International Energy Agency

Source Book for Energy Auditors

Volume 1

Energy Conservation in Buildings and Community Systems Programme. Annex XI. Energy Auditing.

INTERNATIONAL ENERGY AGENCY

Effective cooperation amongst nations and development of new technologies to reduce dependence on fossil fuels are critically important elements of a sound energy future. Agreement by 21 countries to cooperate on energy policy is embodied in an International Energy Program, developed in the wake of the 1973/74 energy crisis and administered by the International Energy Agency (IEA), an autonomous body within the OECD.

ENERGY CONSERVATION IN BUILDINGS AND COMMUNITY SYSTEMS

As one element of the energy program, the IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy.

17 countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering collaborative research in this area. The designation by governments of a number of private organisations, as well as universities and government laboratories, as contracting parties have provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments. The importance of associating industry with government sponsored energy RD&D is recognised in the IEA, and every effort is made to encourage this trend.

THE EXECUTIVE COMMITTEE

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures thet all projects fit into a predetermined strategy, without unnecessary overlap or duplication but with effective liaison and communication. The Executive Committee has initiated the following projects to date (completed projects are identified by ⋆):

- I. Load Energy Determination of Buildings ⋆
- II. Ekistics & Advanced Community Energy Systems ⋆
- III. Energy Conservation In Residential Buildings ⋆
- IV. Glasgow Commercial Building Monitoring ⋆
- V. Air Infiltration Centre
- VI. Energy Systems & Design of Communities ⋆
- VII. Local Government Energy Planning
- VIII. Inhabitant Behaviour with regard to Ventilation
- IX. Minimum Ventilation Rates
- X. Building HVAC Systems Simulation
- XI. Energy Auditing
- XII. Windows and Fenestration
- XIII. Energy Management in Hospitals
- XIV. Condensation

TASK XI ENERGY AUDITING

In order to increase the efficiency of energy saving programmes many IEA countries are using or developing energy audits. An energy audit is a series of actions, aiming at breaking down into component parts and quantifying the energy used in a building, analyzing the applicability, cost and value of measures to reduce energy consumption, and recommending what measures to take. A variety of audits have been used, for different purposes, with different complexity and different audit scope.

The objectives of the Task have been to develop means, methods and strategies for auditing, and contribute to an implementation of the knowledge accumulated during the work on the Task. The work has been directed towards larger buildings, with a certain complexity of energy supply systems and energy use, exemplified by apartment buildings, commercial buildings, schools, administration buildings, etc. The intention has been that results of the Task should be useful for energy auditors, helping them to increase the efficiency and the cost-effectiveness of their work. Also, the results should be useful for building owners and those in charge of energy planning or management for a building, although energy planning or management has not been dealt with in the Task. The subject of national or regional energy planning or management has been outside the scope of the project.

The results are presented as this "Source Book for Energy Auditors".

The content is based on the collective knowledge and experience of the patrticipating experts, and may be characterized as a common basis from which more specific information may be developed. The need for this development is obvious. Building codes and normal building construction vary from one country or region to another, and from time to time. These variations – in addition to local variations of climate, living habits, etc – must always be considered when executing and analyzing an energy audit. In most cases, therefore, the information in this book has to be reviewed and adapted before being used in the field.

PARTICIPANTS IN TASK XI

Belgium	The Science Policy Office of Belgium
Canada	The National Research Council of Canada
CEC	The Commission of the European Communities
Italy	Consiglio Nazionale delle Ricerche
The Netherlands	TNO Institute of Applied Physics (TPD)
Norway	Norges Teknisk-Naturvitenskapelige Forskningsråd
Sweden	Swedish Council for Building Research
Switzerland	L'Office Fédéral de l'Energie
U.K.	Building Research Establishment
U.S.A.	The Department of Energy

The Swedish Council for Building Research has been responsible for the operation of this Task. Operating Agent has been Mr Arne Boysen, Bengt Hidemark-Gösta Danielsson Arkitektkontor, Stockholm.

Volume 1

Source Book for Energy Auditors

Edited by M.D. Lyberg

IEA

Energy Conservation **April 1987**

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FOREWORD

The aim of this Source Book for Energy Auditors is to provide practitioners in the field of energy auditing with a structured collection of material which will assist in improving the auditing process, based on the accumulated knowledge and experience of experts from a number of countries. The material consists of a systematic approach to auditing, supported by a detailed collection of technical material ranging from auditing procedures to techniques for analysis and measurement.

The cost-effectiveness of energy auditing depends on the costs incurred in carrying out the audit and on the cost-effectiveness of the energy saving measures implemented as a result of the auditing. It is important to identify worthwhile measures quickly and at a minimum cost, but the difficulty of doing so will depend on the characteristics of each individual building, and its current energy performance. It is also important to take into account the variations which occur from one part of a building to another and the relative efficiency of different energy consuming systems.

Formulae and instruments cannot be a substitute for experience and knowledge in solving this problem, but the effectiveness of energy auditing can be improved if it is undertaken systematically and if experience and knowledge is documented in an organised and structured manner. It will also be more effective if the building owner has a clear idea of what should be achieved. This is the aim of this Source Book.

The knowledge has been compiled by experts from all participating countries, and evaluated and modified sometimes with assistance from other experts in their countries. Those participating are listed at the end of this foreword. They represent a wide spectrum of background, from practitioners in the field to researchers in laboratories and university professors.

The work was started in 1983, based on an agreement among nine countries and the Commission of the European Community. A preparatory meeting had previously been held with experts representing the interested countries, and at this meeting the first efforts were made to structure the work and draw up some work-plans. This process of defining the work continued during the following meeting. Altogether there has been nine meetings to coordinate the work of the participating experts.

The compilation of material for the Source Book was completed in May 1986, and the editing started in June 1986. A draft of the Source Book was presented to the participating experts in January, 1987. This draft was then revised according to the comments received from the experts. The revised draft was submitted to the executive Committee in April, 1987.

It is believed that this Source Book represents a significant advance in energy auditing methodology. It contains a large amount of knowledge presented in a way that makes it easy to apply. New experience and knowledge is generated continuously, but this Source Book contains a definitive statement of the current position. It is expected that auditors will use the material selectively to suit the prevailing conditions, taking account of different building traditions, lifestyles and climatic conditions and the circumstances prevailing in their own country.

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Gavle, Sweden, April 1, 1987
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INTRODUCTION

Energy auditing is a new term and as such without a precise definition. The term is used by some to define a specific activity, and by others to encompass a wide range of activities in the accounting of energy usage.

In this work, 'Energy Auditing' is taken to entail a series of actions aimed at the evaluation of the energy saving potential of a building <u>and</u> the identification and evaluation of Energy Conservation Opportunities (ECOs).

The approach to energy auditing used in the Source Book seeks to minimise the cost of auditing, to maximise its effect and to pass as quickly as possible to recommendations of Energy Conservation Opportunities (ECOs). This is pursued through the use of a staged process, in which the early stages are wide in scope but low in detail, while the later stages are more detailed but narrower in scope. The Source Book for Energy Auditing contains seven chapters, nine appendices, a reference list, and an analytical index. The content of the various chapters and appendices is described below.

Chapter 1 The Audit Process

Chapter 1 describes how the various results of this IEA Task are designed to be used. The purpose is to give the reader an introduction to the material in subsequent chapters, and an overall idea of the Source Book approach. The relation of energy auditing to energy management is also presented.

Chapter 2 Rating Buildings for Audit

Chapter 2 discusses the problem of how to find in a stock of buildings those which merit an audit or to decide wether a specific building needs a further detailed audit. The use of energy indicators, target values, and data required for rating buildings for audit are described.

Chapter 3 Disaggregation of Energy Consumption

Chapter 3 provides guidance on how to find those areas of a building with potential for energy conservation. The breakdown of energy use into components, and a further breakdown of these components into a weather sensitive and a non weather sensitive part, is discussed.

Chapter 4 Energy Conservation Opportunity (ECO) Identification and Evaluation

Chapter 4 discusses the need to go as quickly as possible from the establishment of the energy consumption overview to recommendations of energy conservation opportunities. The methods for arriving at these recommendations directly, quickly, and with a minimum of effort are given. The need for the development of an ECO implementation strategy is raised and a range of factors affecting the value of retrofit actions, such as ECOs in combination and ECO longevity, are discussed.

Chapter 5 Post Implementation Performance Analysis

Chapter 5 provides the reasons and techniques for checking the performance of energy conservation measures after implementation.

Chapter 6 Building Energy Analysis and Models

Chapter 6 starts by discussing alternative approaches of performing an analysis of energy usage in buildings. This chapter continues by describing the use of models ranging from simple models to sophisticated computer models. Some simple economic models, methods of optimising combination of ECOs, correlation models and selection of calculation techniques are also treated.

Chapter 7 Energy Audit Data Bases

The purpose of chapter 7 is to give an overview of factors which should be regarded in order to evaluate the applicability, validity, and usefulness of data bases. Included is a discussion on the establishment and use of such data bases.

To supplement these chapters a number of appendices provide more detailed information. The Appendices A-D are found in the first volume, the others in the second volume. Subjects covered in these appendices are:

<u>Appendix A Glossary</u>

The glossary defines a number of terms used in the Source Book. The meaning of these terms may not coincide with the readers current understanding of them.

<u>Appendix B List of Symbols and Abbreviations</u>

Appendix B provides a list of symbols and notation used in formulas and equations as well as a list of common abbreviations used in the Source Book.

<u>Appendix C Parameters Influencing Energy Use and Auditing Problems</u>

The purpose of Appendix C is to create a better understanding of the way energy is used in various building systems. The key parameters affecting energy use are described, together with how the various building systems function. This information is vital to the auditor for ECO identification and an understanding of the relationships between various options. Rational choices of ECOs can be made only with a working knowledge of how the complete building functions. The text discusses some of the difficulties associated with the actual identification of the retrofit potential.

<u>Appendix D Energy Conservation Opportunities (ECOs)</u>

Appendix D contains a catalogue of potential energy conservation measures. For each ECO key data are presented, for example, the scope, complexity, side-effects, interactions and cost factors of the ECO.

Introduction

Under the subheading of 'Application' and 'Evaluations' is provided general information that will assist in the initial identification and evaluation processes. Information included under other sub-headings such as 'Side Benefits' and 'Cautions' provides additional information by which the true value of an ECO might be judged. Also, under the sub-heading 'Evaluation', will be found references to specific detailed evaluation methods, which may be useful later on in the evaluation process. These detailed evaluation methods will take the form of either "Audit Procedures", "Measurement Techniques" or "Analysis Techniques" .

Appendix E Checklists

A method is described by which checklists can be developed and used to aid the preliminary identification and sorting of ECOs for a particular building. This provides a formalised basis for the initial ECO identification and evaluation activities. Checklists for various categories have been prepared and a methodology for developing or tailoring checklists to suit particular requirements is described.

Appendix F Audit Procedures

Appendix F includes descriptions of how data can be collected and analyzed in order to identify and evaluate ECOs for a particular building.

"Audit Procedures" are descriptions of site testing methods and contain details of the data collection methods and associated data analyses. Audit procedures may occur anywhere in the audit process, in the building rating for an audit, in the energy disaggregation process, in the checking and ranking of ECOs, or in the detailed evaluation of ECOs. A number of such procedures along with a description of the format are documented in this Appendix. The majority of these procedures, although not all, are applicable to "detailed ECO evaluation". Each procedure provides indications of areas of use, typical cost, accuracy and, alternative procedures, which are intended to aid the auditor to select the most suitable procedures. Procedures are normally, although not always, referenced to specific ECOs or types of ECOs, and are obviously only applicable where such ECOs are under consideration.

Appendix G Measurement Techniques

Appendix G provides a reference of field measurement techniques related to energy auditing. The ECO identification and evaluation process will be more accurate if the auditor can carry out careful measurements using selected instruments instead of estimating important energy parameters. Common building measurements are described, along with descriptions of instruments that are most appropriate for carrying out such measurements. The information, in a summarized form, covers description, cost, accuracy, ease of use, recommended applications, alternative techniques, equipment required, and references.

Appendix H Analysis Techniques

Like Audit Procedures, there may be requirements for analysis in the various audit stages. The topic of analysis is covered in Appendix H, which deals with both general analysis and specific analysis issues related to single ECOs. General analysis issues cover generic calculation methods such as degree-day and bin methods. A range of economic assessment models are also discussed. Specific Analysis Techniques are related to single ECOs or similar types of ECOs, and either give details of the analysis to be performed in the form of equations or provide descriptions of specific details to be considered when using generic methods.

Appendix I Reference Values

Various reference values are identified which can be used during the energy auditing of a building. For ECO identification and preliminary evaluation, the Appendix I provides information such as typical efficiencies for retrofit equipment and target values of performance. One example is insulation levels against which existing conditions can be compared. The usefulness of such data and details of how such data might be derived and used are discussed. The Reference Value forms are referenced in the ECO descriptions and in the Audit Procedures, Measurement Techniques, and Analysis Techniques.

Source Book Cataloguing System

When references are made to particular Audit Procedures, Measurement Techniques, Analysis Techniques, or Reference Values in the chapters or the appendices, the following abbreviations are used:

AP Audit Procedure
MT Measurement Technique
AT Analysis Technique
RV Reference Value.

A classification of building components is used in the Source Book to promote efficient cataloguing and referencing of information. The principal component categories with their respective abbreviations are:

E - Envelope
R - Regulation
H - Heating
H/C-Heating and Cooling (related to equipment which can be used for heating as well as cooling)
C - Cooling
D - Ductwork
P - Pipework
S - Service Hot Water (SHW)
L - Lighting
EL- Electrical Systems
M - Miscellaneous

Then, for example, when reference is made to AP L.6, this means an Audit Procedure belonging to the Lighting Category.

The separation into the above categories catalogues those areas where there is minimum linkage, i.e. the groups are fairly self-contained and auditing activities can be restricted to one or more groups, for example as a consequence of a disaggregation. This is not to say that there is no connection between the groups; certainly this is not the case since, for example, changes to the envelope will have an impact on the seasonal efficiency of a boiler.

The Envelope category encompasses all aspects associated with the exterior fabric of the building, i.e. walls, windows, doors and roofs and internal partitions adjacent to unheated spaces.

The Regulation category covers those aspects related to the control of heating, cooling, ventilation, and exhaust air entering or leaving a space. Included are both the actual quality of the maintained conditions and the efficiency with which these conditions are provided by the HVAC systems and equipment.

The Heating and Cooling categories are oriented towards Central Plant equipment such as boilers and heat pumps and chillers, but is also applicable to the actual conversion processes of localised unitary equipment.

The Pipework and Ductwork categories cover systems that distribute heating or cooling from a central or localised plant to the place where it is used and, in the case of air distribution systems, that carry ventilation or exhaust air to and from a conditioned space. Pipe and duct heat and fluid losses, fluid friction losses, and fan and pump operation would be addressed under this category. ECOs concerned with the actual control of the heating or ventilation are however covered under "Regulation".

Under the Lighting category are all those aspects associated with the production and control of lighting in the space. Lighting controls to make use of daylight would be accommodated in this category, but fenestration changes would be covered under "Envelope."

The Service Hot Water (SHW) category is concerned with aspects of the production and use of service hot water.

Included under the Electrical systems category are those aspects uniquely related to electrical systems such as the performance of electric motors, power factor control, and demand limiting. The actual possibility, for instance, of reduced electrical equipment usage would, however, be covered under categories such as "Lighting." Energy savings associated with electrical appliances are not included in this Source Book as such energy savings are dependent on improvements by the manufacturer and not on the auditor's skill.

The Miscellaneous category includes factors not treated in the other categories, for example, ECOs related to the behavior and habits of occupants are treated in the Miscellaneous category.

CHAPTER 1 THE AUDIT PROCESS

1.1 INTRODUCTION

1.1.1 What is Energy Auditing

Energy auditing is a new term and as such without a precise definition. The term is used by some to define a specific activity, and by others to encompass a wide range of activities in the accounting of energy usage.

In this work, 'Energy Auditing' is taken to entail a series of actions aimed at the evaluation of the energy saving potential of a building and the identification and evaluation of energy conservation opportunities (ECOs).

Many complement the term "energy auditing" with adjectives to better describe some particular characteristic of the audit. For example, the term "walk through audit" is used to describe a brief audit carried out during a simple inspection of a building. Audits may be characteristed by the:

i) Focus: Audits addressing the needs of national and community energy planning have a different purpose than those audits addressing the goal of reducing energy consumption on a building by building basis; i.e. a "building specific audit".

ii) Scope: Audits often address a limited number of aspects of building energy use. An audit might be targeted for one or two aspects of a building but encompass a large number of buildings, as does aerial infrared photography to audit community roof heat loss.

iii) Level of Detail: Level of detail can be associated with audit focus, since different purposes demand different levels of detail. However, even with similar purposes the level of detail required may vary.

In this work, previously adopted audit descriptors have been avoided, since their use is not consistent. Consequently, we have found it necessary to define and, in some cases, re-define many terms. Inevitably some of the terminology used will not coincide with the reader's current understanding. To facilitate the reading, a Glossary of Terms is provided (Appendix A).

1.1.2 The Energy Audit Challenge

Although a detailed understanding of energy flows in a building is possible, this is often costly and hard to justify. In buildings with a poor energy performance, opportunities for saving energy are easy to find, but in good buildings and those with complex energy systems, the auditing process requires more effort. Costs can be reduced by tailoring the scope and level of detail in the audit, but care must be taken not to impair the value of the audit, for example, by missing valuable retrofit opportunities. Also, the impact on the environment and indoor climate should be considered.

1.2 BUILDING ENERGY MANAGEMENT

Energy auditing is an integral part of the management of energy use, which in turn is part of the building management. Energy auditing should be carried out with due regard to the management plan for the building; to do otherwise risks wasting auditing effort and missing desirable retrofit strategies.

The available budget, the medium or long term plans for the building, outstanding or planned refurbishment, and the client's preferences should be considered in developing an auditing approach and in the process of formulating a retrofit strategy. For instance, an audit to identify only operational and maintenance changes might be appropriate where budgets are severely limited, or where it is planned to use the savings to fund more cost intensive audit and retrofit activities. Alternatively, if a client wishes to improve the appearance of a building, as well as saving energy, one should place greater emphasis on envelope or lighting retrofits rather than for instance on boiler replacement.

The input of building owners and users is vital to the cost effectiveness of auditing and the ultimate implementation of ECOs.

1.3 SOURCE BOOK APPROACH TO ENERGY AUDITING

The approach to energy auditing used in the sourcebook seeks to minimise the cost of auditing and maximise its effect. This is pursued through the use of a staged audit process in which the early stages are wide in scope but low in detail, while the later stages are more detailed but narrower in scope. For large projects, it is recommended that these audit stages be considered as milestones. At the end of each stage, the auditor should discuss with the client the results and conclusions of work to date and get his guidance and agreement on the direction and content of work in the next stage.

For simpler projects, this staging is still recommended although it might be carried out in a less formal way. For very simple projects, the various stages might be compressed into a single stage.

These audit stages are:

i) Building Rating for an Audit
ii) Disaggregation of Energy Consumption
iii) ECO Identification
iv) ECO Evaluation
v) Post Implementation Performance Analysis (PIPA)

Figure 1.1 illustrates the concept. Each stage could constitute separate agreements in an energy audit contract between client and auditor.

1.3.1 Building Rating for an Audit

This first step involves the identification of buildings which have a good potential for energy conservation, for example, buildings with abnormally high energy consumption or buildings with such design, material, equipment, or usage that they can be easily and cost-effectively retrofitted. A rough estimate of the energy saving potential and the usefulness of the detailed audit can be made also for a specific building. This initial step is not intended to address specific ECOs. (Oubal, 1983)

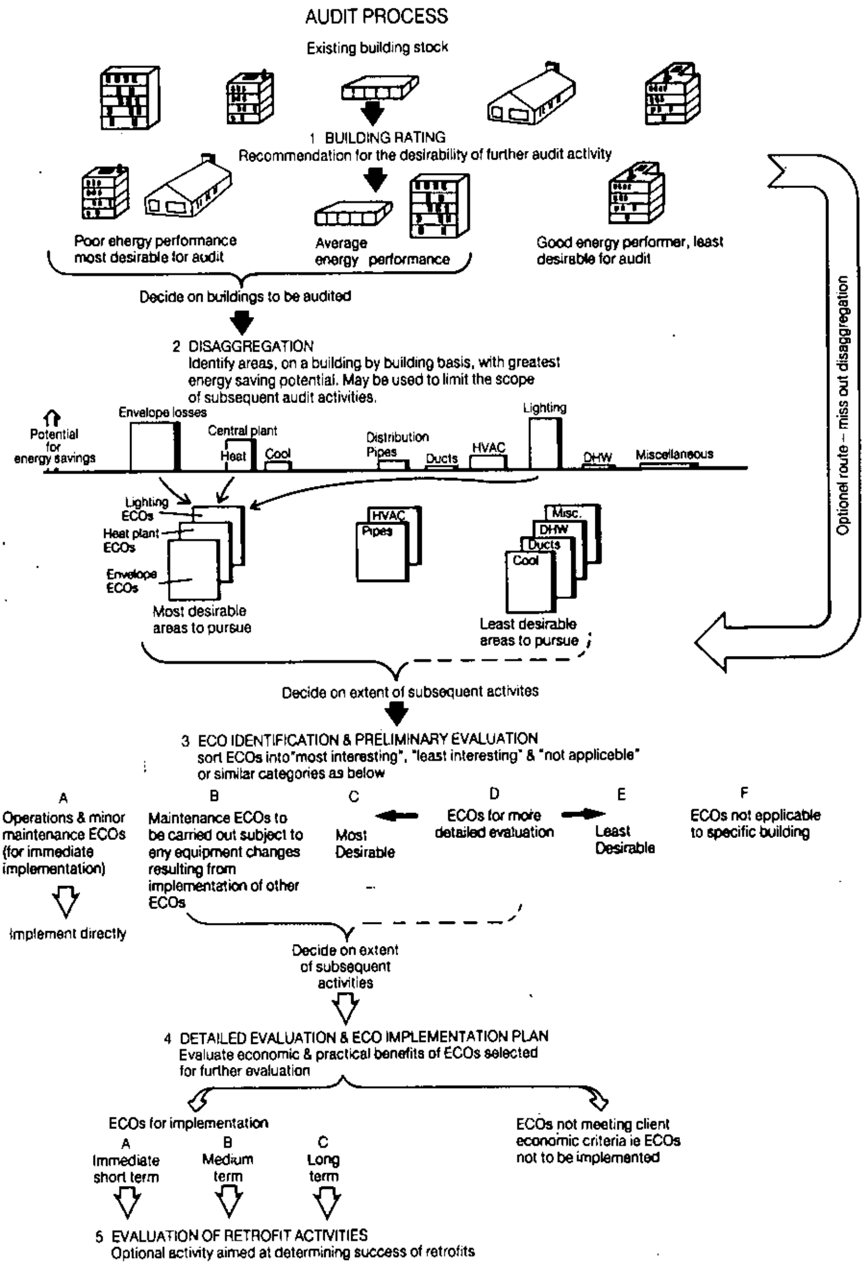


Fig. 1.1 The stages of the audit process.

1.3.2 Disaggregation

The disaggregation of total building energy consumption into its component parts (see section 3.2) can serve two purposes:

i) It can focus the attention to the major energy flows and identify promising areas for retrofit and conservation, and
ii) It can serve as a simple energy model of the building, which can be used in the evaluation of ECOs or for cross checking more detailed models.

Focusing the attention can help limit or restrict subsequent auditing to those areas where most productive retrofits can be found. In many cases, disaggregation will provide directly a basis for some ECO identification and evaluation.

1.3.3 ECO Identification and ECO Evaluation

Auditing economy can be achieved by collecting only those data that are useful for the audit, and by collecting data at a level with no greater accuracy than is required.

This principle can be applied by letting a simple data collection, for the purpose of identifying applicable ECOs, precede the detailed data collection needed for the evaluation of ECOs. This procedure may identify ECOs for implementation or indicate their applicability. The intent is to ensure that every possible ECO is given sufficient attention such that it can be either implemented, considered for more detailed evaluation, or discarded as being inappropriate.

ECO evaluation should follow ECO identification as part of a continuous process of gradually increasing level of detail. As the evaluation process continues, the development of an overall ECO implementation plan must be emphasised and interactions between ECOs and retrofit sequencing need to be given increasingly detailed considerations.

The lower level of detail, particularly as it relates to identification activities, will mostly not require measurements although simple initial measurements may be justified. Final stages of the evaluation of some ECOs may require significant onsite measurements as well as careful analysis.

The process of ECO identification and evaluation may be carried out for the whole of the building, for only those areas identified by disaggregation as offering most energy saving potential, or for those areas chosen with considerations of the desires and plans of the client. The process is described more fully in Chapter 4.

