction with economizer cycle.

COMMENTS: Pre-heat coils usually installed to minimize risk of freezing but often can be eliminated by proper mixing, i.e. avoiding stratification. If this step is not ensured, freeze up may result.

REFERENCES: Haines, 1980.

EMO 17.23 PROVIDE STRATIFICATION SPLITTERS

DESCRIPTION: Modify mixing section to direct warmer return air to hot deck & cooler outside air to cold deck.

APPLICATIONS: Applicable to some types of dual duct and multizone systems with built up central station plant.

EVALUATION: Detailed hourly analysis methods are normally required for reliable estimates of savings.

REFERENCES: Dubin, 1975.

EMO 17.24 CORRECT POOR CONTROL VALVE SELECTION

DESCRIPTION: Correct poor control valve performance by choosing valve with correct "authority". For large coils it may be desirable to replace a single valve with two valves selected to handle 1/3 and 2/3 of the load, respectively.

APPLICATION: Heating and cooling coils.

COMMENTS: When a valve with too low an "authority" is selected, the control valve is forced to operate on a reduced throttling range; control is invariably poor where a valve is trying to control near to its fully closed position.

REFERENCES: Trane, 1977.

EMO 17.25 USE COOLING COIL FOR BOTH HEATING AND COOLING DUTIES

DESCRIPTION: When heating and cooling is not needed simultaneously remove heating coil and pipe heating to cooling coil with appropriate control and isolating valves.

APPLICATIONS: Central air handling plants.

SIDE BENEFITS: Lowers air flow resistance for possible fan power savings. Lower water flow rates for heating fluid may be possible for pumping savings.

CAUTIONS: Ensure water treatment is appropriate.

EMO 17.26 VARIABLE VOLUME CONTROLS FOR FUME HOODS

DESCRIPTION: Add variable air volume controls to existing fume hoods to maintain nominally constant sash velocity over the range of opening positions. Alternative - replace old hoods with new hoods with VAV controls.

APPLICATIONS: All fume hood applications, particularly those where the fume hoods operate continuously (hoods containing toxic equipment often have to operate continuously).

CAUTIONS: Some devices have proved to create some operation problems and noted potential problems include:

- Velocity measuring devices interfere with hood access.
- Low discharge velocity (at building exterior) can create re-entry problems.
- Relative pressures reversed between "clean" and "dirty" areas.
- Incomplete scavaging of all parts of hood at the lower velocity. Users must be trained to close the sashes otherwise the savings will not be realized.

COST FACTORS: High payback potential, particularly in extreme climates.

EVALUATION: Sash can be assumed to be closed for most of the time (check prevailing use) and capable of being operated at around 20% of the rated exhaust rate. Calculate savings associated with 80% reduction in make up air conditioning requirements. There will also be small savings in fan electric consumption. Volume control may be by dampers or motor speed control.

REFERENCES: Bentson, 1985; Wiggin, 1985.

17.6.1.3 - Retrofit

EMO 17.27 LOCATE MAKE-UP AIR AT EXHAUST HOODS

DESCRIPTION: By supplying make-up air directly at the exhaust hood, the make-up air can often be supplied unconditioned or only partially conditioned.

APPLICATION: Most attractive for restaurant range hoods and other high exhaust zones.

SIDE BENEFITS: Supply of cool or fresh air at source of pollution can improve worker comfort.

CAUTIONS: High supply velocities can cool food products and disturb gas flame burners. Codes may require interlocks between supply and exhaust fans.

EVALUATION: Often up to 70 to 85% of air can be supplied unconditioned or conditioned at a temperature other than room temperature.

REFERENCES: Dubin, 1975.

EMO 17.28 HIGH VELOCITY TYPE EXHAUST HOODS

DESCRIPTION: Modify existing exhaust hood or install new hood of type with extract located around the hood perimeter (as opposed to over the full hood area).

SIDE BENEFITS: Capture efficiently can be improved with lower air volumes with consequent saving in fan power and make-up air conditioning requirements.

COMMENTS: Existing hoods can be modified by installing baffles inside the hood.

REFERENCES: Dubin, 1975.

EMO 17.29 CONVERSION TO VAV

DESCRIPTION: Replace reheat coils with or add VAV control boxes to reheat systems. Convert dual duct boxes to two motor operation or blank hot duct and modulate cold duct air supply. Blank off hot duct and add VAV to cold duct terminals. (Multizone)

APPLICATION: Primarily applicable to terminal reheat and dual duct systems. Some applications for multizone systems.

SIDE BENEFITS: Reduced duct noise at part load.

CAUTIONS: Usually close control of space relative humidity is compromized. Low air volumes in direct expansion refrigerant systems may cause frosting at coils. Air diffusion quality in the space can be compromized at low air flow rates; fan driven terminals to maintain local circulation can minimize such effects.

COST FACTORS: Maximum savings with throttle type VAV boxes.

EVALUATION: Estimation of savings normally requires the use of an hourly energy analysis program.

COMMENTS: Fan control not required if dump boxes used but in this case no fan savings possible. Re-heat may still be necessary in some zones.

REFERENCES: Wendes, 1983; Reed, 1983; Pannkoke, 1980; Pearson, 1985; Johnson, 1985; Haines, 1984; Honeywell, 1976.

EMO 17.30 LOAD RESET (DISCRIMINATOR) CONTROL

DESCRIPTION: Reset deck temperature in reheat system upwards so that zone with highest cooling load is met without reheat. In dual duct and multizone reset cold deck temperature as above and reset hot deck as low as possible whilst still satisfying zone with greatest heating. For induction systems reset primary air temperature down during heating season to satisfy zone with minimum heating and in summer as high as possible to satisfy zone with least cooling. Reset heating system supply water temperature in outdoor air reset systems based on one or more space thermostats.

APPLICATION: Not applicable to fan coils, unit ventilators or incremental systems. VAV systems can be treated as reheat except that increase fan power may negate any chiller savings resulting from cooling or COP improvements. Main applications are Terminal Reheat, Multizone and Dual Duct Systems.

EVALUATION: Evaluation of savings normally requires the use of hourly analysis techniques.

COMMENTS: Some loss of humidity control can be expected. In dual duct & multizone systems, hot deck can be shut off if no zone heat demand as can cold deck if no cooling demand. Induction system primary air reset arranged to minimize recool (3 and 4 pipe) and/or over-cooling (2 pipe) in summer. Check, however, secondary heating and cooling capacity adequate.

REFERENCES: Spethmann, 1977; Haines, 1984.

EMO 17.31 AIR MIXING BETWEEN ZONES FOR UTILISATION OF ZONE EXCESS HEAT EXHAUST MAKEUP

DESCRIPTION: Provide fans, rearrange ductwork or install devices to promote natural air movement between spaces at different temperatures where excess heat in one of the spaces can be used to offset heat losses in the other. Examples include: circulation of air between an attached sunspace and the main occupied space when the sunspace temperature is higher than the occupied space; using a common return air duct for interior and exterior zones in the same building or returning air from the exterior zone to the interior zone system and vice versa; or otherwise to promote mixing of internal and external zone air.

APPLICATIONS: Buildings where simultaneous needs for both heating and cooling can be identified.

SIDE BENEFITS: Possibility of more even temperatures between different parts of the building.

CAUTIONS: Avoid mixing air between "dirty" and "clean" areas.

INTERACTIONS: This EMO may be desirable when closing off balconies to make a sunspace/greenhouse. An alternative strategy to air mixing would be to install a heat pump heat recovery system to transfer heat between zones. EMO to minimize stratification, is a special case of this EMO where the two zones are not physically separated and are arranged one above the other.

EVALUATION: Detailed hourly analysis methods are normally required for reliable estimates and should be undertaken where large capital expenditures are concerned. Potential savings of up to 20% are possible if excess heat from internal and southerly exposed areas are utilized effectively.

REFERENCES: Jones, 1985.

EMO 17.32 INSTALL LOCALIZED EXHAUST/MAKE-UP AIR SYSTEMS

DESCRIPTION: Replace large central systems with small local & independently controlled exhaust systems or provide dampers in central systems at point of extract, e.g. garage (car exhaust), welding hoods, fume cupboards.

APPLICATIONS: Where large number of exhaust stations are provided requiring only intermittant use.

EVALUATION: Some idea of the frequency of use is required for an evaluation.

REFERENCES Goldfield, 1985.

EMO 17.33 INSTALL ENERGY MANAGEMENT SYSTEM

DESCRIPTION: Install energy management systems to schedule equipment operation. More sophisticated systems also provide actual control capabilities, e.g.; Direct Digital Control Systems.

APPLICATIONS: Generally larger HVAC systems with multiple plant rooms or a number of smaller buildings/facilities.

CAUTIONS: Much of the potential savings can be lost by unsuitable programming, poorly placed or inaccurate sensors and failure by plant personnel to use the equipment correctly. Personnel training considered to be essential.

COST FACTORS: Cost effectiveness and system sophistication generally increases with number of control points.

INTERACTIONS: Can provide alternative to multiple controls EMOs.

EVALUATION: Desirability and type of system suitable will be most influenced by the number and type (binary or analogue, input or output) of control functions (i.e. amount of equipment to be controlled and manner in which it is controlled).

REFERENCES: Haines, 1982; EMOs No. 10 HVAC.

EMO 17.34 VAV FAN CONTROL IN AC SYSTEMS

DESCRIPTION: Provide or improve fan flow/duct over pressure control by providing speed control or inlet guide vanes or variable pitch vane axial fans.

APPLICATIONS: VAV systems.

SIDE BENEFITS:	Lower pressures will result in lower leakage from ductwork and past dampers.
COST FACTORS:	Usually high but generally good paybacks possible.
INTERACTIONS:	Should be implemented in conjunction with EMO 17.29 Conversion To VAV.
REFERENCES:	Trane, 1979; Honeywell, 1976.

EMO 17.35 MECHANICAL DEHUMIDIFICATION IN SWIMMING POOL HALLS

DESCRIPTION:	Reduce ventilation to satisfy occupancy requirements (not humidity) and control humidity using heat pump dehumidifier. Reject heat from condenser used for pool water, pool hall space or service water heating.
APPLICATIONS:	Swimming pools and spas.
SIDE BENEFITS:	Possible to obtain lower pool hall humidity at lower energy costs than with ventilation. Water and water treatment savings are possible.
CAUTIONS:	Check the requirements of Public Health officials that water returned to the pool from the dehumidifier can be considered as "fresh water make-up". Avoid blowing over water in pool halls as this will tend to increase evaporation rates.
INTERACTIONS:	Highest cost alternative to EMO 17.16 Humidistat Control of Ventilation.
COMMENTS:	In winter the heat from the compressor contributes to the space heating of the pool hall.
REFERENCES:	EMS No. 11 Refrigeration and Heat Pumps, EMS No. 10 HVAC.

EMO 17.36 ADSORPTION FILTERS

DESCRIPTION	Instead of exhausting vitiated air, pass through adsorption filters and return to the space. Activated carbon filters are the most widely used type although other adsorptents are available for specific applications.
APPLICATIONS:	Primarily kitchens in dwellings and special applications such as archive facilities.
CAUTIONS:	Possible compromise on indoor air quality. Lifetime of activated carbon is limited leading to a reduction of filtering capability, although reactivation by heating to high temperatures can restore efficiency to some degree. Grease collection, for example, when used in kitchen range hoods can also compromise filtering efficiency.
COST FACTORS:	Can be economic solution to internal kitchens, where installing ductwork to the outside would be difficult and expensive.
INTERACTIONS:	High cost alternative to EMO 17.27 Locate Make-up Air at Exhaust Hoods.
COMMENTS:	Check that such an option complies with building codes.
REFERENCES:	Dubin, 1975; ASHRAE Equipment, Ch. 11, 1983.

EMO 17.37 LOCAL HEATING AND COOLING

DESCRIPTION:	Use local heating and cooling for comfort conditioning in those locations where it can be provided in place of conditioning the complete building space.

APPLICATIONS: Most potential in large open spaces with low occupancy, e.g. warehouses.
SIDE BENEFITS: Can be adjusted to meet local needs.
COMMENTS: Local space design and freedom from drafts are important to achieve acceptable comfort levels.
REFERENCES: Azer, 1985; EMS No. 11 Refrigeration and Heat Pumps.

EMO 17.38 RADIANT HEATING

DESCRIPTION Replace or supplement air heating with 'high temperature small source' or 'low temperature large source' heating.
APPLICATION: Often found advantagous in large, high and open spaces such as factories. Response is rapid (immediate warm up, quick cool down) making application for intermittant heating particularly attractive. Easy to maintain heat in a desired location, even in open spaces, makes it suitable for local heating.
SIDE BENEFITS: Will permit lower air temperature at equivalent comfort and consequently will minimize infiltration and ventilation losses.
CAUTIONS: Not appropriate where atmosphere contains ignitible dust, gases or vapours. Higher air change rate for combustion and flue gas dilution (if unflued). Excessive radiant heat falling on occupants heads causes discomfort.
EVALUATION: Savings as high as 50% compared to 'convection heating systems' are claimed to be possible.
COMMENTS: Black bulb radiant control thermostats preferable to air temperature thermostats.

EMO 17.39 DIRECT GAS FIRED MAKE-UP UNITS

DESCRIPTION: Replace indirect fired equipment with direct gas fired equipment (products of combustion pass to space being heated).
APPLICATION: Use only where building codes permit, usually only suitable in make-up air applications such as industrial plants, parking garages and door entrance heaters.
COST FACTORS: Typically 20 to 40% more efficient than indirect units. Also cheaper capital cost than indirect.
COMMENTS: See EMO 17.38.

EMO 17.40 REPLACE CEILING DUMP BOXES

DESCRIPTION: Replace ceiling dump boxes ("Bypass type") with throttle type volume control boxes.
APPLICATIONS: VAV systems.
CAUTIONS: Care must be exercized with direct expansion equipment where minimum air flow must be maintained over a coil to prevent ice formation.
INTERACTIONS: See EMO 17.29 and 17.34 Conversion to VAV.
EVALUATION: Evaluation of fan energy savings normally requires use of an hourly energy analysis program.

REFERENCES:	**Pannkoke, 1980.**

EMO 17.41 RE-COOL COILS

DESCRIPTION:	**Add re-cool coil(s) on zone(s) with greatest or most continuous cooling load allowing system deck temperature to be increased.**
APPLICATION:	**Applicable primarily to re-heat systems.**
SIDE BENEFITS:	**Most benefit derived where small system serves areas with largely differing cooling requirements (e.g. interior and exterior zones).**
CAUTIONS:	**Ensure supply fan can overcome additional resistance of coils.**
EVALUATION:	**Evaluation of energy savings normally requires the use of an hourly energy analysis program.**

EMO 17.42 INDIVIDUAL COILS IN MULTIZONE SYSTEM

DESCRIPTION:	Replace systems with a single pair of (heat and cool) coils with systems having a pair of coils per zone.
APPLICATIONS:	Applicable to multizone systems only.
COST FACTORS:	Normally only economical if the unit is nearing the end of its useful life.
EVALUATION:	Evaluation of energy savings normally requires the use of an hourly energy analysis program.
REFERENCES:	Dubin, 1975.

EMO 17.43 SYSTEM REPLACEMENT

DESCRIPTION:	Install more energy efficient HVAC system.
APPLICATION:	Normally only considered worthwhile if equipment is nearing the end of useful life and/or major building retrofit planned.
SIDE BENEFITS:	Better designed systems should provide improved comfort, possibly less noise whilst avoiding the problem of "add-ons" to the existing systems.
CAUTIONS:	Detailed design costs may be incurred and these costs should be weighted in assessing viability of EMO.
COST FACTORS:	High cost, normally only justifiable where the system is nearing the end of its useful life, the building is undergoing major renovation or refitting, and/or there are significant operation, comfort or maintenance problems.
EVALUATION:	Evaluation of system options is a complex process requiring an experienced designer. Evaluation of energy savings normally requires the use of an hourly energy analysis program.
COMMENTS:	More efficient HVAC systems will normally have variable volume air delivery, may utilize heat pumps for heat recovery and heat redistribution purposes, and may utilize storage techniques. In building utilising recovery strategies it is often important to have central (building) control capabilities. For example in a building that is either on all heating and all cooling it would be logical to have different heating and cooling setpoints, e.g. 20^{O}C heating; 26^{O}C cooling. However, for the case where the building has coincident demands for both heating and cooling, it may be bene-

ficial under certain conditions to cool down to 20°C so that more recovered heat is made available to those parts of the building requiring heating.

EMO 17.44 CONVERT 3-PIPE SYSTEM TO 2-PIPE OR 4-PIPE SYSTEM

DESCRIPTION: Convert 3-pipe (common return) system to 2-pipe (change over) or 4-pipe system to avoid fluid mixing losses.
APPLICATION: Main application in induction and fan coil systems.
CAUTIONS: Controls must be provided on 4-pipe systems to prevent simultaneous heating and cooling.
COST FACTORS: Change to 2-pipe system normally more economical than to 4-pipe.
EVALUATION: Energy savings evaluation requires detailed computer analysis.
COMMENTS: Change to 2-pipe system limits ability to handle daily switches between heating and cooling in intermediate seasons.
REFERENCES: Dubin, 1976.

EMO 17.45 AIR TO AIR HEAT RECOVERY TECHNIQUES

DESCRIPTION: Use air to air heat recovery to pre-condition make-up air. Option includes heat wheels, plate, run around, heat pump or heat pipes.
APPLICATION: All buildings where mechanical ventilation systems are provided. Particular benefit in heating situations where exhaust air is hot and humid, e.g. laundries, bakeries and industrial drying processes.
SIDE BENEFITS: Also potentially valuable retrofit in continental type climate with winter summer extremes since plant is used year round.
CAUTIONS: Frost collection on the exchanger can reduce effective savings and block off ventilation air under certain weather conditions. If possible put heat recovery after preheating coil.
REFERENCES Sun, 1979; Chauhan, 1985

17.6.2 - Pipework Systems

17.6.2.1 - Housekeeping

EMO 17.46 MAINTAIN SYSTEM FREE FROM AIR

DESCRIPTION: Check all pipework is under positive pressure (with respect to atmospheric) at all times. Check system on upper floors for trapped air.
APPLICATION: Hot water systems with forced circulation particulary where the expansion tank connection has not been properly located on the pump suction.
SIDE BENEFITS: Even distribution of water flow rate. Improved heat transfer. Helps prevent oxidation of radiators.
COST FACTORS: Negligible.
VALUATION: A partially or completely cold radiator may indicate presence of air in the pipes. Part of regular maintenance.
COMMENTS: Radiators may be cold due to other factors (closed valves, obstructions in

the system). A sealed expansion tank offers better protection against air in the system than open tanks.

EMO 17.47 SWITCH OFF CIRCULATION PUMPS WHEN NOT REQUIRED

DESCRIPTION: Switch off pumps to save on distribution losses and pumping energy. This may be done manually or automatically.
APPLICATION: Systems with non continuous loads.
SIDE BENEFITS: Increases the life-time of the pump. May reduce mixing losses.
CAUTIONS: Ensure the pump operates with heating and cooling plant.
COST FACTORS: Low for manual control. Moderate for automatic control.
INTERACTIONS: Particularly effective if not coupled with reduced flow rates (EMO 17.52). If an energy management system is in use consider using it to schedule the pumps.
EVALUATION: Energy savings are dependent on pump motor power draw and period of time the pump can be turned off.

EMO 17.48 CLEAN FILTERS AND SCREENS

DESCRIPTION: Clean filters and screens.
APPLICATION: All pipework systems.
SIDE BENEFITS: Will increase pump life and reduce exchanger fouling.
CAUTIONS: Will increase pump electric energy consumption unless pump capacity reduced.
COST FACTORS: Negligible.
INTERACTIONS: EMO 17.50 (Balance distribution system). For energy savings, pump delivery needs to be reduced, see EMO 17.52 (Reduce flow rates).
EVALUATION: Do only when filters or screens need cleaning. Part of regular maintenance.

EMO 17.49 REPAIR LEAKS

DESCRIPTION: Check if there are leaks in pipes, tanks, or other pipe-work components. Check for and eliminate fluid leakage past closed control valves.
APPLICATION: Applies to all the components that are likely to be leaky (unions, flanges, valves and pump packing/glands).
SIDE BENEFITS: Will reduce water consumption and water treatment costs, building and insulation damage, mould formation, etc.
CAUTIONS: Make sure that leaks are not produced by excessive water pressure in the circuit.
COST FACTORS: Depends on type of failure. May be very expensive if site is not accessible. Best pay-back for large control valves, where heating and cooling fluids available together, and where fluids not reset according to outside conditions or overall load variations.
INTERACTIONS: EMO 17.51 (Repair/upgrade insulation). If pipes are leaky, consider changing the pipework layout as a complementary EMO. Leaks from control valves may cause loss of space temperature control or loss of

sequencing of heat and cool processes.

EVALUATION: Benefit difficult to estimate. Leakage past control valves (i.e. not out of the piping system) are not immediately obvious or visible. Listen for flow past valve using a stethoscope or check temperatures upstream and downstream of valve.

17.6.2.2 - Low Cost

EMO 17.50 BALANCE PIPEWORK DISTRIBUTION SYSTEM

DESCRIPTION: Correct hydronic imbalances in systems by replacing or adjusting valves on main pipes and adjusting radiator valves. Alternatively install Automatic Flow Control valves (Phillips 1984).

APPLICATION: Where uniform and acceptable conditions are not being maintained over a control zone. Often this EMO is necessary to maximize savings from Envelope and Environmental Control System modifications.

SIDE BENEFITS: Improved comfort.

CAUTIONS: Should be carried out after implementation of other EMOs. Upgrading of distribution pipe insulation (EMO 17.51) may be required after other EMOs to ensure adequate control capability of the system. Balancing must be carried out by skilled personnel.

COST FACTORS: Moderate cost. Mostly cost-effective, dependent on previous imbalance of system. Post-adjustment of system may be necessary.

INTERACTIONS: Most Envelope EMOs and many environment control system EMOs. Incorrect pump sizing may be part of the problem, see EMO 17.53 (Install zone pumping), 17.52 (Reduce flow rates), EMO 17.48 (Clean filters and screens). Poor zoning may be the cause which cannot be corrected by balancing.

EVALUATION: Should only be considered in buildings where indoor temperatures on the average deviate more than 2°C from desired temperatures.

COMMENTS: If heat terminals are oversized, the number of elements in radiators may be reduced or thermostatic valves installed. If terminals are undersized, the number of elements should be increased. Carry out adjustments at a high flow rate if lower system fluid temperatures are being considered.

EMO 17.51 REPAIR/UPGRADE INSULATION ON PIPES AND TANKS

DESCRIPTION: Repair damaged insulation or increase thermal resistance insulation of pipes and tanks.

APPLICATION: Applies to all equipment (pipes, tanks, heat exchangers, etc.) containing heated or cooled fluids, especially to larger, higher temperature difference equipment, where heating (and to a lesser extent cooling) temperatures do not vary with demand and where heat losses do not contribute to space conditioning. Only applicable to easily accessible equipment.

SIDE BENEFITS: Increases the distribution efficiency and lessens moisture condensation problems if fluid temperature is lower than environmental temperatures.

CAUTIONS: Not economical to exceed optimal thickness. Consider possible moisture problems on cold pipes.

INTERACTIONS: EMO 17.49 (Repair leaks), EMO 17.50 (Balance distribution system).

REFERENCES: Danish, C., 1983, Roose, R., 1976, EMS No. 1, Process Insulation.

EMO 17.52 REDUCE FLOW RATES

DESCRIPTION: Flow may be reduced by throttling output, by automatic flow control valves, by reducing impeller size (turn original or fit new impeller of a smaller size), by replacing pump or reducing pump speed. Pump speed may be reduced by changing pulley, gear boxes, or by motor speed control. Will lead to substantial savings on pumping energy consumption.

APPLICATION: May be applicable in the presence of initial system oversizing, loads reduction and increased temperature difference between feed and return.

SIDE BENEFITS: Lower flow rates imply lower flow velocities; noise problems reduced.

COST FACTORS: Throttle is negligible cost but least savings; pump replacement high cost.

INTERACTIONS Motor replacement may be necessary to balance the distribution system (EMO 17.50), EMO 17.47 (Switch off circulation pumps), EMO 17.48 (Clean filters and screens).

EVALUATION: Do if previous EMOs on the building envelope have reduced the thermal loads. May require measurement of temperature drop across radiators.

17.6.2.3 - Retrofit

EMO 17.53 INSTALL ZONE PUMPING

DESCRIPTION: Install separate pumps on circuits having very different pressure drop or where different zones have different requirements. Will lead to pumping energy savings.

APPLICATION: Where index run pressure drop much larger than next highest pressure drop circuit.

SIDE BENEFITS: May improve control strategy.

COST FACTORS: Depends on number of pumps to be installed.

INTERACTIONS: EMO 17.50 (Balance distribution system).

EVALUATION: Do only if pumping costs are very high. Requires determination of flow rates and pressure drops in the different circuits.

EMO 17.54 INSTALL VARIABLE VOLUME PUMPING

DESCRIPTION: As an alternative to variable temperature control, consider variable flow control. Provide staged pumping employing pumps in parallel or single pump with speed control.

APPLICATION: Most advantageous in larger distribution schemes with variable load.

SIDE BENEFITS: Prolonged pump life.

CAUTIONS: Lower flow rates increases susceptibility to freeze up.

COST FACTORS: High.

REFERENCES: Hoffman, J., 1986, Albern, N.F., 1986, Agnon, S., 1978.

EMO 17.55 REMOVE UNNECESSARY PIPEWORK

DESCRIPTION:	Rationalize pipework systems to eliminate unnecessary or disused branches to reduce heat loss, volume of water pumped and/or pressure drop.
APPLICATIONS:	Any system that has been modified or was inefficiently installed.
SIDE BENEFITS:	Additional space 'freed up' for other services.
COST FACTORS:	Entirely dependant upon amount of pipework to be removed or re-routed.
INTERACTIONS:	See also EMO 17.52 (Reduce flow rates).
EVALUATION:	Savings may be easily calculated from the heat lost from the removal of piping and/or saved pumping costs.
COMMENTS:	Normally cost effective unless removals hampered by adverse factors (eg. asbestos insulation on pipework).
REFERENCES:	EMS No. 8, Steam and Condensate Systems.

17.6.3 - Ductwork System

17.6.3.1 - Housekeeping

EMO 17.56 CLEAN FAN BLADES

DESCRIPTION:	Clean fan blades (for reduced fan power).
APPLICATION:	Large fan wheels, particularly forward curved centrifugal types in dirty environments.
SIDE BENEFITS:	Uneven dirt collection can unblance the fan wheel leading to an excessive noise, vibration, and equipment deterioration.
CAUTIONS:	Avoid getting dirt and cleaning materials in the motor or in the fan bearings.
COST FACTORS:	Low cost, nominal energy savings.
EVALUATION:	Part of regular maintenance.

EMO 17.57 MAINTAIN DRIVES

DESCRIPTION:	Align motor and driven load, correctly adjust fan belts, replace belts and couplings (for reduced transmission losses).
APPLICATION:	All belt driven equipment.
SIDE BENEFITS:	Less noise, prolonged life.
COST FACTORS:	Low cost, nominal energy savings.
EVALUATION:	Part of regular maintenance.

EMO 17.58 CLEAN OR REPLACE FILTERS REGULARLY

DESCRIPTION:	Clean or replace filters regularly.
APPLICATION:	All ventilation systems.
SIDE BENEFITS:	Potentially cleaner environment.
EVALUATION:	Maintenance.
COMMENTS:	Seen independently, a ventilation system with clogged filter will cause reduced fan power consumption. But the effect of reduced air flow may

	cause the regulation system to start other power consuming actions (cooling). Important for systems with heat exchangers.
REFERENCES:	Gage, 1977.

17.6.3.2 - Low Cost

EMO 17.59 BALANCE DUCTWORK SYSTEM

DESCRIPTION:	Adjust ventilation system for proper air flows to different spaces.
APPLICATION:	All buildings with mechanical ventilation systems, supply air systems, supply and exhaust air systems and supply and exhaust systems with heat exchangers. Complaints of poor temperature control is often caused by incorrectly balanced systems.
SIDE BENEFITS:	Increased comfort.
CAUTIONS:	Should be preceded by cleaning of air ducts, louvers, dampers, grills, etc. Air tightness of ducts should be checked if high leakage rates suspected.
COST FACTORS:	Normally cost-effective.
INTERACTIONS:	Carry out after other EMOs affecting air flow rates.
EVALUATION:	Consider when occupants complain about uneven conditions.

EMO 17.60 REDUCE AIR FLOW RATE

DESCRIPTION:	Flow rate may be reduced by: throttling air flow, fitting new fan-motor sheaves, motor speed control or by cycling fans.
APPLICATION:	Buildings with mechanical ventilation systems where the original system is oversized, load reduction is carried out or planned, ventilation rates are relaxed or room supply air/room-air temperature difference is increased. Desirability increases with climate severity and period of occupancy.
SIDE BENEFITS:	Reduced draughts, reduced noise.
CAUTIONS:	Using minimum rates allowed by codes may have adverse effect on air quality/thermal comfort. Reduced air flow rate may compromise air diffusion causing draught when cooling. Some electronic speed controllers can introduce electrical systems noise which may affect computer operations.
COST FACTORS:	Cost varies, adjusting dampers is a nominal cost item, although air flow measurement requires skilled technician.
EVALUATION:	Consider in conjunction with EMO 17.63 (Reduce motor size).Easy when air flow is known/measured. Compare against design values and take measurements only if values significantly different or if there is a suspicion that ventilation rates not as designed.
COMMENTS:	Often a possibility in buildings/rooms with low occupancy or low process load. Design flow rates are often over-estimated.
REFERENCES:	Coad, 1983.

EMO 17.61 REDUCE PRESSURE DROPS IN DUCTS

DESCRIPTION:	Remove obstacles, dirt clogged filters, comb damaged coil fins, open dampers on the index run, install turning vanes in sharp bends, expand narrow passages,eliminate long lengths of flexible ductwork or replace

with solid; reduce air flow rates.

APPLICATION: Ventilation plants, particularly those with working pressure 200 Pa and above.

SIDE BENEFITS: Noise reduction.

CAUTIONS: Rebalancing may be needed.

COMMENTS: Energy use will increase unless fan speed is reduced.

REFERENCES: AHSRAE Standard 62.81, 1981.

EMO 17.62 REDUCE AIR LEAKAGE IN DUCTS

DESCRIPTION: Repair all possible leaks in existing ducts.

APPLICATION: All ventilation ducts, especially high pressure systems.

CAUTIONS: If the leakage has been considerable, hydronic heating systems may need new balancing.

COST FACTORS: In structural ducts (especially brickwork) the leakage can be consideable, but the EMO can be expensive.

INTERACTIONS: EMO 17.64 (Duct insulation).

EVALUATION: The air volume lost in leaks can be difficult and expensive to measure. Unless it contributes to space conditioning, it can be considered as lost, and as such the evaluation is to evaluate the price of the delivered conditioned air volume reduced by the leakage percentage.

EMO 17.63 REDUCE MOTOR SIZE (FAN POWER)

DESCRIPTION: Install a smaller motor on the present fan. This may be possible after air flow and ductwork resistance reduction. In installations with large number of fans, it may be possible to interchange fan motors.

APPLICATION: Ventilation systems with motor oversized by a factor of 2 or more. Oversized motors have an adverse effect on power factor.

SIDE BENEFITS: Less noise.

CAUTIONS: Ensure that the new motor has sufficient torque to accelerate fan wheel. Planned or expected future increase in airflow/pressure demand must be checked.

COST FACTORS: Usually moderate - high.

INTERACTIONS: See EMO 17.60 (Reduce air flow rates).

EVALUATION: Estimate reduced consumption with higher efficiency motor operating point multiplied by hours of operation.

COMMENTS: Increased room/supply air temperature difference can permit lower air flows.

REFERENCES: Coad, 1983.

EMO 17.64 DUCT INSULATION REPAIR/UPGRADE

DESCRIPTION: Repair/replace existing duct insulation to prevent excessive heating/cooling loss.

APPLICATION: Ducts where heat exchange with the environment is unwanted. Both for cooling and heating systems. Most benefit where the duct losses do not contribute usefully to the conditioning of the space.

SIDE BENEFITS: Noise reduction, less condensation in cooling applications.

CAUTIONS: Vapor-tight insulation must not be used on leaky ducts. Leaks must be tracked down and repaired before insulation. Inside insulation reduces duct capacity. Inside insulation must be done with care, because later inspection is difficult.

COST FACTORS: Moderate/high. Check labour cost involved. Complete up-grading of insulation can be very costly. With high labour cost, the cost-effectiveness may not be sufficient. Replacement is preferably done when renewing the duct system.

INTERACTIONS: Reduce air leakage in ducts. EMO 17.62.

EMO 17.65 INSTALL BACK-DRAFT OR POSITIVE CLOSURE DAMPER IN VENTILATION EXHAUST SYSTEM

DESCRIPTION: Install dampers to prevent unwanted leakage of conditioned room air out of the building or outside air into the building during those periods when the fan plant is off.

APPLICATION: All buildings with mechanical ventilation systems, but particularly high rise buildings with ventilating systems service several floors and fan shutdown periods.

SIDE BENEFITS: Air pollution from other exhaust systems will not enter the system during off periods.

CAUTIONS: Dependable operation of back-draft dampers is important. Signal lamps showing open/closed are desirable. Fire safety may require back-draft dampers to open for smoke ventilation.

COST FACTORS: Back-draught dampers usually a low cost EMO. Positive closure low leakage dampers most effective, but higher cost and normally only justified on larger ventilation systems.

INTERACTIONS: Combined with shut off during nights/weekends.

EVALUATION: The back flow of room air depends on back flow resistance, the chimney and wind effect i.e., the temperature differential inside/outside duct, system height, and the length of the fan off period.

COMMENTS: Very often underestimated in less sophisticated plants.

EMO 17.66 RELOCATE MOTOR OUT OF AIR STREAM

DESCRIPTION: Relocate motor out of the air stream.

APPLICATION: In air conditioning systems where the cooling loads are more significant than the heating loads. For exhaust systems where the fan motor heat might usefully contribute to the space heating.

SIDE BENEFITS: In heating systems fan motors run cooler for longer life. Motor keeps cleaner when air in duct is dirty. Easier maintenance of motor.

17.6.4 - Heat Pumps

17.6.4.1 - Housekeeping

EMO 17.67 HEAT PUMP AIR LEAKAGE

DESCRIPTION: Check air tightness of ducts or cabinets on heat pumps using air as heat source or heat sink.

APPLICATION: Heat pumps with ducted air handling systems.

CAUTIONS: In integrated heating/ventilating systems balancing of the systems can be affected.

COST FACTORS: Very cheap.

EMO 17.68 MAINTAIN PROPER EVAPORATING AND CONDENSING TEMPERATURES

DESCRIPTION: Maintain correct evaporating and condensing temperatures.

SIDE BENEFITS: Lowers the absolute pressure ratio, thereby reducing discharge temperatures and increasing service life of compressor.

CAUTIONS: Improper temperatures may result in too small pressure differences for proper functioning of expansion devices.

COST FACTORS: Cheap for adjustments. Work on refrigerant circuit expensive.

INTERACTIONS: EMO 17.74 (Sensor functioning), EMO 17.69 (Efficient defrosting), EMO 17.71 (Expansion device).

EVALUATION: Compare the evaporating temperature to the cooling agent temperature by measurement of evaporating pressure. Compare condensing temperature to required supply temperature or external air temperature. Estimate effect of lowered condensing temperature from compressor diagrams.

REFERENCES: EMS No. 11 Refrigeration and Heat Pumps.

EMO 17.69 MAINTAIN EFFICIENT DEFROSTING

DESCRIPTION: Check functioning of defrosting devices. Timing devices causes unnecessary defrosts and should be changed to a more sophisticated system using demand control.

APPLICATION: Air source heat pumps.

SIDE BENEFITS: Minimizing the number of defrost cycles will improve compressor life.

CAUTIONS: Always check sensor operation carefully. Drainage of melted ice is essential. Holes and tubes should be sufficiently large and clean.

COST FACTORS: If improvement is considered this can become costly when work has to be carried out in the refrigerant circuit.

EVALUATION: Check defrost functioning. By measuring running time and number of starts at full load the energy delivery lost during defrosting periods can be calculated. By measuring electricity consumption during defrosting the extra power required for defrosting can be determined.

EMO 17.70 MAINTAIN PROPER HEAT SOURCE/SINK FLOW RATES

DESCRIPTION: Check the flow rates to the evaporator and the condensor.

SIDE BENEFITS: Correct flow rates can reduce noise and improve life expectancy (depending on which way the corrections go).

CAUTIONS: If flow rates have to be increased considerably, piping or duct work may have to be changed to avoid noise, erosion and excessive pressure drops.

COST FACTORS: Normal adjustments are cheap. Changing pumps, fans or piping and ductwork will be costly.

INTERACTIONS: See EMOs 13.1 and 13.2 To alter evaporation and condensing Temperatures.

EVALUATION: If flow rates are not correct first check for leaks, clogged filters, incorrectly set valves and faulty pumps or fans. If nothing is found to be wrong re-adjust valves or speed controls to achieve the correct flow rates, otherwise change to larger/smaller pumps or fans. Also measure power consumption of fans or pumps. Compare measured values with calculated optimum values.

EMO 17.71 MAINTAIN FUNCTIONING OF HEAT PUMP EXPANSION DEVICE

DESCRIPTION: Check operation of expansion device over entire operating range of the heat pump. If correct evaporating and condensing temperatures and correct amount of superheat are not obtained adjust or change the expansion device to more suitable type.

SIDE BENEFITS: Correct refrigerant temperatures/pressures improve compressor service life.

CAUTIONS: Any water vapor or other foreign matter left e.g. from service can impair functioning of expansion devices. Too little super heat may cause liquid to enter compressor.

COST FACTORS Adjustments fairly cheap. Changing expansion devices can be quite costly.

REFERENCES: EMS No. 11 Refrigeration and Heat Pumps.

EMO 17.72 CHECK HEAT PUMP STAND BY LOSSES

DESCRIPTION: Measure electric or thermal energy consumption of heat pump when it is in a stand by mode. In particular check the following items: do circulating pumps/fans continue to operate, are crank case heaters operating and are they required to, losses through insufficient insulation; losses from compressors placed outdoors; are water-cooled condensors placed outside of building (requiring warm water circulation at sub-zero temperatures).

CAUTIONS: Never shut off circulation of water in ourdoor condensors if risk of freezing exists. Be careful with fans that are part of ventilating systems.

COST FACTORS: Corrections are normally cheap. Moving outdoor condensors (splitting a unit) or compressors will be costly.

EVALUATION: Stand by losses are easily estimated by measuring power consumption during off duty periods. Estimate savings by multiplying seasonal number of hours in off duty mode with stand by losses.

EMO 17.73 MAINTAIN FULL CHARGE OF REFRIGERANT

DESCRIPTION: Locate and correct leaks and add refrigerant as necessary.
SIDE BENEFITS: Improved service life of the compressor.
CAUTIONS: Loss of refrigerant has potentially adverse environmental effects. Overcharging can cause liquid refrigerant to enter compressor which can damage compressors and affect performance of all compressor types.
COST FACTORS: Elimination of leaks will remove cost of refrigerant recharging although cost of repairing leaks can be costly.
EVALUATION: Use refrigerant detector to locate leaks.
REFERENCES: Stamm, 1978. EMS No. 11 Refrigeration and Heat Pumps.

17.6.4.2 - Low Cost

EMO 17.74 CHECK SENSOR FUNCTIONING AND PLACEMENT FOR HEAT PUMPS

DESCRIPTION: Check functioning of sensors (operation and calibration) and positioning of sensors (are they really measuring the intended parameter), for example safety thermostats, pressure switches, sensors controlling operation of unit.
SIDE BENEFITS: Correct sensor operation improves heat pump life.
COST FACTORS: Work can be time consuming and therefore costly.
EVALUATION: Evaluate sensor functioning by measuring the respective temperatures, pressures and flow rates and compare them with the set-point values and also check that set-point values are the required settings.
REFERENCES: EMS No. 11 Refrigeration and Heat Pumps.

EMO 17.75 MAINTAIN PROPER STARTING FREQUENCY AND RUNNING TIME OF HEAT PUMP

DESCRIPTION: Check and correct if necessary the storage capacity of domestic hot water or heating water and the start/stop criteria including delayed starts and minimum operating times.
SIDE BENEFITS: Less noise and better life expectancy.
CAUTIONS: Increasing storage capacity can cause larger storage losses.
COST FACTORS: Checks and adjustments of controllers are cheap. Changesin size of heat pump or storage capacity are costly.
EVALUATION: Check starting frequency and running times to ensure that recommended values from the compressor manufacturer are kept.

17.6.4.3 - Retrofit

EMO 17.76 REPLACE OR UPGRADE HEAT PUMP SUPPLEMENTARY HEAT SUPPLY

DESCRIPTION: Replace existing supplementary heat supply with more economic and/or energy efficient type. Modify installation to run heat pump as base load and change control method for supplementary heating.

APPLICATION:	Retrofitted bivalent heating systems where existing boilers have been used as supplementary heat supplies to heat pumps.
SIDE BENEFITS:	Boiler capacity can be reduced, increasing both efficiency and lifetime of the unit.
CAUTIONS:	Always use time delay to start supplementary heat supplies. If electricity will be used as supplement, check load can be accommodated by existing system.
COST FACTORS:	Replacement is expensive. Upgrading can be expensive if existing pipework has to be changed. Changing starting criteria is normally cheap.
EVALUATION:	Evaluate efficiency of existing burner or boiler. Check oversizing and starting criteria by measuring running time and number of starts or comparing installed power and peak load.

18 - BUILDING ENVELOPE

18.1 - Introduction

Understanding how energy is lost through the envelope is fundamental to controlling energy consumption, both in terms of direct energy loss through the envelope itself and the way these losses influence mechanical and electrical system operation which must compensate for 'imperfections' in the envelope system. A discussion on Fundamentals is provided below which should be read in conjunction with EMS No. 18, Architectural Considerations.

18.2 - Fundamentals

Heat is lost or gained through the envelope system by a combination of Conduction, Convection and Radiation.

Conduction is the transfer of heat through a solid material from the warmer surface of the material to the cooler surface. Because all materials have thermal capacity, any change in heat transfer through the material, due to changes in temperatures or energy transferred to the surfaces, must first change the amount of heat stored in the material. Thus, thermal capacity tends to slow down the rate of change of conduction heat flow, and high thermal capacity materials and structures are often spoken of as having a high degree of "thermal inertia" or "thermal mass".

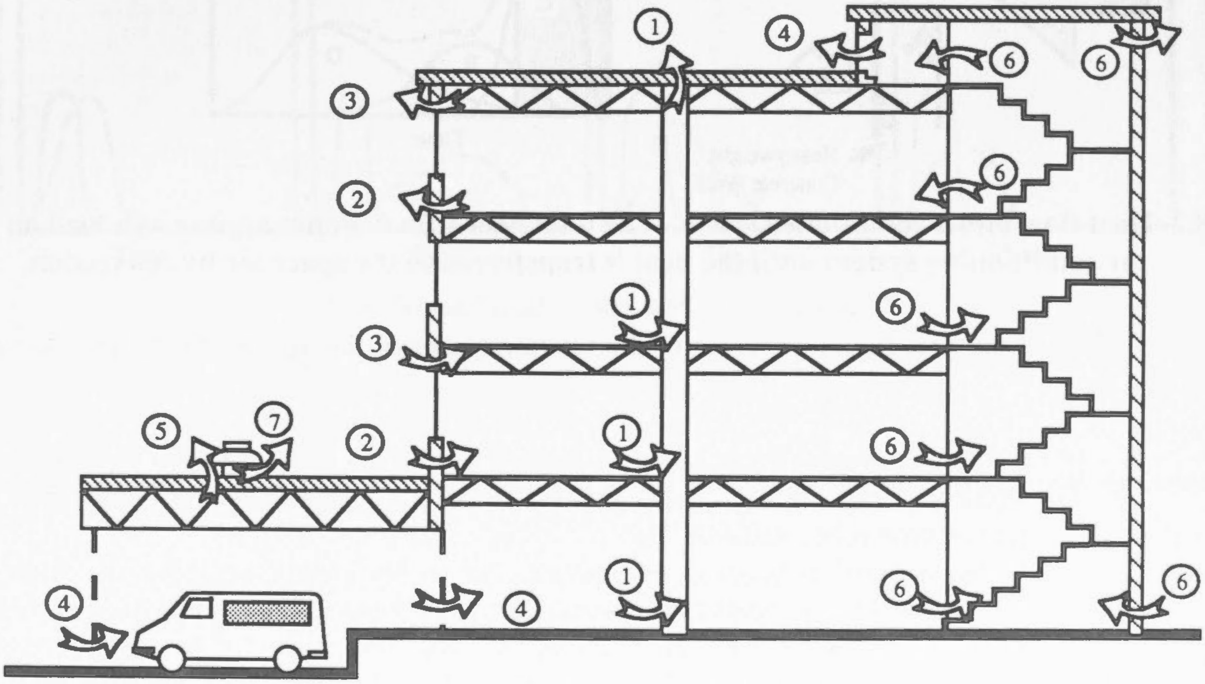
In the case of buildings, conduction will occur through the envelope components, through interior partitions to adjacent spaces maintained at different temperatures, and into or out of the building mass itself and any furnishings where the temperature is different to the air temperature. Conductive heat losses increase with growing moisture content of the insulation. The change may be very large if water penetrates into the insulation. The conduction is greater than the average of the building envelope at, for example, structural building elements. These spots are referred to as "thermal bridges".

In the case of **convection**, heat is transferred by air circulation. Heat transfer by convection will occur at all air to solid interfaces such as between the outside and the exterior layers of envelope material, and between inside air and all other surfaces of the room and furnishings. Convection will also occur in spaces between layers of construction in walls or roofs where convective loops can be established increasing heat transfer. Convection currents created in the space itself by the envelope system can also have a direct effect on occupant comfort. Convection currents caused by down draughts from large cold surfaces, particularly windows, give rise to major local comfort problems.

Infiltration is also a convective loss and differs from the above discussion in that infiltration air actually passes through the envelope. Inside-outside temperature differences cause air density differences between the inside and outside of the building. This buoyancy or "stack effect" pressurizes the upper part of the building which, together with wind pressure on the building exterior, causes air to move into (air infiltration), and out of the building (air exfiltration). Cold outside air entering the lower part of the building can cause significant occupant discomfort.

The relative effects of wind and stack action on the infiltration rate are complex in nature and will depend on building characteristics as well as weather. If there is no wind pressure, infiltration occurs mostly at the lower part and exfiltration at the upper part of the building. If there is a wind pressure, infiltration occurs mainly on the lower part of the windward side and exfiltration on the upper part of the leeward side. Note that pressure difference also occurs across internal floor partitions. Imbalance in the air supply and exhaust rate to the building can also affect pressure distribution and infiltration and exfiltration. For example, an exhaust fan exhausting 200 L/s will induce 200 L/s of infiltration air through the envelope system.

Radiation Unlike convection and conduction, radiation can occur in a vacuum; i.e. it does not rely on a material (solid or gas) to transfer heat. There are a number of important sources of radiative heat transfer in buildings, not least of which is direct solar radiation through windows. It is important to note that radiation occurs not only between the various room surfaces and in the room but between the room surfaces and the occupants and that any hot or cold surface can directly influence thermal comfort regardless of the air temperature.



Exfiltration and infiltration generally occur:

① around plumbing stack, vertical shafts,
② through exterior walls, particularly around and through windows,
③ above dropped ceilings,
④ around entries,
⑤ through penetrations in outer walls and roofs,
⑥ by leakage into and out of interior stair shafts,
⑦ by leakage through mechanical and electrical equipment, e.g. dampers.

Figure 18.1 Common air infiltration and exfiltration paths

18.2.1 - Building Mass and Thermal Response

There are two different aspects relating to building thermal mass which are often confused and misunderstood.

The first relates to the effect that exterior envelope mass has on the conduction heat transfer through the envelope into the space. The (thermally) heavier the wall or roof, the greater the thermal inertia and any temperature disturbance at the outside wall, for example a sudden temperature change or change in solar radiation, will take some time to be felt on the inside surface. See Fig.18.2.