1.3.4 Post Implementation Performance Analysis

Auditing occurring after the ECO implementation serves two basic needs. The first is the identification of developing problems or loss of performance, the second is the evaluation of the retrofit.

i) Problem Identification. Deviations from expected or past performance can be identified through the monitoring and analysis of site collected data, particularly energy consumption data. To minimise energy losses, the monitoring should be carried out frequently, say weekly, so that problems can be detected as they develop. Building managers or owners may also wish to see summaries of these data in order to verify that their buildings are operated and maintained in an efficient manner.

ii) Retrofit Evaluation. The retrofit effect on a building can be determined either by comparing the energy consumption before and after the retrofit; by comparing the actual consumption with that of similar non-retrofitted buildings; or by the use of experimental or testing procedures similar to those used in the identification and evaluation of ECOs. A retrofit evaluation is primarily useful when the retrofit is considered for implementation in other similar buildings. The testing of a retrofit can be used as a guarantee to the building owner.

Further details of post implementation activities can be found in Chapter 5.

CHAPTER 2 RATING BUILDINGS FOR AUDIT

2.1 THE DECISION TO AUDIT

The basis for a decision to audit may differ depending on whether energy conservation forms part of the ordinary building management, or is pursued as a separate activity. In the former case energy conservation measures are often carried out in connection with a planned refurbishment of a building. Energy audits can then be combined with other inspections of the building, for example, checks of building systems or inspections to detect building damages. The integration of energy management into the ordinary building management may then reduce the cost for auditing as well as for the implementation of ECOs. The integration should be carried out at the building manager level and at the building operator level. Simple monitoring and recording of some key variables, such as indoor temperature, fuel consumption and usage of electricity, often provides clues to the areas where energy can be saved. Energy Management Systems (EMS) are available which are capable of monitoring and recording of energy variables. The monitoring is often combined with other features of the systems such as security and fire alarms. EMS systems often contain programs for the analysis and presentation of collected data, which helps making decisions about energy conservation measures.

Where auditing is pursued as a separate activity, one needs a criterion whereupon to base the decision to audit a particular building, or to select which buildings to audit. One applicable approach is the rating of buildings for audit.

2.2 RATING BUILDINGS FOR AUDIT

To give buildings a rating involves a simple assessment of the likely energy saving potential; the aim is to judge whether the potential savings justify an audit of a building, or to rank a number of buildings in order of their energy or money saving potential. Expenditure should be limited until some idea of the potential saving can be established. The rating has to be based on the limited information provided by building owners or administrators, together with data from statistical and professional sources.

A useful tool for rating buildings is an energy indicator, the number obtained by dividing the energy consumed during a period by one or more normalization factors, for example, the conditioned floor area, the conditioned volume, or other building geometrical features.

The building rating can be done by comparing the value of the chosen indicator for a particular building to a reference value such as a target value (the desired value of the indicator), or a legal value (the value defining the performance of building components prescribed by building codes or directives). An example of this approach is shown in Fig 2.1 (CIBS, 1982).

The building rating can also be based on a cost comparison. The difference in cost between the actual and the targeted energy consumption gives an indication on how much money can be saved through energy conservation. This can in turn provide a basis for investment considerations, for example how much to invest in an audit and at what level it should be carried out.

2.3 THE ENERGY INDICATOR METHOD

2.3.1 Energy indicators

Energy indicators can be defined in terms of either the total energy consumption of a building or a particular end-use of energy (space-heating or cooling, SHW, lighting, etc). They can also be expressed in various types of energy source (gas, oil, electricity, etc.) or quality of the energy (e.g. thermal or electrical).

When rating a building for audit, the total energy consumption should be used. Energy for space conditioning alone should only be used when other end-uses can be neglected.

FLOW CHART OF THE DECISION MAKING PROCESS

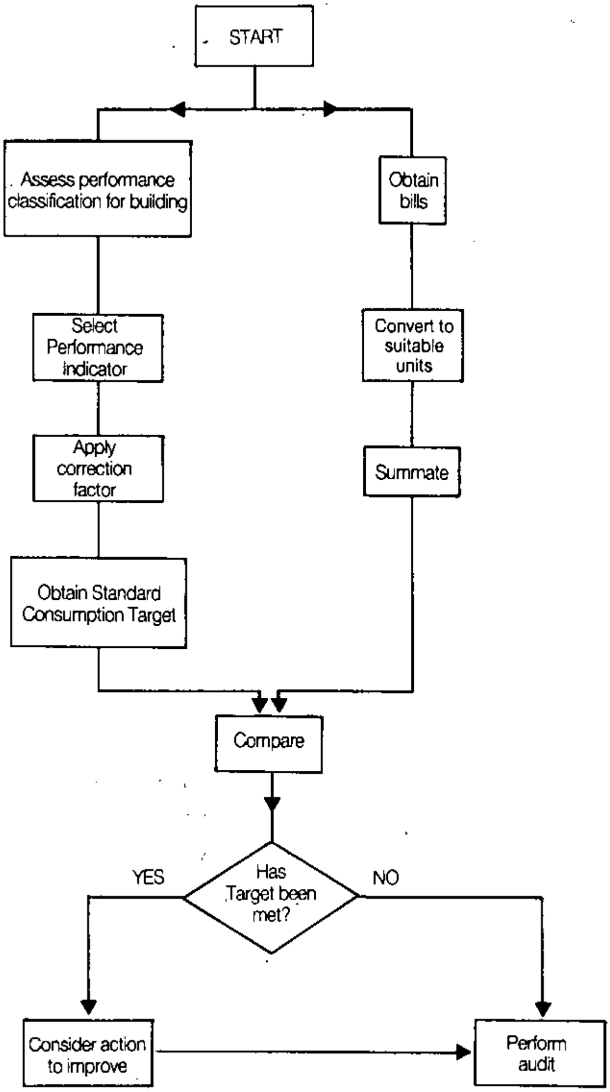


Fig. 2.1 The decision making process of rating buildings for audit.

Energy indicators are used to compare the energy use of buildings that belong to the same building category (residential, commercial, educational, hospitals, etc.); the value of using indicators is greatly reduced when buildings of significantly different size, hours of operation, age or climatic location are compared.

Apart from building geometric features, energy consumption can be normalised against the functional use of a building (for example the number of occupants) or against the production level of service (energy consumption per meal may be an appropriate indicator for a restaurant). Indicators related to functional use take into account not only energy production and supply, but also the use of the building and its energy services.

Building rating methods based on simple energy indicators may be misleading when applied to buildings with mixed functional uses. It may be useful to consider the type and size of various building zones and to compare the amount of energy consumed by different zones.

The indicators discussed above do not provide any explicit information about the magnitude of the energy consumption and hence of the overall energy saving potential. The cost-effectiveness of the audit and the retrofit is related to the magnitude of the energy saving, because the audit cost can be regarded as a fixed cost. More complex indicators can contain information on the saving potential. An example is (Energy Consumption)^2/(Heated Floor Area). This indicator is particularly useful for ranking and selecting buildings for audit because it gives an indication of the overall potential fuel savings (Conti, 1985).

2.3.2 Target values

Target values are values of the indicator for buildings whose energy performance is well above the average; they represent a goal for the energy retrofitting of other buildings. Target values for energy indicators can be established in two ways:

i) By statistical analysis of a large number of similar buildings. The first quartile of the distribution may be a realistic target value (see Fig. 2.2), and

ii) From theoretical calculations of the energy consumptions of typical building types constructed according to energy conscious standards. Such an approach has some advantages; factors out of the retrofitter's control, for example size, shape, hours of use, occupancy, etc. can be accomodated into standard calculation procedures.

In practice the two methods tend to be used in combination, since the validation of the calculation models requires checking against actual values taken from, for example, the database used for the statistical analysis.

The energy saving potential may be expressed as "good" down to "very poor" for different ranges of the indicator value. Table 2.1 (CIBS, 1982) gives as an example a range of U.K. indicator values for some common building types. Buildings in the worst range clearly require further investigation, i.e. an audit. The actual <u>energy saving potential</u> is not, however, evaluated explicitly.

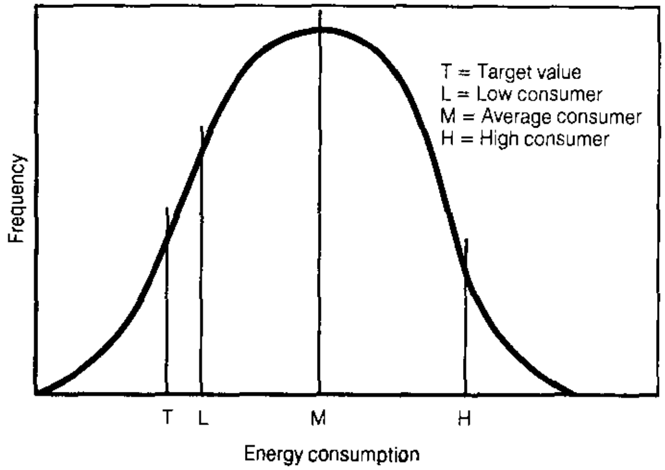


Fig. 2.2 Typical distribution curve for energy consumption indicators.

An indication of the overall energy saving potential can be obtained by taking the difference between the building's indicator value and the target value. This difference, multiplied by the normalising factor, gives the potential energy saving. The savings obtained in this way is only an indication, not a true estimate, since even if it is technically possible to reach the target value, the measures might not be cost-effective.

TABLE 2.1

PERFORMANCE INDICATORS FOR SOME COMMON BUILDING TYPES IN THE U.K.

		Performance indicator for Stated Classification (GJ/m^2)				
Building Type	Occupancy	Good	Satis-factory	Fair	Poor	Very Poor
Office	Single shift 5 day week	<0.7	0.7-0.8	0.8-1.0	1.0-1.2	>1.2
Factories	Single shift 5/6 day week	<0.8-	0.8-1.0	1.0-1.2	1.2-1.5	>1.5
Ware houses	Single shift 5/6 day week	<0.7	0.7-0.8	0.8-0.9	0.9-1.2	>1.2
Schools	Single shift 5 day week	<0.7	0.7-0.8	0.8-1.0	1.0-1.2	>1.2
Shops	Single shift, 6 day week	<0.7	0.7-0.8	0.8-1.0	1.0-1.2	>1.2
Hotels	Continuous, 7 day week	<1.3	1.3-1.5	1.5-1.8	1.8-2.2	>2.2

2.4 DATA REQUIREMENTS FOR RATING BUILDINGS FOR AUDIT

The Energy Indicator Method is not the only one for rating buildings for an audit. Other simple, and easy to collect, information may be used not only to evaluate the need for an audit, but also to get some ideas about the components which are more likely to be retrofitted in a cost-effective way.

Hence two kinds of data can be used:

i) The building energy consumption for comparison with target values, and
ii) Properties of the building envelope, heating/cooling system, lighting design, etc. required for the identification of energy conservation opportunities (ECOs).

The methods for rating buildings should rely on readily available information; examples of useful data are given below.

2.4.1 Energy Consumption

Gas and electricity consumption is usually metered. With fuels such as oil, coal, and wood the bills cannot be used unless the storage containers are filled at each delivery, or the quantity left prior to delivery is known. One can expect errors of less than 5 % when consumption data are taken from monthly meter readings of gas or electricity and somewhat larger when derived from monthly or yearly fuel delivery bills.

An increasing annual energy consumption suggests a potential for savings in a building. After correction for climatic differences between years, the lowest recorded annual fuel consumption could be used as a target value which may be reached by Operation or Maintenance level ECOs.

When consumption data from different fuel bills have to be added to calculate the total consumption, the problem arises how to add energies that are not directly comparable. One can define different energy levels:

<u>Primary energy:</u> as at mine or well head or at the national border,
<u>Delivered energy:</u> as metered at the supply point to the building, and
<u>Useful energy:</u> as energy left for space conditioning after energy conversion at the building, e.g. after heating of fluid in distribution system.

Primary energy values are of interest when making comparisons of energy consumption at a national level or when comparing buildings supplied with different fuels, for example, gas and oil fired space heating. Public authorities often prefer primary energy indicators.

The delivered energy is the energy for which the consumer is billed. Cost is the first concern of building owners and consultants, and the cost of delivered energy should be used.

Energy Consumption expressed in terms of useful energy is related to the building end-use energy requirement. The conversion from delivered energy to useful energy will depend upon the delivered energy type and the building energy conversion equipment.

In order to be able to compare the energy consumption for space conditioning between two buildings, corrections have to be applied for climatic variations. The most common correction involves normalization by the number of degree-days. This can be done in several ways (see AT.E.1). Ideally, the correction should only be applied to the weather sensitive component (See Ch. 3.3).

When planning an audit campaign for retrofit in a region with a variety of climates, retrofits will be more cost-effective in colder climates. It is, therefore, not correct to use indicators that have been normalised for weather severity. Energy indicators that normalise for heating or cooling degree-days should, therefore, not be used for ranking buildings for an audit.

2.4.2 Normalisation of Energy Consumption

Knowledge of the building geometry is needed for normalisation of the energy consumption. Three parameters are commonly used as normalizing factors: conditioned floor area, conditioned volume, and envelope surface area.

The conditioned floor area is the most common normalizing factor, for example air conditioning and lighting usage may depend on the useable floor area. For accuracy one should make allowances for unconditioned rooms, to differing room temperatures, different room heights and intermittent occupancy. The use of the gross or net floor area must be consistent with the use in the corresponding target value.

The conditioned volume is of interest, especially in countries where the volumetric heat loss coefficient (see RV E.2) is used for the design of new buildings. The remarks above concerning the conditioned floor area also apply here.

The envelope surface area can be used for buildings where energy consumption is determined mainly by the climatic load. Transmission losses are proportional to the envelope area defined as the surface area enclosing the gross conditioned volume. Infiltration losses may also be proportional to the building envelope area.

2.4.3 Factors Contributing to the Desirability of an Audit

The energy indicator method only provides information on the potential fuel bill savings. By investigating other basic characteristics of the building we can obtain some preliminary idea of the ease with which these savings might be achieved. A number of these are discussed below.

In many cases the potential ease and cost of implementing specific retrofits might be considered more important than the actual value of the overall potential energy savings. This is often a difficult choice for the building auditor. One method that has been suggested (Sullivan, 19xx) assigns weights to both the energy indicator and certain building characteristics in order to develop a composite building rating index.

Information on the condition and building typology can give some ideas about retrofits on the envelope. For example:

- Building age is related through building construction and techniques, to envelope typologies (percentage glazed area, wall structure, insulation level, type of thermal bridges, etc.)

- Knowledge of the energy behavior of similar buildings may be used to extrapolate missing data about a specific building.

The occupancy profile can be used to evaluate the possibility of improving the matching between HVAC operation time and occupations (see section 3.5), *for example temperature setback. Occupants complaining* about low comfort levels is an additional reason for undertaking an energy audit.

The heating and cooling system is an area where large and very cost-effective savings can be obtained. Useful information are:

- Knowledge of plant age and type of fuel used may provide immediate advice about the feasability of a number of ECOs such as boiler replacement, switching to a cheaper fuel, etc.
- Information on the type of HVAC system may help to identify potential energy savings (for instance, if a high pressure ventilation system is used, fan energy consumption may be easily reduced; a dual duct or terminal re-heat air conditioning system could be replaced by a variable air volume system).

Electrical demand costs can form a significant part of the energy bill and can often be reduced with load shedding equipment. Also, if available, one should review demand profiles in relation to occupancy profiles to check whether suitable scheduling practices are being missed.

It is often advantageous to carry out an energy audit before making any planned refurbishment or any significant changes to a building. In such situations retrofits can *often be implemented as part of the refurbishments*.

Energy saving regulations and incentives are of importance. The existence of a classification of buildings with regard to energy efficiency (as in *Denmark) can encourage owners to seek the advice of an energy* auditor. Similarly, financial incentives offered can be designed to encourage auditing in order to ensure efficient use of energy saving investments (as in France). A knowledge of the local regulations and incentives is, therefore, essential for making decisions on the audit and retrofits at the building rating stage.

CHAPTER 3 DISAGGREGATION OF ENERGY CONSUMPTION

3.1 DISAGGREGATION

In the context of energy auditing, disaggregation is the process of dividing the building energy use, demand, or costs into components. The result can be illustrated in a Sankey diagram (for examples see App. C) that identifies the relative size of the components associated with different building systems. Such a diagram is valuable for presenting disaggregation results; pie charts and bar graphs are easier to construct, but can not illustrate complex energy flows (see Coggins, 1976).

The level of detail of this breakdown of energy use may vary from just a few components to many more components as described below (see Table 3.1). 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.

The primary purposes of disaggregation are:

i) To identify the major areas of energy use, conservation potential, and promising areas of retrofit, and
ii) To serve as or to help develop a means of cross-checking energy calculations and models.

The first purpose helps identify the potentially most productive areas for further audit activity. The relative amounts of energy use in the various categories can be taken as an initial priority of study. The category energy cost also gives a first indication of how much one can afford to spend on auditing and retrofitting a category. To improve the accuracy, the amounts of energy in each category can be compared with target consumptions to indicate the potential for energy savings. Further, the process of disaggregation itself can directly identify the potential of ECOs or ECO categories.

The second purpose of the energy breakdown is a tangible benefit lasting throughout the audit process. The component breakdown as predicted by models can be compared for consistency with that achieved through disaggregation. Further, disaggregation can provide a basis for estimating the effect of various retrofits by bringing forward information such as hours of lighting use and envelope heat loss. Such information defines the parameters of simple, yet often reliable, calculation models. This information is also invaluable in helping construct detailed, predictive models of the building and its energy systems.

Disaggregation may be coupled with the preceding stage (Rating Buildings for Audit), but is normally pursued once a building has been selected for auditing and before proceeding with the search and evaluation of specific ECOs.

Disaggregation might be omitted, particularly where the building is small, with uncomplicated heating and ventilation systems, and where the auditor is experienced and familiar with the building type; or where the client has placed limits on the scope of the audit.

Disaggregation relies on techniques such as pattern recognition, regression analysis, predictive models, simple experimental procedures,and applied engineering. These methods are described in more detail below, in chapter 6 and in the appendices F, G, and H. The process is often interactive; subsequent calculations help 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.

Disaggregation should make use of readily available data including:

i) Utility records,
ii) Plans and specifications,
iii) Operating logbooks, particularly relating to energy use, and
iv) Discussions with building users and operations people.

Site monitoring may provide valuable insights to building operation that might otherwise be obtained with less accuracy and confidence using existing data. In some instances it may also be more economic to use monitoring.

3.2 COMPONENTS OF ENERGY USE

The level of detail of disaggregation can range from a simple to a rather complex breakdown. Detailed breakdowns provide the most benefit, since they are more direct and specific to particular energy uses and ECOs. Inevitably, the finer the level of detail, the more work is involved. Often this increased work leads to a more accurate and detailed picture of energy usage.

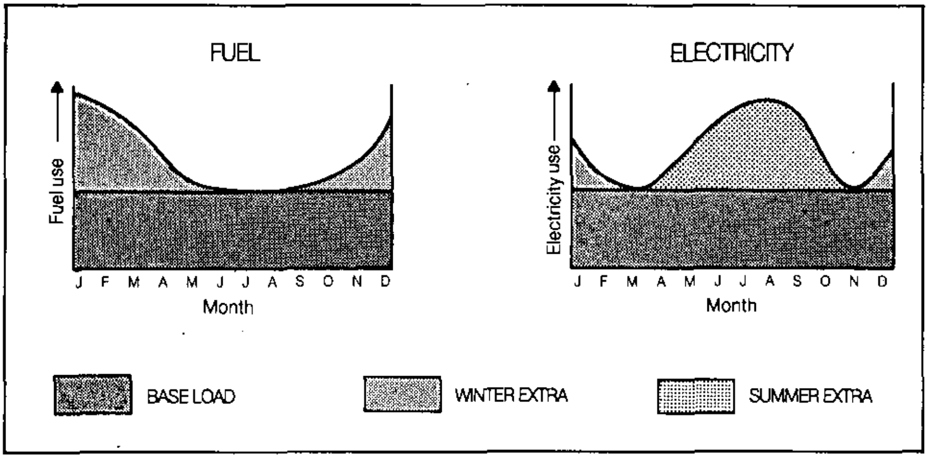


Fig. 3.1 Illustration of a simple energy breakdown by fuel type and weather dependency.

The separation of energy into different fuels, and within fuels to a weather and a nonweather-sensitive (base load) component, is a simple breakdown, achievable with a minimal effort and error (see Fig. 3.1) (Spielvogel, 1984; Munk, 1979). Such a step does not give many firm clues about areas of energy waste and conservation potential, but sets boundaries of energy use of different types of equipment, whose energy use may be totally, partly, or not at all weather sensitive.

More correctly, we can think of energy use as being comprised of:

i) Nonweather Dependent Components. Components of energy use that remain nominally constant over the year, for example, energy for elevators; or nominally constant over a season, for example, energy for constant volume heating circulation pumps. Seasonal components may be directly related to occupancy, as for schools; or related to occupancy habits such as seasonally changing menus or bathing patterns.

ii) Weather Dependent Components. Components of energy use that vary with outside conditions, for example, heating and cooling.

iii) Time and Occupancy Dependent Components. Components that change over the short term (hourly or daily), either as a result of occupant habits, such as opening windows and switching lights, or as a result of the HVAC system response to varying occupancy, or as a result of the scheduling of HVAC systems and equipment.

Table 3.1 provides some information on these components for a range of energy use categories. This table applies to typical cases but is not universally true. 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 disaggregated picture of energy usage and identifying the component retrofit potential.

3.3 WEATHER AND NONWEATHER SENSITIVE ENERGY COMPONENTS

It is first necessary to construct annual energy profiles (Coad, 1975 and 1979) (see Fig. 3.1) 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 even unapplicable.

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. The method can not be considered reliable when there is a summer demand for space conditioning; where there is a possibility for control losses (simultaneous heating and cooling); where the same fuel is used for heating and SHW production; or where the summer occupancy or pattern of use is significantly different from that during the winter (for example in schools).

One must also be careful to take account of 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 consumptions 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.

TABLE 3.1

TYPICAL COMPONENTS OF ENERGY USEAGE FOR A RANGE OF END USES OF ENERGY

ENERGY END "USE"	NONWEATHER DEPENDENT
1. SPACE HEATING	
.1 Boiler Losses	Jacket losses nominally constant over operating season
.2 Duct Losses .3 Pipe Losses	Nominally constant over heating season
.4 HVAC/Control Losses	Present in varying degrees depending
.5 Ventilation	-
.6 Conduction	-
.7 Infiltration	-
.8 Humidification	-
2. SERVICE HOT WATER	
.1 Useful Heat Consumption	NORMALLY CONSTANT, although may have different systems for summer & winter, may be seasonal use, patterns and production efficiencies. Mixed production systems (e.g. solar + oil) not constant.
.2 Pipe Losses	SUBSTANTIALLY CONSTANT
3. FAN ENERGY	
.1 Heating Only	NORMALLY CONSTANT for heating season except where VAV
.2 Cooling Only	NORMALLY CONSTANT for cooling season except where VAV
.3 Heat & Vent, Cool & Vent (or Heat-Cool & Vent)	NORMALLY CONSTANT throughout year except where VAV
.4 Exhaust Systems	NOMINALLY CONSTANT throughout the year
4. PUMP ENERGY	
.1 Heating .2 Cooling	NOMINALLY CONSTANT over heating and cooling season, respectively

WEATHER DEPENDENT COMPONENT	TIME & OCCUPANCY DEPENDENT COMPONENT
Cycling losses increase with milder conditions	INDIRECTLY & to the degree by which use impacts on heat load
SOME variation can be expected primarily where the conveyed fluid temperature varies significantly & to a lesser degree as a result of change in ambient temperatures	-
on particular arrangement	INDIRECTLY, where use affects control operation
Energy losses depend on temperature difference and humidity even if ventilation rate constant	ONLY where ventilation shut off when building is unoccupied or vent rate varied with occupancy
Obvious, usually the major component	ONLY where setback practiced
Obvious, usually the major component	In that exterior door usage & window opening will increase infiltration
Obvious, usually the major component	Primarily ONLY when humidication not added during unoccupied periods
MINOR due to changes in cold water supply temperature. Mixed systems may be weather dependent	Water usage will vary with time of day and occupancy
MINOR due to changes in space temp.	Minimal effect
ONLY when fan cycles on & off to meet the load	ONLY where fan is switched off during unoccupied periods
ONLY when fan cycles on & off to meet the load	ONLY where system shut off during unoccupied periods or occupancy affects load in VAV systems
-	ONLY where system shut off during unoccupied periods or occupancy affects load in VAV systems
NOT NORMALLY unless used to provide some cooling	ONLY where under occupant control or significant changes in occupancy throughout the year
MINOR to MEASURABLE if variable speed, variable volume pumping, control by throttle valves, or where operation scheduled with outside air temperature or other weather variable.	ONLY when shut off during unoccupied periods or use impacts on load in variable volume or sheduled pumping systems

TABLE 3.1 continued..