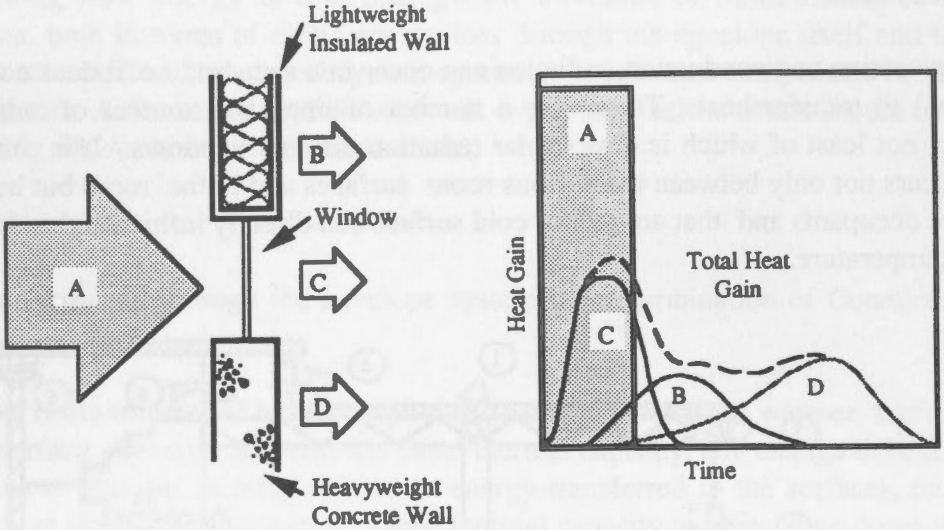


Fig. 18.2 Heat flow into a conditioned space. The total heat gain does not appear as a load on the air conditioning system until the heat is transferred to the space air by convection.

The second concerns the heat flow into or out of the interior spaces of the room. These heat flows are precipitated by:

- radiant exchanges from warm surfaces to cooler surfaces, for example from warm sunlit walls and radiators to cooler walls and floors and from direct solar radiation falling onto room surfaces, and
- from convection induced exchanges, caused by normal temperature drifts and setback and setup scheduling, resulting in changes in space temperature. These aspects are illustrated in Fig. 18.4.

The total heat capacity is a function of the thermal mass of the building, while the speed at which heat can be absorbed or released is a function of the conduction of the interior surfaces of an enclosure. The effect of an insulating layer, for example a carpet and under pad, over a heavy mass element such as a concrete floor tends to reduce the impact of the mass in that it makes the space perform more like a low mass space; i.e. thermally more responsive. Mass then affects energy flows in two ways; i.e. to slow down heat flows into the space from outside and from inside into the structure (including back into the outside wall or roof). These effects can be manipulated to advantage by the building designer, and, to a lesser extent, by the retrofitter. Conversely, incorrect handling can have a negative impact on energy consumption and thermal comfort. Mass is only of advantage where space load demand swings between surplus and shortage of heat; heat being stored in the building mass or delayed in the building envelope when there is a surplus and released into the space when there is a deficit. Because these heat flows are not readily controllable, the storage release cycle is never completely efficient. It can be considered worthwhile only when the excess heat is free, or in the case, during cooling, when the delayed cooling load appearing in the space can be removed cheaply; for example by ventilation as opposed to mechanical cooling.

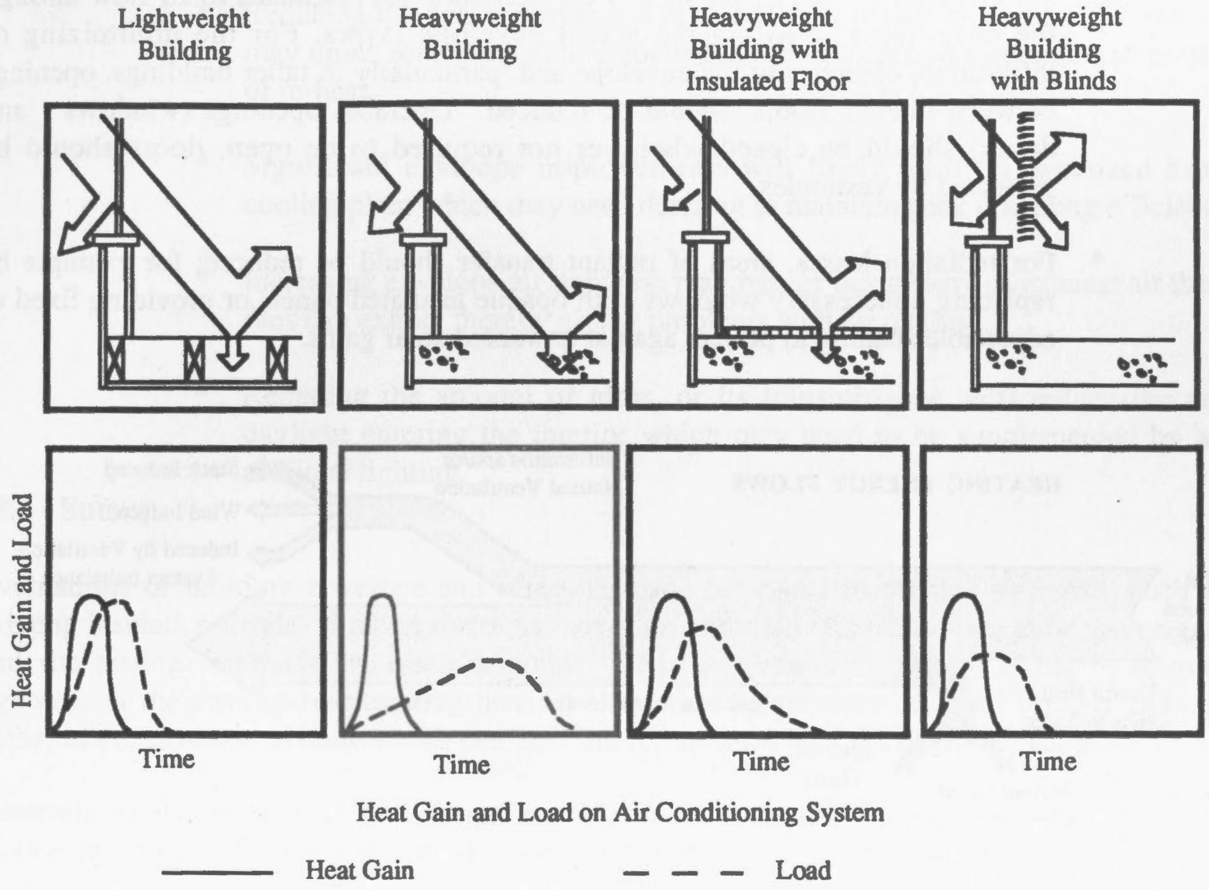


Fig. 18.3 Simplified illustration of the effects of building thermal mass on thermal response.

In the case of heating, setback strategies tend to negate the effects of excess heat stored during the day since, at the start of setback, heat stored in the fabric is released to the space helping to maintain the space temperature above the setback level. During preheat additional heating is required to recharge the heat lost from the structure. Because it takes some time for cold walls to reach equilibrium with the air temperature, comfort will be somewhat lower. Setback and setup times can be adjusted to preserve comfort and still save energy.

18.3 - Energy Losses

Figure 18.4 provides an overview of the various energy flows into and out of a conditioned space. The width of the arrows gives some idea of the relative magnitudes of the energy flows, although the relationships vary greatly between different climates and constructions.

Basic strategies for reducing envelope energy losses include:

* For conduction losses, the primary option entails reducing the rate of conduction by the addition of thermal insulation; i.e. materials with low conductivity, especially at thermal bridges, and by protecting the insulation from moisture.

- * For convection losses, options rely on increasing the resistance to air flow through the envelope and within the actual envelope layers. For the minimizing of infiltration, openings in the envelope and, particularly in taller buildings, openings between interior floors, should be reduced. Operable openings (windows and doors) should be closed whenever not required to be open, doors should be protected by vestibules.

- * For radiation losses, areas of radiant transfer should be reduced; for example by replacing unnecessary windows with opaque insulated panels or providing fixed or adjustable shading to protect against unwanted solar gains.

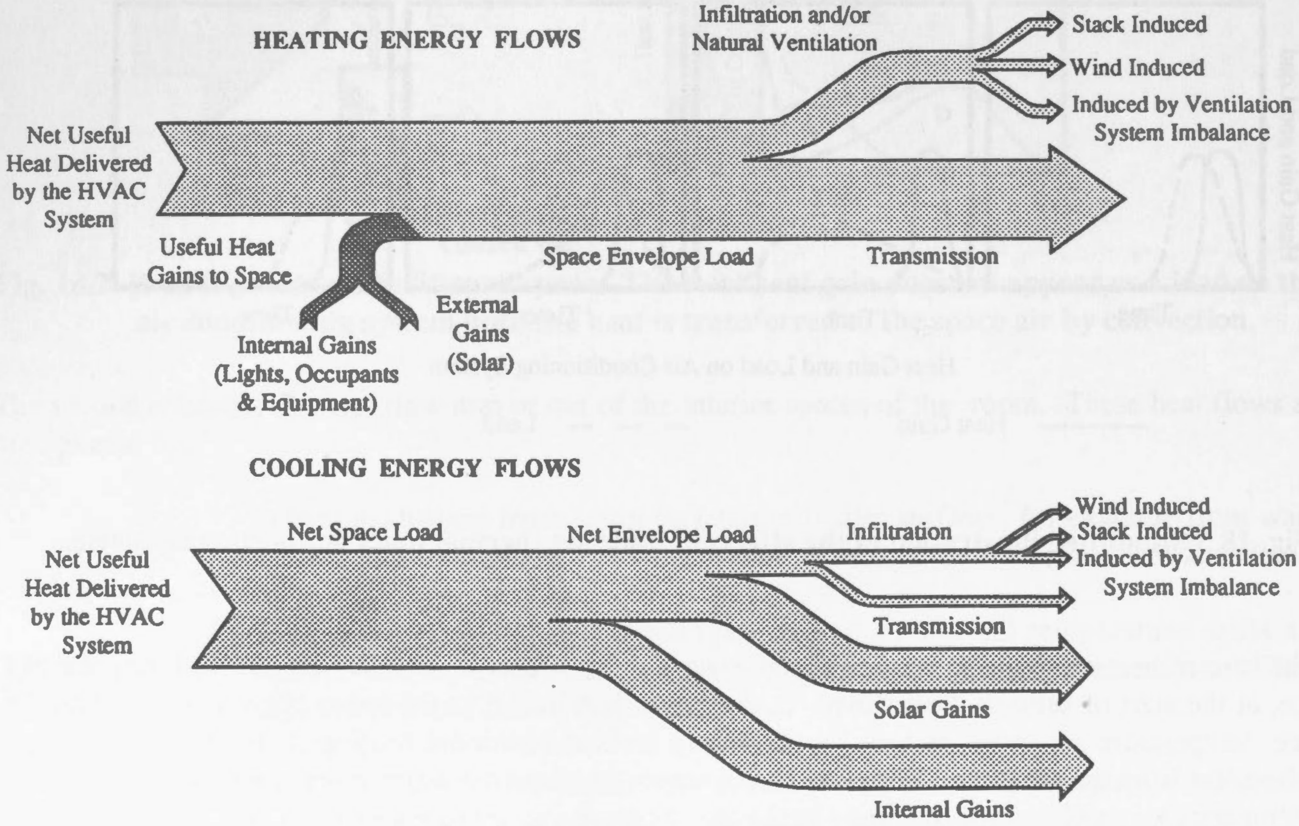


Fig. 18.4 Energy Flows in an occupied space

18.4 - Interactions

Almost all envelope changes that are likely to be made will impact in some way on other subsystems and their interactions must not be overlooked by the auditor otherwise adverse effects may occur or full benefit of the EMO may not be realized. Some general areas of interaction are presented below, more specific information is given in Section 18.6.

- * Reducing solar gains through windows will reduce cooling loads but may increase heating requirements; fixed shading devices are rarely as 'efficient' as properly controlled adjustable devices.

- Reducing the heat transmission or window solar gain of some areas and not others may upset zone temperature controls causing localized discomfort or excessive use of re-heat.
- Significant envelope improvements will likely result in oversized heating and cooling plant which may need derating to maintain peak operating efficiency.
- Increasing envelope air tightness may reduce the amount of exhaust air that exhaust fans can extract thereby giving problems with air quality.
- Reducing the amount of glass, or its transmittance, will reduce the amount of daylight entering the interior which may need to be supplemented by additional artificial lighting.

18.5 - Survey

Evaluations of building envelope can often be made by visual inspection or noting such things as existing insulation levels. Such evaluations, however, are often either incomplete or misleading or both and site testing methods are often desirable. This is particularly true in trying to assess the air tightness of the envelope or spotting thermal anomalies (conductive thermal bridges and convection paths) in the envelope system, which can account for up to 20% of the overall U value.

Determining the amount of air leakage is problematic because testing methods are normally fairly labour-intensive and often only practical on smaller buildings. Identifying leakage is an easier task with a number of options ranging from simple (smoke puffer) to sophisticated (thermographs). In cold climates warm moist air leaving the structure can condense or freeze in the outer layers of the envelope and the auditor should be particularly alert for such occurrences which can lead to serious building degradation problems.

Infra-red scanning procedures are useful for detecting thermal leakages, but like infiltration measurement the procedure is expensive.

The auditor during his walk-through should be alert for symptoms resulting from poor envelope performance, and should resort to more sophisticated, and expensive techniques only where problem areas appear not to be readily solved or quantifiable by simpler means.

18.5.1 - Walk-through Audit Procedure

The following information should be collected during the initial review of plans and specifications and during the walk-through.

Windows
Window review should include windows between conditioned and non conditioned spaces.

Glazing Materials Note the number of panes and whether sealed units or separate sashes, the glazing material (e.g. whether clear or special glass such as heat reflecting or low emissivity). Record any missing or damaged glazing or presence of water vapor or condensation between window panes.

Frame construction Note the type of frame material (wood or metal) and if metal try to determine if the frame is "thermally broken". Determine if windows are operable, if so check to see if they still open and close properly, check if catches function; record the type of opening (e.g. pivoting, sliding) and the type and condition of weather seals. Check for leaks around the window with a smoke pencil.

Shading devices Record detail of interior and exterior shading devices and note the method of shade operation. Note if outside vegetation provides protection from summer sun.

Window utilization Make an evaluation of the usefulness of the window. For example windows in unoccupied storage spaces could be considered for replacement by insulated panels whereas in occupied areas this is unlikely to be a desirable option.

Window area Estimate the extent of glazing, either total area or percentage of wall area; photographs taken of each facade will allow an accurate enough estimate to be made.

Doors Door review should include interior doors between conditioned and non-conditioned spaces and doors providing barriers to floor to floor air movement (e.g. doors into stair shafts).

Door traffic Determine type (people, freight) and frequency of use.

Door configuration Note where doors are not protected by vestibules and whether or not vestibules are correctly sized i.e. so that both doors are not normally open together.

Door construction Note construction materials and arrangement and condition of weather stripping.

Door use Note where door closers are provided and whether or not they operate satisfactorily. Note where doors are wedged open.

Spare Walls

Wall inspection should include walls between heated and unheated spaces.

Construction Record construction for each wall type, and estimate the U value. This may be difficult to determine where construction drawings are not available; consider cutting a small test hole in non critical space. Make a note where radiators are installed against exterior walls.

State of repair Note the general state of repair and record evidence of air leakage sites (gaps, cracks, etc.); evidence of thermal bridges (discoloration); and evidence of moisture problems (wetness, stains, mould growth, etc.) and general condition problems such as spoiling stucco, missing siding and masonry joint deterioration and efflorescence.

Roofs

Construction For each roof design, note the type of construction and estimate the U values (see also walls construction).

Ventilation Review adequacy of venting in ventilated roof spaces and attics. Note any instances where interior exhaust systems discharge into the space.

State of Repair Note incidence of water leaks, ice dams, wet insulation, rot and mold.

18.6 - Annotated List of Energy Management Opportunities

18.6.1 - Housekeeping

EMO 18.1 CLOSE/OPEN WINDOWS AND DOORS TO MATCH CLIMATE

DESCRIPTION:	Adjust windows and doors to control ventilation rates in order to satisfy minimum air quality criteria or cool the interior. The objective is to limit the use of space heating or cooling.
APPLICATION:	All buildings with operable windows.
CAUTIONS:	This is the simplest ventilation and cooling method but it can be easily misused as a method of temperature control for an overheated or cooled building. The degree of air mixing can cause local discomfort.
COST FACTORS:	This is a no-cost operational procedure.
INTERACTIONS:	Should be first method of achieving appropriate building temperatures when outside conditions are favourable. Also see EMOs 18.3 Operate shades and 18.10. Automatic door closing.
EVALUATION	Use of on site inspection and, possibly, a questionnaire to determine prior behaviour may prove useful.
COMMENTS:	Closely related to HVAC EMOs.
REFERENCES:	Government Institutes Inc. 1981; Gatts 1974.

EMO 18.2 ENSURE PROPER VENTILATION OF ATTIC SPACES

DESCRIPTION:	Ventilation under the roof system limits ceiling temperature and moisture build-up (moisture in insulation will increase heat transfer).
APPLICATION:	All buildings with ventilated roof spaces.
SIDE BENEFITS:	Lower roofing temperature prolongs roofing life. Limiting moisture build-up protects the wood.
CAUTIONS:	Over-ventilation can cause additional energy loss.
COST FACTORS:	No cost is involved using existing vents.
INTERACTIONS:	Air vents should not direct air into insulation or attic spaces. See EMO 18.9 Add Insulation and 18.13. Correct excessive air leakage.
EVALUATION:	Inspect for improper venting of moist air into attic space.
COMMENTS:	This EMO is high priority for ensuring material and building lifetime.

EMO 18.3 OPERATE SHADES AND SHUTTERS

DESCRIPTION:	Control of building envelope elements to regulate effects of solar energy. Consider automatic equipment to perform function.
APPLICATION:	All windows except those on northern elevations.
SIDE BENEFITS:	Control of solar energy can assist building heating and limit building cooling load.

CAUTIONS: These controls must be used properly, or glare, over-heating, or excessive cooling loads can result. Care must be exercised to avoid deterioration of materials due to the effects of sunlight.
COST FACTORS: No-cost option if manually operated, automatic systems generally provide greater saving.
INTERACTIONS: Interactions with occupant comfort is a prime concern. Conditions resulting from solar gain can be localized.
COMMENTS: Should be high priority item.
REFERENCES: Dubin 1976; ECM 1982.

EMO 18.4 CLOSE CONVECTION PATHS IN SHAFTS AND STAIRWELLS

DESCRIPTION: Convection via shafts and stairwells can cause energy loss and complicate building control. Sealing smaller openings involves sealants, (polyurethane and plastic). Doors on stairwells may be appropriate but fire regulations must be observed.
APPLICATION: All multi-storey buildings.
SIDE BENEFITS: Improved comfort.
CAUTIONS: Sealing materials must be compatible with achieving appropriate indoor air quality (e.g. non-toxic and without strong odour).
COST FACTORS: Cost can vary greatly depending on the problem to be overcome. At the low cost end, retrofit can have very high cost benefit.
EVALUATION: Use smoke tracers to investigate leakage paths.
COMMENTS: Should be ranked high in EMO priorities.
REFERENCES: Dubbing, 1976; Harrie, 1983; Silvers and Tue, 1985.

EMO 18.5 REPAIR BROKEN GLAZING

DESCRIPTION: Repair broken glazing.
APPLICATION: All buildings.
SIDE BENEFITS: Improved building security.
CAUTIONS: Glazing material should be carefully chosen in high breakage locations.
COST BENEFITS: Cost benefit completely over-shadows cost.
INTERACTIONS: Possibly combine with other EMOs such as double or triple glazing replacement or installation of window films or tinted glass.
EVALUATION: Do without further evaluation.
COMMENTS: This is an first priority EMO.
REFERENCES: Gatts 1974.

EMO 18.6 MAINTAIN LATCHES AND OTHER MECHANISMS

DESCRIPTION: Maintain hardware; windows, doors, vents, etc., to ensure tight closure. Repair doors and windows not closing properly to limit air infiltration.
APPLICATION: All buildings.
SIDE BENEFITS: Comfort, improved security and added component lifetime.
CAUTIONS: Final tightness must allow proper ventilation in space.
COST FACTORS: Cost can be low if quality materials have been used on original installation.

INTERACTIONS: Combined inspection with other infiltration items especially EMO 18. Caulking and weatherstripping.

EVALUATION: Use smoke tracers.

COMMENTS: High priority EMO.

EMO 18.7 REPAIR/UPGRADE SEALS, CAULKING AND WEATHER-STRIPPING

DESCRIPTION: Repair or upgrade systems limiting convection and conduction losses through building envelope. Consider using superior caulking and weather-stripping for up-grading to trouble-free control of air leakage.

APPLICATION: All buildings.

SIDE BENEFITS: Occupant comfort improved.

CAUTIONS: Choose non-toxic and odour acceptable materials. Do not reduce ventilation in poorly ventilated massive buildings. Do not reduce ventilation where risk of indoor pollution.

COST FACTORS: Cost should consider repair versus replacement. Durable, flexible caulking is available at reasonable prices and may be cost effective over the long term.

INTERACTIONS: Combine with inspection of other air infiltration items, for instance, EMO 18.6 Door and window latches. See, also EMOs 18.11 Storm doors and windows and 18.13 Correct excessive air leakage

COMMENTS: Priority should be high when normal maintenance is due. See Figure 18.1 for typical leakage sites.

REFERENCES: Dubin 1976, EMS NO. 18, Architectural Considerations.

18.6.2 - Low Cost

EMO 18.8 ADD INSULATION BEHIND EXTERIOR RADIATORS

DESCRIPTION: Add insulation, especially reflecting type, behind radiators on exterior walls. Remove obstructions to air flow around radiators.

APPLICATION: Buildings that are inadequately insulated.

INTERACTIONS: Alternative (lower cost) option or can compliment EMO 18.18 (insulate walls).

COMMENTS: The walls behind radiators experience the highest temperatures of the building envelope and therefore it is a key area for increasing the level of insulation.

EMO 18.9 ADD ATTIC INSULATION

DESCRIPTION: Add attic insulation by blowing, pouring or installing batts to raise the insulation level to recommended amount.

APPLICATION: All buildings with sub-standard insulation levels in attic or under the roof.

SIDE BENEFITS: Elimination of cold ceilings which cause discomfort and condensation and mould problems. Insulation can also reduce air infiltration energy losses.

CAUTIONS: Application must avoid blocking attic ventilation louvers, covering lighting fixtures that could cause overheating and possible fire damage. Some of the insulation materials are comprised of small particles, therefore, care should be taken that the insulation material does not drift down into the occupied space.

Moisture damage may be caused if insulation is covered by materials preventing diffusion.

COST FACTORS: Insulation levels are related to energy savings but the addition of the first portion of the insulation has a much greater effect than adding more insulation to an adequate system. This must be taken into account in the cost benefit analysis.

INTERACTIONS: With EMO 18.2 Ensure proper ventilation of attic spaces.

COMMENTS: If insulation levels are low this item should be given a very high priority EMO.

REFERENCES: Dubin 1976; Jacobson 1985.

EMO 18.10 ADD AUTOMATIC DOOR CLOSING SYSTEM BETWEEN HEATED AND UNHEATED SPACE

DESCRIPTION: Automated systems help limit air movement between unconditioned and conditioned spaces.

APPLICATION: Any frequently used door system.

SIDE BENEFITS: Greatly improved comfort in the adjacent spaces.

INTERACTIONS: Related to EMO 18.1 Close/Open windows but with automated feature. See also EMO 18.12 Improved door designs.

EVALUATION: Use simple infiltration checks and local space temperature measurements to check existing situations.

EMO 18.11 INSTALL STORM WINDOWS AND DOORS

DESCRIPTION: Add a window or a door in series with the existing unit.

APPLICATION: Most buildings. High priority on windows if building has single glazing.

SIDE BENEFITS: Can reduce air infiltration in addition to improving U-value.

COST FACTORS: Cost factors important with this EMO, especially for doors.

INTERACTIONS: Interaction with EMOs 18.6 Maintain latches and 18.7 Upgrade seals demands good seal to achieve performance. Window upgrade EMOs and EMO 18.15 Convert windows are alternatives.

COMMENTS: Storm window added to original window can save more energy than double glazing if air gap is correctly sized.

REFERENCES: Dubin 1976.

EMO 18.12 REPLACE DOORS WITH IMPROVED DESIGN

DESCRIPTION: Use revolving doors, vestibules and insulated doors to replace poor entrance design and eliminate air curtains. Use dock seals and strip doors on loading bays.

APPLICATION: Revolving doors can be considered in larger, particularly multi-storey buildings.

SIDE BENEFITS: Both improved U-values and reduced air infiltration can result from proper entrance design.

INTERACTIONS: Competes with EMO 18.6 Maintain latches, EMO 18.10 Automatic door closures, EMO 18.11 Storm windows and doors.

COMMENTS: Priority will depend on exposure of the entrance to wind, amount of pedestrian and freight traffic and building height.