ENERGY END "USE"	NONWEATHER DEPENDENT
5. LIGHTING	
.1 Interior	NOMINALLY CONSTANT, may be some seasonal variation with changes in daylight availability
.2 Night/Security	NOMINALLY CONSTANT
.3 Outside	*BASE COMPONENT plus VARIABLE with seasonal* change in daylight hours
6. SPACE AIR CONDITIONING (ELECTRICAL INPUT)	
.1 Duct Gains	-------------------------------------
.2 Pipe Gains	-------------------------------------
.3 Control Losses	-------------------------------------
.4 Ventilation	-
.5 *Conduction*	-
.6 Internal Loads	Often the most significant component
.7 Infiltration	-------------------------------------
.8 Solar	The minimum solar gain can be thought of as a constant component
7. MISCELLANEOUS	
.1 Portable Equipment	Mostly can be considered the only significant component
.2 Elevators	Normally the only significant component
.3 Snow Melting	None unless left uncontrolled throughout year or season
.4 Kitchen Equipment	Often can be considered the only significant component, may be seasonal *changes if menus change.*
.5 Laundry	For the domestic situation the washload may vary seasonally and/or drying habits might vary
.6 Block Heaters	-

WEATHER DEPENDENT COMPONENT	TIME & OCCUPANCY DEPENDENT component
NOT USUAL	Obvious. Tends to be very userdependent
NO	-
NO	-
as detailed under 1.2--	
as detailed under 1.3--	
as detailed under 1.4--	
Latent & sensible load will be influenced by different weather parameters	ONLY where ventilation is shut off when building unoccupied or where ventilation rate is varied with the number of occupants
Primary component	ONLY where set up or shut off is practiced: normally a minor affect
GENERALLY, NO	Obvious
as detailed under 1.7--	
Major component will be primarily calendar and weather dependent	ONLY where occupants have control over & make use of shading devices
GENERALLY NO	ONLY where significant changes in equipment use due to occupancy changes
-	Varies with use of elevator
Obvious	-
NOT DIRECTLY or SIGNIFICANTLY (see also S.H.W.)	Hourly variations with schedule of meal preparations
NOT DIRECTLY or SIGNIFICANTLY (see also S.H.W.)	
Primary component	Depending on automatic usage

Knowledge of installed equipment and operating patterns may help disaggregate the weather and nonweather dependent components, although ideally those should serve as an overall check to supposed or derived equipment operation.

3.4 DETERMINATION OF WEATHER DEPENDENCY

The primary aim of investigating 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 monitoring to identify hour by hour effects. Such techniques ultimately lead to an understanding, or give some indication of importance, of specific energy flows; 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.

3.4.1 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 signature method. One then plots energy consumption for a period of fixed length versus the average indoor-outdoor temperature difference, or versus the average outdoor temperature. A simple case is illustrated in Fig. 3.2. A more detailed discussion on such a model is given in AT M.1 (for examples of the use of energy signature models, see Fels, 1986; Cowan, 1984; FATRA, 1982).

For many applications, particularly in simple heating onl situations, an acceptable linear relationship between energy use and outside temperature is normally obtained. Typically the regression coefficient, r^2, 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 weather months (near the beginning and the end of the heating season) e.g. because:

i) Window openings are expected to increase, tending to force the curve upwards,
ii) Boiler/furnace performance may decrease because of the shortened equipment duty cycle, also tending to force the curve uppwards, and
iii) Changing solar contributions can force the curve either upwards or downwards depending on the window orientation, changing hours of sunshine; use of shading devices.

For these reasons, the transition from weather-dependent load to the baseload (such as service water heating) is not clear-cut as pointed out in Figure 3.2

If this building had cooling equipment, we would observe a cooling energy signature, an inclined energy use slope as temperature increases. Often we are evaluating two different energy sources, electrical use for cooling and oil or gas for heating and, therefore, the cooling energy signatures and heating energy signatures can be easily separated. If the building was both heated and cooled by electricity, the two signatures would merge, making it difficult to establish the level of the baseload.

Figure 3.3 is a schematic diagram of just how the various energy relationships influence the energy signature when the building requires heat, and how retrofitting the building can save energy.

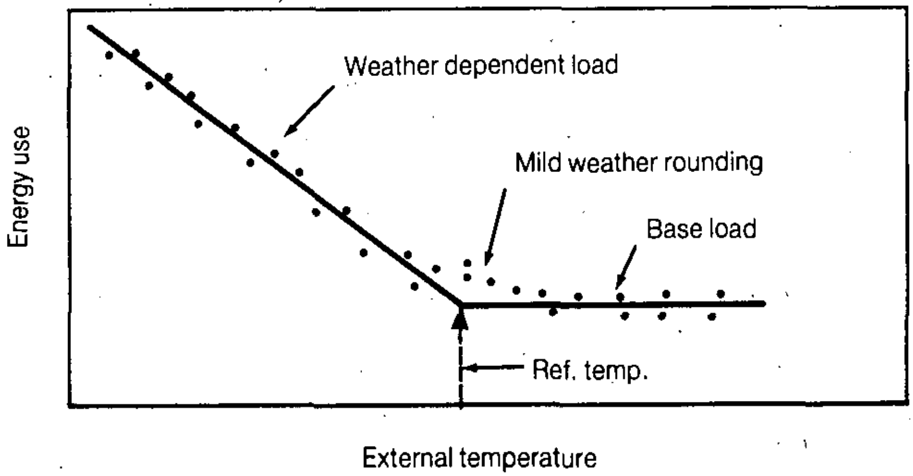


Fig. 3.2 Illustration of a simple weather dependent model of heating consumption derived from utility records and showing a base load component.

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.

3.4.2 Regression Based on Site Measurements

Data obtained by site measurements have 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 for 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 (Albern, 1983). Shutting off nonweather dependent loads for a short period can also be considered in order to determine their impact on the overall consumption (Wulfinghoff, 1984).

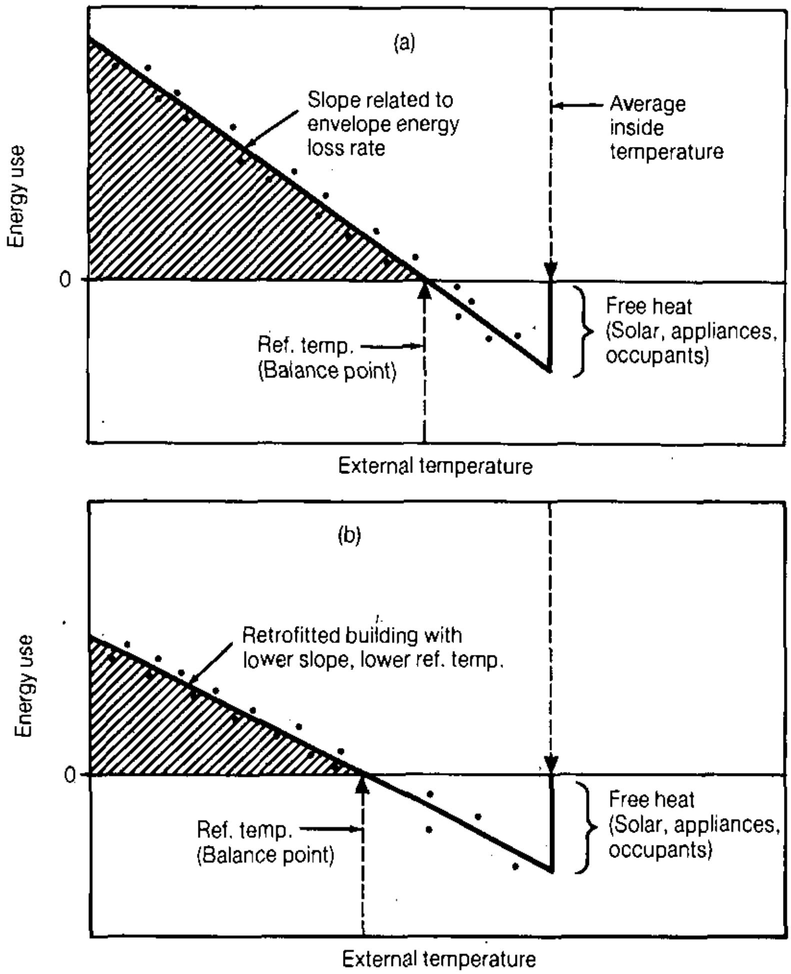


Fig. 3.3 Schematic diagram illustrating the basis for the energy signature method. Free heat, average indoor temperature, slope related to envelope energy loss rate and the reference temperature are placed in perspective.
Schematic (b) illustrates energy loss of retrofitted building. Note that both the slope and the balance point change.

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 from 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 <u>and</u> cooling, data from different parts of the year may have to be collected.

Site measured data can be analysed in a similar manner to that described above for utility data, although one will have the benefit of more data points, albeit over a smaller range of building operating conditions.

In order to estimate nonweather dependent factors such as boiler standby losses, water heating and cooling, or other process energies, one can extrapolate data down to the nonweather driven load conditions, although this procedure is less reliable if data cover 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 tells 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 ECO categories show promise of significant savings and warrant a more careful analysis or further monitoring.

3.5 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 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 in the length of the monitoring period. 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 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 and give an overall picture of how the building energy systems are in tune with occupancy. The monitoring period should cover weekdays as well as weekends. The potential for scheduling type ECOs 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 (see MT EL.6 and M.1). Run time meters (MT EL.7) 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 analysed by looking at long term data, specifically by calculating the electrical load factor (AT EL.2) for the non-weather sensitive part of electric usage, and by 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.

3.6 DISAGGREGATION BY PREDICTION

Predictive methods can be used to disaggregate some components of the 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 accounted for.

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.

The use of predictive methods often requires validation by field monitoring or simulation models (see Ch. 6). Table 3.2 summarises how disaggregation techniques can be used to estimate or determine category energy usage.

TABLE 3.2

SUMMARY OF DISAGGREGATION TECHNIQUES FOR DETERMINING CATEGORY ENERGY USAGE

1. SPACE/ - HEATING	By identification of the (winter) weather sensitive component of energy use (sections 3.3 and 3.4) - Base load can be estimated from the consumption during the months with least consumption (distribution and control losses will not be included).
2. SPACE AIR/ CONDITIONING	- By identification of the (summer) weather dependent component of energy use. - The size of the nonweather dependent component can give preliminary indications of the magnitude of the internal load.
3. SERVICE/- HOT WATER	By recording the use of SHW 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 periods when there is no water use.
4. FAN ENERGY	- By calculation based on 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. - Difficult to estimate where fan operation is controlled by a thermostat. - Some problems with this method where VAV fans are employed. - (Hourly monitoring of electricity or individual equipment can help establish reliable operation profiles).
5. PUMP/ ENERGY	- By calculation on 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. - Some problems with the method where variable flow (i.e. throttle valves, motor speed control, staged pumping).
6. LIGHTING	- By calculation based on assumed or observed pattern of usage. - Hourly load recording can help establish a reliable profile of use. - By monitoring lighting usage. - An indication of the efficiency of lighting switching devices can be obtained by comparing the lighting use load factor with i) calculated value, based on connected load x a reasonable lighting on time, or ii) a target value.

CHAPTER 4 ECO IDENTIFICATION AND EVALUATION

4.1 IDENTIFICATION AND EVALUATION OF ECOS

Following the selection of a building for auditing and disaggregation, the process of identifying appropriate ECOs for the building must begin. For the client it is important that the identification of possible ECOs is complete; i.e., that valuable retrofit opportunities are not missed.

To ensure completeness of the audit, it is desirable to start with a list of all possible ECOs. ECOs not applicable or desirable should be discarded with as low a level of detail and effort as possible, while the remaining ECOs should be evaluated with the smallest possible amount of detail. The process is illustrated in Fig. 4.1 and described below.

4.1.1 Eliminating ECOs

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

i) Specific request of the client not to look at certain categories or items as retrofit candidates,
ii) Low projected energy savings as identified through energy disaggregation techniques,
iii) Type of system, process, or occupancy not relevant to the building. For example, all ECOs concerning cooling can be descarded for buildings sited in a region where cooling is not necessary, and
iv) Clearly unfavourable paybacks or capital cost. For example, if the client has set the limit of a two year payback, retrofits with longer paybacks could be eliminated unless specific reasons for retaining the ECO for further consideration are present.

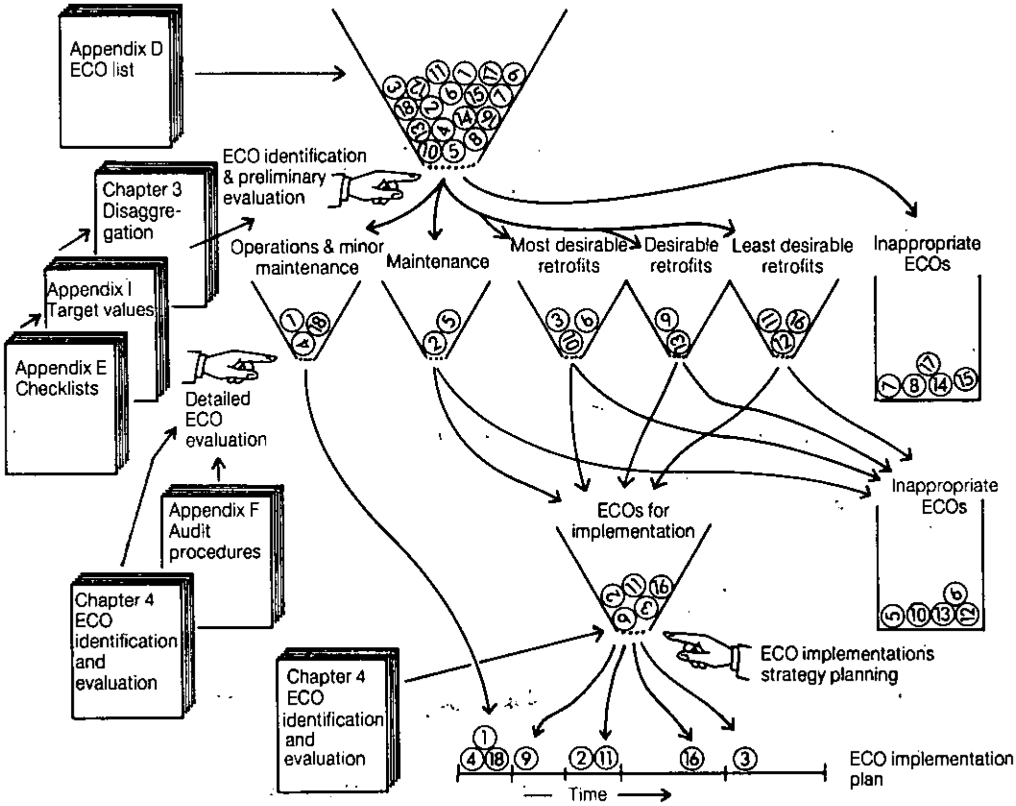


Fig. 4.1 Flowchart of the ECO identification and evaluation process.

4.1.2 Preliminary Evaluations

Using readily available information, for example, as built drawings and maintenance records, and then information from site inspections, remaining ECOs can be discarded or sorted into the following groups:

i) ECOs which should be implemented immediately, consisting of operational or minor maintenance items. Included are ECOs identified as ultimately involving automatic operation but until then can be carried out manually.

ii) ECOs that should be implemented without further evaluation if the equipment concerned is not to be considered for replacement. They mainly consist of maintenance or small works items.

iii) ECOs, essentially equipment and building component modifications or replacements, that appear promising, but require further evaluation. These ECOs should be categorised or ranked according to their apparent potential value.

4.1.3 Detailed Evaluations and Implementation Strategy

At this stage, the task of the auditor is to evaluate those ECOs 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 ECOs for implementation and an overall implementation plan giving details of cash flows. One should consider, for example, the clients plans for the building and budget limitations, the choice of ECOs where alternatives may be chosen, and the effects of combinations and interactions between ECOs. The building owner has a choice of options for implementation of the evaluated ECOs which include:

i) The sequence of retrofits to effect changes in the following order: loads, terminal equipment, distribution systems, and finally the central plant. This is logical as, for example, any boiler derating should only be carried out once when all other loads have been minimized,

ii) Implementing in order of ascending payback or capital cost (see App. H),

iii) Using retained savings from energy reductions to fund capital works, and

iv) Combining energy retrofitting with other maintenance or refurbishment.

4.2 FACTORS AFFECTING THE VALUE OF AN ECO

4.2.1 Cost Benefit

The reasons for making investment decisions will vary , and may include hard to enumerate benefits such as improved appearance. Consequently, an auditor should not make cost benefit decisions in isolation of the building owner. Examples of perspectives on cost benefit include:

i) A utility company might want to invest in conservation activities less costly than new generation and distribution equipment (which would otherwise be required to meet a growing electrical demand).

ii) Believing it more attractive to potential purchasers, an owner of a multi-family complex might replace group metering with individual metering; the concern being primarily for investment enhancement, not energy savings (even though separate metering should encourage energy cost sensitivity on the part of the tenants).

4.2.2 Retrofit Longevity and Cost Effectiveness

Retrofit longevity and cost over the expected lifetime are closely associated with the evaluation of directly quantifiable cost benefits.

Total annual operating cost should be considered, hence lifetime and maintenance costs should be parameters in any ECO evaluation, which may not prove to be a simple matter. The durability of retrofits is 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.

4.2.3 Combination of ECOs and ECO packaging

In analyzing a single ECO, it must be kept in mind that retrofitting existing buildings usually involves ECOs in combination. The first question is: are the individual ECOs directed at the same component of energy loss and therefore not additive? An example would be installing more efficient burners in a boiler in addition to a flue gas heat exchanger. Perhaps the chosen ECOs 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 leakage sites under insulation not only reduces air infiltration, but can increase the thermal resistance. Often there is a degree of overlap between different ECOs. Reference to past history of similar retrofit actions helps making sound judgments.

Calculation of the energy savings from a successive application of a number of ECOs also presents difficulties; this is especially the case where optimal combinations are being sought (see App. H).

It is often advantageous to group a set of complementary ECOs into an ECO package which has been demonstrated to provide energy savings. Examples of such packaging include insulation upgrade with window ECOs, and heating system furnace efficiency improvements with enhanced controls.

4.2.4 Side Effects, Comfort Allowance, and Interactions

Focusing only on direct energy savings and cost in ECO choices may prove to be shortsighted. Side effects may prove highly beneficial or, conversely, there may be detrimental effects suggesting that the ECO 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 ECO 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 worsen 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 <u>and</u> minimising energy use should be sought. ECO choices adding to human comfort may not only mean extra energy savings, but can win the confidence of the occupants, which is so essential to an effective energy saving campaign. Energy conservation 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. (OFAC, 1983)

Indirect effects in the form of tangible energy consequences must not be overlooked, especially where the implementation of an ECO in one area impacts upon the use of energy or an ECO 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-cooling would not be realized.

4.2.5 Choice of Alternative ECOs and Coupled Opportunities for ECOs

In some cases, alternative ECOs 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 strategy being to capitalise 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 ECOs may be a logical way to justify a particular ECO. For example, it is often hard to justify roof insulation where this would require removal of the roofing material; however, coupling insulation with needed roof replacement can make this ECO a high energy saver because of the small incremental cost - a cost freed from the roofing cost which was already inevitable.

4.2.6 Group Opportunities

Where many similar buildings are being considered for retrofitting, 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 retrofit cost should also be reduced as the same ECOs 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 ECOs as the investment cost is modified. This can lead to ECO combinations, which are optimal, not for energy conservation, but from the point of view of cost efficiency for a given budget.

On a smaller scale, cooperation 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, thermostatic steam or hot water radiator valves could, if they prove successful in one of the buildings of a housing authority, also be employed in other buildings, thereby permitting a major purchase with a bulk discount.

4.2.7 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, he has little interest in implementing any ECOs. 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.

4.2.8 Grants, Subsidies and Tax Write-offs

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

CHAPTER 5 POST IMPLEMENTATION PERFORMANCE ANALYSIS

5.1 WHY AND WHO

Those managing, paying for, and benefiting from the auditing and the Energy Conservation Opportunity (ECO) implementation may wish to agree on a Post Implementation Performance Analysis (PIPA). The content of the analysis will depend on the type of contract between the building owner and the company implementing the ECOs.

Different interested parties can be identified:

1. The building owner (building manager, consulant firm).
   Aim: To check the effectiveness of the ECOs implemented, not only the energy saving, but the workmanship and, hence, anticipated durability.

The building owner may be interested in the success of the ECO for application to other buildings. He may also be interested in the impact of the ECO on comfort, appearance, and functionality.

2. A company implementing the ECOs and compensated on the basis of the energy saved.
   Aim: To evaluate the level of savings and the payments due.

The parties will have to agree on a methodology for the PIPA, including a clear definition of the energy saved. Different definitions and scorekeeping methods can be used, depending on whether a single building or a group of buildings (see section 5.2) is involved. The company may also be interested in identifying the most profitable ECOs and in establishing a track record to show to prospective clients.

3. Government or local agencies.
   Aim: To check whether the conditions for public financing have been met.

An energy audit and ECO implementation may be checked by governmental or local agencies distributing subsidies according to the post-implementation energy performance or some other criteria. In France, for instance, the requirements for a state subsidy are that the energy audit be complete, carried out by licensed professionals and achieve a 10 per cent energy savings.

4. Local administrations or energy utilities (electric or gas).
   Aim: *To assess the effects of the ECOs (see 1 above).*

Here the interested party carries out retrofits to a large number of buildings. More importance is given to the overall results and the effects on the total energy consumption than to the results for specific buildings. Information on how the retrofit has affected the load growth, and how the expenditure on load reduction compares with the expenditure required for new equipment, is of interest.

5. Oil and gas utilities offering contracts for the supply of useful heat to dwellings instead of selling fuel.
   Aim: A post-implementation audit to check investments of the company.

This type of contract normally guarantees not only comfort levels, but reductions in heating expenditure as well. The longer the duration of the contract, the greater the amount of investment the firm can afford and, hence, the greater the energy savings which can be agreed or guaranteed.

6. Policy makers in regional and national governments planning financial support for large-scale energy conservation.
   Aim: Information on the cost-effectiveness of ECOs and their impact on the energy consumption of the building stock.

Other parties involved in the energy conservation process, though having no direct financial *role in the ECO implementation, may nevertheless* be interested in the results of the retrofit. They are:

i) Occupants interested in the quality of the job, the comfort level, and the change in energy expenditure,
ii) Energy audit companies interested in improving their auditing methods and collecting field data on ECO performances, and
iii) Manufacturers, dealers, and installers interested in improving the performance of their product to promote future sales.

The problem of a simple and reliable check of the retrofit work is not only technical, but also has legal implications. The selection of checking procedures must, therefore, be adapted to national or local laws and habits.

5.2 RETROFIT EVALUATION

Depending on the type of audit and energy conservation action, the post-implementation check can address either a stock of buildings, a specific building, or a building component. Auditing methods, therefore, have to be chosen with regard to the interested parties and the retrofit complexity.

Three basic methods (see Fracastoro-Lyberg, 1983) are available for quantifying the energy savings due to retrofitting. These methods are:

i) The before/after experiment,
ii) The test/reference control experiment, and
iii) The on/off experiment.

The first two methods are the most used in energy auditing. Due to difficulties of measuring energy consumption, uncertainties in climatic corrections, and building dynamic effects, the results from any of these methods should only be considered significant if the retrofit has a noticeable effect on the building energy use or the component of energy use studied. In practice this often means an effect of at least five to ten per cent.

The on/off experiment can only be applied when retrofits are reversible. This requirement limits its applicability to a few cases. For example, the effect of night setback can easily be checked with the on/off method. This method can be considered a particular case of the more general before/after method.

The before/after experiment is the most common check procedure, and is the most appropriate for an individual buildings. It is applicable both to building energy consumption and to the performance of retrofitted building components. *For the check of energy savings at the building level, the method* relies on the definition of "energy saved" as "the difference between actual consumption and the consumption that would have occured had there been no retrofit intervention." This implies that:

a) The same type of consumption or performance data must be collected both before and after the ECO implementation,
b) Weather corrections must be applied to space conditioning consumption,
c) Corrections must be made for changes in indoor climate,
d) The occupant's behavior must be assumed unchanged, and
e) Other changes in equipment or envelope must be considered and their effect must be isolated.

Different procedures for weather correction are in use (see AT E.1). The data from either the before or the after period can be corrected for comparison with the data from the other period. The before and after periods can also both be corrected to a normalized annual consumption using test reference year weather data (Fels, 1982). The last option is preferable because the energy data, normalized and corrected to standard conditions, can be compared with similar data from other retrofitted buildings.

Point (c) above should not be overlooked, since it is well known that, in dwellings, occupants tend to forgo a part of the savings which retrofitting could bring, in order to enjoy a higher level of comfort.

The test/reference control type of check is recommended when the ECO is applied to a number of buildings and when there are reasons to believe that the savings achieved can be masked by external events, such as drastic changes in fuel prices, fuel switching, or changes in occupant behavior. In this case, the buildings to which the retrofit has been applied (test group) are compared with a group of similar buildings (reference or control group) which have received no retrofit. Two types of control are applicable:

i) Matched control, and
ii) Aggregated control.

The matched control group and the test group should contain the same number of buildings with similar characteristics, location, and occupancy. Changes in consumption in the control group can then be presumed to occur also in the test group.

The use of aggregated control requires consumption data for a large (municipal or regional) building stock against which to compare test group data. It is important to stress that, in this case, the energy savings are the difference between the actual consumption and the consumption that would have occured had the buildings acted like average buildings. Due to the required size of the control group, this method is in practice mostly applied to residential buildings.

If the goal is to evaluate the effect of a large energy conservation program in a building stock, the use of aggregated control is a suitable method.

Both the matched and aggregated control methods have advantages and drawbacks (Darley, 1980). A combined method can also be envisaged, applying the aggregated control first for estimating general trends, and then a matched control for a more accurate measure of the savings due to retrofits alone.

ECOs may be implemented not only to save energy, but also to improve the indoor climate, for example, in dwellings, previously unheated rooms can be transformed into habitable, heated areas using the excess heating power resulting from upgraded insulation. An improved environment can also be obtained by upgrading lighting, noise reduction, better internal mobility, moisture elimination, and better air quality. A simple comparison of the before and after fuel expenditures is then no longer valid. More detailed evaluations are required; the increased comfort must be expressed in terms of energy, and this energy subtracted from the building energy use before comparing with the pre-retrofit consumption.

5.3 CHECK AND MEASURING PROCEDURES

Once the retrofit has been completed and the building owner informed, a joint procedure for checking the work can begin. The check procedure includes not only energy performance aspects, but also the quality, conformity to contract specifications and norms, safety standards, etc. A great deal of retrofitting work can be checked after only a short inspection. Direct measurements are needed, however, when energy savings of specific ECOs are to be determined.

Acceptance can only be given on a provisional basis when other aspects of the work require a longer period for the check; for example:

i). Seasonal or annual energy consumption,
ii) Seasonal or annual plant efficiencies,
iii) Performance of conditioning systems during extreme climatic situations and response to climatic influences such as sun and wind, and
iv) Ability to reach the required comfort level

When evaluating the overall energy savings obtained, this entity can be determined by direct measurement. For instance, a simple building energy signature measurement is an inexpensive and reliable method. Usually, the building owner is not interested in knowing how the energy is measured; he wants to know how much money he has saved. The most popular method for measuring global energy savings is, therefore, based on the analysis of energy bills (fuel and electricity).

The periods chosen for defining the before and after consumption levels cannot be very short. It is common to determine the before consumption on the basis of bills from two or three years, although the after consumption could be determined in a much shorter time. Nevertheless, a check period, limited to a single year, does not give the client a sufficient guarantee of the durability of the energy savings achieved. The installation of various meters (heatmeter, fuelmeter, SHW meters, etc.), or computerized monitoring devices, could be justified as ECOs because it allows for before/after analysis as well as long-term control of the building energy performance.

Performance checks of retrofitted components are related not only to the particular retrofit and the expenditure, but also to the type of contract and warranty. Detailed measurements (see App. F and G) may be used to test the efficiency of the retrofit. Since these tests are costly due to instrumentation and working time, they should be planned with due consideration of need, level, and cost. For example, when justifiable, the following tests could be carried out:

i) If the retrofit consists of upgrading the insulation: a thermographic inspection, a U-value measurement of the insulated walls, or a determination of the wall global heat loss coefficient (see AP E.1, E.2)

ii) If the retrofit consists of improving the building air tightness: a pressurization test (see AP E.5 and E.6), and

iii) If the retrofit consists of boiler performance improvement or boiler replacement: measurement of boiler combustion and steady-state efficiency and a measurement of boiler stand-by losses (see AP H.1 and H.2). These measurements should be carried out by the boiler installer without any additional charge.

A second measurement campaign taking place after some time could involve the same tests as in the first campaign. (Weinman, 1986.) This might allow the detection and estimation of changing conditions.

5.4 THE GUARANTEE CHECK

A guarantee check may be required when the parties involved in building retrofitting expect money and energy savings in agreement with the predicted savings (see section 5.1, 2 and 5). The discrepancy between the predicted and actual savings is in many cases rather large (Norlen-Holgersson, 1981; Hirst, 1984), see Fig 5.1. An auditor or utility should apply an appropriate safety margin when determining the energy savings guaranteed to the client. This margin could be obtained from data on the average savings of past auditing activity. The building owner will wish to be compensated if the actual savings are less than those guaranteed. For the first year, the penalty could *be proportional to the difference* between the guaranteed and the actual energy savings. The proportionality factor should increase sharply with time if the conservation company does not modify and improve the installed ECOs.

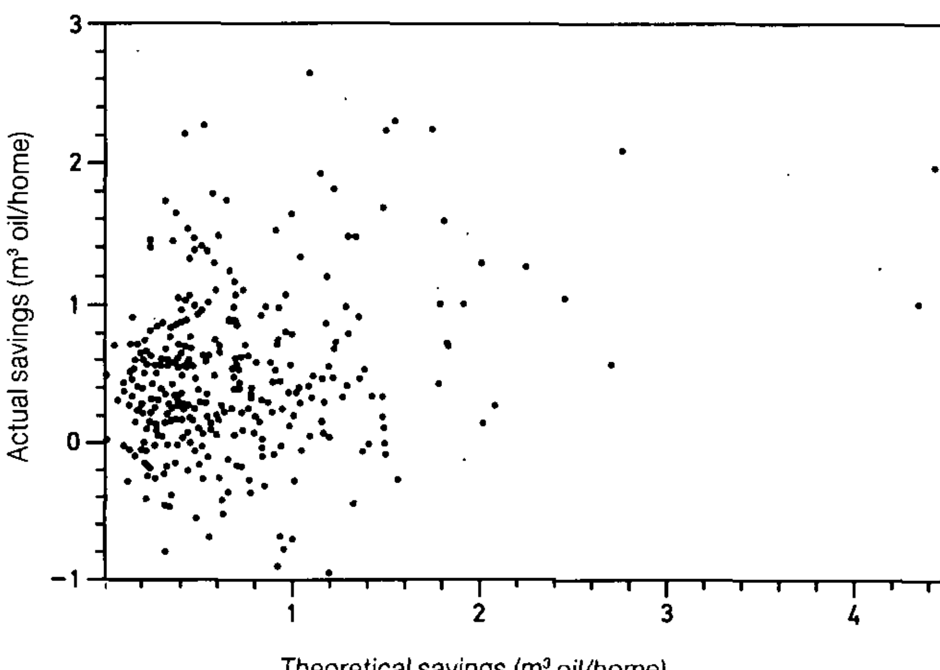


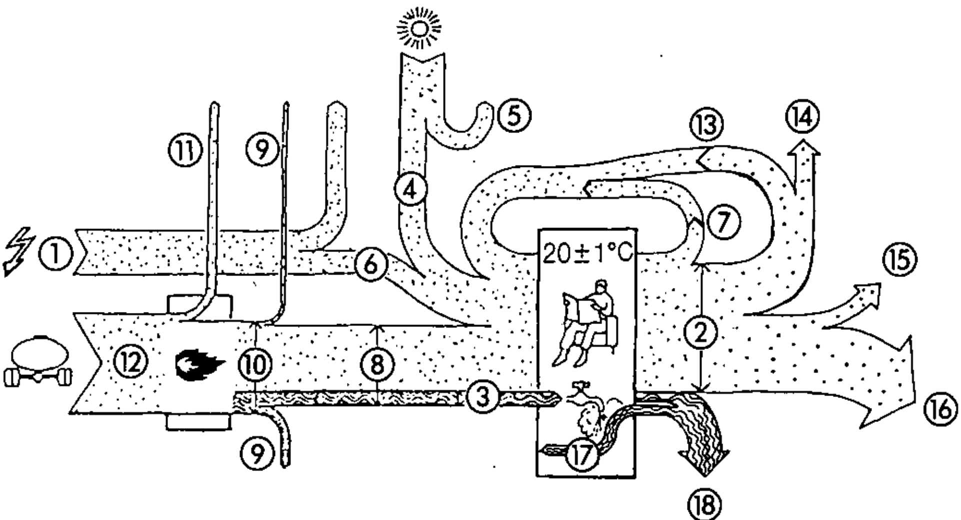
Fig. 5.1 An example of actual savings versus predicted savings for 200 retro-fitted homes (after Norlen, 1981).

CHAPTER 6 BUILDING ENERGY ANALYSIS AND MODELS

6.1 THE BUILDING COMPONENT APPROACH AND THE ENERGY FLOW APPROACH

When analyzing energy usage in a building, two different approaches can be used, the building component approach and the energy flow approach.

The energy flow approach aims at describing the whole building energy performance, at establishing the energy balance of a building and at a detailed understanding of interactions between energy flows and components (see Fracastoro-Lyberg, 1983). One then starts by identifying the energy flows and their relative magnitude. Disregarding minor energy flows, one proceeds by identifying the building components affecting different energy flows. A simple example of some energy flows that may be present in residential buildings is illustrated in Fig. 6.1.



1 Electricity
2 Energy delivered for heating
3 Energy delivered for hot water
4 Useful solar gains
5 Non useful solar energy
6 Useful contribution of electrical energy
7 Recirculated air
8 Energy necessary for heating and SHW before free gains
9 Distribution losses SHW/heating
10 Energy delivered by boiler plant
11 Boiler plant losses
12 Fuel delivered to boiler plant
13 Heat recovery from ventilation exhaust air (heat exchanger)
14 Ventilation energy losses
15 Infiltration losses
16 Envelope (transmission and radiation) losses
17 Cold weter losses
18 Sewage water energy losses

Fig. 6.1 Example of a Sankey diagram showing energy flows in a building.

Some examples of the energy flow approach used in this Source Book include the use of Sankey diagrams to illustrate the relative importance of connected energy flows on an annual or seasonal basis, and the use of simple disaggregation techniques to split up energy flows into a weather and a non-weather dependent part (see sections 3.3 and 3.4). Using the energy flow approach this disaggregation is often advantageous to an auditor. However, the use of a fully developed energy flow approach is seldom cost-effective in auditing, possibly except for large and complex buildings, as it involves either extensive monitoring or computer simulations.

When the building component approach is applied, one starts by analysing the performance of the building components one by one. For an auditor, this approach has the advantage that there is often a direct relationship between ECOs and building components. Using this approach, one can choose to disregard from the start of the analysis some components or component categories, especially if the major energy flows are directly associated with a few building components. The drawback of the component approach is that it may be difficult to assess the interaction between energy flows and the whole building thermal performance.

Much of the material contained in this Source Book has been arranged in such a way that it can be directly useful to an auditor applying the building component approach.

6.2 BUILDING COMPONENTS AND INTERACTIONS

The complexity of the interaction between energy flows in a building can be illustrated by the example of the illumination level. It is influenced by factors from the exterior environment (insolation or day-lighting). Lighting is part of the comfort, but may also be a major energy consumer, and is also a component of the building electrical system. Lighting may also be the major contributor to casual heat gains, thereby greatly affecting the heating and the cooling load. This example shows the importance of a systems approach.

In order to describe a system, models of the individual components and there interactions are required. The building components of major interest in a building energy analysis, and their interactions, are illustrated below with the aid of a graph (Courville, 1981). A more complete description of how different building components affect energy usage is given in Appendix C.

The energy use and thermal performance of a building are influenced by the exterior environment and by internal components and factors. The external environment can be broken down into temperature, humidity, insolation, wind and siting. There are diurnal, seasonal and random variations which must be accounted for if building thermal performance is to be analysed. An example of how the interior components and factors can be subdivided is illustrated in Fig. 6.2. These main elements can be further subdivided to facilitate a detailed analysis.

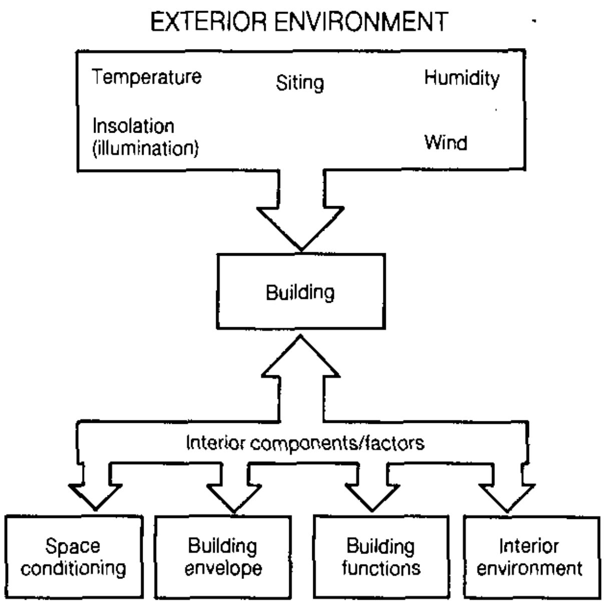


Fig. 6.2 Overall building components, factors and interactions.

6.3 *BUILDING ENERGY MODELS*

The energy flows between the building and the environment as well as internal energy flows and interactions between energy flows and building components can be described by different *building energy models. Depending on the* complexity of the building and its environment, the model will have to account for varying conditions. These conditions may be constant or vary with time (described by static or dynamic models), or be uniform or vary throughout the building (unizone or multizone models).

<u>Static unizone models</u> are mostly based on an equation describing the energy balance of a building. Many of these models calculate heat gains (or losses) only and do so using a steady state assumption. It is sometimes assumed that the energy required to maintain comfort depends on a single parameter (the outdoor dry-bulb temperature or the indoor-outdoor temperature difference). These models are refered to as <u>single-measure</u> models. The equation may then involve the concept of heating degree-days (see AT E.1). Another example of single-measure models is the <u>energy signature model</u> (see section 3.3 and AT M.1). Unizone models are sometimes quasi-static rather than static, the energy required to maintain comfort is assumed to depend on a series of repeatable daily fluctuations (air temperature, solar radiation, etc.). Unizone models may also be multiple measure models rather than single-measure, for example, the Bin Method (see AT M.2).

For buildings where the heat output is governed by the indoor temperature, where there are thermal zones having different temperature setpoints or different HVAC systems or control zones, these models are too restrictive for use in auditing. However, static unizone models can be used for energy analysis of buildings where the indoor temperature is uniform, for example, residential buildings where the heat output is determined by the outdoor temperature and the heating system is balanced.

For estimating cooling energy requirements one can use tabulated cooling degree-days in a manner similar to the heating degree-day method (see AT E.1). Because of the additional complexities involved in a cooling as opposed to a heating calculation, attempts to predict cooling energy requirements against a single parameter have not been very successful (ASHRAE, Ch. 28, 1985).

Static multizone models are appropriate for the evaluation of ECOs related to the building envelope. One problem is the evaluation of ECOs related to intermittent conditioning, because static models can not take into account the effect of the building thermal mass.

A distinction between static and dynamic models is that static models work with a time step from one day up to one month, while dynamic models are based on time steps of one hour, or less. Thus, results from static models can only be considered as average values in contrast to dynamic models which can predict peak values of interest for the sizing of equipment or for the analysis of overheating problems.

Dynamic unizone models allow for an evaluation of ECOs related to intermittent conditioning, but not for a multizone description of the HVAC system. These models treat the building interior as being uniform. However the envelope may be assumed to consist of several different wall elements, each being connected to the indoor temperature. Dynamic unizone models can be incorporated into a static multizone model to allow for an evaluation of intermittent conditioning type ECOs. To simplify calculations, dynamic unizone models should in this case be simplified and aggregated as much as possible.

Dynamic multizone models are often based on iterative calculations of the major energy flows at frequent time steps. The calculations utilize models of the HVAC system and the building envelope to follow their constantly changing response to the building loads and control systems. This calculation is often followed by an economic evaluation. Detailed simulation models such as dynamic multizone models are of use for design purposes or when a detailed simulation of the building thermal performance is required, which is often not the case in auditing situations.

There are several hundred detailed simulation programs. Several published bibliographies of computer programs of this kind exist (for a review see Sullivan, 1982). However, it is difficult to obtain any type of comparative information regarding the use and quality of these programs from other than the program developers, except for the few programs which are widely available because of the support provided by government agencies. If little is known about the flexibility, versatility and applicability of these programs, generally even less is known about their validation.

In comparisons of simplified models to more detailed simulation models (Kallblad, 1983, Jones, 1981 and Kusuda, 1981) it has often been found that, if used by the same analyst, results produced by two different methods are similar. The difference is often smaller than the differences produced by several analysts using different detailed programs.

HVAC system models currently used vary enormously in complexity from simple single parameter single time step to multi parameter hourly (or less) simulation models. For example, a boiler might be "modelled" as a piece of equipment with an average or constant operating efficiency over the heating season; the operating efficiency usually being assumed to lie somewhat below the steady state combustion efficiency, to account for off cycle losses, acording to the type of boiler and burner. More accurate methods might use part load efficiency relationships to determine discrete operating points either as part of a bin method (AT M.2) or detailed hourly method. Even more detailed methods might consider the actual dynamic simulation of the boiler, it's controls and their interaction with the building heating system and building air balance. The significance of building air balance being that the operation of the boiler and the discharge of combustion products out of the chimney will affect the amount of outside air being drawn into the boiler. In a large building with a separately contained and ventilated boiler room this would not be of interest, but in a smaller building the operation of the boiler can increase the infiltration rate into occupied areas of the building.

Normally HVAC system models will be contained within building energy models where interactions between plant and building, such as given in the example above, can be addressed. Normally, more detailed HVAC system models can be expected in the more detailed building energy models although this is not always the case. When choosing an analysis technique or model the auditor should be particularly careful to ensure that the method being chosen is sensitive to the specific characteristics offered by the ECO he wishes to evaluate. This means he must understand the model he is using, which in turn requires that the simulation model equations (algorithms) be reviewed for suitability.

Many simple heating system models in use evaluate emission, distribution and regulation losses by using default values (see AP H.1 and RV H.2) of the corresponding efficiencies (for a more thorough discussion of regulation losses, see App. C, section C.3). On the other hand, existing detailed simulation models are too complex for evaluating the heating system in auditing situations.

6.4 ECONOMIC EVALUATION MODELS

Models making cost comparisons containing, for example, pay-back period or return-on-investment are essential to arrive at an optimal ECO selection. The main problem when using these models is to have reliable data related to unitary cost for evaluating investments including costs for material and work costs. Some economic indicators are described in AT M.4 through M.9. Economic evaluations of ECOs are, however, highly uncertain due to unknown factors such as future interest rates, fuel prices, energy savings, maintenance costs and inaccuracies and errors in the building energy models. Due to the uncertainties, one may perform a sensitivity analysis of the estimated economic indicators. This can be done by defining a maximal and a minimal value for each of the uncertain factors, or even by associating to each factor a statistical distribution defining the probability for these factors taking a certain value. The sensitivity analysis can identify the factors which have a significant impact on the economic indicators.

6.5 ECO RANKING AND OPTIMAL ECO COMBINATIONS

As soon as the investment cost and the energy savings for single ECOs are known, the ECOs can be ranked according to some economic indicator. The economic indicator chosen depends on the financial objective formulated by the client, for example, maximization of the savings or minimization of the pay-back time. Different methods can be used to determine optimal ECO combinations:

i) Single ECOs are ranked according to an economic indicator. They are combined by adding to the ECO combination one ECO at a time according to the ranking, until the maximally allowed investment cost is reached. This does not lead to an optimal combination of ECOs.

ii) ECO combinations are formed according to some ad-hoc procedure. These ECO combinations then have to be evaluated independent of any previous ranking of the ECOs, as an ECO combinaation can have the highest economic ranking although the single ECOs in the combination do not reach high in the ranking.

iii) All potential ECO combinations are considered in order to obtain an optimal ECO selection. This work becomes very tedious as soon as there are more than a few ECOs. The work starts by a screening of the ECO combinations according to a set of economic constraints defined by the client. They may be related to the allowed investment cost, the allowed annual energy cost, etc. The remaining ECO combinations are then ranked according to an economic indicator.

6.6 CORRELATION MOOELS

Most of the previous discussion has dealt with the issue of energy analysis in the context of the simulation or <u>prediction</u> of energy use or cost, i.e. energy use (or cost) is calculated based on a model built up from a description of the various component building parts.

In energy auditing, particularly at the disaggregation stage, details of the consumption is generally known. Variations in consumption, either on an hourly, monthly or seasonal basis, i.e. patterns of energy consumption, have a tale to tell and an analysis of the consumption patterns can yield useful information about the building (see Ch. 3.4). Techniques are available for the analysis of historical consumption data. Most rely on regression techniques to look for trends against certain variables such as outside temperature and windspeed and are referred to as "Correlation" or "Regression Models". More complex models introduce pattern recognition techniques (Cowan, 1984) to further decipher the data. A common element of all such models is that they try to disaggregate the energy use into components - a full discussion of disaggregation is presented in Chapter 3.

6.7 SELECTION OF CALCULATION TECHNIQUES

Estimations of energy savings resulting from the implementation of ECOs can vary enormously in degree of difficulty and accuracy. In many situations the estimation of energy savings may actually involve more cost in the analysis than in actually implementation of the ECO - this is often the case for minor system control set point changes or complex HVAC systems. Futher, in some instances the cost of carrying out an analysis of potentially usable ECOs, particularly where we would have to use detailed hourly analysis models, would be prohibitive.

Before proceeding along an analysis of a retrofit the auditor should ask himself and <u>his client</u>, just how accurate the analysis needs to be and proceed with the simplest calculation that will satisfy the desired accuracy. In many cases it might be sufficient just to demonstrate that the ECO savings fulfil the chief economic criteria for implementation without actually calculating by how much. For example it might be demonstrated that the cost of providing a sheduled shut off or an exhaust fun can be justified on the fun savings alone - a very simple calculation; to complete the energy picture, that is estimating the ventilation losses, is a far more difficult and less accurate calculation and would in such a situation, serve no real useful purpose.

CHAPTER 7 ENERGY AUDIT DATA BASES

7.1 WHAT IS AN ENERGY AUDIT DATA BASE?

An Energy Audit Data Base (EADB) is a computerized system in which data and information relevant for practical energy conservation in the built environment is entered and organized. Time consuming tasks, such as looking up books and tables for required data and cross checking, can be avoided if data bases are available. The maintenance of a data base consists of analysing incoming data, checking it for accuracy, and storing it for easy retrieval. A data base is made up also of software needed to provide the interrogation and retrieval facilities (data base management system) and of application programs.

The organization and software of a data base ensure that only relevant data are retrieved. Moreover, the continuous up-dating of the information ensures that old data are discarded as soon as more recent and more reliable data become available.

7.2 WHAT ROLE CAN AN EADB PLAY IN ENERGY AUDITING?

An efficient and cost-effective energy audit requires a great deal of information to supplement site-collected data. Up to date information on buildings of the category being audited is required, and this is where the data base can help. The cycle: audit -> data base -> audit thus forms a rapid response learning process, greatly benefitting the auditor.

Although data collection is not the prime objective of a building specific audit, a great deal of data, potentially valuable to auditors, is gathered. This data flow can be used to improve the reliability and the detail of information on energy use in buildings, but this goal can be achieved only if a data base is created on a sufficiently wide scale. A data base can be of help to an auditor in several stages of the audit process described in the previous chapters, for example:

i) An EADB can be used to establish reference values for indicators such as energy consumption per unit area. These indicators can be used for rating buildings for audit (see ch. 2).

ii) The auditor can make use of energy indicators of various end uses, subdivided in building categories and types, during the disaggregation stage (see ch. 3).

iii) An EADB can provide data for an estimate of energy savings of particular ECOs (energy conservation opportunities) or combinations of ECOs (see Ch. 4). Recorded data may also be used to convince present clients of the reliability of the proposed retrofits and potential clients of the whole energy audit service.

iv) Data on detailed measurements of parameters such as component heat losses, plant efficiencies, etc., can be used for ECO identification (see ch. 4) or to obtain typical values which can, in turn, be used to substitute measured values in model calculations, provided this is consistent with the accuracy required.

v) Information from a post implementation performance analysis (see ch. 5) of retrofitted buildings can be used to convince sponsors of energy conservation programs that the program is justified.

vi) An EADB can be used to plan an energy audit. Information about the typical energy consumption and equipment performance can be of help for identifying auditing problems that are likely to be encountered and the amount of instrumentation needed.

vii) An EADB can document side effects of ECOs such as comfort improvements or problems that need to be handled early on by the auditor such as air quality or moisture problems.

The interaction between an EADB and the various stages of a building specific audit is illustrated in Fig. 7.1.