REFERENCES: Dubin 1976. EMS No. 17, Materials Handling and On Site Transportation.

EMO 18.13 CORRECT EXCESSIVE ENVELOPE AIR LEAKAGE

DESCRIPTION: Identify and improve seals and construction details in problem areas creating convection and infiltration paths.

APPLICATION: Those buildings with common design deficiencies.

SIDE BENEFIT: Improved comfort through reduction of cold surfaces and drafts. Reduced exfiltration of moist air in to attic areas which can cause condensation problems.

CAUTIONS: Lack of infiltration, unless supplemented by ventilation systems, can reduce air space quality, create condensation problems and upset draft requirements for fuel burning devices.

COST FACTORS: Cost is highly variable especially when problems are not easily accessible, e.g. leakage into walls.

INTERACTIONS: Similarities with EMO 18.4 Close convection paths in stairwells but degree of corrective measures is more costly. Also interacts with EMO 18.2 Properly vent attic, insulation upgrades and EMO 18.7 Upgrade seals.

COMMENTS: High priority item governed by cost.

REFERENCES: Silvers and Tye 1985; Dutt 1986, EMS No. 18, Architectural Considerations.

EMO 18.14 INSTALL WINDOW FILM

DESCRIPTION: Add stick on films to existing windows. Two types of films are available: summer solar reflective and winter internal heat retaining.

APPLICATION: Window systems with low U-values or clear glass.

SIDE BENEFITS: Special films can markedly lower window U-value. Window films can limit local overheating and glare from sky and sunlight.

CAUTIONS: Durability of stick-ons should be evaluated. Check for user acceptability before installation. Can reduce daylight contribution and useful solar gains.

INTERACTIONS: Has impact on local comfort and day lighting; alternate to window replacement (EMOs 18.23). Can be high priority if occupants are uncomfortable.

REFERENCES: Dubin 1976.

EMO 18.15 COVER, INSULATE OR CONVERT UNNECESSARY WINDOWS AND DOORS

DESCRIPTION: Cover, seal off and/or insulate window systems that are not necessary for ventilation or day lighting. Alternatively, consider converting windows or doors to wall system.

APPLICATION: Buildings where there are too many windows.

CAUTIONS: Day-lighting levels will be reduced and occupant satisfaction may be diminished. Solar benefits will be eliminated.

COST FACTORS: Converting windows to walls is more expensive than covering or insulating windows.

INTERACTIONS: Unless this retrofit is undertaken correctly, it may encourage moisture condensation or over heating of materials in the window insulation sandwich. Alternative to window upgrade or storm windows.

REFERENCES: Dubin 1976.

EMO 18.16 MODIFY VEGETATION TO SAVE ENERGY

DESCRIPTION: Vegetation on south side of building should allow solar energy to reach buildings in winter and shade building in summer. Vegetation should also be considered on the windward side of the building.

APPLICATION: Buildings with flexibility in tree and shrub plantings.

SIDE BENEFITS: Enhanced appearance.

CAUTIONS: Planting too near to the building can result in structural damage.

COST FACTORS: Cost can vary from trimming trees and shrubs to planting substantial trees for wind protection.

INTERACTIONS: Interacts with day lighting EMOs and local comfort. Control system must be able to accommodate winter heat gains without causing overheating.

COMMENTS: Vegetation growth is slow.

REFERENCES: Harrie, Buckley, Heissler, 1982; Mattingly, 1979.

EMO 18.17 INSTALL SHUTTERS, BLINDS OR SHADES

DESCRIPTION: Addition of heat and light control elements over windows lowers U-values of window system. Can be fixed or movable, manual or automatic control.

APPLICATION: All windows requiring heat and/or light control.

SIDE BENEFITS: Improved thermal and visual comfort.

CAUTIONS: Effective insulating internal shutters may trap solar radiation causing window damage by raising window temperatures to high levels. Can be avoided by leaving the upper part of shutters unsealed.

COST FACTORS: Wide variety of cost. Most savings if movable, automated devices but most occupant satisfaction if manual control.

INTERACTIONS: Alternative or complimentary to glazing replacement. See also EMO 18.3 Operation of shades, also alternate to EMO 18.22 External shading devices.

COMMENTS: Priority item where windows are the dominant heat loss.

REFERENCES: Dubin, 1976; Government Institutes Inc., 1981.

18.6.3 - Retrofit

EMO 18.18 INSULATE WALLS

DESCRIPTION: Add insulation to exterior walls and walls between heated and unheated spaces by: filling voids in cavity walls, adding insulation and cladding to exterior of wall, and adding insulation and new drywall to interior of wall.

APPLICATION: Building without insulation or with sub-standard insulation levels.

SIDE BENEFITS: Improved comfort at lower air temperatures because inside wall surface temperature increased; often reduced air infiltration. Convection loop problems can be eliminated through added cavity insulation. Air infiltration through walls may be markedly reduced by this action. Possible elimination of condensation and mould problems where existing walls very much below recommended insulation standards.

CAUTIONS: When adding interior insulation to walls with vapour barrier, insulation on warm side of vapour barrier should be no greater than 1/3 insulation value on cold side. Some of the insulation materials are composed of small particles, therefore care should be taken that insulation materials do not enter into the living space. Materials that have odour or any toxic characteristics must be avoided in wall insulation (e.g. ureaformaldehyde). New condensation problems may occur if vapour diffusion is prevented or restricted. Adequate drainage is important after upgrading of below grade insulation.

COST FACTORS: Outside insulation becomes financially attractive if the building facade is due for maintenance or repair.

INTERACTIONS: Can be combined with EMO 18.15 Cover unnecessary windows and doors or EMO 18.13 Correct air leaks. For optimal savings combine with distribution system adjustment. Heating plant seasonal efficiency may drop as a result of this EMO, unless the boiler is downsized. See also EMO 18.21 Thermal bridges and EMO 18.8 Insulation behind radiators.

REFERENCES: Dubin 1976, EMS No. 18, Architectural Considerations.

EMO 18.19 UPGRADE INSULATION OF FLAT ROOFS

DESCRIPTION: Increase insulation level of existing roof by adding or replacing existing exterior insulation or increasing level of cavity or interior insulation.

APPLICATION: Buildings with flat roofs and sub-standard insulation levels. Buildings where the roof is due for maintenance or repair.

SIDE BENEFITS: Elimination of cold ceilings causing discomfort, condensation or mould growth.

CAUTIONS: Make sure that the old surface material, which prevents diffusion, will not cause any future damage.

COST FACTORS: Payback of exterior insulation most beneficial when existing roof membrane is being replaced for maintenance purposes.

REFERENCES; EMS No 18, Architectural Considerations.

EMO 18.20 ADD INSULATION TO FLOORS

DESCRIPTION: Add insulation to those floors that constitute the thermal envelope. In crawl-spaces, insulate the exterior walls surrounding the crawl-space.

APPLICATION: Buildings with sub-standard insulation to the ground.

SIDE BENEFITS: Improved comfort by eliminating a cold floor. Can suppress sound from basement such as from furnace/boiler.

CAUTIONS: The crawl-space will become warmer which may cause mould growth. Ensure sufficient ventilation. Check for moisture and mould growth during the first year.

COMMENTS: A major concern with this retrofit action is to make certain that there is a justifiable heat loss through the floor. Often insulation is better applied to basement walls rather than basement ceiling (living space floor).

EMO 18.21 LOCATE AND MINIMIZE THE EFFECT OF THERMAL BRIDGES

DESCRIPTION:	Locate thermal bridges, add insulation where possible.
APPLICATION:	Those buildings which exhibit structural anomalies causing thermal bridging to take place.
SIDE BENEFITS:	Minimizes local thermal anomalies which can seriously affect building envelope performance including local moisture problems (condensation).
COST FACTORS:	Cost directly dependent upon accessibility of thermal bridge.
INTERACTIONS:	Heavily influenced by insulation EMOs.
COMMENTS:	Basic architecture of building is generally the cause of problem, hence it is characteristic of certain designs.
REFERENCES:	Silvers and Tye, 1985.

EMO 18.22 REPLACE OR COMPLIMENT INTERNAL BLINDS WITH EXTERNAL SYSTEMS.

DESCRIPTION:	Use external systems to replace internal blinds to reduce solar load. Intercepting solar load is much more efficient with external systems.
APPLICATION:	Primarily in air conditioned buildings or buildings with undersized cooling systems.
SIDE BENEFITS:	Improved comfort; can be considered as an alternate to air conditioning.
CAUTIONS:	If used in winter may reduce the amount of useful solar gain released in the space unless accommodated in control strategy.
INTERACTIONS:	May permit cooling system capacity reductions. More expensive alternative to window replacement and interior solar control systems (films and shades).

EMO 18.23 REPLACE EXISTING GLAZING SYSTEM

DESCRIPTION:	Seek low U-value glazing and frames in replacement windows, i.e. double, triple or low E windows, solar control glazing.
APPLICATION:	All buildings with single-pane windows as a priority .
SIDE BENEFITS:	More comfort (less radiant losses in heating season) and reduction or elimination of condensation on glass and frames.
CAUTION:	Three-pane units have had problems with air leakage causing interior condensation between panes.
COST FACTORS:	Quality windows can be very expensive, shop carefully.
INTERACTIONS:	Alternative to EMO 18.11 Install storm windows and doors. Especially attractive in more extreme climates.
COMMENTS:	Energy and sound reduction may be better achieved with two-pane, one-pane combination.' Sliding windows generally have very high air leakage.

EMO 18.24 EMPLOY EVAPORATIVE COOLING ROOF SPRAY

DESCRIPTION:	Use an evaporative roof spray to lower roof surface temperature. System dispels heat as it reaches roof.

APPLICATION: Flat roof buildings.

SIDE BENEFITS: Can prolong roof life by limiting temperature build-up.

CAUTIONS: Care must be taken to avoid water level build-up and roof leaks.

COST FACTORS: Cost needs to be justified against reduced heat load. Evaluate water cost and determine whether or not water use is allowed by local regulatory body.

INTERACTIONS: See Cooling EMOs - can be high priority item where conditions are favorable.

COMMENTS: Original cooling equipment may prove to be greatly oversized and thus may operate with less efficiency when EMO is initiated.

REFERENCES: Dubin, 1976; Gatts, 1974.

EMO 18.25 REDUCE EFFECTIVE HEIGHT OF ROOM

DESCRIPTION: Lowering ceilings in rooms can reduce conditioned volume, saving heating and cooling energy.

APPLICATION: Those rooms where excessive height serves no useful purpose.

SIDE BENEFITS: Reduces temperature stratification.

CAUTIONS: Esthetics of rooms may change. Air circulation in room should be maintained. Window heights may pose problems.

COST FACTORS: Cost can vary from that of simple suspended ceiling to expensive changes in rooms.

INTERACTIONS: Retrofit can be coupled with upgrade of insulation level. Alternatively, for spaces 4 to 5 meters or higher, consider destratification devices.

COMMENTS: For high ceiling rooms this EMO can be very appropriate. It may not always save on cooling because of the change in affected mass.

19. 0 - UTILITY RATE STRUCTURES

It is quite common in utility rate structures that energy consumption and energy costs are not directly equitable to one another. This is because the cost of production, delivery and accounting are not directly related to units of energy and most energy suppliers devise rate structures that best reflect their cost. Consequently the auditor will sometimes be faced with the choice of saving money or energy.

In order to evaluate where savings can be made, and to calculate these savings accurately, it is vital to understand the specific rate structure under which energy is, and could be, purchased in the locality of the building under consideration.

A general discussion of typical rate structures is given below as background, but the auditor should obtain details of all applicable rates for fuels used.

The actual fuel rates may comprise of any one, or combinations, of the following charges:

* Flat Rate Charges:Energy purchased is charged at a common per unit rate, eg. 26 cents per litre of oil, 5 cents per kWh electricity.
* Sliding Rate Charges:The unit charge rate is varied as a function of the amount of energy purchased. The sliding scale is not normally continuous but arranged in blocks, eg. in the case of electricity, the first 250 kWh at 6 cents, the next 12,250 at 5 cents and so on.
* Demand Charges:Charges are made for the rate, usually the maximum rate, at which energy is consumed. These charges are normal for an energy supply system without the capacity for energy storage; eg. electricity and district heating, and reflect the cost of providing sufficient energy production systems to meet the maximum demands.
* Time of Day Charges:Units of energy and/or maximum demand charges may be charged at different rates depending on the time of day, hour, or season that the units or demand are recorded. Charges are based on similar considerations to those expressed in 3. above.
* Interruptible Clauses:Where the overall cost might be charged at a lower rate if the utility has the right to interrupt or limit supply to the building should the utility demand exceed a certain limit. Such rates obviously demand that the building be provided with its own fuel storage or generator as an alternative source of fuel.
* Minimum Billing Charges: Occasionally levied to cover the cost of administering an account.
* Delivery Charges: May sometimes be billed as an item separate from the amount of fuel delivered.
* Late and Early Payment Charges:Early payment discounts or late payment penalties are often levied.

Opportunities for savings can be pursued by seeking ways within the existing or alternative rate arrangements to minimize those effects contributing to the cost. Examples would include:

* Providing large storage facilities for solid and liquid fuels and making smaller numbers of bulk purchases, taking advantage, where possible, of seasonal

fluctuations in fuel cost.

- Providing alternate (dual fuel) sources to take benefits of lower unit energy costs.
- Restricting maximum demand and purchasing cheaper off-peak energy by rescheduling equipment usage and/or providing secondary storage system (eg. hot and chilled water).
- Arranging bulk purchase of energy with other energy users in the area.

19.1 - Electrical Rates

More so than with any other fuel system, electrical energy use and energy cost are not normally directly equitable to one another. Often the choice of saving cost will have to be made against the possibility of using more energy.

In addition to the above possibilities for charges, electrical bills may include Reactive Power charges in which actual consumption charges may be based upon units of volt ampere hours, as opposed to watt hours; or demand charges may be based on volt ampere as opposed to watts. In some cases a separate charge based on recorded power factor might be levied.

Charges may also vary depending on the voltage at which the electrical energy is purchased with high voltage power normally being cheaper than low voltage since the utility does not have to cover the cost of voltage transformation.

Demand charges take on a special significance in electrical systems since, in many instances, they can form a significant percentage, as much as 50% or more, of the electrical energy bill. The demand charged is based on an average demand measured over a set period of time as defined in the rate agreement - typical 20 or 30 minutes. It is not the instantaneous demand which is a misconception amongst many engineers and operators. The demand charge may be based on the maximum demand recorded over the period of a year or it may be billed for instance on a month by month basis, in which case the demand recorded in July would not, for instance, affect the demand charge for August.

Supplementary information on electrical rate structures can be found in EMS No. 3 Electrical

GLOSSARY

Audit Boundaries	The exact limits or extent of an energy audit.
Audit Site	The location of an energy audit.
Audit Survey	That part of an energy audit involving physical examination of the Audit Site.
Baseload	The load component that is not substantially affected by weather and normally consisting of such loads as lighting and water heating.
Checklists	Forms provided to assist in undertaking a walk-through energy audit.
Cost of Useful Fuel	The cost of energy taking into account the (Energy) conversion and transportation losses incurred on site.
Diagnostic (Energy) Audit	The second stage of an audit examining specific EMOs and quantifying potential costs and savings.
Dissagregation (of Energy)	The determination and quantification of the components that constitute the energy balance of a building.
EMO Package	A series of complementary or inter-related EMOs intended for implementation together.
Energy Audit	A procedure undertaken, often as part of an Energy Management Program, to examine a building, facility or process to identify and quantify potential energy management opportunities.
Energy Balance	The result of a dissagregation process defining the constituent building energy flows both into and out of the building.
Energy Efficiency	The effectiveness with which delivered energy is converted into useful energy for heating, lighting, processes, etc.
Energy Management Opportunities (EMOs)	Specific retrofit, operational and maintenance changes intended to save energy.
Energy Management Program	A strategy developed within an organisation comprising a series of planned activities to reduce energy costs and improve energy efficiency.
Energy Profile	A plot of energy consumption versus outside air temperature, indoor/outdoor temperature difference or degree days.
Energy Systems	The engineering services within a building or facility that provide heating, cooling, lighting, etc.

Energy Sub-Systems	Specific parts of an energy system (ie. outdoor lighting, fuel burners).
Fuel Conversion Systems	Components of the energy systems which change the grade or quality of energy supplied to suit the end use required.
Gross Cost of Fuel (Energy)	The cost of energy supplied 'at the meter'.
Housekeeping EMO	An EMO carrried out on a regular basis (at least once a year) involving little capital expenditure; the benefits of which would normally disappear if the practice is discontinued.
Low Cost EMO	An EMO involving some capital expenditure with a payback period of less than one (1) year.
Monitoring	An energy management procedure involving a structured program of recording energy use and analysing energy performance achieved.
Payback Period	The length of time taken for an EMO to recoup the cost of implementation.
Record Drawings	Drawings showing the 'as installed' features of a building.
Retrofit EMO	An EMO involving substantial capital expenditure with a payback period greater than one (1) year.
Sankey Diagram	A pictorial representation of an energy balance showing the relative size and direction of component energy flows.
Targetting	An extension to a monitoring system involving a prediction of future energy use for use as a cross check and motivator to achieve energy savings.
Walk-through (Energy) Audit	The first stage of the audit survey process involving a mainly qualatative examination aimed at identifying simple EMOs for implementation and areas requiring further examination.
Worksheets	Documents provided to assist in the calculation of costs and savings for specific energy management opportunities.

ENERGY CONTENTS

The following typical values for conversion factors may be used when actual data are unavailable. The MJ and Btu equivalencies are heats of combustion. Hydrocarbons are shown at the higher heating value, wet basis. Some items listed are typically feedstocks, but are included for completeness and as a reference source. The conversion factors for coal are approximate since the heating value of a specific coal is dependent on the particular mine from which it is obtained.

Consistent factors must be used when calculating Base Year and Current Year energy usage.

ENERGY TYPE	METRIC	IMPERIAL
COAL		
-metallurgical	29,000 megajoules/tonne	25.0 x 106 Btu/ton
- anthracite	30,000 megajoules/tonne	25.8 x 106 Btu/ton
- bituminous	32,100 megajoules/tonne	27.6 x 106 Btu/ton
- sub-bituminous	22,100 megajoules/tonne	19.0 x 106 Btu/ton
- lignite	16,700 megajoules/tonne	14.4 x 106 Btu/ton
COKE		
- metallurgical	30,200 megajoules/tonne	26.0 x 106 Btu/ton
- petroleum		
- raw	23,300 megajoules/tonne	20.0 x 106 Btu/ton
- calcined	32,600 megajoules/tonne	28.0 x 106 Btu/ton
PITCH	37,200 megajoules/tonne	32.0 x 106 Btu/ton
CRUDE OIL	38,5 megajoules/litre	5.8 x 106 Btu/bbl
NO. 2 OIL	38.68 megajoules/litre	5.88 x 106 Btu/bbl 168 x 106 Btu/IG
NO. 4 OIL	40.1 megajoules/litre	6.04 x 106 Btu/bbl .173 x 106 Btu/IG
NO. 6 OIL (RESID. BUNKER C)		
@ 2.5% sulphur	42.3 megajoules/litre	6.38 x 106 Btu/bbl .182 x 106 Btu/IG
@ 1.0% sulphur	40.5 megajoules/litre	6.11 x 106 Btu/bbl .174 x 106 Btu/IG
@ .5% sulphur	40.2 megajoules/litre	6.05 x 106 Btu/bbl .173 x 106 Btu/IG

ENERGY TYPE	METRIC	IMPERIAL
KEROSENE	37.68 megajoules/litre	.167 x 106 Btu/IG
DIESEL FUEL	38.68 megajoules/litre	.172 x 106 Btu/IG
GASOLINE	36.2 megajoules/litre	.156 x 106 Btu/IG
NATURAL GAS	37.2 megajoules/m^3	1.00 x 106 Btu/MCF
PROPANE	50.3 megajoules/kg	.02165 x 106 Btu/lb
	26.6 megajoules/litre	.1145 x 106 Btu/IG
ELECTRICITY	3.6 megajoules/kWh	.003413 x 106 Btu/kWh

COMMON CONVERSIONS

1 barrel (35 Imp gal) (42 US gal)	=159.1 litres	1 kilowatt	= 3600 kilojoules
		1 Newton	= 1 kg-m/s2
1 gallon (Imp)	=1.20094 gallon (US)	1therm	= 10Btu
1 horsepower (boiler)	= 9809.6 watts	1 ton (refrigerant)	=12002.84 Btu/ hour
1 horsepower	=2545 Btu/hour	1 ton (refrigerant)	=3516.8 watts
1 horsepower	= 0.746 kilowatts	1 watt	= 1 joule/second
1 joule	= 1 N-m	Rankine	= (deg. F + 459.67)
Kelvin	= (deg. C +273.15)		

Cubes		**Squares**	
1 yd^3	= 27 ft^3	1 yd^2	= 9 ft^2
1 ft^3	= 1728 in^3	1 ft^2	= 144 in^2
1 cm^3	= 1000 mm^3	1 cm^2	= 100 mm^2
1 m^3	= 106 cm^3	1 m^2	= 10000 cm^2
1 m^3	= 1000 L		

SI PREFIXES

Prefix	Symbol	Magnitude	Factor
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^{9}
mega	M	1 000 000	10^{6}
kilo	k	1 000	10^{3}
hecto	h	100	10^{2}
deca	da	10	10^{1}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	u	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pica	p	0.000 000 000 001	10^{-12}

UNIT CONVERSION TABLES
METRIC TO IMPERIAL

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
amperes/square centimetre	A/cm^2	amperes/square inch	A/in^2	6.452
Celsius	deg. C	Fahrenheit	deg. F	(deg. C x 9/5) + 32
centimetres	cm	inches	in	0.3937
cubic centimetres	cm^3	cubic inches	in^3	0.06102
cubic metres	m^3	cubic foot	ft^3	35.314
grams	g	ounces	oz	0.03527
grams	g	pounds	lb	0.0022
grams/litre	g/L	pounds/cubic foot	lb/ft^3	0.06243
joules	J	Btu	Btu	9.480×10^{-4}
joules	J	foot-pounds	ft-lb	0.7376
joules	J	horsepower hours	hp-h	3.73×10^{-7}
joules/metre, (Newtons)	J/m, N	pounds	lb	0.2248
kilograms	kg	pounds	lb	2.205
kilograms	kg	tons (long)	ton	9.842×10^{-4}
kilograms	kg	tons (short)	tn	1.102×10^{-3}
kilometres	km	miles (statute)	mi	0.6214
kilopascals	kPa	atmospheres	atm	9.87×10^{-3}
kilopascals	kPa	inches of mercury (@ 32 deg. F)	in Hg	0.2953
kilopascals	kPa	inches of water (@ 4 deg. C)	in H_2O	4.0147

UNIT CONVERSION TABLES
METRIC TO IMPERIAL

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
kilopascals	kPa	pounds/square inch	psi	0.1450
kilowatts	kW	foot-pounds/second	ft-lb/s	737.6
kilowatts	kW	horsepower	hp	1.341
kilowatt-hours	kWh	Btu	Btu	3413
litres	L	cubic foot	ft^3	0.03531
litres	L	gallons (Imp)	gal (Imp)	0.21998
litres	L	gallons (US)	gal (US)	0.2642
litres/second	L/s	cubic foot/minute	cfm	2.1186
lumen/square metre	Im/m^2	lumen/square foot	Im/ft^2	0.09290
lux, lumen/ square metre	lx, Im/m^2	footcandles	fc	0.09290
metres	m	foot	ft	3.281
metres	m	yard	yd	1.09361
parts per million	ppm	grains/gallon (Imp)	gr/gal (Imp)	0.07
parts per million	ppm	grains/gallon (US)	gr/gal (US)	0.05842
permeance (metric)	PERM	permeance (Imp)	perm	0.01748
square centimetres	cm^2	square inches	in^2	0.1550
square metres	m^2	square foot	ft^2	10.764

UNIT CONVERSION TABLES
METRIC TO IMPERIAL

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
square metres	m^2	square yards	yd^2	1.196
tonne (metric)	t	pounds	lb	2204.6
watt	W	Btu/hour	Btu/h	3.413