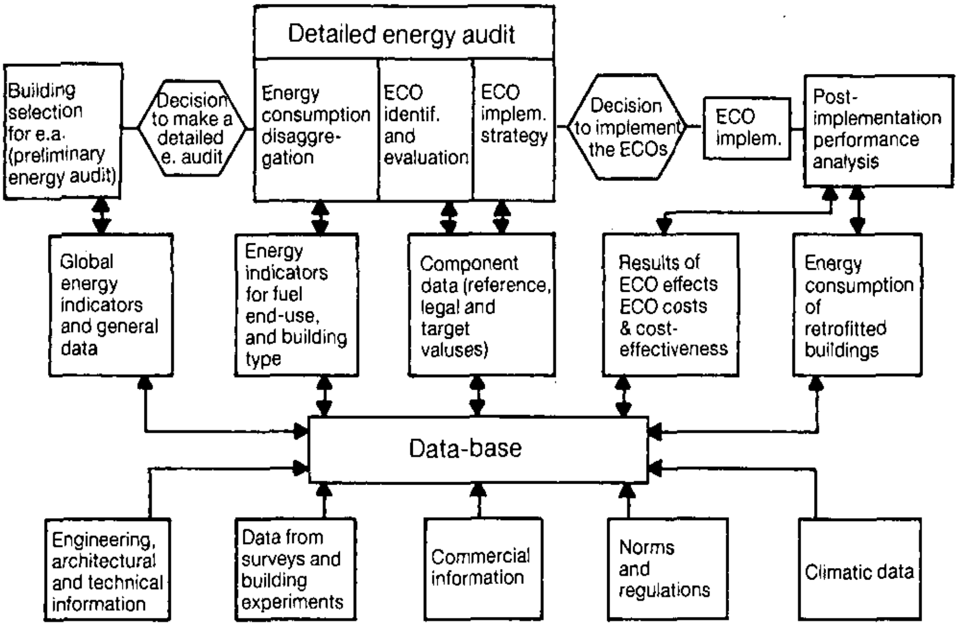


Fig. 7.1 Data base interaction with building specific energy audits.

There are, however, other users of EAOBs than auditors, and an EADB can be used for other purposes than building specific audits:

i) An EADB can be used for evaluations of aggregated (large scale) energy conservation actions. Although this type of analysis is only pertinent to public administrations or large building owners, the results may affect the energy conservation policy and indirectly influence the auditor's activities (see Fig. 7.2).

ii) An EADB may allow a public administration to check the impartiality, technical accuracy and completeness of auditors recommendations, by comparing the cost-effectiveness of the ECOs suggested by each auditor. This type of control will also augment the confidence of possible clients in the audit service.

iii) The availability of an EADB is of practical help also to manufacturers of energy saving equipment, utilities, architects, and other professionals interested in auditing.

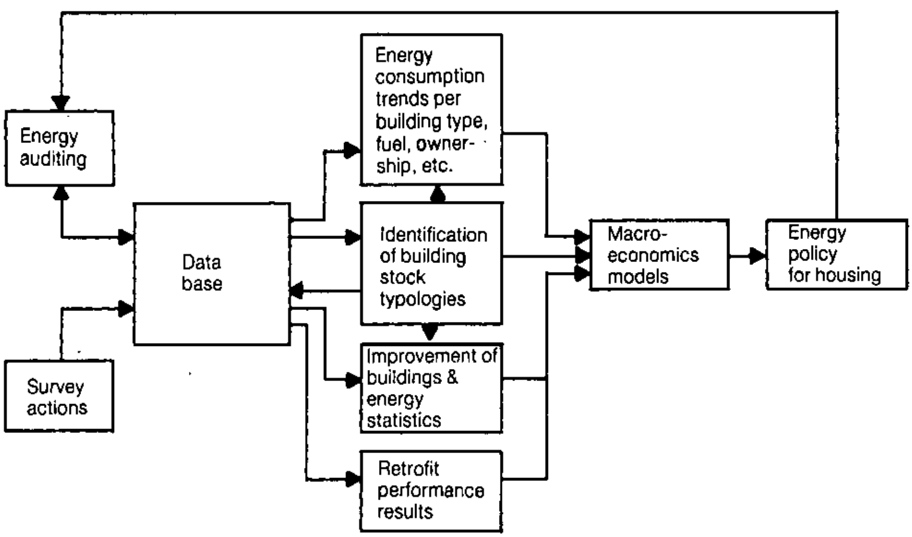


Fig. 7.2 Data base use for energy audit and conservation purposes.

7.3 LIMITATIONS AND PROBLEMS OF USING EADBs

The usefulness of an EADB is mainly determined by two factors, the size (i.e. the number of buildings and building categories included) and the data content (what energy useage and building properties contained) of the EADB.

The usefulness of a data base in general increases with its size; also, it is easier to collect data to provide an adequate statistical basis for common building categories such as residential buildings. However, the establishment of an EADB is an expensive project which requires skilled personnel and financing for computer hardware, software licenses and infrastructures. Any decision on the establishment of an EADB requires a careful cost-benefit analysis; for a single auditor it may be a large investment. Therefore, EADBs are usually set up by research institutes, public authorities, or large building owners involved not only in auditing but also in building management and retrofitting. This also guarantees a sufficient number of buildings and the continuous up-dating of the EADB.

The data content varies greatly between existing EADBs (Conti-Helcké, 1985). Obviously, the data content and the data quality depends on the purpose for collecting the data and the type of audit that has been invoked.

To be useful to auditors in different situations, an EADB should contain a broad spectrum of data, depending on building size, category and complexity, which can be collected only by means of rather detailed audits. Treating huge masses of data requires a large effort in data elaboration and storage, and a detailed building description is therefore avoided if an engineering approach to auditing has not been one of the purposes for establishing an EADB. EADBs established mainly for the purpose of, for example, energy conservation planning are more directed towards providing data at an aggregated level than at a building specific level. Whether an existing EADB is useful to an auditor or not generally has to be determined from case to case.

Other problems associated with EADBs are the quality of data and the randomness of data. When data from different sources are merged, it is necessary not only to check the quality of data (for example, measured, calculated, or evaluated data), but also the accuracy of data. Furthermore, the buildings contained in an EADB do not constitute a random sample of the building stock, as the buildings have been selected after a process aimed at identifying the poorest performing buildings.

A pool of auditors could agree to establish a common EADB to reduce the investment for each participant and to ensure an adequate size of the EADB. It would then be necessary to agree on a standard format for the data collection. Problems of confidentiality could also arise. In this case every auditor should be free to transmit either no data, only aggregated data or energy indicators, or transmit data in a form that a particular building can not be identified.

APPENDIX A GLOSSARY

1. AUDIT PROCEDURE

An experiment or test that can be used in an energy audit, involving the collection and analysis of data, aiming at the determination of the energy performance of a building or a building component.

2. BUILDING CATEGORY

The grouping of buildings according only to their use (for example, residential, educational, etc.).

Building Type is a sub-grouping of buildings within a particular category (for example, for residential buildings one may have detached, semi-detached, multi-family, etc.)

3. DISAGGREGATION

The determination and quantification of the components that constitute the energy balance of a building.

4. ENERGY AUDIT

A series of actions aiming at the evaluation of the energy saving potential of a building as well as the identification and evaluation of different energy conservation opportunities for that building.

5. ENERGY CONSERVATION OPPORTUNITY (ECO)

Retrofitting, operational and maintenance changes that, if implemented, could effect a reduction in energy consumption.

6. ENERGY INDICATOR

Energy consumption of a building, or a building component, normalised with regard to specific features of the building, or the building component, such as area, volume, temperature difference, etc.

A reference (Energy) Indicator is a value, or a range of values, of an energy indicator, determined from a statistical treatment of observed energy indicators.

7. (BUILDING ENERGY) MODEL

A simplified description of the (energy) performance of a building (or building component) in terms of a mathematical relationship involving properties of the building (component) and environmental variables.

7a Correlation (Regression) Model

A model where the value of the model parameters (the properties of the building or building component) are determined by a fit to measured data (for example, data on energy consumption and climate variables).

7b Simulation (Predictive) Model

A model which calculates the energy consumption of a building, given the properties and use of the building, and its components, and a set of climatic data.

8. MONITORING

Measurements at regular intervals of energy flows in a building and of indoor as well as outdoor climate variables.

9. RATING BUILDINGS FOR AUDIT

A series of actions aiming at the collection of information necessary for decisions whether a specific building should be subjected to a more detailed audit, or for the identification of what buildings in a building stock should be subjected to an audit.

10. REFERENCE VALUE

A numerical value describing the performance of a building (type) or building component/service (often stated in terms of the energy consumption or building component characteristics). A reference value is used for comparisons to measured performance of a particular building or building component. Reference values can be divided into:

10a Target Value
The desirable performance of a building or a building component.

10b Legal Value or Standards
Values defining the required performance of a building, or its components, prescribed by building codes or directives.

10c Design Value
Performance values of buildings or building components specified by designers or manufacturers.

11. POST IMPLEMENTATION PERFORMANCE ANALYSIS (PIPA)

An evaluation of the performance of a building or building component/service performed after the implementation of a retrofit to assess the effects of the retrofit.

APPENDIX B SYMBOLS AND ABBREVIATIONS

Appendix B provides a list of symbols and notation used in formulas and equations as well as a list of common abbreviations used in the Source Book. In the symbol list are also given the basic SI-units for each symbol. Note that this unit is not always identical to the unit most commonly used in this Source Book, for instance, the basic SI-unit for energy is Joule (J), whereas the most frequent energy unit used here is the kilowatthour (kWh).

LIST OF SYMBOLS		BASIC SI-UNIT
A	area	m^2
A	effective leakage area (infiltration and ventilation)	m^2
A_e	envelope area	m^2
A_w	working plane area (illumination)	m^2
C_d	discharge coefficient (flow through orifice)	
C_s	tracer gas concentration (duct work)	-
CCT	correlated color temperature (illumination)	K
CDD	cooling degree days	days*K
CO_2	carbon dioxide content (heating)	-
COP	coefficient of performance (heating and cooling devices)	-
COP_c	coefficient of performance for cooling	-
COP_h	coefficient of performance for heating	-
CS	cost for savings	-
CU	room coefficient of utilization (illumination)	
c_p	specific heat at constant pressure	J/kg,K
c_s	Siegert constant (boilers)	
D	hydraulic diameter	m
DD	degree days	days*K
d	diameter	m
d_i	insulation thickness	m

E_{net}	net energy input to building	J
E_v	illuminance level	lux
E_w	*working plane illuminance*	lux
F_i	collector overall factor (solar systems)	-
F_x	heat exchanger factor (solar systems)	-
f	performance factor (solar systems)	-
H	enthalpy	J
H_a	enthalpy of air entering burner	J
H_f	enthalpy of flue gases	J
HDD	heating degree days	days*K
h	heat transfer coefficient	$W/m^2.K$
h	height	m
h	specific enthalpy	J/kg
h_f	specific enthalpy of fluids	J/kg
h_g	specific enthalpy of gases	J/kg
I	current (electric)	A
I	radiation level (solar systems)	W/m^2
I_l	line current (electric)	A
I_p	phase current (electric)	A
I_t	total radiation (solar systems)	W
i	current (electric, instantaneous value)	A
K_w	global heat loss coefficient	$W/m^2.K$
kW_c	constant speed device electrical demand (electric motors)	W
kW_i	variable speed device electrical demand (electric motors)	W
L	fractional heat loss	-
L_d	fractional dry flue loss	-
L_h	fractional heat loss (buildings)	-
L_j	fractional jacket losses	-
L_{oc}	fractional off-cycle losses	-
L_s	fractional storage losses (hydronic heating)	-

L_{sb}	fractional stand-by losses (heating plants)	-
LLF	light loss factor (illumination)	-
LLMF	lamp lumen maintenance factor (illumination)	-
LMF	lumen maintenance factor (illumination)	-
l	length, distance	m
m	mass	kg
n	rate of air exchange	s^{-1}
P	power	W
P_a	installed power after retrofit	W
P_b	installed power before retrofit	W
P_{el}	electric power	W
P_k	compressor power	W
P_t	total power of a unit	W
PBT	pay-back time	-
PF	power factor (electrical systems)	-
p	pressure	Pa
p_d	dynamic pressure (velocity pressure)	Pa
p_s	static pressure	Pa
Q	heat	W
Q_a	annual heating requirement	W
Q_{aux}	heat from auxiliary equipment	W
Q_{el}	electric heat gains	W
Q_g	free heat gains	W
Q_h	heating system energy output	W
Q_i	heat content of fuel	J/kg
Q_j	jacket losses	W
Q_{load}	heat load	W
Q_{loss}	heat losses	W
Q_m	metabolic heat gains	W
Q_{sb}	stand-by losses	W
Q_{sol}	solar heat gains	W

q	flow rate (general)	
q	heat flow	W/m^2
q_c	volumetric flow rate of cooled fluid (heat pumps and chillers)	m^3/s
q_h	volumetric flow rate of heated fluid (heat pumps and chillers)	m^3/s
q_m	mass flow rate	kg/s
q_p	volumetric flow rate of primary side (heat exchangers)	m^3/s
q_s	volumetric flow rate of secondary side (heat exchangers)	m^3/s
q_s	volumetric flow of tracer gas (duct work)	m^3/s
q_v	volumetric flow rate	m^3/s
R	resistance (electric)	ohm
R	resistance (thermal)	$m^2.K/W$
R_a	color rendering index (illumination)	K
$R_{s,e}$	external surface resistance	$W/m^2,K$
$R_{s,i}$	inside surface resistance	$W/m^2,K$
RI	room index (illumination)	-
RSMF	room surface maintenance factor (illumination)	-
r	latent evaporation heat	J/kg
r	radius	m
SPF	seasonal performance factor (heating and cooling equipment)	
T	temperature	K
T_a	air temperature	K
T_b	base temperature (degree-day calculations)	K
T_b	base temperature (heat storage)	K
T_c	temperature of cooled fluid (heating and cooling)	K
T_{co}	condensation temperature	K
T_e	external temperature (buildings)	K
T_{ev}	evaporation temperature	K
T_{ex}	exhaust temperature	K
T_f	flue gas temperature	K
T_f	fluid temperature (ductwork and pipework)	K
T_h	heated fluid temperature (heat pumps)	K
T_h	temperature of heated fluid (heating and cooling systems)	K

T_i	internal temperature (buildings)	K
T_m	average temperature	K
T_r	return temperature (heating and cooling systems)	K
T_s	supply temperature (heating and cooling systems)	K
T_v	vapor temperature	K
T_w	water temperature	K
t	temperature	^oC
t	time	s
t_a	operating time per year after retrofit	s
t_b	operating time per year before retrofit	s
t_c	constant speed device, total operating time	s
t_d	tracer gas temperature in duct (duct work)	^oC
t_T	total operating time (equipment)	s
t_f	tracer gas temperature at flow-meter (duct work)	^oC
U	U-value (heat transfer coefficient)	$W/m^2,K$
U_l	heat loss factor (solar systems)	-
u_v	flow velocity	m/s
V	voltage (electric)	V
V	volume	m^3
V_l	line voltage (electric)	V
V_p	phase voltage (electric)	V
W	mechanical work	J
w	fractional operating time (burners)	-
w	width	m
w_m	average burner on-time	-
x	moisture content, humidity	kg/kg
x_{df}	dryness fraction (water in steam)	
α	absorptance (radiation)	-

Δ_1	change in electrical demand of electric equipment	W
Δ_1'	effect of Δ_1 on total building demand	W
ΔE	annual cost saving	$
ΔI	cost of investment	$
ΔM	annual maintenance cost	$
Δp	pressure difference	Pa
ΔPF	change in power factor	-
ΔT	temperature difference	K
η	efficacy (illumination)	-
η	efficiency	-
η	emissivity (materials, radiation)	-
η_a	installed efficacy after retrofit (illumination)	lm/W
η_b	installed efficacy before retrofit (illumination)	lm/W
η_b	boiler full load thermal efficiency	-
$\eta_{b,s}$	burner seasonal efficiency	-
η_c	combustion efficiency (burners)	-
η_d	distribution efficiency (heating systems)	-
η_f	fan efficiency (duct work)	-
η_{lamp}	lamp efficacy (illumination)	lm/W
η_{lum}	luminaire efficiency (illumination)	-
η_m	motor efficiency (electric motors)	-
η_p	plant efficiency (heating systems)	-
η_p	pump efficiency (pipework)	-
$\eta_{p,s}$	heat plant seasonal efficiency	-
η_{saf}	supply air fan efficiency (ductwork)	-
η_t	total efficiency (systems)	-
η_t	transmission efficiency (fans, pumps)	-
θ	temperature difference between radiator and room (heat distribution)	K
λ	conductivity	W/m,K
λ_i	conductivity of insulation material	W/m,K
σ	Stefan-Boltzman constant	$W/m^2,K^4$

τ	transmission coefficient (radiation)	-
Φ	light flux (illumination)	lm
φ	phase angle	-

LIST OF ABBREVIATIONS

A ampére (electricity)
AC alternating current (electric)
ACC air cooled condensor
AP audit procedure
AT analysis technique

CT cooling tower

DC direct current (electric)
DM digital type meter

EMS energy management system
ES energy savings

HID high intensity discharge lamps
Hz Hertz (=s^{-1}, frequency)
h hours
hp horse power (=745 W, Imperial horse power)

K degrees Kelvin (absolute temperature or temperature difference, SI units)
kPa kilo-pascal (pressure)
kV kilovolt
kVA kilo volt-ampére
kVAr kilo volt-ampére reactive power

APPENDIX C ENERGY USE AND AUDITING PROBLEMS

C.1 INTRODUCTION TO APPENDIX C.

The intent of this appendix is to present a review of the principal factors influencing energy use in and between the various building components and systems so that an auditor might gain an appreciation of the physics of the situation leading to a better understanding of the problems he has to address. Primarily, this appendix will be of interest to the auditor who is not a specialist, or does not have much experience, in a particular area he is required to audit. Since few auditors will be specialised or experienced in all areas, most auditors should find some benefit in one or more of the discussions of the various component areas. Further, even where the auditor is not interested in auditing all aspects of the building, he should have an understanding of the reaction in other areas to changes introduced in areas of which he has specific knowledge. For example, reducing the heat loss through the envelope is likely to impact upon the seasonal efficiency of the boiler plant and the full extent or potential of the proposed changes may not be realised.

These discussions also highlight aspects in each component area that may limit the auditors effectiveness and point out those general areas (parameters) having greatest significance on component energy use. An integral part of the presentations include discussions of the parameters that can be most effectively manipulated for energy savings.

The discussions are arranged mainly according to the component category system as used in the Source Book (see Introduction p. 5). The Envelope is discussed in section C.2, Regulation in section C.3, Heating and Cooling in section C.4, Distribution System (Air, Steam and Water) in section C.5, Service Hot Water (SHW) in section C.6, Lighting in section C.7, and Electrical Systems in section C.8. In section C.9 is given a discussion of the occupant's impact on Energy Conservation, and finally, in section C.10 is discussed the importance of Fuel Tariffs for Energy Conservation issues.

C.2 THE ENVELOPE

Figure C.1 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 can vary greatly between different climates and constructions. A number of factors influence these diverse energy flows and it is important to have an understanding of the various heat transfer mechanisms in order that ECO selection can be made wisely.

C.2.1 Steady State and Transient Heat Flows

The fabric of the building, furnishing, and HVAC systems exist in either a steady state or transient state. The steady (static) state is present when outside and inside air temperatures remain constant and there are no changes to the rate of space heating gains from equipment, people or direct solar radiation, or changes in the operation of the building or the behavior of the occupants. Only over limited periods of the heating or cooling season would this occur, for example, a prolonged overcast cold period. In contrast, a transient (dynamic) state exists when conditions change. This may occur for instance during changes in the weather, or when the inside temperature changes due to night setback or changes in thermostat setpoint. Not only do these effects directly influence the transfer and storage of heat through and within the building (fabric and structure), but they indirectly influence the operation of heating and cooling systems.

C.2.2 Conduction, Convection and Radiation

There are three basic ways in which heat can be transferred; namely, 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 environmental 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. For example, if we lay a hot brick on a cold brick and wait a few minutes, the side of the cold brick facing the hot brick will heat up; the other side will still be cold; i.e., transient heat transfer has taken place but a steady-state condition hasn't been reached. If we placed the two bricks in a zero heat loss container and waited a few hours, both bricks would end up at the same temperature - halfway between the original temperature of the hot and cold bricks. One could say the original hot brick had stored energy and then released energy to the cold brick.

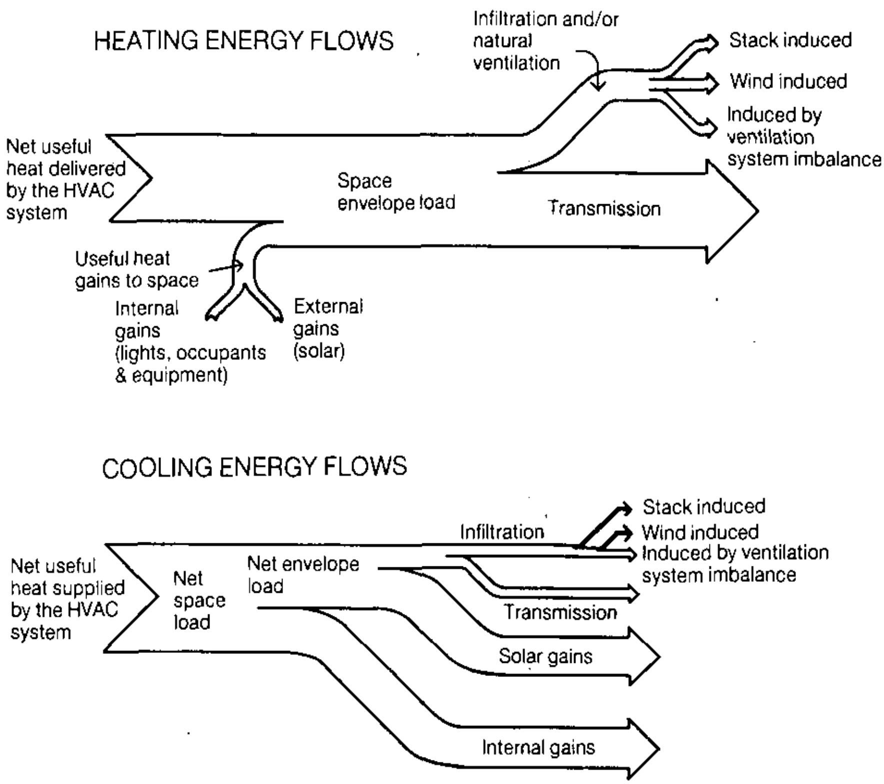


Fig. C.1 Energy flows in an occupied space.

In the case of buildings, conduction will occur through the envelope components, through interior partitions to adjacent spaces maintained at a different temperature, and into or out of the building mass itself and any furnishing 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 liquid 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.

The primary option for retrofit 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.

In the case of <u>convection</u>, heat is transferred by air circulation. If we placed two bricks, one hot and one cold in a zero heat loss container so that the bricks were not touching and could not "see each other", even though an air path existed between, the convection process would begin with the air near the hot brick rising to the top of the container and air cooled by the cold brick falling to the bottom. Initially the air would be stratified, hot on the top, cold on the bottom. However, when the hot air reached the cold brick, it would be cooled and the cold air reaching the hot brick would be heated causing the air to circulate between the bricks forming a convective loop. After passing through a transient phase both bricks would reach the same temperature.

The time delay in this case is not caused by the thermal inertia of the small air mass, but by the slow conduction of heat into the brick. For most practical purposes, convection can be thought of as being instantaneous.

Heat transfer by convection will occur at all air to solid interfaces such as between the <u>outside and inside air</u> 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. Such problems are best detected using infrared scanning procedures (see AP E.9). Insulation can be completely circumvented by a convective loop carrying outside air into a void between the wall board and insulation.

Convection currents created in the space itself by the envelope system can also have a direct effect on occupant comfort. Convection currents caused by air infiltration or down draughts from large cold surfaces, particularly windows, give rise to major problems. Retrofit options for reducing heat loss through convection rely on increasing the resistance to air flow through the envelope and within the actual envelope layers.

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. To continue the previous example, if two bricks were placed in the same zero loss container and the air extracted, energy would be radiated from the hot brick to the cold brick. No air movement is needed just as we on earth are warmed by the sun. Again, in time, the two bricks would reach the same temperature and like the convection the time lag is associated with the slow conduction of heat into the bricks; i.e. the radiation is essentially instantaneous.

There are a number of important radiation transfers in building science, not least of which is the 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 the thermal comfort regardless of the air temperature. Consequently, limiting adverse radiation sources is an important retrofit strategy.

C.2.3 Air Infiltration

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 slightly and together with wind, (see Fig. C.2) which causes pressure on the building exterior, it causes air to move into the building (air infiltration), or out of the building (air exfiltration, see Fig. C.3). Cold outside air entering the lower part of the building can cause significant occupant discomfort.

The relative effects of wind and stack actions on the infiltration rate are complex in nature and will depend on building characteristics as well as weather. The primary options for the minimisation of infiltration lie in *reducing the openings in the envelope and*, *particularly* in taller buildings, reducing the opening between interior floors.