UNIT CONVERSION TABLES
IMPERIAL TO METRIC

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
ampere/in^2	A/in^2	ampere/cm^2	A/cm^2	0.1550
atmospheres	atm	kilopascals	kPa	101.325
British Thermal Unit	Btu	joules	J	1054.8
Btu	Btu	kilogram-metre	kg-m	107.56
Btu	Btu	kilowatt-hour	kWh	2.928×10^{-4}
Btu/hour	Btu/h	watt	W	0.2931
calorie, gram	cal or g-cal	joules	J	4.186
chain	chain	metre	m	20.11684
cubic foot	ft^3	cubic metre	m^3	0.02832
cubic foot	ft^3	litre	L	28.32
cubic foot/ minute	cfm	litre/second	L/s	0.47195
cycle/second	c/s	Hertz	Hz	1.00
Fahrenheit	deg. F	Celsius	deg. C	(deg. F - 32)/1.8
foot	ft	metre	m	0.3048

UNIT CONVERSION TABLES
IMPERIAL TO METRIC

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
footcandle	fc	lux,lumen/ square metre	lx, Im/m^2	10.764
footlambert	fL	candela/ square metre	cd/m^2	3.42626
foot-pounds	ft-lb	joule	J	1.356
foot-pounds	ft-lb	kilogrammetres	kg-m	0.1383
foot-pounds seconds	ft-lb/s	kilowatt	kW	1.356 x 10^{-3}
gallons (Imp)	gal (Imp)	litres	L	4.546
gallons (US)	gal (US)	litres	L	3.785
grains/gallon (Imp)	gr/gal (Imp)	parts per million	ppm	14.286
grains/gallon (US)	gr/gal (US)	parts per million	ppm	17.118
horsepower	hp	watts	W	745.7
horsepower-hours	hp-h	joules	J	2.684 x 10^{6}
inches	in	centimetres	cm	2.540
inches of Mercury (@ 32 deg. F)	in Hg	kilopascals	kPa	3.386
inches of water (@ 4 deg. C)	in H_2O	kilopascals	kPa	0.2491
lamberts	* L	candela/square metre	cd/m^2	3.183

UNIT CONVERSION TABLES
IMPERIAL TO METRIC

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
lumen/square foot	Lm/ft^2	lumen/square metre	Im/m^2	10.76
lumen	Lm	watt	W	0.001496
miles (statute)	mi	kilometres	km	1.6093
ounces	oz	grams	g	28.35
perm (at 0 deg C)	perm	kilogram per pascal-second-square metre	kg/Pa-s-m^2 (PERM)	5.721×10^{-11}
perm (at 23 deg C)	perm	kilogram per pascal-second-square metre	kg/Pa-s-m^2 (PERM)	5.745×10^{-11}
perm-inch (at 0 deg. C)	perm. in.	kilogram per pascal-second-metre	kg/Pa-s-m	1.4532×10^{-12}
perm-inch (at 23 deg. C)	perm.	kilogram per pascal-second-metre	kg/Pa-s-m	1.4593×10^{-12}
pint (Imp)	pt	litre	L	0.56826
pounds	lb	grams	g	453.5924
pounds	lb	joules/metre, (Newtons)	J/m, N	4.448
pounds	lb	kilograms	kg	0.4536
pounds	lb	tonne (metric)	t	4.536×10^{-4}
pounds/cubic foot	lb/ft^3	grams/litre	g/L	16.02
pounds/square inch	psi	kilopascals	kPa	6.89476
quarts	qt	litres	L	1.1365

UNIT CONVERSION TABLES
IMPERIAL TO METRIC

FROM	SYMBOL	TO	SYMBOL	MULTIPLY BY
slug	slug	kilograms	kg	14.5939
square foot	ft^2	square metre	m^2	0.09290
square inches	in^2	square centimetres	cm^2	6.452
square yards	yd^2	square metres	m^2	0.83613
tons (long)	ton	kilograms	kg	1016
tons (short)	tn	kilograms	kg	907.185
yards	yd	metres	m	0.9144

* "L" as used in Lighting

Summary of Recommendations

Item	Description	Capital Cost	Savings		Payback Period
			$	GJ	

Audit Mandate Checklist

Boundaries

Location of audit:

Areas to be examined:

- ☐ Whole site
- ☐ Individual buildings

Detail ....

....

....

External site services

- ☐ Lighting
- ☐ Heating mains
- ☐ Other (Describe) ....

....

Individual services

- ☐ Boiler plant
- ☐ Distribution systems
- ☐ Domestic/process water
- ☐ Process refrigeration
- ☐ Production/process operations

Detail ....

....

....

- ☐ Lighting
- ☐ Electrical
- ☐ HVAC
- ☐ Building envelope
- ☐ Rate structures

Resources:

In house staff

- ☐ Technical
- ☐ Clerical
- ☐ Other (Describe) ....

....

External

- ☐ Consultants
- ☐ Utility companies
- ☐ Track organizations
- ☐ Government organizations
- ☐ Contractors

Audit Mandate Checklist - cont'd

Measuring and Monitoring Equipment Available:

....
....
....
....
....
....
....

Data Available:

Drawings available ☐ None ☐ Some ☐ Comprehensive
Production records ☐ None ☐ Some ☐ Comprehensive
Energy usage records available ☐ None ☐ Some ☐ Comprehensive

Overall Building:

Remaining life of:

Building structure .... years
Envelope system .... years
HVAC system .... years
Interior (partitioning) systems .... years

Detail of planned changes, major refurbishments, etc:

....
....
....

Possibility of Audit Recommendations Being Applied to Other Buildings:

☐ Yes ☐ No

Details: ....
....
....

Time Scales:

Completion date required ....
Preliminary findings required ....

Reporting Format Required:

Level of detail ....
Financial analysis required ....
Payback period acceptable ....

Audit Mandate Checklist - cont'd

Implementation:

Housekeeping time scale ....
Low cost time scale ....
Financial limits ....
Retrofit time scale ....
Financial limits ....

Investment and Operational Needs/Desires:

To save:

- ☐ Energy
- ☐ Specific fuel type (detail) ....
- ☐ Maximum demand

☐ Accommodate increased load in building
☐ Pass energy costs directly to tenants
☐ Limit manual operation
Other (Describe)

....
....

Applicable Grants, Subsidies and Tax Advantages:

....
....
....

Building Conditions:

Note all problems:

- ☐ Comfort
- ☐ Breakdowns
- ☐ Lack of capacity
- ☐ Appearance
- ☐ Noise

Other (Describe)..
....
....
....
....
....
....
....
....
....

Boiler Plant Systems
Walkthrough Audit Checklist No. 9

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Condition of boilerhouse:

....

Items	Boiler No. 1	Boiler No. 2	Boiler No. 3	Boiler No. 4	Boiler No. 5
Details of boilers (Fire tube/ Water tube/ Coil tube)					
Fuel (Gas/ Coal/ Oil)					
Rating (Btuh/ lbs per hr/ kW)					
Condition					
Age					
Water or smoke leaks					
Instrumentation readings					
Flue gas (Temperature/ O /CO)					
Burner flame conditions					
No. of boilers on line					
Boiler cycling time					
Ancilliary equipment					
Blowdown control (Steam boilers)					
Output control (Aquastat/ Sequencer/ Manual)					

EMO Checklist No. 9

EMO No.	Description	Implementation Recommended	Further Evaluation Required			Not Applicable or Desirable	Comments
			Potential				
			High	Average or Unknown	Low		
HOUSEKEEPING							
9.1	Reduce number of on-line boilers as load reduces						
9.2	Reduce boiler flow termperature/pressure with heat demand						
9.3	Maintain correct system pressurization						
9.4	Service burner and adjust air-fuel ratio						
9.5	Remove scale and soot						
9.6	Recalibrate monitoring/control equipment						
9.7	Maintain chemical treatment program						
9.8	Minimize load swings						
9.9	Monitor plant operational logs						
9.10	Maintain air tightness of boiler system gas side						
9.11	Reduce oil storage temperature						
LOW COST							
9.12	Reduce blowdown losses						
9.13	Repair or upgrade insulation on boiler/ furnace						
9.14	Repair refractory						
9.15	Install flue dampers						
9.16	Decrease firing rate of the burner or fit smaller burner						
9.17	Install monitoring equipment						
9.18	Relocate combustion air intake						

EMO Checklist No. 9

EMO No.	Description	Implementation Recommended	Further Evaluation Required			Not Applicable or Desirable	Comments
			Potential				
			High	Average or Unknown	Low		
RETROFIT							
9.19	Install more efficient burner						
9.20	Install dual fuel burner						
9.21	Install summer domestic hot water boiler						
9.22	Install flue gas heat exchanger						
9.23	Install automatic oxygen trim controller						
9.24	Install sequence firing of multi-unit boiler plant						
9.25	Replace obsolete heating plant						
9.26	Install waste heat boiler						
9.27	Replace steam feed pumps						
ADDITIONAL							

Process Furnaces, Dryers and Kilns Walkthrough Audit Checklist No. 10

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5	Area No. 6
Type of equipment						
Rating/size						
Fuel type						
Flame appearance						
Missing or damaged insulation						
Badly fitting doors						
Operating schedule						
Evidence of inefficient operating procedures						

EMO Checklist No. 10

EMO No.	Description	Implementation Recommended	Further Evaluation Required			Not Applicable or Desirable	Comments
			Potential				
			High	Average or Unknown	Low		
HOUSEKEEPING							
10.1	Service burner and adjust air-fuel ratio						
10.2	Remove scale and soot						
LOW COST							
10.3	Repair or upgrade insulation on furnace						
10.4	Repair refractory						
10.5	Reinstall doors or covers						
10.6	Minimize load swings						
10.7	Maintain air tightness of product side and gas side						
RETROFIT							
10.8	Install monitoring equipment						
10.9	Install heat recovery of process cooling water						
10.10	Install flue gas heat exchanger						
10.11	Reinsulate furnace enclosure						
10.12	Replace burner						
10.13	Install automatic oxygen trim controller						
ADDITIONAL							

Steam and Condensate Systems
Walkthrough Audit Checklist No. 11

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5	Area No. 6
System condition						
Steam leaks						
Plumes from vents						
Trap operation						
Redundant steam mains						
Condition of insulation						
Condensate return temperature						
Underground steam mains condition						

EMO Checklist No. 11

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
HOUSEKEEPING							
11.1	Repair leaks						
11.2	Maintain steam traps						
11.3	Maintain chemical treatment program						
LOW COST							
11.4	Repair/upgrade insulation on pipes and tanks						
11.5	Rationalise pipework						
RETROFIT							
11.6	Heat recovery from condensate						
11.7	Separate flash steam from condensate						
ADDITIONAL							

Domestic and Process Hot and Cold Water Walkthrough Audit Checklist No. 12

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5
Domestic Hot Water					
Heating source					
Circulation pump					
Storage tank size					
Temperature of stored water					
Delay at faucet					
Water temperature at faucet					
Flow and return temperatures					
Domestic Cold Water					
Water pressure					
WC flush system					
Faucet type					
Process Water Use					
Process description					
Consumption					
Discharged temperature					
Schedule of use					

EMO Checklist No. 12		Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
EMO No.	Description		High	Average or Unknown	Low		
HOUSEKEEPING							
12.1	Reduce water temperature						
12.2	Reduce use of circulation pumps						
12.3	Install or improve water temperature regulation						
12.4	Use DHW in appliances						
12.5	Shut off water heating when not required						
LOW COST							
12.6	Install heat pump water heater						
12.7	Heat recovery from waste DHW						
12.8	Install flow restrictors						
12.9	Install controls to reduce pump use						
12.10	Install water softener						
12.11	Replace pilots with electric ignition						
12.12	Install pressure reducing valves						
12.13	Install trace heating on dead legs						
RETROFIT							
12.14	Optimize size of DHW storage tank						
12.15	Consider automatic DHW taps						
12.16	Add instantaneous booster to storage system						
12.17	Install metering devices						
12.18	Install solar water heating						
12.19	Switch from storage to instantaneous DHW system						
12.20	Decentralize DHW production						

EMO Checklist No. 12

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
ADDITIONAL							

Process and Air Conditioning Refrigeration Walkthrough Audit Checklist No. 13

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5
Area and processes served					
System description					
Equipment description					
Cooling requirements					
Operation and sequencing of multiple chillers					
Evaporating and condensing temperatures					
Heat rejection equipment					
Refrigerant level					
Capacity control					
City water usage					
Size/rating					

EMO Checklist No. 13

EMO No.	Description	Implementation Recommended	Further Evaluation Required			Not Applicable or Desirable	Comments
			Potential				
			High	Average or Unknown	Low		
HOUSEKEEPING							
13.1	Raise chilled water temperature and suction gas pressure						
13.2	Lower condensing water temperature and head pressures						
13.3	Shut off auxilliaries when not required						
13.4	Sequence operation of multiple units						
13.5	Clean and maintain cooling tower circuits and heat exchanger surfaces						
13.6	Maintain full charge of refrigerant						
LOW COST							
13.7	Clean condenser tubes						
13.8	Repipe/operate chillers or compressors in series or parallel						
13.9	Replace internal cold cabinet lights with external ones						
13.10	Provide night covers for cold cabinets						
13.11	Reduce cooling losses from open refrigerated display cabinets						
RETROFIT							
13.12	Heat recovery of condenser heat						
13.13	Atmospheric cooling						
13.14	Exhaust (cool) conditioned air over condensers and through cooling towers						
13.15	Use city water for cooling						
13.16	Central chiller/refrigeration control						
13.17	Use natural water sources for condensing						
13.18	Minimize adverse external influences on cooling tower and air cooled condenser						

EMO Checklist No. 13

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
13.19	Free cooling chillers						
13.20	Use of desiccant for de-humidification						
13.21	Use of "piggy back" absorption system						
13.22	Chilled water and ice storage systems						
13.23	Improve capacity control						
13.24	Reduce compressor capacity or fit a smaller compressor						
13.25	Replace or upgrade cooling equipment						

ADDITIONAL

Production and Process Equipment Walkthrough Audit Checklist No. 14

Facial: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5
Compressed air leaks					
Air compressors idling					
Equipment operating unnecessarily					
Condition/cleanliness of aisles and production areas					
Raw material product stockpiles maintained outside					

Notes:

....

....

....

....

....

....

....

EMO Checklist No. 14

EMO No.	Description	Implementation Recommended	Further Evaluation Required			Not Applicable or Desirable	Comments
			Potential				
			High	Average or Unknown	Low		
HOUSEKEEPING							
14.1	Maintain system free from air						
14.2	Minimize/eliminate air wastage						
14.3	Maintain air filters and dryers regularly						
14.4	Maintain air line lubricators						
14.5	Maintain gas turbine inlet filters						
14.6	Operate turbines at optimum inlet and outlet conditions						
14.7	Ensure aisles are marked and kept clear						
14.8	Minimize operating hours of powered transportation equipment						
14.9	Minimize materials outdoor storage times						
14.10	Review production schedules to optimize energy use						
LOW COST							
14.11	Modify turbine air intake						
14.12	Install heat recovery from gas turbine oil cooler						
14.13	Install additional insulation						
14.14	Upgrade control components						
RETROFIT							
14.15	Install heat recovery from waste streams						
14.16	Install cooling tower mist eliminators						
14.17	Install compressed air dryers						
14.18	Replace pipework with lower friction coefficient equivalent						

EMO Checklist No. 14

EMO No.	Description	Implementation Recommended	Further Evaluation Required			Not Applicable or Desirable	Comments
			Potential				
			High	Average or Unknown	Low		
14.19	Recirculate water in cooling, flushing, washdown process systems						
14.20	Reduce fluid system operating pressures						
14.21	Replace air compressors with new higher efficiency units						
14.22	Install heat recovery equipment in compressor cooling water system						
14.23	Segregate compressor from main building						
14.24	Utilize compressor waste heat for building heating						
14.25	Replace low pressure compressors with blowers						
14.26	Install air cooled compressed air aftercoolers						
14.27	Install variable speed compressor drive						
14.28	Replace central compressors with multiple units						
14.29	Install microprocessor energy management system						
14.30	Install an air receiver						
14.31	Preheat gas turbine combustion air with exhaust gas						
14.32	Utilize heat from gas turbine exhaust						
14.33	Modify turbine inlet and exhaust tracts						
14.34	Utilize surface heat from turbines						
14.35	Upgrade turbine components						
14.36	Improve steam turbine control						
14.37	Install back pressure turbine to serve as pressure reducing device						
14.38	Optimize steam turbine operating conditions						

EMO Checklist No. 14

EMO No.	Description	Implementation Recommended	Further Evaluation Required			Not Applicable or Desirable	Comments
			Potential				
			High	Average or Unknown	Low		
14.39	Revise total material handling operations						
14.40	Install microprocessor based control system						
14.41	Reduce frequency of deliveries						
14.42	Improve materials flow monitoring						
14.43	Consolidate warehouse operations						
ADDITIONAL							

Lighting
Walkthrough Audit Checklist No. 15

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5
Lighting controls					
Unnecessary lighting usage					
Lighting levels					
Non-uniform tasks over area (i.e. potential for task lighting)					
Installed lighting load					
Luminaire types					
Luminaire maintenance					
Room finishes					

Notes:

....

....

....

....

....

EMO Checklist No. 15

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
HOUSEKEEPING							
15.1	Switch off unnecessary lights						
15.2	Limit lighting during cleaning periods						
15.3	Use low level lighting for security periods						
15.4	Rearrange work space to make best use of daylight						
15.5	Remove lamps						
15.6	Luminaire maintenance						
15.7	Clean interior wall surfaces. Repaint with lighter colors						
LOW COST							
15.8	Reduce exterior, grounds, sign, display lighting						
15.9	Improve geometric arrangement of luminaires						
15.10	Use task lighting						
15.11	Use efficient ballasts						
15.12	Replace low wattage lamps with fewer high wattage lamps						
15.13	Install more efficient light source						
15.14	Install more efficient reflectors and lenses in luminaires						
15.15	Add switches, timers, presence sensors, dimmers for better control						
RETROFIT							
15.16	Install automatic control system to maintain constant illuminance						
15.17	Install controls to enable better use of daylighting						
15.18	Switch to a more efficient lighting system						
15.19	Install central light control						

EMO Checklist No. 15

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
ADDITIONAL							

Electrical Systems
Walkthrough Audit Checklist No. 16

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

General Details and Background: Complete before survey where possible

Is there a need for additional load capacity? ☐ Yes ☐ No

Is there a problem with voltage regulation? ☐ Yes ☐ No

Rate structure details:

Demand charges? ☐ Yes ☐ No ☐ KW or ☐ KVA
Power factor penalty? ☐ Yes ☐ No Details: ....
Time of day rates? ☐ Yes ☐ No Details: ....

Peak demand?............................ Month: .... Hour: ....

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5
General conditions of motors and drives					
Meter recordings					
Maximum demand limiters					
Power factor correction					
Motor power factor correction					
Motor speed controllers					
High efficiency motors					

EMO Checklist No. 16

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
HOUSEKEEPING							
16.1	Motor & drive maintenance						
16.2	Balance phase voltage						
16.3	Motor & drive alignment						
16.4	Reduce elevator and escalator usage						
LOW COST							
16.5	Load demand control						
16.6	Correct matching of driven load & motor						
16.7	Peak shaving using on site generation						
16.8	Power factor controllers						
RETROFIT							
16.9	Power factor correction						
16.10	Motor speed control						
16.11	High efficiency motors						
ADDITIONAL							

Environmental Control Systems
Walkthrough Audit Checklist No. 17A

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	**Area No. 1**	**Area No. 2**	**Area No. 3**	**Area No. 4**	**Area No. 5**	**Area No. 6**
Space temperature controls						
Heating and cooling controls						
Time controls						
Space temperature						
Space humidity						
Heating distribution						
Space heating controls						
Space cooling controls						

Environmental Control Systems - Cont.d
Walkthrough Audit Checklist No. 17A

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5	Area No. 6
Mechanical ventilation and exhaust systems						
Swimming pool halls						
Humidity controls						
Indoor garages						
High spaces						
Induction systems						
Dual duct, multizone and reheat systems						
Rooftop packaged air handling units						
Fume hoods and cabinets						

EMO Checklist No. 17A

			Further Evaluation Required				
			Potential				
EMO No.	Description	Implementation Recommended	High	Average or Unknown	Low	Not Applicable or Desirable	Comments
HOUSEKEEPING							
17.1	Maintain proper space setpoints						
17.2	Set-back, set-up space temperatures						
17.3	Shut off humidification & ventilation equipment						
17.4	Night flushing						
17.5	Shut off coil circulators when not required						
17.6	Maintain proper system control setpoints						
17.7	Replace worn nozzles in induction systems						
17.8	Special considerations, roof top air conditioning units						
17.9	Shut down hot or cold duct in dual duct system or minimize temperature difference						
17.10	Cycle air conditioning						
LOW COST							
17.11	Preoccupancy cycle						
17.12	Install automatic ventilation control						
17.13	Sequence heating and cooling						
17.14	Mixing damper replacement						
17.15	Install radiator thermostatic valves						
17.16	Humidistat control of swimming pool hall ventilation						
17.17	CO control of parking garage ventilation						
17.18	Minimize stratification during heating season						
17.19	Install air economiser						

EMO Checklist No. 17A

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential High	 Average or Unknown	 Low	Not Applicable or Desirable	Comments
17.20	Provide evaporative cooling						
17.21	Install deadband thermostats						
17.22	Discontinue or relocate pre-heat coils						
17.23	Provide stratification splitters						
17.24	Correct poor control valve selection						
17.25	Use cooling coil for both heating and cooling duties						
17.26	Variable volume controls for fume hoods						
RETROFIT							
17.27	Locate make-up air at exhaust hoods						
17.28	High velocity type exhaust hoods						
17.29	Conversion to VAV						
17.30	Load reset (discriminator) control						
17.31	Air mixing between zones for utilization of zone excess heat exhaust make-up						
17.32	Install localised exhaust/make-up air systems						
17.33	Install EMS system						
17.34	VAV fan control in AC systems						
17.35	Mechanical dehumidification in swimming pool halls						
17.36	Absorption filters						
17.37	Local heating and cooling						
17.38	Radiant heating						
17.39	Direct gas fired make-up units						
17.40	Replace ceiling dump boxes						
17.41	Re-cool coils						

EMO Checklist No. 17A

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
17.42	Individual coils in multizone system						
17.43	System replacement						
17.44	Convert 3-pipe system to 2-pipe or 4-pipe system						
17.45	Air to air heat recovery techniques						
ADDITIONAL							

Pipework
Walkthrough Audit Checklist No. 17B

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5	Area No. 6
General						
Fluid leaks						
Potential for flow reductions						
Pump motor type and loading						
Condition of pump drives						
Air in system						
Redundant pipework						
Pump operating schedule						
Potential for zone pumping						
Potential for variable volume pumping						
Balancing problems						

EMO Checklist No. 17B

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
HOUSEKEEPING							
17.46	Maintain system free from air						
17.47	Switch off circulation pumps when not required						
17.48	Clean filters and screens						
17.49	Repair leaks						
LOW COST							
17.50	Balance pipework distribution system						
17.51	Repair/upgrade insulation on pipes and tanks						
17.52	Reduce flow rate						
RETROFIT							
17.53	Install zone pumping						
17.54	Install variable volume pumping						
17.55	Remove unnecessary pipework						
ADDITIONAL							

Ductwork Systems
Walkthrough Audit Checklist No. 17C

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5	Area No. 6
General						
Dirty filters						
Excess ductwork resistance						
Air leaks						
Potential for air volume reductions						
Fan motor type and loading						
Condition of fan drives						
Backdraft dampers						
Balancing problems						

EMO Checklist No. 17C

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
HOUSEKEEPING							
17.56	Clean fan blades						
17.57	Maintain drives						
17.58	Clean or replace filters regularly						
LOW COST							
17.59	Balance ductwork system						
17.60	Reduce air flow rate						
17.61	Reduce pressure drops in ducts						
17.62	Reduce air leakage in ducts						
17.63	Reduce motor size (fan power)						
17.64	Duct insulation repair/upgrade						
17.65	Install back draught or positive closure damper in ventilation exhaust system						
ADDITIONAL							

Heat Pumps
Walkthrough Audit Checklist No. 17D

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	System No. 1	System No. 2	System No. 3	System No. 4	System No. 5	System No. 6
Area served						
System description						
Equipment description						
Energy loads						
Heat rejection equipment						
Refrigerant level						

EMO Checklist No. 17D

EMO No.	Description	Implementation Recommended	Further Evaluation Required			Not Applicable or Desirable	Comments
			Potential				
			High	Average or Unknown	Low		
HOUSEKEEPING							
17.67	Heat pump air leakage						
17.68	Maintain proper evaporating and condensing temperatures						
17.69	Maintain efficient defrosting						
17.70	Maintain proper heat source/sink flow rates						
17.71	Maintain functioning of heat pump expansion device						
17.72	Check heat pump stand by losses						
17.73	Maintain full charge of refrigerant						
LOW COST							
17.74	Check sensor functioning and placement for heat pumps						
17.75	Maintain proper starting frequency and running time of heat pump						
RETROFIT							
17.76	Replacement or upgrade heat pump supplementary heat supply						
ADDITIONAL							

Building Envelope
Walkthrough Audit Checklist No. 18

Facility: ....

Survey date: ....

Surveyed by: ....

Other comments: ....

....

....

Items	Area No. 1	Area No. 2	Area No. 3	Area No. 4	Area No. 5	Area No. 6
Windows						
Glazing materials						
Frame construction						
Shading device						
Window utilization						
Window area						
Doors						
Door traffic						
Door configuration						
Door construction						
Door use						
Walls						
Construction						
State of repair						
Roofs						
Construction						
Ventilation						
State of repair						

EMO Checklist No. 18

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
HOUSEKEEPING							
18.1	Close/open windows and doors to match climate						
18.2	Ensure proper ventilation of attic spaces						
18.3	Operate shades and shutters						
18.4	Close convection paths in shafts and stairwells						
18.5	Repair broken glazing						
18.6	Maintain latches and other mechanisms						
18.7	Repair/upgrade seals, caulking and weather-stripping						
LOW COST							
18.8	Add insulation behind exterior radiators						
18.9	Add attic insulation						
18.10	Add automatic door closing system between heated and unheated space						
18.11	Install storm window and doors						
18.12	Replace doors with improved design						
18.13	Correct excessive envelope air leakage						
18.14	Install window film						
18.15	Cover, insulate or convert unnecessary windows and doors						
18.16	Modify vegetation to save energy						
18.17	Install shutters, blinds or shades						
RETROFIT							
18.18	Insulate walls						
18.19	Upgrade insulation of flat roofs						
18.20	Add insulation to floors						

EMO Checklist No. 18

EMO No.	Description	Implementation Recommended	Further Evaluation Required Potential			Not Applicable or Desirable	Comments
			High	Average or Unknown	Low		
18.21	Locate and minimize the effect of thermal bridges						
18.22	Replace or compliment internal blinds with external blinds						
18.23	Replace existing glazing systems						
18.24	Employ evaporative cooling roof spray						
18.25	Reduce effective height of room						

ADDITIONAL

INSTRUMENTATION FOR ENERGY AUDITING

E.1 - Introduction

This appendix describes the instrumentation and measurement techniques relevant to energy audit activities. It is important that an auditor has a basic understanding of measurement techniques and instrumentation in order to be knowledgeable in the purchase and use of the equipment. Both the correct instrument and its correct use are fundamental requirements for obtaining useful measured data. (This appendix is supplementary to and should be read in conjunction with EMS No. 15 "Measuring, Metering and Monitoring".)

Measurement of electrical energy use, amps, volts, watts etc., should only be undertaken by trained technical staff. Under no circumstances should live electrical equipment be opened by unqualified persons.

E.2 - Understanding Measurement Accuracy

The accuracy of the actual measuring device (instrumentation) and the actual use of the instrument are two items that can affect measurement accuracy. Before purchasing or leasing instrumentation it is important to determine how accurate the measurement needs to be and to select instrumentation and measurement strategies in accordance with those needs. One can generally expect to pay more for more accurate instrumentation but more expensive and accurate instruments often demand more careful and time consuming measurement techniques.

For specialized and "once only type" measurements it may often be beneficial, both in terms of accuracy and overall cost, to engage competent independent technicians to undertake the measuring task.

When evaluating instrumentation for purchase or lease, it is useful to know how different manufacturers define the accuracy of their equipment. Some common ways of defining accuracy are:

- percentage of full scale,
- percentage of actual reading value,
- a "resolution"; this is common for instruments with digital read out and is often stated as the number of digits.

In most cases, particularly for quality instruments, the stated accuracy will be for a particular set of circumstances; e.g. the type of wave forms or frequency might be stated for electrical measurements; often some indication of loss of accuracy that will occur when the instrument is used outside the particular circumstances will be given.

The following notes give guidance on appropriate instrumentation and techniques for a range of measurement tasks.

E.3 - Electrical Measurements

E.3.1 - Factors That May Affect Instrument Accuracy

Before purchasing or using an instrument its potential accuracy in the intended application should be checked. Manufacturer's information often indicates the accuracy of instrumentation for specific ranges of conditions eg.

- frequency - often a single frequency or frequency range is given,
- waveform - accuracy is often quoted for a pure sine wave or with reference to a maximum "crest factor",
- range - accuracy may vary from one range to another and may be specified for a mid range application,
- power factor - applies to power factor and power measurements only: accuracy of instruments may be limited at very low power factors.

E.3.2 - Conventional and Digital Type Meters

For auditing and many other purposes, digital type meters (DM) are replacing conventional analogue instruments of the moving iron and electro-dynamometer type because of lower cost and ease of use. Their accuracy is normally more than adequate for auditing purposes. Some advice in this regard is given below.

- Cheaper instruments tend to be very frequency and waveform dependent. Avoid purchasing instruments that give accuracy for DC amp or volts only, since DC range will seldom be used and is inherently the most accurate of all the "waveforms" that might be encountered. Instruments providing true rms (root mean square) measurements will normally have better accuracy over a wide range of frequencies and waveforms.
- Most quality DM instruments are suitable for use with crest factors up to 3:1 (some up to 6:1) and should be suitable for most power measuring needs (a pure sine wave has a crest factor of 1.4:1).

Other factors to look for when selecting digital meters are:

- Range of measurements - single meters often have the capability to measure two or more of the following: - amp, volt, ohm, power factor, rpm and temperature.
- Analogue or digital displays. Digital displays avoid read out errors especially where the instrument must be used in difficult locations.
- Reading freeze - facilitates reading where meter dial cannot be read as measurement is taken.
- Display invert - may ease reading of meter in difficult locations.
- Analogue output - which can be used with a strip chart or data logger to provide a permanent and continuous record.

E.3.3 - Measurement of Current

The methods of measurement depend on instrument choice and loads being measured. Options for AC systems include:

- moving iron analogue instrument installed in series with load (Fig. E.1). Method is limited to the range of the instrument, typically up to 100 A. Inherently measures rms value but has non-linear scale (cramped at low end, open at high end), typical accuracy 0.5% full scale.
- moving iron analogue instrument used with a current transformer (Fig. E.2). Current transformer extends range of instrument.
- The use of a clamp on ammeter/current probes (Fig. E.3) is the preferred method for auditing purposes since it is not necessary to interrupt the power circuit to take a measurement. Typical ranges available 0.1 to 1000 A full scale, less expensive instruments 3-500 A, typical accuracy 1 to 2% full scale.

Instruments are often multi use; i.e. volt, amp, ohm. Recording amperemeters are available giving a permanent record of current variation with time.

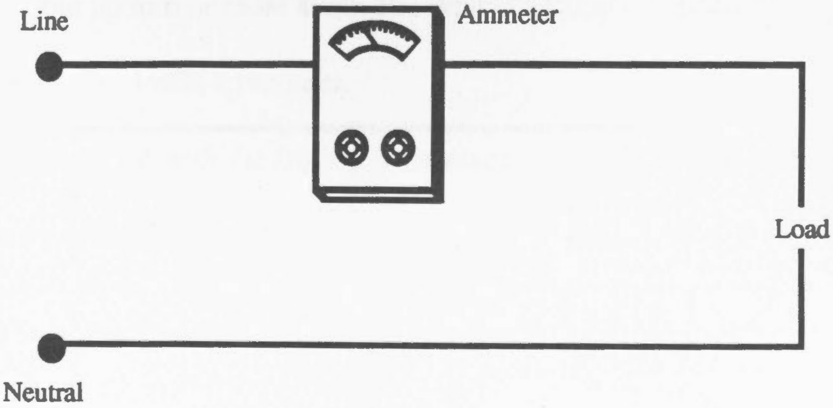


Figure E.1 Amperemeter in series with loads.

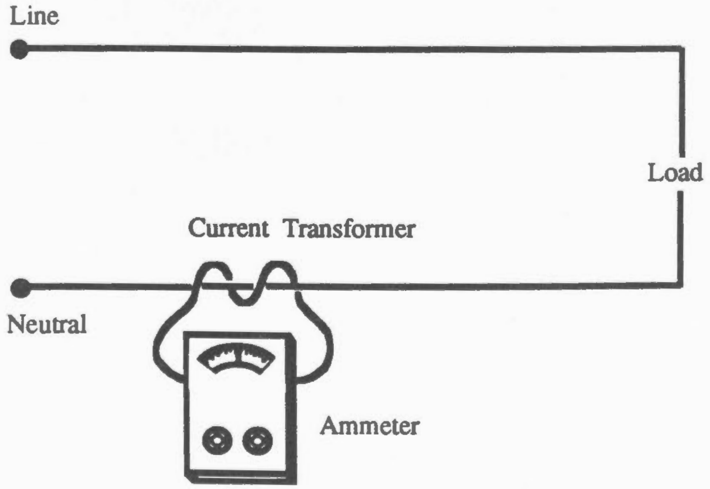


Figure E.2 Amperemeter and current transformers.

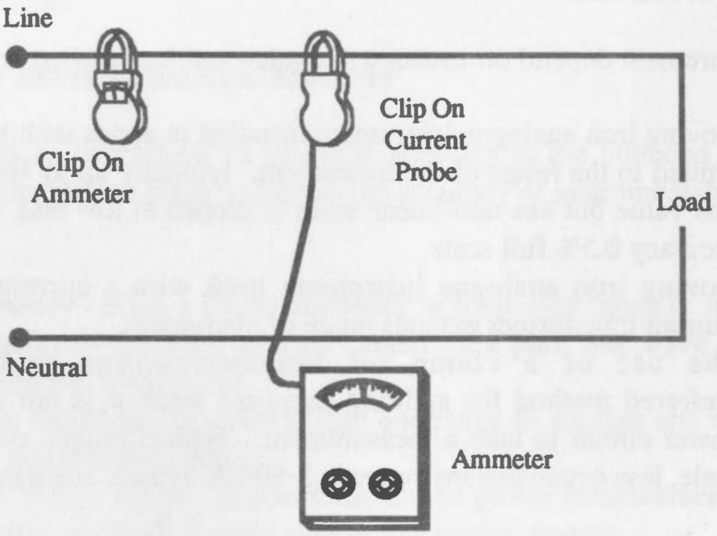


Figure E.3 Using clamp on amperemeter or current probe and remote device.

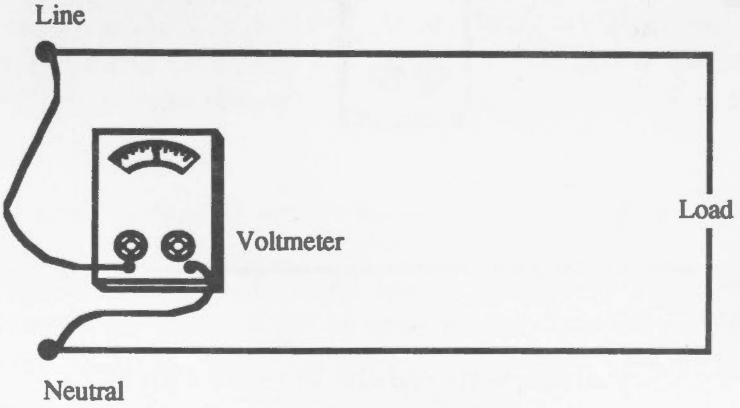


Figure E.4 Measurement of voltage.

E.3.4 - Measurement of Voltage

For all low voltage applications (less than 1000 V) the voltmeter is connected across the terminals of the circuit to be measured. See Fig. E.4.

Instrument choices for AC power systems measurement include:

- Moving Iron (analogue) types. Typical range 0-950 V, inherently measures rms value, typical accuracy 0.5% full scale.
- Digital type. Most suitable and least expensive for audit work. Typical range 0.1 to 1000 V full scale, less expensive 100 to 600 V, typical accuracy 0.8 to 2% full scale.

Instruments are often multi use; e.g. volt, amp, ohm.

E.3.5 - Measurement of Electric Power Demand

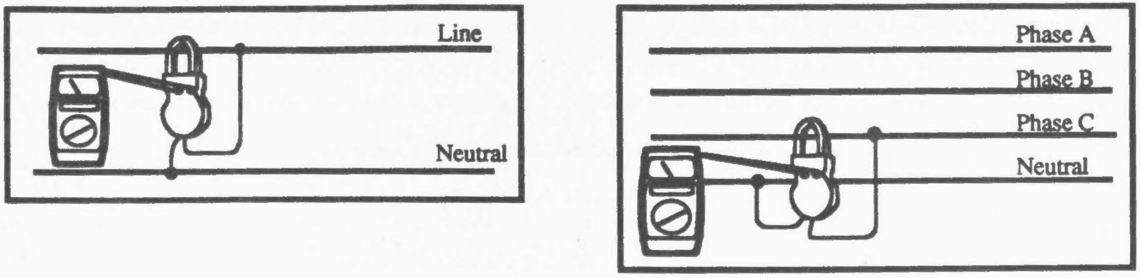
Power demand measurements are normally made using a portable wattmeter. The exact details of the method of measurement depend upon the size of the load, type of distribution (single or three phase) and instruments used.

Instrument choices include:

* Electrodynamometer (analogue) wattmeter. Typical range 120/240 V and 0.1 to 25 A (i.e. 12 W to 6 kW). Range can be extended indefinitely with the use of current and potential transformers. They have the ability to measure power of waves with high crest factor, typically up to 8 or more, typical accuracy 0.5% full scale. Note: Electrodynanometers are fragile and easily damaged by overloads, especially when measuring very low power factor.
* Digital. Uses voltage probe(s) and clip on amp probe(s). Typical range is 2 to 200 kW although higher wattage instruments (up to 2MW) are available. This is the preferred instrument for audit purposes. Fig E.5 illustrates the method of connection for power measurements. Typical maximum crest factor range of 3 but up to 6 or more available, typical accuracy 1 to 2%.

Some instruments can be used with a recorder.

Often instruments are provided with the facility for measuring current, voltage and power factor.



Single Phase - Total active power (W) is read directly

Three Phase 4 Wire Balanced - Total active power (W) is three times meter reading

Three Phase 3 Wire Balanced and Unbalanced Total active power (W) is read directly

Three Phase 4 Wire Unbalanced - Total active power (W) is read directly

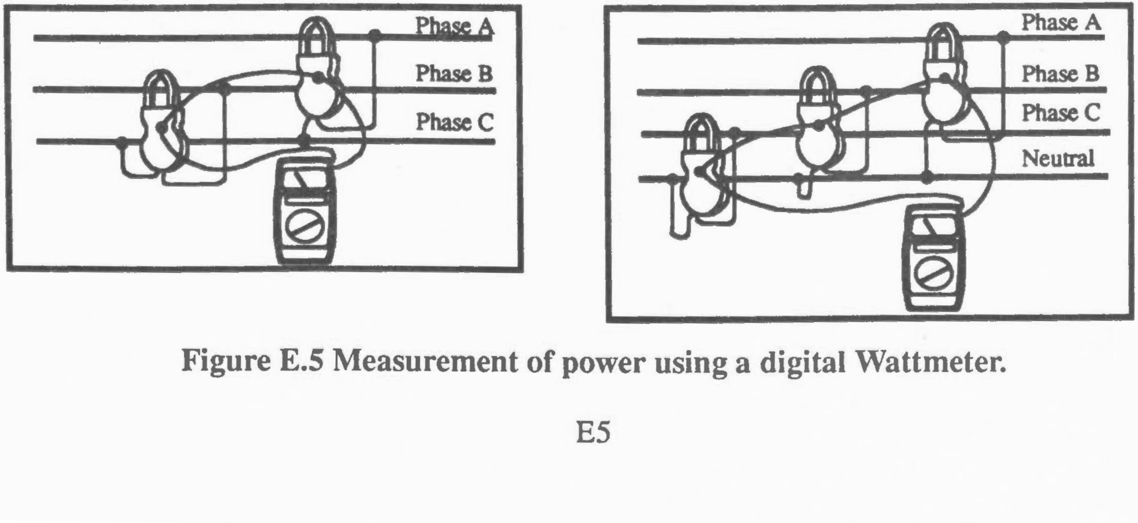


Figure E.5 Measurement of power using a digital Wattmeter.

Alternatively power demand can be:

- * Approximated by measuring current (a voltage being assumed) or current and voltage if the power factor is known or can be estimated.
- * Read directly where watt demand meters are installed. Note that some demand meters record VA not W.
- * Obtained by measuring the time for the consumption of X kWh; where kWh meters are installed. In this case X is read from the meter dial and the demand is given by;

$$\frac{X \quad 60}{\text{time for consumption (minutes)}}$$

If 'X' is not given in units of kWh, 'X' has to be multiplied by the meter multiplier, which is normally indicated on the face of the meter.

E.3.6 - Measurement of Power Factor

Measurement of power factor can be made directly using a power factor meter. (Often such a function is combined with power measurement in a single instrument.)

Instrument choices include:

- * Analogue. These instruments often have limited volt and amp range requiring the use of current transformers. Special instruments are required for measuring very low power factors; i.e. power factors less than 0.5; typical accuracy 3% full scale.
- * Digital. Typical range 0 to Unity power factor, 0-600 V, 3-500 A although accuracy falls off at lower power factors. This is the preferred instrument for audits since there is no need to interrupt the power supply, typical accuracy 3% full scale. See Fig. E.6 for hook-up details.

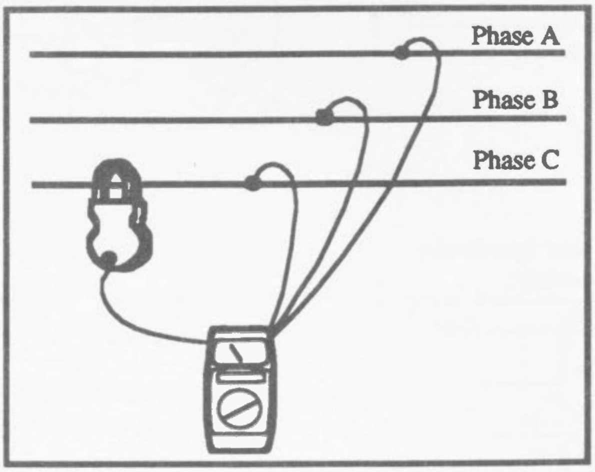


Figure E.6 Measurement of power factor using a power factor meter.

Alternatively power factor may be determined:

- * By measuring power, voltage and current separately and calculating the power factor using the relationship:

$$\text{Power factor} = \frac{\underline{\text{Power (as indicated by wattmeter)}}}{\text{volt * Amps}}$$

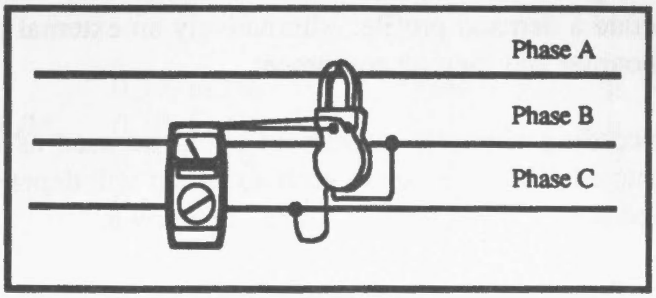
In order to determine the power factor for the complete building the utility watt hour meter could be used to give a power reading.

* By measuring the power and reactive power separately using a wattmeter, see Fig. E.7, and calculating the power factor using the relationship:

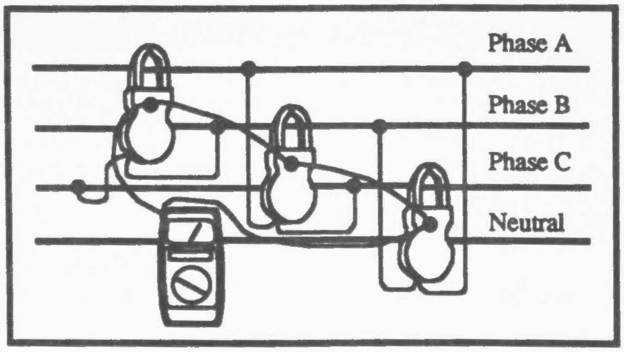
$$\text{Power factor} = (\text{Real Power})/\sqrt{((\text{Real Power}\ )^2 + (\text{Reactive Power}\ )^2)}.$$

Note that this method is strictly correct for pure AC (sinusoidal) wave forms only. The power factor so calculated will, however, give a reliable indication of the potential for power factor correction.

Three phase 3 Wire Balanced
Total reactive power (VA) = $\sqrt{3}$ (meter reading)



Three Phase 4 Wire Balanced and Unbalanced
Total reactive power (VA) = 1 / 2 (meter reading)



Three Phase 3 Wire Unbalanced
Total reactive power (VA) = $\frac{1}{\sqrt{3}}$ (meter reading)

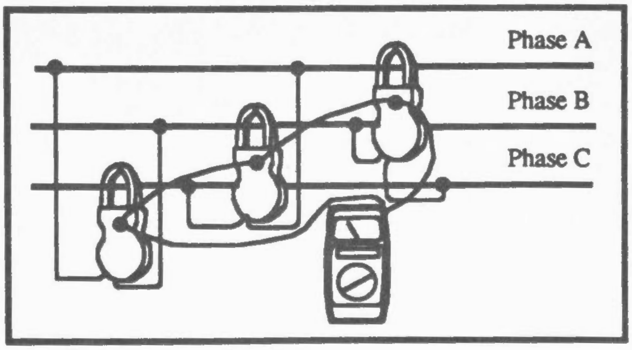


Figure E.7 Measurement of reactive power.

E.3.7 - Measurement of Electrical Energy Consumption

Electrical energy consumption can be measured directly by using either an integrating watt-hour meter or a recording wattmeter.

Integrating watt-hour meters. This is the simplest type of instrument which provides a single record of accumulated energy use (kWh). Digital type portable instruments or electromagnetic rotating disc type (as used by utility companies for billing purposes) can be used. Unless the meter is read frequently, it gives no indication as to the profile of the electrical energy use.

Recording watt-hour meters. These instruments provide a record of the variation of power demand (kW) with time. The record may be given on a chart or the demand might be printed out at selected intervals. Electrodynamometer and digital type instruments are available. Manual integration is required to find the actual energy consumption. Digital type instruments with clip on current probes are the most appropriate for auditing purposes.

Equipment connections are similar to those described for power measurements. Some instruments (digital type) offer both functions. Devices are also available for monitoring the energy use of appliances and small equipment straight from the equipment line cord.

A utility watt-hour meter can be used for measuring and recording total building consumption. In order to provide an automatic logging facility the utility can sometimes provide a pulse generating meter which generates a pulse for each meter disc rotation. This can then be recorded and used to generate a demand profile. Alternatively an external pulse initiating device can be installed along with the counter and logging equipment.

A recording ammeter instrument could be used as another option to provide an estimate of power consumed. The accuracy of such a method will depend on the extent to which voltage and power factor can be assumed to be constant and are known.

E.4 - Temperature Measurements

E.4.1 -Types of Temperature Sensors

Table E1 (reproduced from EMS No. 15) gives a range of characteristics for various temperature sensors.

E.4.2 - Field Measurements

The following advice is offered for carrying out measurements in the field:

* Calibration.Thermometers should always be calibrated before being used for the first time and thereafter at regular intervals.

* Measurement of surface temperature.The sensor should be shielded from contact with the air by providing a cover of insulating material over it. The sensor should not be facing radiation sources such as the sun, radiators or windows. If a representative or average temperature is required avoid placing sensor on non representative parts such as over a thermal bridge; alternatively several measurements can be taken over a representative area and their values averaged. Avoid placing sensors close to air inlets or outlets or in draughts. Infrared sensors and cameras may also be used for the measurement of surface temperature.