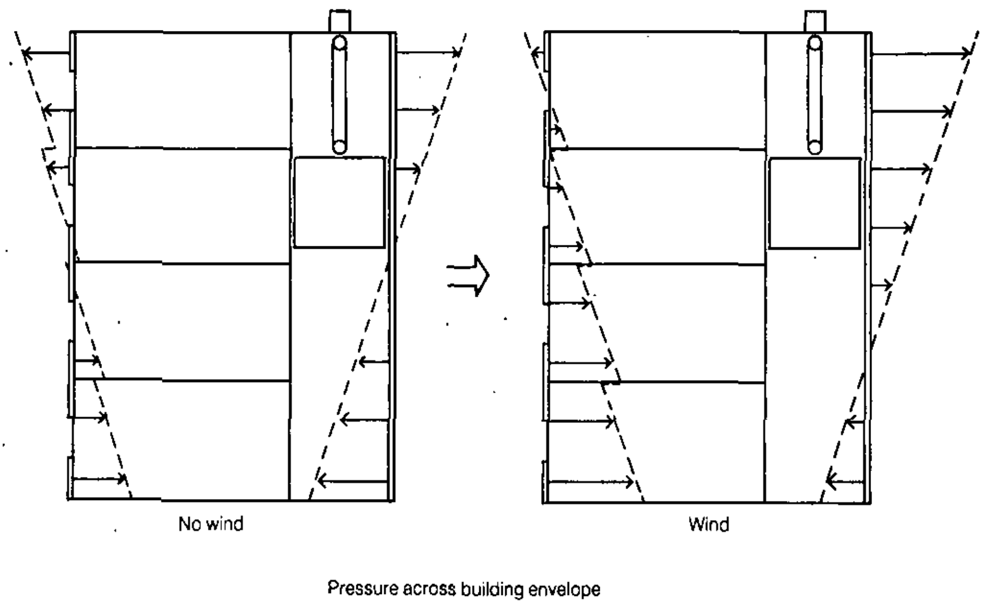


Fig. C.2 *Pressure across building envelope. If there is no wind* pressure, infiltration occurs mostly at the lower part and exfiltration at the upper part of the building. If there is a wind pressure, infiltration occurs mainly on the lower part of the windward side and exfiltration on the upper part of the leeward side. Note the pressure difference across internal floor partitions.

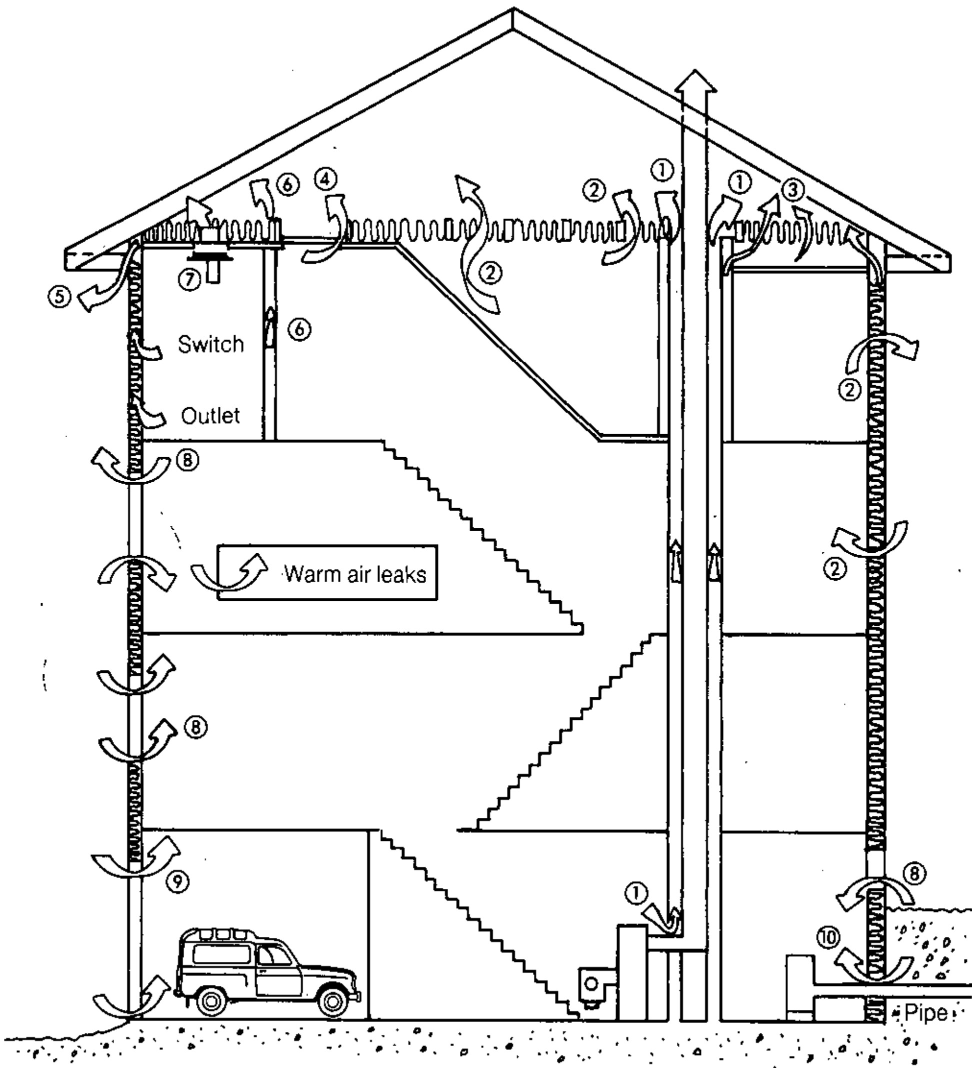


Fig. C.3 Common air infiltration and exfiltration paths. Exfiltration generally occurs at the upper and infiltration at the lower portions of the house:
(1) around flue and plumbing stack,
(2) through the insulation,
(3) above dropped ceilings,
(4) around entries,
(5) penetrations in outer walls and eaves,
(6) leakage up through interior walls and electrical systems,
(7) recessed lights,
(8) through basemement windows,
(9) through garage and basement doors,
(10)at openings for buried pipes.

With infiltration, the major problem facing the auditor is to quantify the amount of air leakage, testing methods are normally fairly labor-intensive and often only practicable 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 the and the auditor should be particularly alert for such occurrances which can lead to serious building degradation problems.

C.2.4 Building Mass and Thermal Response

There are two different aspects relating to building thermal mass which are often confused and misunderstood.

The first of these aspects 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. A good example of the application of such a phenomenon is the adobe buildings in the U.S. Southwest which relay upon wall mass to delay the heat of the day to reach the interior in the cool of the night.

The second aspect is concerned with the heat flow into or out of the interior spaces of the room. These heat flows are precipitated by

i) radiant exchanges from warm surfaces to cooler surfaces, for example from warm sunlit walls and radiators to cooler ones and from direct solar radiation falling into room surfaces, and
ii) 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. C.4 and C.5.

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 enclosure. The effect of an insulating layer, for example a carpet and underpad, 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 demands swing 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.

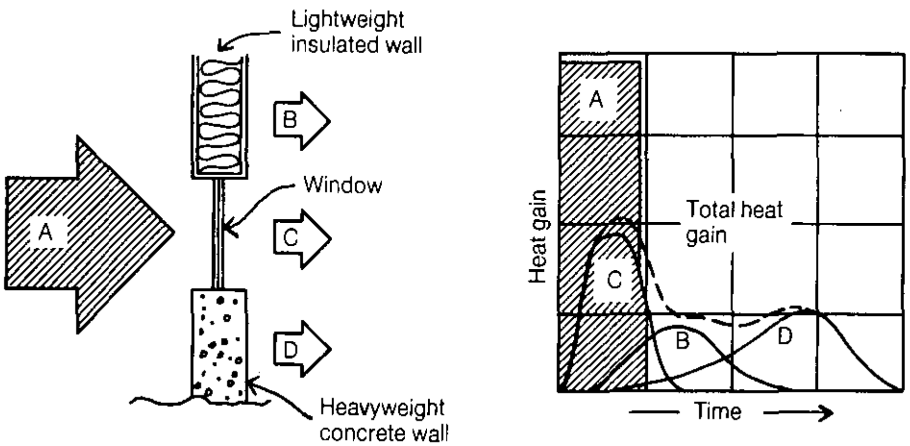


Fig. C.4 Heat flow into a conditioned space. The total heat gain does <u>not</u> appear as a load on the air conditioning system until the heat is transferred to the space air by convection.

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 maintain the space temperature above the setback temperature. During the preheat time 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.

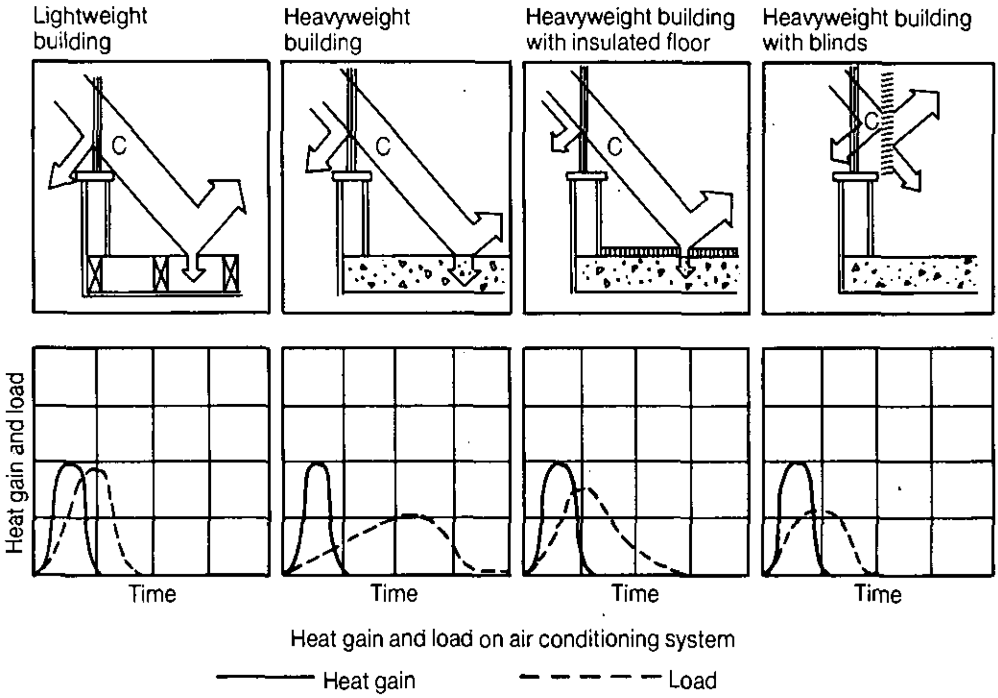


Fig. C.5 Simplified illustration of the effects of building thermal mass on thermal response.

C.2.5 Building Envelope Evaluation

Evaluations of building envelope can often be made simply 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 airtightness of the envelope or spot thermal anomalies (conductive thermal bridges and convection paths) in the envelope system, which can account for up to 20% of the overall wall U value.

Appendix F contains a number of audit procedures appropriate to the evaluation of the envelope system ranging from simple smoke puffer tests to trace air leaks to detailed thermographic inspections used to discover hidden defects. Such testing needs to be cognizant of the problems associated with moisture passing through or being held in the building structure. Such instances of moisture collection can undermine the effect of an otherwise useful ECO. The main sources of moisture problems can be found where warm moist air leaves the building (see Fig. C.3). Further aspects are presented in the ECO descriptions in App. D. Care should be taken when selecting ECOs for implementation with the impact of the ECO on all three methods of heat transfer being considered. For example, if air change levels are excessive (convective heat loss), adding additional insulation (to control conductive heat loss) will be ineffective unless it or additional measures tightens the building envelope at the same time, since air passing through the insulation will compromise its insulation (resistance to conductance) value.

For simple buildings, for example residential buildings with heating only and no solar devices, savings resulting from envelope changes can be estimated using simple algorithms such as degree day methods. However, more detailed methods are required for air conditioned buildings, particularly those with multiple zones, and for buildings with passive and active solar heating, daylighting, or heat recovery systems.

Changes to fenestration systems should always include appraisals of the effect of the flow of solar heat through the glass even where mechanical cooling is not provided.

C.3 REGULATION

There are two principal groups of factors affecting energy use consumed under this category of building components; one is related to the quality of the environment being provided, the other with the efficiency with which the heating, ventilating and air conditioning (HVAC) systems maintain this environment. These overall energy flows are illustrated in Fig. C.6.

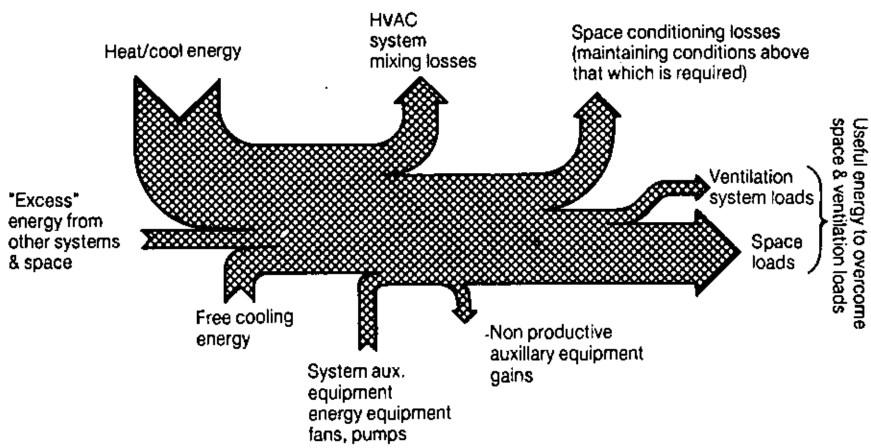


Fig. C.6 Example of energy flows in an environmental regulation system.

For practical purposes, these two groups are discussed separately since ECOs addressing the quality of the environment can normally be identified by an audit of the environmental conditions, however those addressing the efficiency of conditioning require an audit of the actual HVAC equipment. This is not to say that identification of this first group of ECOs should necessarily be through an observation of the thermal environment, since they may be more easily identified by an inspection of the environmental control equipment.

C.3.1 Environmental Quality

Thermal comfort is an expression of man's thermal sensation of the interaction between his body and the environment. The heat balance of this interaction will depend on a combination of six major parameters (Olesen, 1982, see also Fracastoro-Lyberg, 1983):

i) Air temperature
ii) Mean radiant temperature
iii) Air velocity
iv) Humidity
v) Activity level
vi) Clothing thermal resistance

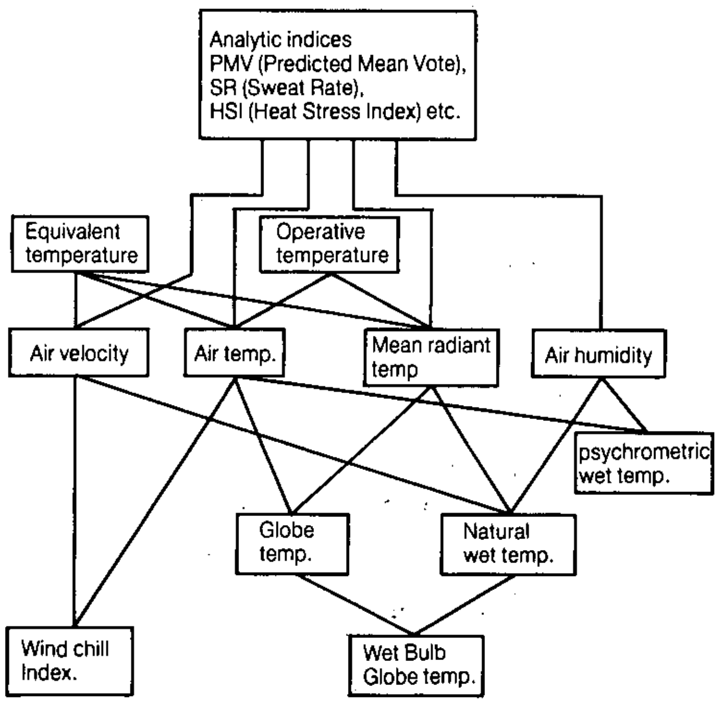


Fig. C.7 Relationship between climatic measures and indices.

The relation between these parameters and the concept of thermal comfort can be expressed in different comfort indices according to Fig. C.7 (Holmer, 1984). The *mean radiant temperature* can be considered to be the temperature of a uniform black enclosure in which a solid body or occupant would exchange the same amount of radiant heat as in the existing non-uniform environment. The value is closely related to the mean surface temperature.

Also, thermal comfort can be accounted for in different types of comfort diagrams (see ASHRAE Standard 55-1981 and ISO Standard 7730-1984).

Significant variations in concentration and type of substances composing the ambient air will affect comfort (e.g. through bad smell) 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 can not readily be removed from the air by increasing the ventilation rate. A fuller discussion of air quality is provided in ASHRAE Standard 62-1981.

The six parameters listed above affect energy use through heat losses. To minimise these losses, it is important to avoid excessive air temperatures and ventilation rates without lowering the level of thermal comfort or air quality. When analysing the comfort situation of a particular building, this should be done in terms of the types of activities it is used for by identifying optimal values of the comfort temperature and ventilation rates.

The six parameters listed above have different impact on the thermal comfort and the energy consumption when one considers the heating mode.

The air temperature can often be lowered by dealing with the other parameters affecting thermal comfort. This will directly decrease thermal losses. Also excessive temperature gradients should be avoided in the zone of occupancy.

Increasing the mean radiant temperature will provide the same thermal comfort with a lower air temperature. This can be done by improving the building envelope (upgraded insulation, smaller and better insulated windows and doors, etc.), changing the heating system to provide larger heating surfaces. and using shutters or venetian blinds.

Air velocity greatly affects the comfort temperature. This makes it important to optimise air velocities in the design of HVAC systems. Especially one should be careful with where and how air is introduced in a building by forced convection. It is also important to identify places of self induced convection currents (e.g. cold windows) and make the necessary adjustments (see Fig. C.8).

Low humidity levels increase the evaporative losses from a person and therefore directly affects the thermal comfort (as well as having such negative consequences as increased levels of static electricity). On the other hand, excessive humidity levels may be detrimental to the building envelope or cause indoor air quality problems by encouraging mould growth and should therefore be avoided.

Activity level and Clothing are often to be considered as assumptions to be made for calculating optimal values for air temperature and humidity level.

Production rates of contaminants should be studied prior to changing ventilation systems. Contaminants should be treated at the 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.

Techniques for the measurement of air temperature, radiant temperature, air velocity, humidity and contaminant concentrations can be found in App. F and App. G (see also Fracastoro-Lyberg 1983).

Common to all parameters affecting thermal comfort and air quality are seasonal as well as short term variations. It is therefore important to identify critical periods to avoid excessive measuring or getting irrelevant results (ISO/DIS Standard 7726-1982).

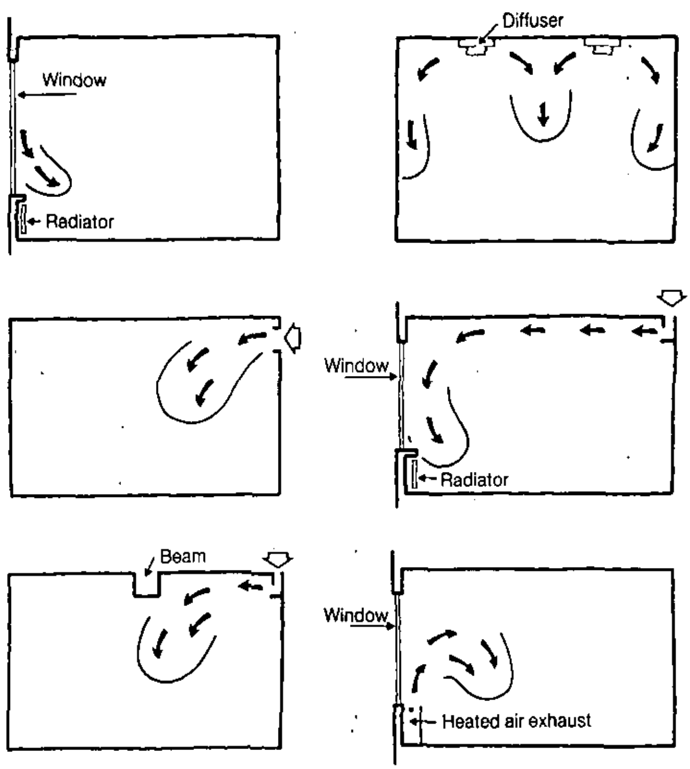


Fig. C.8 Places where the air velocity may exceed 0.15 m/s.

C 3.2 HVAC Regulation

For greatest efficiency of energy usage, it is desirable to tailor the standard of the environment with that of building occupancy. Such a tailoring of conditions is normally achieved through some HVAC system scheduling or control strategy which can take one or more of a number of specific forms. The 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:

i) Shutting off ventilation and humidification equipment when the building is unoccupied, and
ii) Setback and setup when the space temperature setpoint during unoccupied periods is reduced in the heating and increased in the cooling season.

Measures involving space monitoring include varying ventilation rate based on measured CO_2 levels, humidistat control of swimming pool hall ventilation rate and CO 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 becomes shortened.

In some cases it may not be possible to obtain the desired conditions with the environmental conditioning system as installed. Beside the 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 wasteage. This is particularly so where occupants respond to overheating by opening windows. The most common cause of such problems are the use of feed forward (open loop) control strategies (see Fig. C.9) and poor zoning.

In feed forward control systems there is no information feedback from the space being conditioned to the heating or cooling system controller and thus it is not possible to directly correct space conditions deviating from those desired. With such systems control of heating or cooling to the space is controlled according to some measurement value outside of the conditioned space, typically this is outside temperature although some systems allow compensation for solar radiation and wind speed variations.

Feed forward control system can be replaced by feedback control (closed loop) systems for improved control and generally improved efficiency. In a feedback 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 from simple measures such as correcting balancing deficiencies to the installation of additional terminal control devices, through to system replacement.

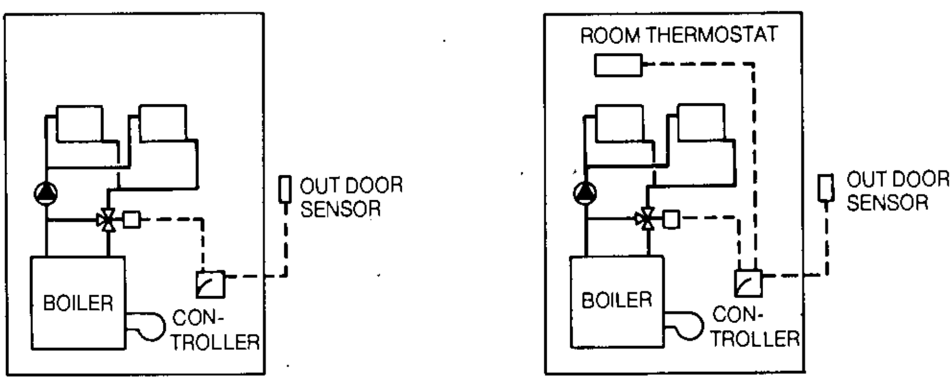


Fig. C.9 Examples of feed-forward (left) and feed-backward (right) control systems in building with central heating and hydronic heat distribution system.

Regulation losses are due to an inadequate response, in time as well as in space, of the building as a system to fluctuations in the space conditioning load. Some examples of regulation losses due to an inadequate response at the building level are:

a) losses due to the building thermal inertia during temperature setback,

b) losses due to the building thermal inertia during the start-up after a temperature setback and

c) losses due to heat exchange between spaces having different temperature setpoints.

An inadequate response of the space conditioning systems may cause, for example, the following heat losses:

d) losses before the setpoint has been reached during the start-up period after a temperature setback due to the limited power of the heat production system,

e) losses (the preceeding situation as in a) from the instant when the set-point has been reached till the setpoint temperature is actually required,

f) losses due to the bandwidth of thermostats and

g) losses due to unbalanced heating systems.

The above losses create a difference between the indoor temperature that is actually reached and the required temperature profile (see Fig. C.10).

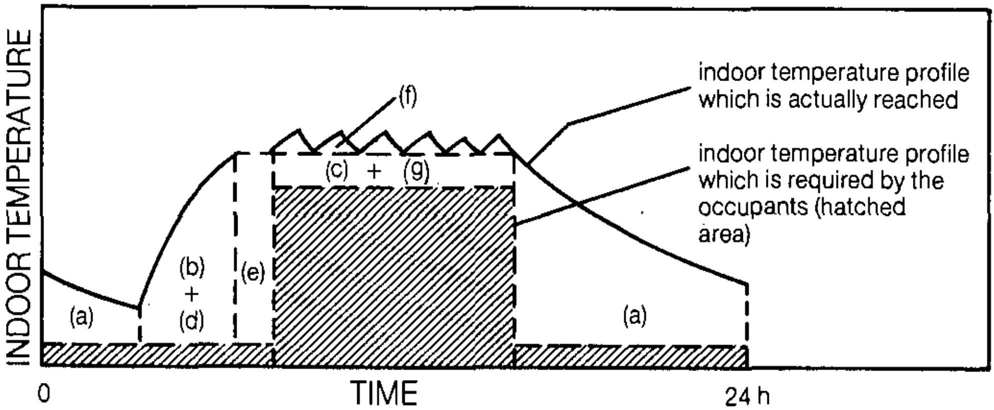


Fig. C.10 Illustration of Regulation losses. For notation, see text.

When setback or setup strategies are used, the space air temperature as well as inside surface temperatures are affected (see Fig. C.11). Energy and cost savings are derived from (Harrje, 1983):

i) Temperature setback for one or more periods each day (heating).

ii) Temperature setup for one or more periods each day (cooling).

iii) Precooling building (cooling) to reduce energy demand level.