TEMPERATURE SENSORS
CHARACTERISTIC/RELATIVE COST COMPARISON
TABLE 3

TYPE	RECOMMEND RANGE LIMITS	RELATIVE COST	ACCURACY "% SPAN	REPEAT ABILITY	RESPONSE TIME
Glass Stem Thermometer	-50°C, +800°C	L	1% to 2%	E	G
Filled Thermal*					
Liquid	-30°C, +400°C		0.1% to 2%	F	G
Vapour	-15°C, +300°C	L/M	0.5% to 2%	F	F
Gas	-265°C, +800°C		0.5% to 2%	F	G
Mercury	-40°C, +650°C		0.5% to 2%	F	F
Bimetallic	-60°C, +425°C	L	1% to 4%	F	G
Thermocouple					
Type T	-150°C, +260°C		0.3% to 1%	G/E	E
Type J	-160°C, +800°C	L/M	0.3% to 1%	G/E	E
Type K	-150°C, +1500°C		0.3% to 1%	G/E	E
Type R & S	-15°C, +1700°C		0.3% to 1%	G/E	E
RTD					
Nickel	-150°C +260°C	L/M	0.1%	E	G/E
Platinum	-255°C +650°C	L/M	0.1%	E	G/E
Pyrometers					
Optical	+760°C, +3500°C	M/H	1% to 2%	-	F/G
Infrared	0°C, +3300°C		1% to 2%	-	E
Radiation	500°C, +3900°C	H	0.5% to 1%	G/E	G

*This type is non linear and may only be able to measure above or below the ambient temperature.

LEGEND

E - Excellent	L - Low	RTD - Resistance Temperature Detector
G - Good	M - Medium	
F - Fair	H - High	

Table E1 Characteristics of Temperature Sensors.

E.5 - Miscellaneous Field Measurements

E.5.1 - Measurement of Humidity

The psychrometer, or wet and dry bulb thermometer, is the most common instrument used and consists of two temperature sensors, one with a cotton sock wetted with distilled water. The sensor with the sock will register a temperature close to the thermodynamic wet bulb temperature. Knowing the dry bulb and wet bulb temperatures and the barometric pressure, the relative humidity can be determined.

Psychrometers cannot be used when the air temperature is below 0°C. They need frequent cleaning and replacement of the cotton sock. If properly maintained, the accuracy is about 0.5 K if the relative humidity is above 20%.

The lithium-chloride cell is an alternative to the psychrometer. It is a simple and comparatively cheap instrument, with an operating range from -29 to 70°C and an accuracy of 2 K. Air velocities above 10 m/s may shift the calibration, however exposure to high humidities and a simultaneous loss of power, e.g. due to a power failure, may dissolve the salt and necessitate a refurbishment of the instrument.

Another relatively inexpensive instrument uses an ion exchange resin (or Pope-type) sensor. Because of its fast response and durability this type of sensor is often found in hygrometers monitoring the RH of relatively constant temperature air streams. The Pope-type sensor is limited to temperatures lower than 75°C and is highly sensitive to organic solvents (e.g. oil vapor) and polystyrene adhesives.

Many versions of RH sensors utilizing a thin film polymer or ceramic are also now commercially available. Sensors with high sensitivity (2% RH accuracy) and fast response are available in the medium to low price range. The operating temperature range is approximately 5 to 55°C. Some sensors are equipped with a sintered metal filter to shield the sensor from the majority of particulate matter found in the air. Exposure to high humidities for several minutes may result in loss of calibration or even loss of the sensor itself.

E.5.2 - Measurement of Process and Flue Gas Temperatures

Flue gas temperatures should be measured at the middle of the smoke stack at an approximate distance of one diameter from the boiler exit. Allow the boiler to reach steady state temperature before taking measurements. A bimetal thermometer, or electronic thermometer with resistive or thermocouple sensors must be used.

E.5.3 - Measurement of Illuminance

An illuminance meter is used with a cosine and colour-corrected sensor. Ideally the sensor should be connected by a flexible cable to an analogue or digital display; this minimizes the risk of shading the sensor when taking readings.

The measurement should be made under steady state conditions (allow for warm-up time for the lamps). Ensure that daylight does not influence the measurement of the electric light. Take measurements at night where possible. If readings must be taken during daylight hours, draw shading devices and take the measurements with and without lights and subtract the daylight contribution.

As the age of lamps and maintenance of fittings and room influence the illuminance, care must be taken when comparing the performance of an old installation with a new one.

E.5.4 - Measurement of Indoor Air Velocity

The measurement of indoor air flow is generally difficult because the flow pattern is seldom stable and the air velocity is relatively low. The velocity fluctuations are often of the same magnitude as the speed of the air. This makes it very difficult to take measurements by visual reading of the instrument.

Before measurements are made of the air velocity in a space, it is important to determine where the space air velocities are greatest. The simplest way of measuring the average air speed is by using a smoke-stick, or a smoke puffer, and a stop watch. This method can generally only be used for concentrated air streams with limited diffusion.

Some sensors that can be used are the heated thermocouple anemometer and the thermistor anemometer. The heated thermocouple anemometer has a rather slow response to rapid velocity fluctuations, and is rather insensitive to low air velocities. Therefore, this type of instrument should only be used for steady-state measurements and for air velocities greater than 5 cm/s. The heated thermocouple anemometer is a comparatively cheap instrument.

F. - BIBLIOGRAPHY AND REFERENCES

F.1 -General Reading, Chapters 1-8 and Multidisciplinary Documents

ANSI/ASHRAE/IES, 1981
100 Series 1981. "Energy Conservation in Existing Buildings", Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers.

ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers Inc., New York).

ASHRAE, 1987.
ASHRAE Handbook: Systems and Applications.

ASHRAE, 1988.
ASHRAE Handbook: Equipment.

ASHRAE, 1985.
ASHRAE Handbook: Fundamentals.

ASHRAE, 1988.
ASHRAE Journal, (Dec.), 1988, pp 25-28.

CMHC (Canadian Mortgage & Housing Corporation), 1982.
Energy Efficiency in Multi-Unit Residential Buildings. A Handbook for Owners and Operators, CMHC.

Coad, W.J., 1975.
"Energy Audits I - Components of Energy Use", Heating / Piping / Air Conditioning, (July), pp. 105-106.

Coad, W.J., 1975.
"Energy Audits II - Components of Energy Use", Heating / Piping / Air Conditioning, (Aug.), pp. 93-97.

Coad, W.J., 1979.
"Energy Audits III: Components of Energy Use", Heating / Piping / Air Conditioning, (Sept.).

Coad, W.J., 1979.
"Energy Audits IV: The Use of Audits", Heating / Piping / Air Conditioning, (Oct.).

Dubin, F.S. 1975.
"Guidelines for Saving Energy in Existing Buildings", Engineers, Architects and Operators Manual ECM-2, U.S. Federal Energy Administration.

Dubin, F.S., Mindell, H.L., and Bloome, S., 1976.
"How to Save Energy and Cut Costs in Existing Industrial and Commercial Buildings" Noyes Data Corporation, Park Ridge, NJ.

Energy, Mines & Resources Canada 1989.
Energy Management Series, Energy Management/Employee Participation.

Energy, Mines & Resources Canada 1989.
Energy Management Series, Financial Analysis.

Energy, Mines & Resources Canada 1989.
Energy Management Series, Energy Accounting.

Energy, Mines & Resources Canada 1988.
Energy Management Series, Waste Heat Recovery.

Energy, Mines & Resources Canada 1987.
Energy Management Series, No. 1 Process Insulation.

Gatts, R.R., Massey, R.G., and Robertson, C., 1974.
Energy Conservation Program Guide for Industry and Commerce, National Bureau of Standards, Washington DC, NBS Handbook 115.

Jack Dale & Associates, Inc., 1984.
Governments Institutes Inc., Energy Audits Manual, Rockville, U.S.A.

Lyberg, M.D., 1987, "Source Book for Energy Auditors", Swedish Council for Building Research, Stockholm (This is an IEA Publication, available through Leslie Jones & Associates, Ottawa).

Piette, M.A. & Anderson, B. 1988.
"Performance Evaluation of Energy Saving Measures", ASRAE Journal (June)
pp 34-39.

Wulfinghoff, D.R., 1984.
"Common Sense about Building Energy Consumption Analysis", ASHRAE Transactions, Vol. 90, part 1.

F.2 - Boiler Plant and Systems

Energy, Mines & Resources Canada 1989.
Energy Management Series No. 5 "Combustion".

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 6 "Boiler Plant Systems"

Hallanger, P.E., 1980.
"Design Principles of Boiler Optimization", ASHRAE Journal, (May), pp 28-31.

Hateman, L., 1987.
"Microcomputer Combustion Controls", Heating / Piping / Air Conditioning, (November), pp 55-57.

Javrell, G.A., 1987.
"Boiler Energy Audits", Heating / Piping / Air Conditioning, (September), pp 101-103.

Kelly, J.F. and Didion, D.A., 1975.
"Energy conservation potential for modular gas fired systems", NBS Buildings Service Services No. 79.

Macriss, R.A., and Zawacki, T.S., 1985.
"Effect of retrofit on combustion characteristics & seasonal efficiency of gas fired furnaces & boilers", Westinghouse, Combustion Control News, Winter (Feb.), 1985.

Neff, C.H., 1986.
"Mechanical Aspects of Boiler Feed Water treatment", Heating / Piping / Air Conditioning, (November), pp 79-85.

Oven, M., 1983.
"Automatic boiler blowdown with heat recovery", Heating / Piping / Air Conditioning, (Aug.), pp. 68-73.

Pattison, J.R. & Sharma, V.
"The Selection of gas fired boiler plant for the heating of commercial premises", A British Gas Corporation Publication circa 1975.

F.3 - Process Furnaces, Dyers and Kilns

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 7, "Process Furnaces, Dryers and Kilns".

F.4 - Steam Distribution and Condensate Return Systems

Batherman, R.E., 1982.
"Steam Traps", Heating / Piping / Air Conditioning, (Nov.), pp. 45-60.

EMC (Energy Management Canada), 1983.
"Steam Traps - Energy in Steam Form can be Recycled for Maximum Savings", (June/July).

Energy, Mines & Resources Canada 1987.
Energy Management Series No. 8, "Steam & Condensate Systems"

Spirax Sarco, 1985.
"Steam Utilization Course", Spirax Sarco Inc., Pennsylvania.

F.5 - Domestic and Process Hot and Cold Water

Coad, W.J., 1984.
"Energy Economics of domestic hot water systems", Heating / Piping / Air Conditioning, pp 109-111.

Dawson, W., 1985.
"Many Options for reducing energy costs in DHW in commercial buildings", Heating / Plumbing / Air Conditioning, (November, December), pp 15-16.

Jones, L., 1980.
"Hot water consumption & performance of an automatic storage type service water heating installation in a School Building", ASHRAE Transactions, Volume 1 pp 909-916.

Manian, V.S., 1977.
"Reduce supply temperature in service water heating systems", ASHRAE Journal, (April), pp 25-29.

Muller, J.G., 1975.
"The potential for energy savings through reductions in hot water consumption", "Conference on Water Conservation & Sewage Flow reduction with water saving devices", (April).

Perlman, M., 1986.
"Water heaters: energy conservation options", Electrical Equipment News, (August), pp 15 -17.

F.6 - Process Refrigeration

See also F.10 Heating & Air Conditioning Systems.

ASHRAE 1986
ASHRAE Handbook: Refrigeration

Cole, R.A., 1984.
"Reduced Head Pressure Operation of Industrial Refrigeration Systems", Heating / Piping / Air Conditioning, (July), pp. 119-132.

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 11, "Refrigeration & Heat Pumps".

Prasad, M., 1981.
"Optimum Interstage Pressure for 2-Stage Refrigeration Systems", ASHRAE Journal, (Jan.), pp. 58-60.

Stamm, R.H., 1984.
"Industrial Refrigeration: Compressors", Heating / Piping / Air Conditioning, (July), pp. 93-111.

F.7 - Production Processes and Operations

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 12, "Water & Compressed Air Systems".

Energy, Mines & Resources Canada 1987.
Energy Management Series No. 16, "Compressors & Turbines".

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 17, "Materials Handling & On-Site Transportation Equipment".

F.8 - Lighting

Dulanski, G., 1987.
"Managing Energy with Lighting Controls", Lighting Design & Application, (November), pp 44-46.

Electrical Construction & Maintenance (EC&M), 1987.
"Daylight Fluorescent Dimming cuts Energy Usage", EC&M, (November), pp 82-83.

Energy, Mines & Resources Canada 1989.
Energy Management Series No. 2, "Lighting".

IES (Illuminating Engineering Society of North America), New York.

IES, 1982.
IES LEM-1-1982 "IES Recommended Procedure for Lighting Power Limit Determination", Lighting Energy Management Series.

IES, 1984.
IES LEM-2-1984 "IES Recommended Procedure for Lighting Energy Limit Determination", Lighting Energy Management Series.

IES, 1984.
IES LEM-4-1984 "IES Recommended Procedure for Energy Analysis of Building Lighting Design and Installations", Lighting Energy Management Series.

Knisley, J.R., 1986.
"Powerline control trims lighting energy use", EC&M, (June), pp 53-57.

Zackrison, H., 1985.
"Today's current lighting technology", Lighting Design and Application, (July), pp 25-36.

F.9 - Electrical Systems

Bell, C.J. and Hester, L.R., 1980.
"Power Factor Correction", Heating / Piping / Air Conditioning, (December), pp. 31-34.

Berutti, A., 1984.
"Cycling of Motors for Energy Conservation", Electrical Construction & Maintenance. (January).

Choi, S., Hirsch J. & Birdsall, B., 1982.
"Peak Shaving in Buildings Through Use of Diesel Engine Driven Emergency Power Generation System", ASHRAE Journal, (Jan.), pp. 33-37.

Dalrymple, M., 1984.
"PM Programs Reduce Motor Failures", Electrical Construction & Maintenance, (Oct.), p. 34.

Dautovich, D.R., 1980.
"Motor Efficiency Study at Ontario Hydro", Engineering Digest (Association of Professional Engineers of Ontario, Canada), (Jan.), p. 15.

ECM (Electrical Construction and Maintenance).

ECM, 1983.
"Adjustable Frequency Control Systems for AC Motors", (Feb.), p. 40.

ECM, 1984, (A).
"Selecting Energy Efficient Motors", (March), p. 38.

Feldman, E.J., 1983.
"Nameplate Data - For Better Motor Installation and Maintenance", Electrical Construction & Maintenance, (December).

Energy Mines & Resources, 1989.
Energy Management Series No. 3, "Electrical Systems".

Energy Mines & Resources, 1989.
Energy Management Series No. 4, "Energy Efficient Motors".

Freeborn, M., 1980.
"Cut Your Energy Bill Through Power Factor Correction", Electrical Contractor & Maintenance Supervisor, (July), pp. 18-21.

Freund, A., 1981.
"Reducing Motor Losses", Electrical Construction & Maintenance, (March), p. 69.

National Electric Contractors Association (NECA), 1975.
Electric Load Management, Electrical Design Library Series.

PM & E, 1984.
"Peak Power Shaving with On-Site Generators", Plant Management & Engineering, (June).

Spethmann, D.H., 1981.
"Electrical Energy Management", ASHRAE Transactions, V. 87, part 1.

Tedrow, L.E., 1984.
"How to Grease Motors", Electrical Construction & Maintenance (Apr.), p. 50.

Timpone, R.E., 1982.
"Consider Practical Aspects when Buying High Efficiency Motors", Electrical Construction & Maintenance, (Aug.), p. 24.

F.10 - Heating Ventilation and Air Conditioning

ACGIH (American Conf. on Governmental Industrial Hygienist), 1980.
Industrial Ventilation, Edwards Brothers Inc.

Agnon, S., 1978.
"Design Considerations for Multiple Pump Circuits", ASHRAE Journal, (March), pp 26-30.

Albern, W.F., 1983.
"Simultaneous Heating and Cooling - The Undetected Energy Consumer",
ASHRAE Journal, (Sept.), pp. 38-39.

Albern, W.F., and Lacey, R.D., 1984.
"Use Chilled Water Preheat Coils", ASHRAE Journal, (May), pp. 28-30.

Albern, W.F., 1986
"Variable Flow Pumping?" ASHRAE Journal, (June), pp 34-36.

ASHRAE, 1981.
ANSI/ASHRAE 55-1981 "Thermal Environmental Conditions for Human Occupancy".

ASHRAE, 1981.
ANSI/ASHRAE 62-1981 "Ventilation for Acceptable Indoor Air Quality".

ASHRAE, 1974.
Seminar: Energy Conservation Pumping Systems - A condensation. ASHRAE, (Feb).

Azer, N.Z., 1985.
"A Design Procedure, Spot Cooling Systems", ASHRAE Journal, (June), pp. 40-45.

Backus, A.O., 1982.
"Energy Savings Through Improved Control of Heat Pump Setback", ASHRAE Journal, (February), pp. 24-28.

Baillie, J.D., and Langford, Ph. L., 1985.
"Microprocessor Control of a System", ASHRAE Journal, (September), pp. 22-27.

Baltimore Air Coil Company Inc., 1984.
"A Guide to Ice Storage Systems", ASHRAE Journal, (July), (Bulletin E140/1-OA. Baltimore Air Coil, Maryland, U.S.A.).

Beier, R., and Gorton, R.L., 1978.
"Thermal Stratification in Factories - Cooling Loads and Temperature Profiles", ASHRAE Transactions, Vol. 84, part 1.

Bentsen, L., 1985.
"New VAV Controls for Fume Hoods", Heating / Piping / Air Conditioning. (Feb.), pp. 67-69.

Burger, Robert, 1980.

"Cooling Tower: Energy Conservation Workhorses", ASHRAE Journal, (April), pp.33-35.

Chauan, R.B., 1985.
"Field Test on an Exhaust Air Heat Recovery Heat Pump", Building Research Note No. 226, (Feb.), National Research Council Canada.

Coad, W., 1983.
"Retrofit Design requires painstaking engineering", Heating / Piping / Air Conditioning. (Jan.), pp121-125.

Coad, W.J., 1985.
"Hydronic energy economics", ASHRAE Journal, (June), pp 52-63.

Danish, C., 1983.
"Pipe Insulation Choices", Heating / Piping / Air Conditioning, (Oct.), pp 81-84.

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 9, "Heating & Cooling Equipment".

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 10, "Heating, Ventilating and Air-Conditioning.

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 11, "Refrigeration & Heat Pumps".

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 13, "Fans & Pumps".

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 16, "Automatic Controls".

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 19, "Thermal Storage".

Erth, R.A., 1980.
"Power Inverters and Off-Design Chiller Performance", Heating / Piping / Air Conditioning, (Nov.), pp. 63-67.

Eskra, N., 1980.
"Indirect/Direct Evaporative Cooling Systems", ASHRAE Journal, (May), pp. 21-25.

Fizzel, J.A., 1977.
"Analyzing Vertical Temperature Gradients", Heating / Piping / Air Conditioning, (Nov.), pp. 81-84.

Francis, E., 1985.
"Annual Ice Storage for Cooling", Solar Age, (April), pp. 67-70.
Fullman, C., and Helm, B.M., 1981.

"Deadband Thermostats Pro & Con", ASHRAE Journal, (July), pp. 51-53.

Gage, E.H., 1977.
"TBA Procedures", Heating / Piping / Air Conditioning, (Feb.), pp 39-93.

Garland, Milton W., 1980.
"Compressor Capacity Control for Air Conditioning Systems", ASHRAE Journal, (April), pp. 37-39.

Goldfield, J., 1985.
"Contamination Reduction: General vs Local Exhaust Ventilation", Heating /Piping / Air Conditioning, (Feb.), pp. 47-51.

Haines, R.W., 1980.
"Stratification", Heating / Piping / Air Conditioning, (Nov.), pp. 70-71.

Haines, R.W., 1981.
"Economy Cycle Controls", Heating / Piping / Air Conditioning, (March), pp. 70-71.

Haines, R.W., 1981.
"Economy Cycle Controls", Heating / Piping / Air Conditioning, (April), pp. 111-113.

Haines, R.W., 1982-1983.
"Roger Haines on Controls - Series of Articles", Heating / Piping / Air Conditioning, (Aug. -82 to March -83).

Haines, R.W., 1984.
"Retrofitting Re-Heat Type Systems", ASHRAE Journal, (Sept.), pp. 35-38.

Hensley, John C., 1981.
"Cooling Tower Energy", Heating / Piping / Air Conditioning, (Oct.), pp.51-57.

Hensley, John C., 1983.
"External Influences on Cooling Tower Performance", ASHRAE Journal, (Jan.), pp. 86-89.

Hill, C.R., 1984.
"Integration of Cooling Storage with Chiller Plant Operation", Heating / Piping / Air Conditioning, (May), pp. 105-113.

Holman, J., 1986.
"Variable Speed Pumping Makes Sense", Heating / Piping / Air Conditioning, (October), pp 95-98.

Honeywell, 1976.
Variable Air Volume Systems Manual, Honeywell, Minneapolis, U.S.A.

Johnson Controls, 1982.
"Energy Conservation Control", EC2, (Dec.), Johnson Controls Company, Milwaukee.
Johnson, G.A., 1985.

"From Constant Air to Variable", ASHRAE Journal, (Jan.), pp. 107-114.

Kallen, Howard P., 1982.
"Analysis: Off-Peak Cooling Methods to Reduce Energy Consumption", ASHRAE Journal, (Dec.), pp. 28-30.

Kao, J.Y., and Pierce, F.T., 1983.
"A Study of Sensor Error on Building Energy Consumption", ASHRAE Journal, Vol. 25, No. 12.

Kao, J.Y., 1985.
"Sensor Errors", ASHRAE Journal (Jan.), pp. 100-106.

Kinsey, R.A., 1979.
"Power and Fuel Savings with Central A/C and Furnaces", ASHRAE Journal, (June), pp. 58-62.

Klassen, J., 1981.
"Project Icebox - An Annual Energy Storage System", ASHRAE Journal, (May), pp. 48-50.

Kingler, R., 1980.
"Efficiency Considerations for Two Stage Systems", ASHRAE Journal, (Dec.), pp. 33-37.

Korte, B., 1976.
"Retrofitting & Replacing Energy Intensive Rooftops", Heating / Piping / Air Conditioning, (Oct.), pp. 31-41.

Kragh, R.W., 1976.
"Brush Cleaning of Condenser Tubes Saves Power, Cost", Heating / Piping / Air Conditioning, (Sept.), pp. 60-64.

Landman, W.J., 1976.
"Chilled Water Storage", Heating / Piping / Air Conditioning, (Nov.), pp. 73-75.

Landman, W., 1983.
"The Search for Chiller Efficiency", Heating / Piping / Air Conditioning, (July), pp. 77-81.

Leitner, G., 1980.
"Controlling Chiller Tube Fouling", ASHRAE Journal, (Feb.), pp. 40-43.

Levine, M., Moll, L.W., 1981.
"Beyond Setback: Energy Efficiency Through Adaptive Control", ASHRAE Journal, (July), pp. 37-39.

Liptak, B.G., 1979.
"Savings Through CO_2 Based Ventilation", ASHRAE Journal, (July), pp. 38-41.

Meyer, J.R., 1983.
"Evaporative Cooling for Energy Conservation", Heating / Piping / Air Conditioning, (Sept.), pp. 111-118.
Nelson, L.W., and MacArthur, J.W., 1978.

"Energy Savings Through Setback", ASHRAE Journal, Vol. 20, No. 9, pp. 49-54, and ASHRAE Transaction, Vol. 84, pt. 2, 1978, pp. 319-334.

Pannkoke, T., 1980,
"Air Terminal Units", Heating / Piping / Air Conditioning, (Dec.)

Pannkoke, T., 1980,
"Air Terminal Devices: What's Available", Heating / Piping / Air Conditioning, (Nov.), pp. 31-37.

Paoluccio, J.P., and Burfield, J.A., 1981.
"University Evaluates Dead Band Control Strategy", ASHRAE Transactions, Vol. 87, part 1.

Pearson, R.J., 1982.
"Evaporative Cooling", Heating / Piping / Air Conditioning, (Dec.), pp. 80-89.

Pearson, F.J., 1985.
VAV System Retrofit in an Industrial Building", Heating / Piping / Air Conditioning, (Aug.), pp. 109-113.

Phillips, D., 1984.
"Energy Conservation with automatic flow control valve", Heating / Piping / Air Conditioning, (Dec.), pp 91-94.

Roose, R., 1976.
"Insulation Wrap-Up", Heating / Piping / Air Conditioning, (April), pp 51-61.

Shavit, G., 1974.
"Enthalpy Control Systems Increased Energy Conservation", Heating / Piping / Air Conditioning, (Jan.), pp. 117-122.

Spethmann, D.H., 1977.
"Load Reset, A Basic Optimization Tool", Heating / Piping / Air Conditioning, (Dec.), pp. 35-40.

Stamm, R.H., 1978
"Recirculated Refrigerant Systems and HVAC Energy Conservation", Heating /Piping / Air Conditioning, (Feb.), pp. 51-56.

Stoecker, W.F., and Daber, R.P., 1978.
"Conserving Energy in Dual Duct Systems by Reducing the Throttling Ranges of Air - Temperature Controllers", ASHRAE Transactions, Vol. 84.

Stoecker, W.F., 1980.
"Refrigeration Control with Enhanced Microcomputers", Heating / Piping / Air Conditioning, (Nov.), pp. 48.

Sun, T.Y., 1979.

"Heat Recovery vs Economizer Cycle", Heating / Piping / Air Conditioning, (Feb.), pp. 81-87.

Supple, R.G., 1982.
"Evaporative Cooling for Comfort", ASHRAE Journal, (Aug.), pp. 36-42.

Tamblyn, R.T., 1977.
"Thermal Storage: A Sleeping Giant", ASHRAE Journal, (June), pp. 53-57.

Tao, W., and Janis, R., 1985.
"Modern Cooling Plant Design", Heating / Piping / Air Conditioning, (May).
pp. 51-56.

Thielman, D.E., 1983.
"Chiller Optimization by Energy Management Control Systems", ASHRAE Journal, (Nov.), pp. 60-62.

Trane Company of Canada, 1977.
"Coil Control - Part II", TRANE Engineers Newsletter, (Oct.).

Trane Company of Canada, 1978.
"Large Chillers: Series or Parallel Flow?", TRANE Engineers Newsletter, (May).

Trane Company of Canada, 1979.
"Fan Selection & Control in Variable Air Volume Systems", TRANE Engineers Newsletter, (Oct.).

Welsh, J.W., 1984.
"Chilled-Water Free Cooling", ASHRAE Journal, (March), pp. 49-50.

Wendes, H.C., 1983.
"Estimating VAV Retrofit Cost", Heating / Piping / Air Conditioning, (Aug.), p. 93.

Wiggin, M.E., and Morris, R.H., 1985.
"Electronic Control for Fume Hoods", Heating / Piping / Air Conditioning, (Feb.), pp. 59-64.

Winger, Ph., 1983.
"Atmospheric Cooling Retrofit", Heating / Piping / Air Conditioning, (Nov.), pp. 64-65.

Woods, J.E., Winakur, G., Maldonadoz, F., and Kipp, S., 1982.
"Subjective and Objective Evaluation of CO2-Controlled Variable Ventilation System", ASHRAE Transactions, Vol. 88, part 1.

F.11 - Building Envelope

Arasteh, D. et al., 1980.
"Performance of a Selective Surface Water Wall Retrofit", Proceedings of the 5th Passive Solar Conference, Amherst, MA.

Energy Mines & Resources Canada 1985.

Energy Management Series 18, "Architectural Considerations".

Dutt, G.S., Harrie, D.T., Gadsby, K.J., 1986.
"Convective Loop Losses in Buildings", Proc. of Thermal Performance of the Exterior Envelopes of Buildings III, ASHRAE: Atlanta.

Harrje, D.T., Buckley, C.E., and Heissler, G.M., 1982.
"Building Energy Reductions: Windbreak Optimization", ASCF Energy Journal.

Harrje, D.T., and Cerceo, J.A., 1983 (8).
"Recommended Retrofit Actions Based on Air Infiltration Evaluations in a Variety of Buildings", 4th AIC Conference - Air Infiltration Reduction in Existing Buildings, Annex V Air Infiltration Centre Doc AIC-PROC-11-83.

Mattingly, G.E., Harrje, D.T., Heissler, G.M., 1975.
"The Effectiveness of an evergreen windbreak to Reducing Residential Energy Consumption", ASHRAE Transactions Vol. 85, 2.

Shaw, C.Y., 1981.
"Air tightness: Supermarkets and Shopping Malls", ASHRAE Journal, Vol. 23, No. 3, pp. 44-46.

Silvers, J.P. and Tye, R.P., 1985.
"A Survey of Building Envelope Thermal Anomalies and Assessment of Thermal Break Materials for Anomaly Correction - Vol. II", Proceedings of Federal Workshop on Building Envelope Thermal Anomalies, ORNL/SUB-83/70376/2.

F.12 - Instrumentation For Energy Auditing

Electrical Construction and Maintenance (ECM), 1984.
"What's the Story? Factors Affecting Accuracy of Digital Multimeters", (March), p 52.

Energy, Mines & Resources Canada 1985.
Energy Management Series No. 15, "Measuring, Metering & Monitoring".

Harrje, D., and Cooper, 1979.
"Instrumenting Energy Audits", Princeton University Center of Energy & Environmental Studies Report PU-CFFS 91.

Johnson, G.L., and Jones, L., 1980.
"A Low Cost Data Logging System", DBR/NRC Building Research Note No. 166, (Aug.), Ottawa: National Research Council of Canada.

DETAILED ENERGY BALANCE

G.1 - General

This appendix provides guidance on disaggregating energy use to provide an energy balance.

The energy balance should make use of readily available data including:

- Utility records
- Plans and specifications
- Operating logbooks, particularly relating to energy use
- Discussions with building occupants and operations staff

Site monitoring may provide valuable insights to building operation than might otherwise be obtained with less accuracy and confidence using existing data. In some instances it may also be more economic to use monitoring.

G.2 - Disaggregation

The separation of energy into different fuels, and within fuels to weather and non-weather sensitive components, is a simple breakdown, previously introduced in Section 4. Such a step does not give many firm clues about areas of energy waste and conservation potential, but sets boundaries of energy use for different types of equipment, whose energy use may be totally, partly, or not at all weather sensitive.

Non-weather Dependent Components are components of energy use that remain nominally constant over the year or part of the year, for example, energy for elevators or for constant volume heating circulation pumps. Within this group of non-weather components there may be seasonal components either directly related to occupancy, as for schools; or related to occupancy habits such as seasonally changing menus or bathing patterns.

Weather Dependent Components are components of energy use that vary with outside conditions. For example heating and cooling.

A third category is introduced at this stage, i.e.

Time and Occupancy Dependent Components. These are components that change over the short term (hourly or daily), as a result of: occupant habits, such as opening windows and switching on lights, the HVAC system response to varying occupancy, or the scheduling of HVAC systems and equipment.

Table G.1 provides information on these components for a range of energy use categories. This table applies to typical cases but is not universally applicable. Therefore, each item will have to be checked in practical applications. An understanding of these components, and the factors that influence them, is essential when developing a detailed energy balance

G.3 - Weather and Non Weather Sensitive Components

It is first necessary to construct annual energy profiles (see Fig. G.1) for the fuel sources used; a demand profile is also desirable. Profiles can be constructed from utility data or from site consumption records. Problems of nonregular billing periods, estimated billings, and fuel delivery uncertainties make such a process less straight forward, or sometimes inapplicable.

The base load for fuel consumption can be taken as the consumption during the month(s) with least consumption, the weather dependent component being what is left once the base load has been subtracted. This simplistic approach cannot be relied upon to give reliable results where there is a summer demand for space air conditioning; where the same fuel is used for heating and DHW production; or where the summer occupancy or pattern of use is significantly different from that during the winter (for example, in schools). In these cases further analysis is required to help disaggregate the weather sensitive energy uses.

Care must also be taken to account for possible changes in operating efficiency between seasons. A good example of where efficiency of operation can vary quite dramatically is in the production of hot water from a single combined space heating and domestic hot water plant. In such a situation summer production can be at a considerably lower efficiency than during the winter months.

For electricity use, spring and fall consumption and demand can be taken as a first approximation of the base load if electric heat, heating systems auxiliaries, and all cooling system components are off for these periods. Often this is not the case, and estimates to separate out these components are necessary. For buildings without air conditioning these problems do not occur, but even then differing summer occupancy patterns can create difficulties. The use of lighting may also differ between the seasons.

Knowledge of installed equipment and operating patterns may help disaggregate the weather and non-weather dependent components, although ideally those should serve as an overall check to supposed or derived equipment operation.

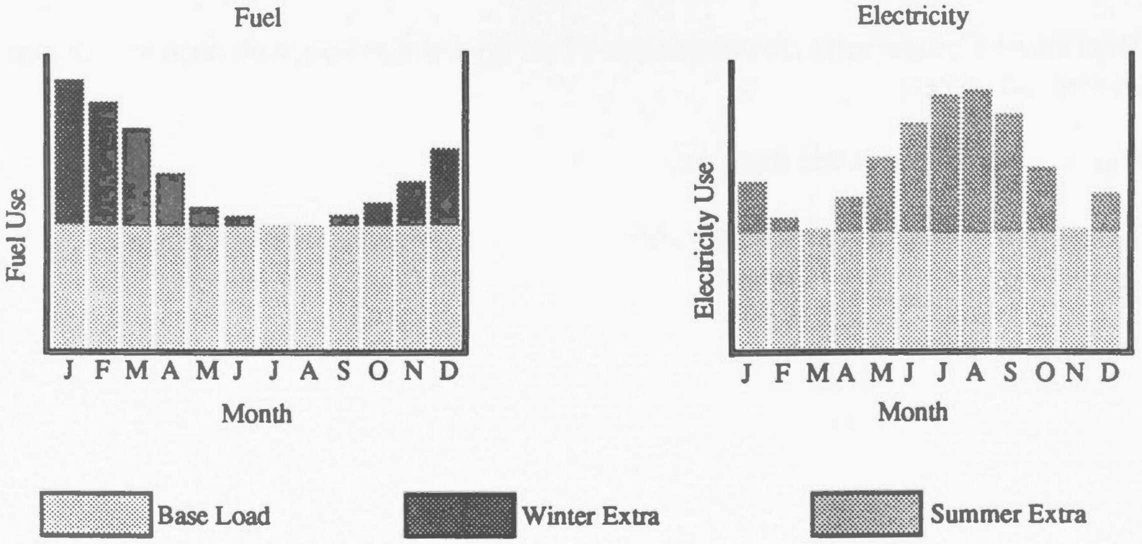


Figure G.1 Illustration of a Simple Energy Breakdown

TABLE G.1

TYPICAL COMPONENTS OF ENERGY USAGE FOR A RANGE OF END USES OF ENERGY

ENERGY END "USE"	NONWEATHER DEPENDENT	WEATHER DEPENDENT COMPONENT	TIME & OCCUPANCY DEPENDENT COMPONENT
*** SPACE HEATING**			
* Boiler Losses	Jacket losses are nominally constant over operating season.	Cycling losses increase with milder conditions.	
* Duct Losses	Nominally constant over heating season.	Some variation can be expected primarily where the conveyed fluid temperature varies significantly and to a lesser degree as a result of change in ambient temperatures.	
* Pipe Losses			
* HVAC/ Control Losses	Such situations as leakage between hot and cold ducts or pipes can create a continuous control loss.	Losses generally are higher at low loads. A good example of a weather dependent control loss is re-heat in a re-heat system.	Can occur where occupant interferes with the proper control action.
* Ventilation		Energy losses depend on temperature difference and humidity even if ventilation rate is constant.	Present where ventilation systems are shut off when building is unoccupied or the ventilation rate is varied with occupancy.
* Conduction		Usually the major component.	Present where setback practiced.

ENERGY END "USE"	NONWEATHER DEPENDENT	WEATHER DEPENDENT COMPONENT	TIME & OCCUPANCY DEPENDENT COMPONENT
***SPACE HEATING**			
* Infiltration		Usually the major component.	Exterior door usage and window opening will increase infiltration.
* Humidification		Usually the major component.	Lower ventilation rates e.g. during unoccupied periods will lower the humidification load. Conversely humidity gains from occupant will reduce humidifying needs.
*** SERVICE HOT WATER**			
* Useful Heat Consumption	Normally constant, although will vary for instance where there are different systems for summer and winter. Will also vary if there are seasonal use patterns.	Minor component due to changes in cold water supply temperature. Mixed systems e.g. gas/solar will be weather dependent.	Water usage will vary with time of day and occupancy.
* Pipe Losses	Substantially constant.	Minor due to changes in space temperature.	Minimal effect
*** FAN ENERGY**			
* Heating Only	Normally constant for heating season except with VAV systems.	Present where fan cycles on and off to meet the load.	Will be present where fan is switched off during unoccupied periods.
* Cooling Only	Normally constant	Present where fan	Will be present

ENERGY END "USE"	NONWEATHER DEPENDENT	WEATHER DEPENDENT COMPONENT	TIME & OCCUPANCY DEPENDENT COMPONENT
	for cooling season except for VAV systems.	cycles on and off to meet the load.	where system shut off during unoccupied periods or occupancy affects load in VAV systems.
*Heat & Vent. Cool & Vent (or Heat-Cool & Vent)	Normally constant throughout year except with VAV systems.		Will be present where system is shut off during unoccupied periods or occupancy affects load in VAV systems.
* Exhaust Systems	Nominally constant throughout the year.	Normally no weather dependency unless used for free-cooling.	Will be present where systems are under occupant control.
* PUMP ENERGY			
* Heating * Cooling	Nominally constant over heating and cooling season, respectively.	Some small weather dependency if variable volume pumping; controlled by throttle valves, or where operation is scheduled with outside air temperture or other weather variable.	Will be a small effect where pumps shut off during unoccupied periods or use impacts on load in variable volume or scheduled pumping systems.
* LIGHTING			
* Interior	Often constant, over the year although there may be some seasonal variation with changes in daylight availability.		Tends to be very user-dependent, especially over short periods.

ENERGY END "USE"	NONWEATHER DEPENDENT	WEATHER DEPENDENT COMPONENT	TIME & OCCUPANCY DEPENDENT COMPONENT
* Night/ Security	Nominally constant.		
* Outside	Nominally constant except where controlled by photocells or astronomical time clocks.		Varies with seasonal change in daylight hours.
*** SPACE AIR CONDITIONING (ELECTRICAL INPUT)**			
* Duct Gains	--	as detailed under 1.2	----------------------------
* Pipe Gains	--	as detailed under 1.3	----------------------------
* Control Losses	--	as detailed under 1.4	----------------------------
* Ventilation	--	as detailed under 1.5	----------------------------
* Conduction	--	as detailed under 1.6	----------------------------
* Internal Loads	Often the most signifnificant component.		Over the short term load primarily dependent on occupancy.
* Infiltration	--	as detailed under 1.7	----------------------------
* Solar	The minimum solar gain can be thought of as a constant component.	Primarily influenced by calendar and weather.	Present where occupants have control over and make use of shading devices.
*** MISCELLANEOUS**			
* Portable Equipment	Generally can be considered the only significant component.		
* Elevators	Normally the only		Varies with use of

ENERGY END "USE"	NONWEATHER DEPENDENT	WEATHER DEPENDENT COMPONENT	TIME & OCCUPANCY DEPENDENT COMPONENT
	significant component.		elevator.
* Snow Melting	Normally completely weather dependent unless systems left uncontrolled throughout year or season. year or season.		
* Kitchen Equipment	Often can be considered the only significant component; may be seasonal changes if menus change.		Hourly variations can be expected with schedule of meal preparations.
* Laundry	For the domestic situation the washload and drying habits may vary seasonally.		
* Block Heaters		Primarily a weather dependent load.	Temperature or timer controls can significantly change usage patterns.

G.4 - Determination of Weather Dependency

The primary purpose of studying weather dependency is to develop an understanding of how external parameters, such as outside wet and dry bulb temperatures, solar radiation, or wind speed, affect energy usage. The effects might be studied over a long period, for example, using utility records to look at a years operation, or short term to identify hour by hour effects. Such techniques ultimately lead to an understanding, or give some indication of importance, of specific energy flows. For example if extreme energy use peaks are observed to coincide with high wind speeds but moderate temperatures, one should suspect infiltration to be a significant component of the overall heat load. It would, however, be incorrect to assume that there is a relationship with wind speeds if high wind speeds coincide with low temperatures (where the low temperature could be responsible for the effects). A number of techniques for determining weather dependency are introduced briefly below.

G.5 - Regression Techniques Based on Utility or Consumption Records

The simplest of regression techniques rely on the best straight line fit through a number of data points. Many software packages and hand held calculators can provide such an analysis, failing this, relationships can be derived by plotting the results and fitting a straight line by eye.

This simple regression technique is well suited to the analysis of seasonal trends such as the variation of heating or cooling consumption with variations in climate. A commonly used technique is the energy profile method, the energy consumption for a fixed period being plotted against the average indoor-outdoor temperature difference, average outdoor temperature, or degree days in the period. A simple case is illustrated in Fig. G.2.

For many applications, particularly in simple heating only situations, an acceptable linear relationship between energy use and outside temperature is normally obtained. Typically the regression correlation coefficient values are greater than 0.96 (and more likely 0.98) meaning that all but 4 per cent (or 2 per cent) of the data variation can be accounted for. When utility data are estimated for a winter month, data scatter will naturally increase. An adjustment can be made to reduce this problem by increasing the time interval for that data (group the estimated month with the next month's actual reading to form an accurate "two-month" interval). A loss in linearity is sometimes experienced in milder months (near the beginning and the end of the heating season) which may be attributed to:

* Window openings that are expected to increase in mild weather increasing fuel consumption and tending to force the curve upwards.

* Normally decreasing boiler and furnace efficiency at low loads also tending to force the curve upwards, and

* Changing solar contributions forcing the curve either upwards or downwards depending on the window orientation, changing hours of sunshine and use of shading devices.

For these reasons, the transition from weather-dependent load to the baseload (such as service water heating) is not always as clear-cut as suggested by Figure G.2

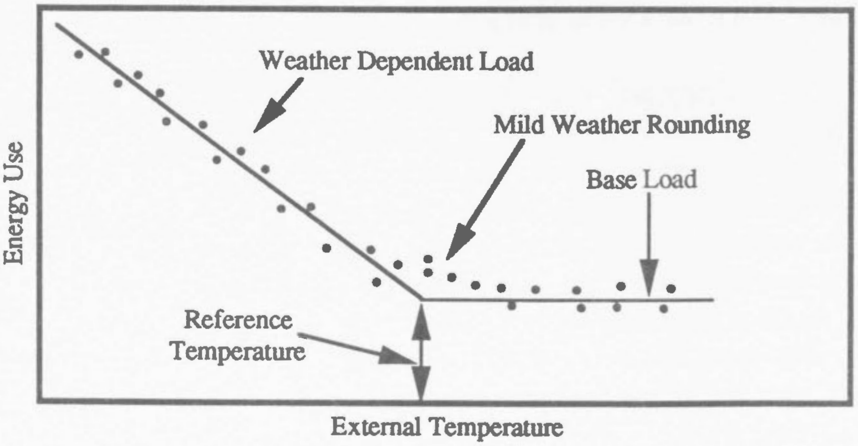


Fig. G.2 Energy Profile

Often there are two different energy sources to be evaluated, electrical use for cooling and oil or gas for heating and, therefore, the cooling energy profiles and heating energy profiles can be easily separated. If the building is both heated and cooled by electricity, the two profiles will merge, making it difficult to establish the level of the baseload.

Where the procedure is being applied to cooling consumption, it is worth trying regression based alternately on dry bulb and wet bulb data. If a better fit is obtained with wet bulb data, this is an indication that a significant portion of the cooling load can be attributable to ventilation.

G.6 - Regression Based on Site Measurements

Data obtained by site measurements has the advantage over utility bill data of being more detailed and more frequent. Further, site measurement allows for simple experimentation to aid the disaggregation process. For example, monitoring over a period with ventilation fans turned off will enable estimates of the fraction of the weather dependent component attributed to mechanical ventilation. Similarly, shutting off the heating on alternate days during the cooling season and observing the effect on cooling energy consumption will help determine control losses. Shutting-off nonweather dependent loads for a short period can also be considered in order to determine their impact on the overall consumption.

Other tests, such as a combustion efficiency test and a measurement of boiler fuel consumption when the space load has been removed (for example by setting down the space thermostat), can help establish the portion of the building heating consumption attributed to boiler standby and combustion losses.

For buildings with heating only it is, in general, sufficient to collect daily or weekly data for part of the heating season. If heating is only needed for part of the day, it may be necessary to collect hourly data. For buildings with heating and cooling, data from different parts of the year should be collected.

Site measured data can be analyzed in a similar manner to that described for utility data, although there will be the benefit of more data points, albeit over a smaller range of building operating conditions.

Non-weather dependent factors such as boiler standby losses, water heating and cooling, or other process energies, can be established by extrapolating data down to the nonweather driven load conditions, although this procedure is less reliable if the data covers only a small temperature range. In this case, monitoring should include a wide range of weather conditions.

Monitoring inside temperatures is important, since temperature fluctuations and differences between various building zones tell something about how control systems respond to weather fluctuations.

With the installation of monitoring equipment, more specific weather effects might be investigated. For instance, more complex model techniques can be used to determine the influence of climatic parameters such as wind speed, wet bulb temperature, and solar radiation on energy consumption. Such an analysis can indicate which EMO categories show promise of significant savings and warrant a more careful analysis or further monitoring. In many cases this may be beyond the scope of the auditor and the use of specialist consultants should be considered.

G.7 - Determination of Short Term Effects

The previously described disaggregation techniques have been related to long term effects. Equally important are short term effects; i.e. hourly and daily variations. The largest and most cost effective savings have been obtained by re-scheduling of building systems, and it is therefore important to know, for instance, the energy demand during occupied and unoccupied periods. An office building is, for example, unoccupied for a much longer time than it is occupied.

The determination of short term effects will require site monitoring, unless information can be obtained from operating logs. Monitoring can vary in detail, in sophistication, and time. The more detailed and longer the monitoring period, the more useful the data, but there is normally a point of diminishing returns and a budget to work within. Recording for one to two weeks would be ideal, but in most cases this is too long a time to spend on the disaggregation stage. For large buildings, one or two weeks of hourly records of the total electrical and fuel demand can usually be justified, giving an overall picture of how much the building energy systems are in tune with occupancy. The monitoring period should cover weekdays as well as weekends. The potential for scheduling type EMOs can be explored by plotting the energy consumption, or the demand profile, along with the occupancy profile versus time. The method is particularly effective for determining the potential for electrical demand limiting.

Photographic techniques or other simple data loggers can be used to record utility meter readings. Run time meters can be applied to determine the operation of key pieces of equipment.

Satisfactory, but less informative, results can be obtained by reading utility and other installed meters at the beginning and end of every work day and comparing average consumptions for occupied and unoccupied hours.

Building equipment operation can be analyzed by looking at long term data, specifically by calculating the electrical load factor for the non-weather sensitive part of electric usage, and comparing it to a target load factor representative of a similar, well-tuned building. The target value can be calculated based on the operating hours or taken from records of similar well-tuned buildings.

G.8 - Disaggregation by Prediction

Predictive methods can be used to disaggregate some components of energy usage by making assumptions or having information about operation profiles and installed capacities.

Items of equipment with predictable or known schedules of operation, such as pumps and fans, lend themselves to this approach but others, such as occupant use of lighting, do not. In many cases the use of energy, for example, for lighting and elevators must be assumed to equal the remainder when all other predictable equipment consumption has been taken into account.

The method can also be applied to other categories of energy use such as the identification of the relative contributions of wall, window, roof, infiltration and ventilation losses to the overall space heat loss. Table G.2 summarizes how disaggregation techniques can be used to estimate or determine component energy usage.

TABLE G.2

SUMMARY OF DISAGGREGATION TECHNIQUES FOR DETERMINING CATEGORY ENERGY USAGE

***SPACE HEATING**	Space Heating is given by the winter weather dependent component. The Base load can be estimated from usage during the months with least consumption; distribution and control losses however will not be included in this figure.
*** SPACE AIR CONDITIONING**	Space Air Conditioning is given by the summer weather dependent component. The size of the nonweather dependent component can give preliminary indications of the magnitude of the internal load.
***DOMESTIC HOT WATER**	Can be identified by recording the use of DHW for a short period. Some allowance should be made for seasonal changes of feed water temperature and possible seasonal variation in pattern of use and for variations in efficiency. An estimate of tank losses can be obtained by recording fuel consumption of water heater during a period when there is no water use.
*** FAN ENERGY**	Can be calculated using design or installed capacities and derived or assumed profile of operation. As a rule of thumb take 90% of the rated power since most motors are rarely fully loaded. Estimation is difficult where fan operation is controlled by a thermostat, and problematic where VAV fans are employed. Hourly monitoring of electricity or individual equipment can help establish reliable operation profiles.
*** PUMP ENERGY**	Can be calculated using design or installed capacities and derived or assumed profile of operation. As a rule of thumb take 90% of the motor rated power since most motors are rarely fully loaded. There are some problems using the method with variable flow systems e.g. systems with throttle valves, motor speed control or staged pumping.
*** LIGHTING**	Can be calculated using assumed or observed patterns ofusage. Hourly load recording or monitoring lighting usage can help establish a reliable profile of use. An indication of the efficiency of lighting switching devices can be obtained by comparing the actual lighting use load factor with a calculated figure, based on the connected lighting load multiplied by an assumed reasonable lighting on-time.