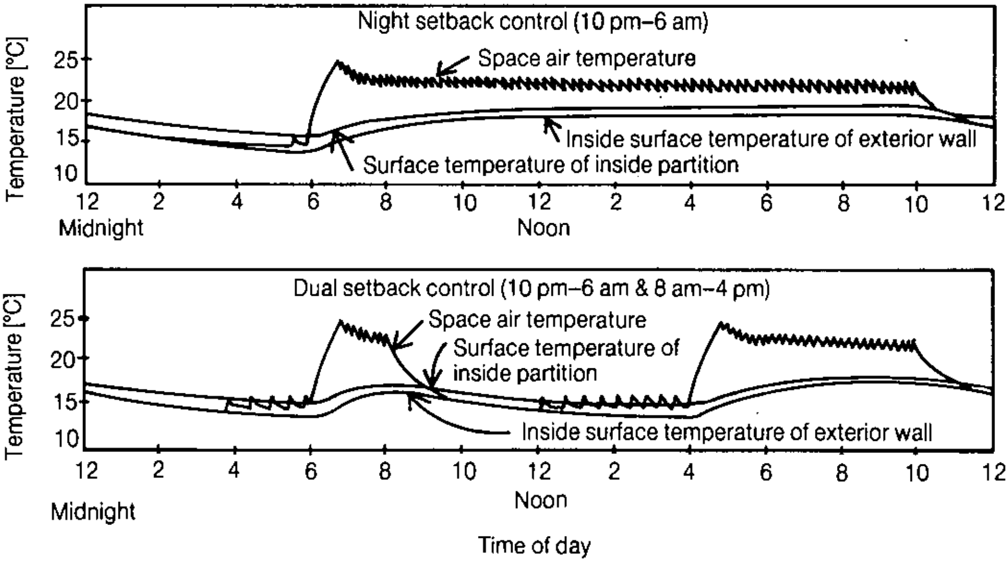


Fig. C.11 Details of the surface temperatures and heating plant operation with single and dual temperature setback. Similar profiles, but in the opposite direction, would be present for temperature setup.

The way a feed-forward control system may cause regulation losses can be illustrated by the case of a building with central heating and a hydronic heat distribution system. If the heat demand for a certain outdoor temperature is expressed in terms of the dependence of the required supply temperature on the outdoor temperature, the <u>heat demand curve</u> may look like in Fig. C.12. The shape of this curve depends on the kind of heat terminals that are used.

Depending on the amount of free heat (solar radiation, internal heat gains, etc.) available, the curve may be translated along the abscissa of Fig. C.12. The magnitude of this translation will vary with the time of the year if solar radiation makes a significant contribution to the free heat. The heat demand curve is an intrinsic property of the building and the heating system, and is not influenced by the control system.

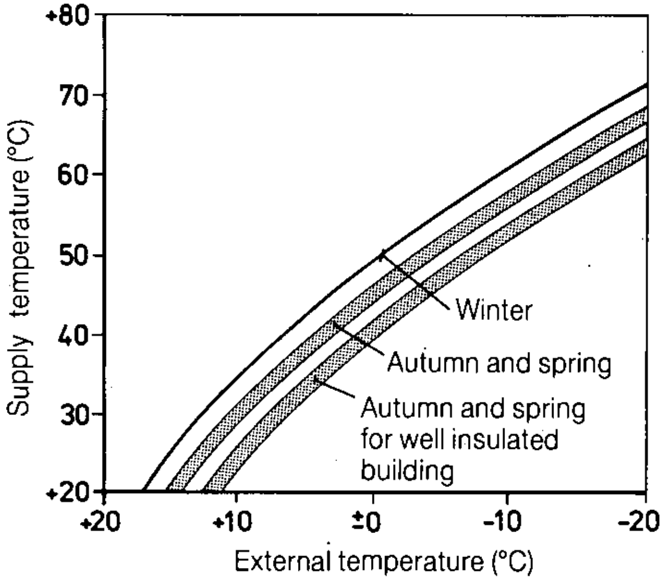


Fig. C.12 Example of heat demand curves for a hydronic heat distribution system. The winter curve for a well insulated building is not displayed in the fig.

For a feed-forward control system where the supply temperature is determined by the outdoor temperature only, the dependence of the supply temperature, determined by the control system, on the outdoor temperature is given by the characteristic curve of the control system. For most control systems this curve is either approximately linear or slightly convex (see Fig. C.13). It can, in general, only be shifted along the abscissa of Fig. C.13. and it may also be possible to change the curvature.

The best control efficiency is achieved if the heat demand curve and the characteristic curve of the control system coincide. This can, however, never be the case if the two curves do not have the same curvature. The best that can be achieved in practice is, in general, that the two curves cross for two values of the outdoor temperature. For other values of the outdoor temperature, the supply temperature will not be the most suitable. The control efficiency may be bad if the curvature of the heat demand curve and the characteristic curve of the control system are of very different shapes. For control systems that do not use the outdoor temperature as the only input, the situation may be analogous, but more complex. In this case the control efficiency cannot be illustrated by just comparing two curves.

Hydronic systems in buildings with large pipes and radiators respond slowly to changes in heat demand. In new buildings with well adjusted systems and small water volumes the response may be quick. The ability to exploit free heat depends on the response time of the heating system.

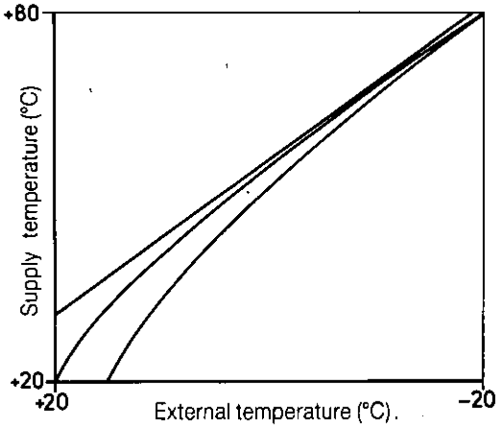


Fig. C.13 Examples of characteristic curves for feed-forward control systems.

There are two main requirements for the heating system to be efficient from an energy point of view:

i) The distribution of heat must be as even as possible between different rooms in the same zone, and
ii) The room temperature must be kept within certain limits independent of the swings of the outdoor temperature.

If the first requirement is to be fulfilled, the heating system must be balanced by adjusting the heating system, i.e., presetting of valves so that the distribution of water between radiators is such that the temperature difference between rooms is small. The requirement for a certain indoor temperature everywhere will then mean that the coldest room will determine the energy consumption.

Even if the heating system has been adjusted, there will often still be a need for a post-adjustment of the heating system to detect anomalies. This can be achieved by lowering the supply temperature until complaints by the occupants are received. In practice, this often leads to detection of irregularities of the ventilation system and the thermal insulation as well (Fracastoro-Lyberg, 1983). ECOs such as improved thermal performance of exterior walls and windows, or decreased ventilation, changes the energy demand by an amount that varies from one room to another.

The second requirement listed above can, in principle, be achieved when the supply temperature is determined by the outdoor temperature. However, the dependence of the supply temperature upon the external temperature is a non-linear one, and the dependence is not the same for different seasons. The situation is then the one described above; the supply temperature will be the correct one only when the heat demand curve and the characteristic curve of the control system cross.

When there are rapid changes of the outdoor temperature, there will be a time lag between the required and the actual supply temperature, and the amplitude will be smaller than what is required to counteract the change of the outdoor temperature (see Fig. C.14). The cause of this is that the reading of the outdoor thermostat is influenced by the external wall. The damping of the supply temperature amplitude will in general not affect the indoor temperature because of the thermal intertia of the building. The reading will also be affected by solar radiation, wind, and air humidity.

C.3.3 HVAC System Inefficiencies and Energy Use Reduction.

Once all necessary steps to reduce space loads have been pursued, the auditor's attention needs to be focused towards the inefficiencies involved in meeting these loads. These major inefficiencies and opportunities can be broken down into the following categories:

i) Use of "free" cooling,
ii) Minimising HVAC systems "mixing losses",
iii) Re-use strategies,
iv) Equipment related opportunities, and
v) Minimisation of auxiliary equipment (primarily transportation energy).

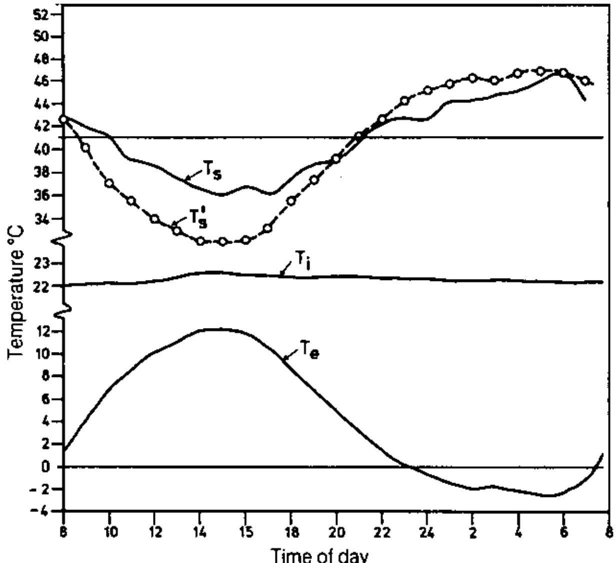
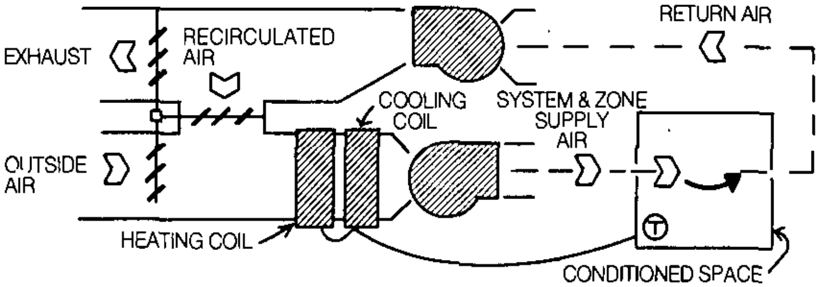


Fig. C.14 Example of recorded temperature.
T_i = internal air temperature,
T_e = external air temperature,
T_s = actual supply temperature,
T_s' = theoretical supply temperature,

Each of the first four of the above categories are discussed in detail below with illustrative examples as appropriate (the last category is dealt with in section C.5). To make these discussions more meaningful to the reader, Figures C.15 to C.20 document the unique characteristics of a number of generic HVAC system types. The reader should note that these are generic only and he should not automatically assume that controls installed in the field will be identical to those illustrated; it will be up to the auditor to <u>apply the principles discussed</u> here, not necessarily the specifics.



MODE OF OPERATION

CONSTANT OR VARIABLE VOLUME: Constant

SINGLE OR MULTIZONE: Single Zone

ZONE CONTROL: See System Supply Air Control.

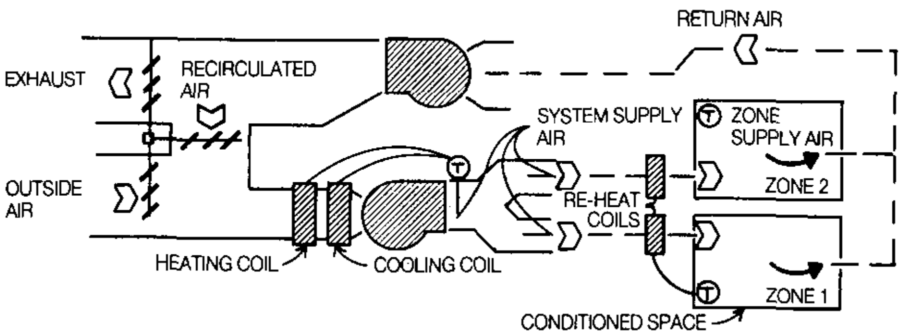
SYSTEM SUPPLY AIR CONTROL: By Room Thermostat.

OUTSIDE AIR & ECONOMISER: Optional, shown on schematic. Sequenced with heating and cooling coil for optimum energy efficiency.

TYPICAL SET-BACK OR UNOCCUPIED OPERATION: Minimum outside air allowed to go to zero, heat (or cool) coils on full output and fan cycles to maintain set-back (set-up) temperature.

OTHER COMMENTS:

Fig. C.15
Basic characteristics - single zone HVAC system.



MODE OF OPERATION

CONSTANT OR VARIABLE VOLUME: Constant

SINGLE OR MULTIZONE: Multizone

ZONE CONTROL: By room thermostat controlling addition of re-heat. Re-heat may be in duct heating coil or baseboard/perimeter heating.

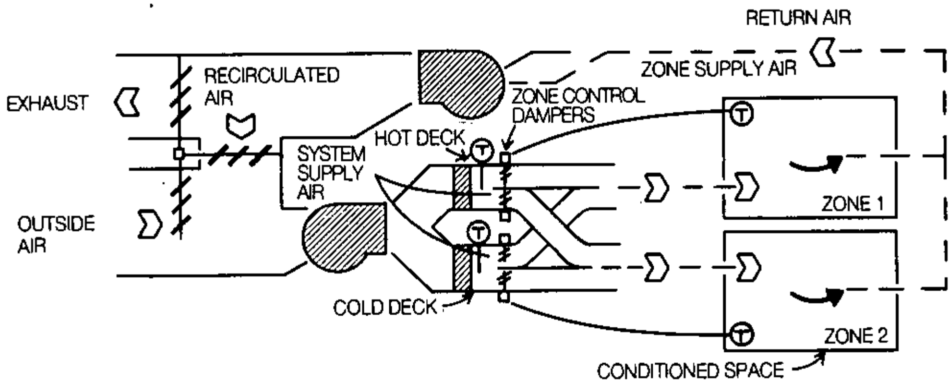
SYSTEM SUPPLY AIR CONTROL: Fixed in basic system. Advanced strategies reschedule temperature seasonally with outside conditions or reset temperature with variations in zone demand.

OUTSIDE AIR & ECONOMISER: Optional, shown on schematic. Sequenced with system supply air controls for optimum energy performance.

TYPICAL SET-BACK OR UNOCCUPIED OPERATION: Minimum outside air allowed to go to zero. Fan operates continuously. Alternatively discontinue re-heat and operate as Singel Zone System.

OTHER COMMENTS:

Fig. C.16
Basic characteristics - terminal re-heat system.



MODE OF OPERATION

CONSTANT OR VARIABLE VOLUME: Constant

SINGLE OR MULTIZONE: Multizone

ZONE CONTROL: Each zone thermostat controls corresponding zone dampers in system to mix hot and cold air streams to provide desired zone supply air temperature.

SYSTEM SUPPLY AIR CONTROL: Individually controlled hot and cold decks in basic system. Advanced control strategies would involve scheduling of deck temperatures with outside conditions or resetting with zone load variations.

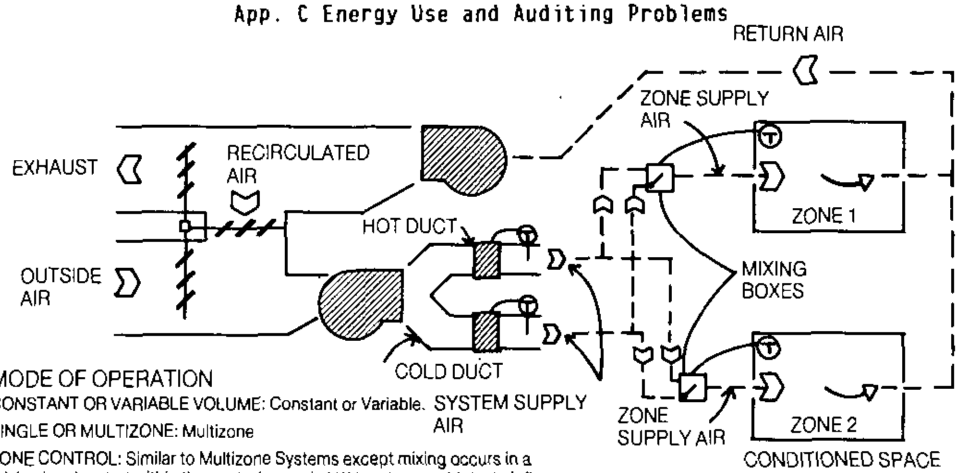
OUTSIDE AIR & ECONOMISER: Optional, shown on schematic. Sequenced with hot and/or cold deck system supply air controls for optimum and/or provide stratification guides to direct outside air, return air to hot and cold decks respectively.

TYPICAL SET-BACK OR UNOCCUPIED OPERATION: Minimum outside air allowed to go to zero. Shut off cold deck during set-back (and hot deck during set-up) and operate as Single Zone System.

OTHER COMMENTS: Newer systems may have individual (zone) coils as opposed to a common heating and a common cooling coil.

Some packaged systems utilise heat from refrigerant condenser heat hot deck.

Fig. C.17 Basic characteristics - multizone system.



MODE OF OPERATION

CONSTANT OR VARIABLE VOLUME: Constant or Variable.

SINGLE OR MULTIZONE: Multizone

ZONE CONTROL: Similar to Multizone Systems except mixing occurs in a mixing box located within the control zone. In VAV systems cold duct air flow is throttled to a minimum volume before hot duct damper opened.

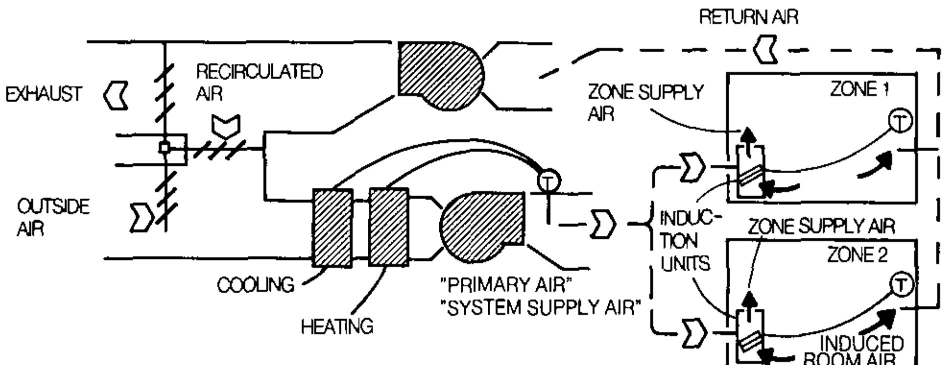
SYSTEM SUPPLY AIR CONTROL: Similar to Multizone Systems.

OUTSIDE AIR & ECONOMISER: Similar to Multizone Systems.

TYPICAL SET-BACK OR UNOCCUPIED OPERATION: Similar to Multizone Systems.

OTHER COMMENTS:

Fig. C.18
Basic characteristics - dual duct system.



MODE OF OPERATION

CONSTANT OR VARIABLE VOLUME: Constant

SINGLE OR MULTIZONE: Multizone

ZONE CONTROL: Zone thermostat controls amount heat (or cool) added to secondary (induced air) at the zone terminal.

SYSTEM SUPPLY AIR CONTROL: Normal to schedule primary air supply temperature in winter with outside conditions and in summer supply air at a fixed temperature. Advanced control strategies reset primary air temperature with variations of zone demand.

OUTSIDE AIR & ECONOMISER: Optional, shown in schematic. Often not provided when primary air volume matches minimum ventilation rate.

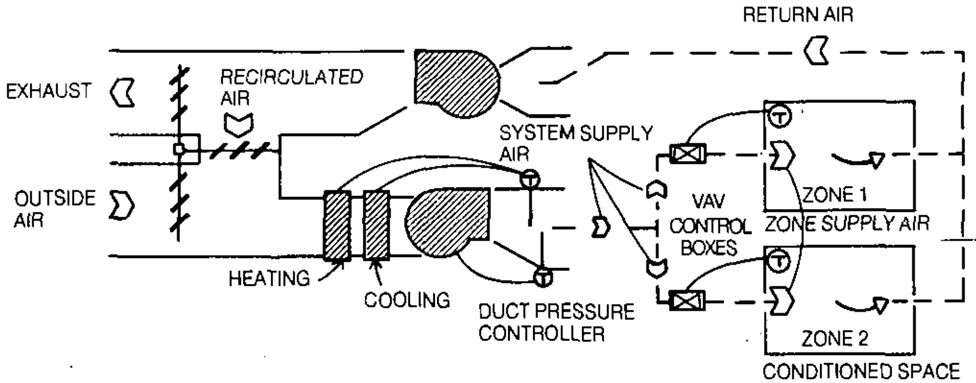
TYPICAL SET-BACK OR UNOCCUPIED OPERATION: During set-back primary air can be shut off and fluid temperature to terminals raised to permit system to function like a natural convector perimeter heating system.

OTHER COMMENTS: In winter the system acts like a re-heat system with heating provided at the induction (zone) terminals and cooling achived by the "cold" primary air.

In summer the systems acts like a re-cool system with cooling provided at the induction (zone) terminals.

Terminal heating and cooling can be from a single-exchanger 2 pipe system or from a two exchanger (one heating, one cooling) 3 or 4 pipe system.

Fig. C.19
Basic characteristics - induction system.



MODE OF OPERATION

CONSTANT OR VARIABLE VOLUME: Variable

SINGLE OR MULTIZONE: Multizone.

ZONE CONTROL: Zone thermostat controls volume of air flow supplied to zone (down to some predetermined minimum acceptable flow rate). Optional zone re-heat sequenced to operate once this minimum is reached is a *common feature where system used for heating as well as cooling.* "Re-heat" may be in duct type or perimeter baseboard of convector heating.

SYSTEM SUPPLY AIR CONTROL: Fixed in basic system. Advanced strategies include sequencing with outside conditions or resetting with zone load variations but such a strategy will have an adverse effect on fan power consumption.

OUTSIDE AIR & ECONOMISER: Optional, shown on schematic. Sequenced with system supply air temperature control for optimum energy performance.

TYPICAL SET-BACK OR UNOCCUPIED OPERATION: Minimum outside air allowed to go to zero. Open all zone boxes and heat (cool) coil valves and operate as a Single Zone System. Where re-heat is not dependent on system air, e.g. baseboard, shut air system off during set-back.

OTHER COMMENTS: some systems throttle the air supply thereby reducing *the overall air supply fan power but increasing duct pressure. In these* systems duct static pressure and fan volume control is desirable and normal.

Other systems maintain a constant system air supply by "dumping" zone air, not required in the zone, to the return duct. This is normally a simpler system but fan power savings are not realised with part load operation.

Fig. C.20 Basic characteristics - variable air volume system.

Further, considerations of maximum demand, especially where this translates into time of day or peak demand charges, need to be made. For example, in night setback strategies with electric heating the energy consumption may be reduced but demand charges can result in higher overall costs. Demand control is discussed in section C.10.

Evaporative cooling and cooling by outdoor air can be considered as free cooling sources. Utilising 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 with outdoor air can be achieved through the sensible use of operable windows, through separate stack and fan driven ventilation systems or by the integration of an air economiser into the HVAC system. An air economiser 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. C.21. Such a system has 4 basic stages.

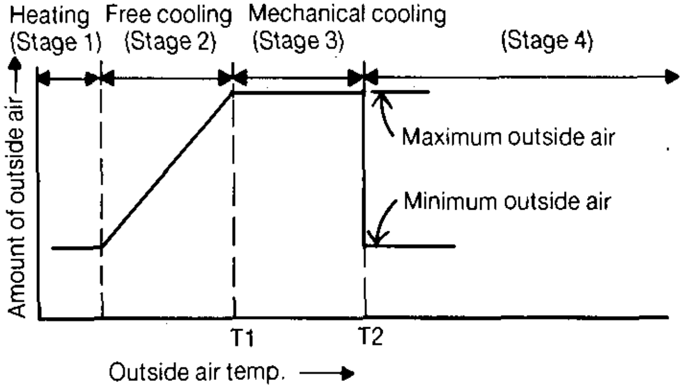
i) Heating: where the outside air is at a minimum to satisfy ventilation requirements;
ii) The free cooling stage in which the control dampers are modulated to maintain the desired supply air temperature,
iii) Mechanical cooling when outside air is still of a lower enthalpy than space air and is consequently 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, and
iv) 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. C.21) 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 content 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.

Despite this advantage, the extra cost and potential reliability problems has led many engineers to stay with temperature-controlled systems. Nighttime ventilation using cool outside air can also be integrated into combined ventilation and mechanical cooling systems where it can be of benefit.
Mixing losses are common in practically all types of HVAC systems and their elimination or minimisation provide 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 a 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 minimised by sequencing heating, cooling and latent heat transfer processes, by resetting system setpoints according to zone demands and by minimising leakage between hot and cold fluids by maintaining valves and dampers and controlling correctly.

The basic philosophy for sequencing is that for any fluid undergoing a process of heating, cooling or mixing or any air stream undergoing humidification or dehumidification, the various stages should be sequenced so that energy in one stage is not wasted offsetting what has been achieved in a previous stage. Deadband thermostats can be considered a form of sequencing which minimises 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.



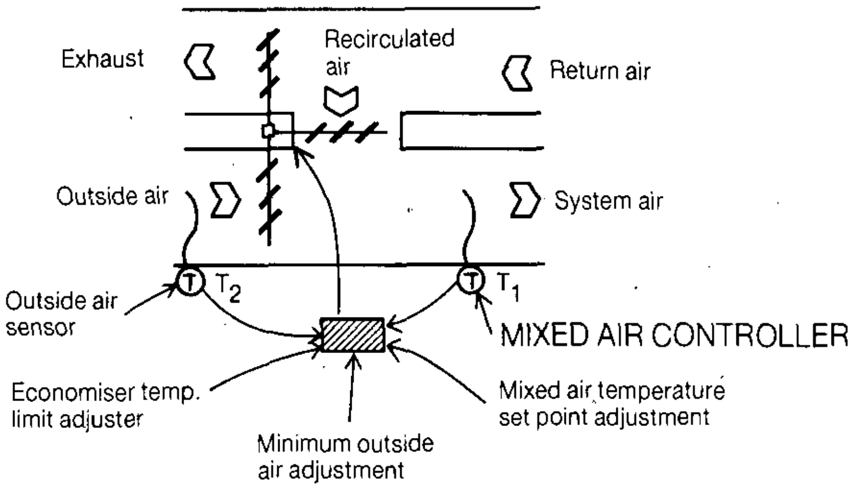


Fig. C.21 Temperature controlled economiser cycle.

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 philosophy 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.

This 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 involve the collection and re-use of surplus heat and cool 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 significant savings (Jones, 1985).

Re-use of heat being discharged from the space involves either the direct re-use 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. Under this last category falls 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 (see discussion and ECO sheets on Cooling Plant in App. E).

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.

Energy conservation opportunities not classifiable in the above groups have been categorised as <u>equipment related opportunities</u>, that is energy savings are brought about by substituting existing equipment with new, thermodynamically more effective systems. 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 pool hall humidity control in swimming pool ventilation systems. Other opportunities are given in App. E.

<u>Auditing strategy</u> for regulation systems is primarily one of inspecting existing controls and systems and checking to see if energy is being wasted by one or more of the various mechanisms discussed. Difficulties are encountered, however, in that:

i) 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 involve verification of control.
ii) What is installed and should work in theory 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 on the annotated ECO sheets in App. E.

C.4 HEATING AND COOLING PLANTS

The following discussion is concerned with the conversion of delivered energy into potentially useful heating and cooling flows. While the material is presented substantially in the context of a central heating or cooling plant situation, much of it is relevant to decentralised heat conversion equipment. A discussion of the relative merits of central and decentralised plant is beyond the scope of this text and in most cases would be beyond the interest of an energy auditor unless a complete HVAC system replacement is being considered.

Energy required for conditioning of a building will depend on:

i) Efficiency of the heating or cooling process itself,
ii) Heat gains or losses in the central plant,
iii) Heat gains or losses in the distribution system and
iv) Heat gains or losses in the building.

Only items i) and ii) will be treated in this section. The others are dealt with in sections C.2, C.3 and C.5.

The material is organised in five main sections covering Fossil Fuel Fired Boiler Plant, Electric Boilers and Furnaces, Heat Pumps, Air to Air Heat Recovery and Cooling Plant.

C.4.1 Boiler Plant

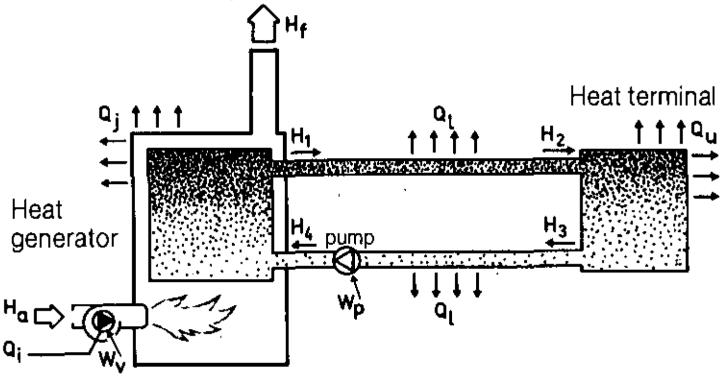
Fig. C.22 gives a visual indication of the energy flows and losses taking place in a boiler plant. The following text discusses the parameters affecting these losses. The discussion is focused on boiler plants heating water or raising steam, but the discussions can, with obvious differences considered, be applied to furnaces, i.e. heating units where air is the heated fluid, and to fuel-fired sections of unitary HVAC equipment.

The combustion efficiency, η_c [%], is defined as the ratio of the useful energy from the energy conversion to the energy content of the fuel:

$$\eta_c = 100 * [1 - (H_f - H_a)/Q_i] \qquad [C.1]$$

The enthalpy difference H_f-H_a constitutes the <u>stack losses</u> (see also Fracastoro-Lyberg, 1983) and is composed of:

i) Sensible heat carried by the gas ("dry flue gas losses"),
ii) Loss due to unburnt fuel carried by the flue gas and
iii) Latent heat carried by the flue gas.



GENERALIZED PICTURE OF ENERGY FLOWS IN A HEATING SYSTEM CONSISTING OF HEAT GENERATOR, HEAT DISTRIBUTION SYSTEM, AND HEAT TERMINAL (THE CHIMNEY IS NOT INCLUDED)

Q_i = HEAT CONTENT OF FUEL
Q_j = RADIATIVE AND CONDUCTIVE HEAT LOSSES FROM THE GENERATOR (JACKET LOSSES)
Q_l = HEAT LOSSES FROM THE DISTRIBUTION SYSTEM
Q_u = HEAT GIVEN OFF BY THE TERMINALS
H_a = ENTHALPY OF AIR ENTERING BURNER
H_f = ENTHALPY OF SMOKE GASES AND VAPOUR ENTERING THE CHIMNEY
H_1 = ENTHALPY OF HEATED FLUID LEAVING GENERATOR
H_4 = ENTHALPY OF HEATED FLUID ENTERING GENERATOR
H_2 = ENTHALPY OF HEATED FLUID ENTERING TERMINAL
H_3 = ENTHALPY OF HEATED FLUID LEAVING TERMINAL
W_v = WORK PERFORMED BY BURNER
W_p = WORK PERFORMED BY PUMP OR FAN

Fig. C.22 Energy flows in a boiler.

Assuming complete combustion and steady state conditions and neglecting vapor content, it is possible to derive an expression for the combustion efficiency (the dry combustion efficiency, see AP H.1) as depending on the temperature difference between the flue gas and the intake air and the carbon dioxide content of the flue gases. However, for modern boilers of a design that causes water vapor in the flue gases to condense, the use of the dry combustion efficiency may lead to efficiencies greater than 100% being obtained. It is obviously important for the auditor to be aware of which definition is used when comparing alternative boiler plant efficiencies.

A further point to note is whether the calorific values used for the heat contents of the various fuels are "gross" or "net", see RV H.1 (in many countries these are referred to as the "upper" and "lower" heating values). Net calorific value (or heat content) excludes the heat that would be available if all the vapor in the products of combustion were condensed. The ratio of Gross to Net Calorific Values varies with fuel types, for example, Natural Gas: 1.11, Liquified Petroleum Gas: 1.09, Oil: 1.07. Combustion efficiencies should, therefore, be calculated on a gross or net calorific value basis.

By taking into account jacket losses the boiler efficiency, η_b [%], is defined as (for notation see Fig. C.22):

$$\eta_b = 100 * [1 - (H_f - H_a + Q_j) / Q_i] = (H_1 - H_4)/Q_i \qquad [C.2]$$

The efficiencies defined in eq. [C.1] and [C.2] refer to steady state efficiencies at a fixed load (see AP H.2). By taking into account off cycle stack losses one can define the cyclic or seasonal efficiencies (see AT H.1). The variation in load with time then has to be known.

Combustion efficiency in general increases with increasing carbon dioxide content of the flue gas and decreasing temperature difference between flue gas and intake air.

Carbon dioxide concentration is at a maximum when just enough oxygen is provided to completely burn the fuel (carbon) and this is known as Stoichiometric combustion. Providing more than sufficient air, or "excess air", cools the flame, somewhat reducing its ability to transfer heat to the boiler heat transfer surfaces, and increasing the volume of flue gases and hence heat loss. In practice, stoichiometric combustion is not possible, excess air values of 3-5% for gas and 3-8% for oil being practice as lower limits for full load firing.

For reasons discussed below, actual realistic setting for most equipment is considerably higher. Values of percentage excess air are limited by air leakage into the combustion chamber and by the inability of burners to provide a perfect fuel-oxygen mix. Correct and regular adjustment of the excess air requirement is one way of obtaining optimal combustion efficiency for existing boiler plants. Ensuring tight combustion chambers and choosing better burners will lead to improved combustion efficiency. Because of variations in fuel heat values, oil viscosity, gas density and of air temperature and humidity, and to allow for maintenance depreciation on the fuel burning equipment, percentage excess air levels are often set on the conservative side, i.e. with greater than necessary values. For modulating burners, percentage excess air requirements are normally set higher to compensate for less effective fuel air mixing at lower loads. The use of an oxygen trim control system, which provides closed loop control of the combustion process by trimming the fuel air mix to obtain a preset excess air level, can provide useful savings.

A complete discussion on the various types of burners available and their inherent advantages and disadvantages are beyond the scope of this text. Such information can be obtained in one or more of the referenced material covering boilers (see References).

For nonsteady-state operation, i.e. when the full continuous output of the boiler is not required, other considerations are involved which tend to increase the stack losses.

Before and after burner operation it is necessary, as a safety precaution, to purge the boiler of combustible gases, which is achieved by blowing combustion air through the boiler. Heat is carried out of the boiler and is lost through the stack. Uncontrolled leakage of air through the boiler combustion chamber and up the stack during non-firing periods, along with these purge losses, are primarily responsible for the significant drop in boiler performance at part load; obviously anything that can limit the cycling of the burner will reduce the flue gases. Measures would include not oversizing heating plant, using burners with a variable firing rate, either HIGH-LOW firing or fully modulating burners, or using a number of boilers and scheduling the number being operated at any one time with the demand for heat.

Fully modulating burners are not fully modulating in that they can turn down uniformly to the off position. The turn down ratio varies according to the burner type and size and has practical lower limits imposed by the difficulty of maintaining correct fuel air ratios at very low flows. For instance, a 10:1 turndown ratio implies a 100:1 difference in pressure drop in the wind box which is generally not considered achievable with commercially available dampers and linkages. Turndown ratios of greater than 4:1 are unusual. The implications of a limited turndown means that grossly oversized boilers with modulating controls can operate in an ON-OFF mode for many of their operating hours. Further, it is not a good idea to put reduced firing rate modulating burners on oversized boilers because of condensation problems in the boiler and flue creating corrosion problems.

For gas fired equipment, stack losses during the off cycle can be minimised by using forced draught combustion equipment, as opposed to natural draught equipment, and by providing dampers on the stack to open and close with burner operation, this last action being also appropriate to oil fired plants.

Other factors influencing dry combustion efficiency are the combustion air and flue gas temperatures. The gas temperature drop across the boiler is primarily related to the success or failure of the boiler in exchanging heat between the heated fluid (water, steam, or air) and the heating source (the flame and the hot gases). The temperature of the heated medium will somewhat affect the temperature drop, i.e., the higher the heated medium temperature, the lower the temperature drop, for a given heat exchanger arrangement. Improving heat transfer efficiency should be one retrofit strategy to be evaluated for boiler plants and could include increasing heat transfer by the use of additional (stack) heat exchangers, increasing heat transfer in fire tube boilers by the addition of turbulators, derating the firing rate of the burner, replacing poorly designed boiler plants, or simply maintaining existing heat transfer surfaces clean.

Boiler heat transfer can also be maximised by preheating the combustion air, but this is only considered a benefit where the combustion air can be heated by waste heat.

Improving heat transfer and its consequent effect on the flue gas temperature has two practical limiting factors for most conventional boiler plants. The first occurs with the economics or diminishing returns of heat transfer improvement per incremental capital cost of the boiler; the second comes with the need to avoid condensation occurring in the flue - this condensation is acidic and can cause considerable equipment damage and is particularly a problem in oil burning equipment burning high sulphur content oils. Recent boiler developments, however, has led to the production of boilers capable of condensing out the water contained in the flue gases without detriment to the boiler. Such boilers have very high efficiencies because they capture the latent heat of the otherwise discharged flue gas.

Radiation and conduction losses of the heating plant, i.e. the <u>jacket losses</u> (see Fig. C.21), depend on the surface area of the elements, their surface temperature and the surrounding temperature. Losses occur all the time while the boiler is hot and remain nearly the same if the burner is running or not. The losses of the boiler are generally expressed in per cent of the power of the boiler and are generally of the order of 1 to 4 per cent at full load.

A certain amount of additional heat will also be lost from pipework and fittings in the boiler house (see section C.5).

Many publications use the term standby losses which refer to the losses from the boiler when it is not firing. Standby losses are comprised of the jacket loss and the off cycle stack losses previously referred to.

Jacket losses can be reduced by ensuring the integrity of jacket insulation, increasing it if necessary. For multiple boiler plants, standby losses can be reduced by shutting off, and thereby isolating from the heating distribution and flue system, those boilers not required to meet an immediate heating demand.

Although small compared to the energy losses of the boiler, other losses can be reduced by the shutting off of boiler auxiliaries such as fuel line and tank heating (heavy oils), fuel delivery pumps, gas pilot lights, etc.

Blowdown losses occur in steam plants only and result from the necessity of periodically bleeding water from the boiler and replacing it with fresh. This water replacement is required to reduce the build up of solids in the boiler water as pure steam is removed from the boiler leaving behind dissolved solids originally present in the feed water. Good water treatment, only blowing down as necessary, and recovering heat from the blow down, e.g. using it to heat the feedwater replacing it, offer operational savings.

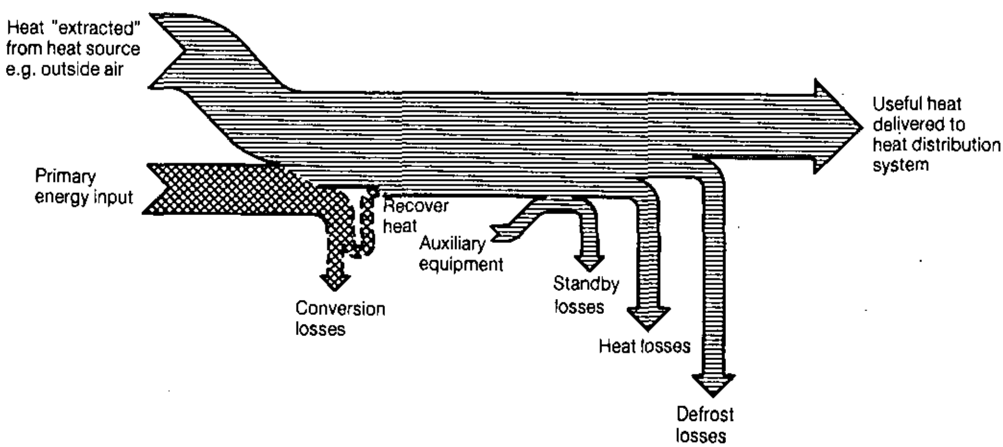
Unburnt fuel losses are normally only present with solid fuel boilers where unburnt fuel is contained in the fuel residue left after firing. Unburnt fuel can, however, be present in gas and liquid fuel burners but is only significant when burners are very badly and dangerously adjusted, i.e. starved of sufficient oxygen to permit combustion - under these conditions unacceptable levels of carbon monoxide will be present in the flue gases. Also under normal operation in oil burning equipment, there is a usually negligible amount of unburnt fuel which manifests itself in the form of smoke.

Perhaps the most common and unfortunately often the only audit activity involves the direct measurement of combustion efficiency (see AP H.1). When carrying out such measurements, it makes sense to make necessary adjustments to the fuel air mix to ensure optimal combustion of the installed equipment. It should be remembered that this adjustment needs to be repeated at regular intervals. Readings of low combustion efficiency are, however, only an indication that something is wrong or could be improved and additional investigation is required to identify weakness in the plant and potential retrofit measures.

Because a boiler plant will spend by far the largest part of its operating life running below its maximum output, it is extremely important to consider part load operation and such aspects as load variations, boiler oversizing, standby losses and boiler sequencing. Procedures for carrying out some of these evaluations are detailed in App. F.

C.4.2 Electric Boiler or Furnace

Normally the only losses occurring from electric boilers are heat losses from the casing and losses from the distribution system (such as pipes, ducts, pumps, fans etc. which are covered elsewhere). Auditing problems are primarily concerned with the determination of these losses (see section C.4.1 and AP H.3) but consideration should also be given to possible economic gains using heat storage charged during off peak load periods (see section C.10).



EXPLANATION OF TERMS

PRIMARY ENERGY INPUT: Electricity or fuel to engine driven machines.

CONVERSION LOSSES: Due to combustion losses (not applicable to electrically driven).

HEAT RECOVERY: From jacket or exhaust (not applicable to electrically driven).

AUXILIARY EQUIPMENT: Fans, Pumps, Heaters, etc.

STANDBY LOSSES: Auxiliary equipment consumption when heat pump not operating.

HEAT LOSSES: From warm heat pump components to ambient.

Fig. C.23 Heat pump energy flows.

C.4.3 Heat Pump Plant

Heat pumps can operate according to a number of different refrigeration cycles and 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 Fig. C.23.

The theoretical heat pump cycle efficiency is defined by the Carnot coefficient of performance, COP1, which is is given by:

$$COP1 = T_{co} / (T_{co} - T_{ev}) \quad \text{(vapor compression)} \qquad [C.3]$$

where T_{co} = condensing temperature [K] and T_{ev} = evaporating temperature [K].

For absorption systems,

$$COP1 = T_{ev} / (T_{co} - T_{ev}) = (T_h - T_{co})/T_h + 1 \quad \text{(absorption)} \qquad [C.4]$$

where T_h *is the temperature of the heated fluid supplied to the generator.*

From the equations [C.3] and [C.4] it is readily seen that the <u>process efficiency</u> is strongly dependent of the condensing and evaporating temperatures. Therefore choice and implementation of heat sources and heat sinks should be made with great care to minimise the condensing temperature and the difference between condensing and evaporating temperatures.

Compressor operation at part load in most instances 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 affect 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 to 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.

Heat exchanges with the surroundings (ambient losses) occur in a similar fashion as for 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 differences to those of the surroundings. 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 storage 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.

Auditing should be focused on heat source and heat sink temperatures and flow rates. Functioning of control equipment is important and 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 (see App. F).

C.4.4 Air to Air Heat Recovery

The performance of air to air heat exchangers (e.g. Heat Recovery Ventilator, HRV) is usually expressed in terms of their effectiveness in transferring

i) Sensible heat (dry-bulb temperature),
ii) Latent heat (humidity ratio) or
iii) Total heat (enthalpy).

The effectiveness, η, of a heat exchanger is defined as the ratio of the actual transfer for the given device to the maximally possible transfer between the air streams. Using the notation of Fig. C.24, one can then define the effectiveness as:

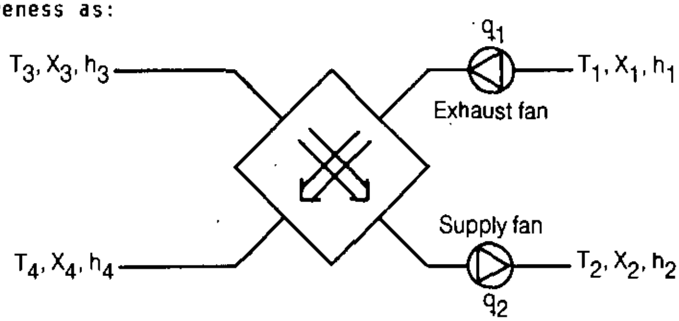


Fig. C.24 Flows in an air to air heat exchanger.

T = temperature [°C]
q = mass flow rate [kg/s]
x = moisture content [kg/kg]
h = specific enthalpy [J/kg]

for sensible heat: $\eta = c_{p,1} * q_1 * (T_1 - T_4) / [c_{p,2} * q_{min} * (T_1 - T_3)]$

for latent heat: $\eta = q_1 * (x_1 - x_4) / [q_{min} * (x_1 - x_3)]$

for total heat: $\eta = q_1 * (h_1 - h_4) / [q_{min} * (h_1 - h_3)]$

where
c_p is the specific heat at constant pressure [J/kg,K] and
q_{min} is the smallest one of q_1 and q_2.

It should be noted that the fan energy consumption and energy for defrosting has not been included in any of these definitions.

Auditing should include considerations of operating hours, fan energy consumption, balancing of air flows, energy for defrosting and air leaks. An important item is inspection of filters. Clogged filters reduces the flow rates and hence the heat transfer. Checking the setpoint of the defroster thermostat is another important item.

C.4.5 Chillers and Air Conditioning Equipment

Energy flows for a cooling plant are shown in Fig. C.25.

The process efficiency of a cooling process will always be affected by operation at part load conditions. Sizing should therefore be treated with care. Both cooling loads and heating loads are often overestimated leading to inefficient operation.

The thermodynamic efficiency of a cooling process will greatly depend on evaporating and condensing temperatures. Therefore, losses in the distribution system will affect the process efficiency by lowering the average evaporating temperature. The theoretical coefficient of performance for the Carnot vapor compression cooling process, COP2, is:

$$COP2 = T_{ev} / (T_{co} - T_{ev}) \qquad [C.5]$$

where T_{co} = condensing temperature [K] and T_{ev} = evaporating temperature [K].

Strategies to lower the condensing temperature and increase the evaporating temperature will improve process efficiency. A number of such strategies are discussed in Appendix D.

Absorption cooling plants burning fossil fuels will lose energy through stack losses and burner inefficiency (see section C.4.1). Chillers using motor driven compressors will lose energy through motor inefficiency (greatly dependent on load both for combustion engines and electric motors), compressor inefficiency (friction losses, dead space, leakage, suction gas heating, hot gas recirculation) and cycle efficiency (theoretical efficiency for a particular cycle using a particular refrigerant).

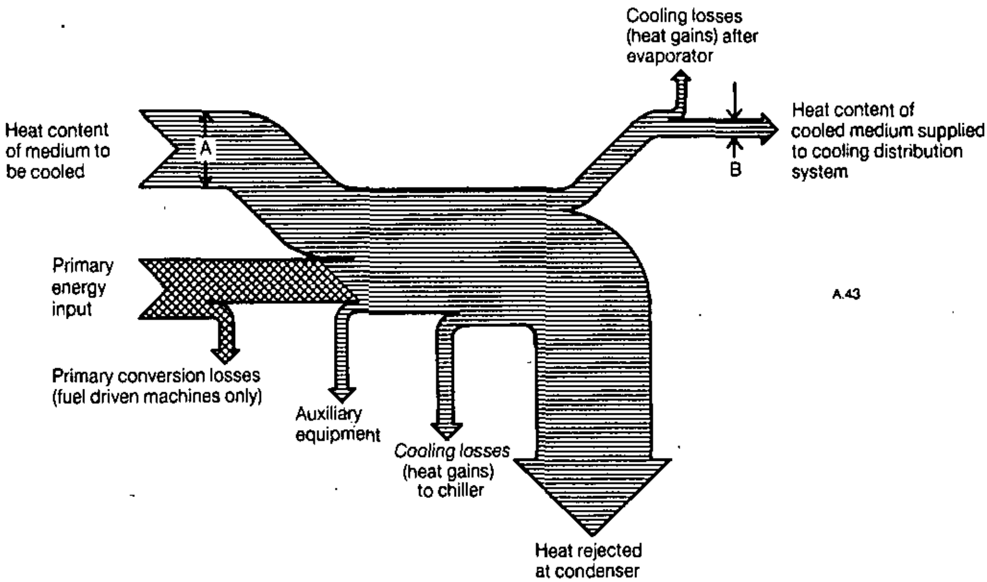


Fig. C.25 Cooling plant energy flows. Note that the net cooling delivered to the cooling distribution system is the difference between A and B above.

Cooling towers and spray coolers lose energy by circulation losses and replacement of evaporated water. Solar operated cooling units use free energy but will require increased collector area when the efficiency of the collector goes down.

As long as there is a temperature difference between the cooling plant and its surroundings, cooling losses will occur by radiation, conduction, and convection.
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 affect a system operating on-off more than a continuously working system (depending on relative running time). In particular losses from storage systems can be considerable, thereby discarding any gains in process efficiency accomplished by the store.

Standby losses will include the above mentioned heat gains as well as energy expended on control equipment, crank case heaters, pumps or fans. Even small standby losses can be important if running times are short.

The auditing problems concerning the central cooling plant will be similar to those of the central heating plant. The aim is to reduce losses and to improve process efficiency. Such an aim, however, often requires skilled staff and can be quite costly.

For electrically driven equipment the auditor should also be congnisant of the possible effects of chiller operation on electrical demand charges.

C.5 DISTRIBUTION SYSTEMS

C.5.1 Ductwork

Energy losses in ductwork systems take place in three principal areas

i) Actual loss of heat energy by conduction and air leakage from the ductwork into the building,
ii) Energy lost in pushing air through the system, and
iii) Loss incurred as a result of either cold outside air entering the ductwork system or warm air leaving the ductwork system and building. These losses are shown schematically in Fig. C.26.

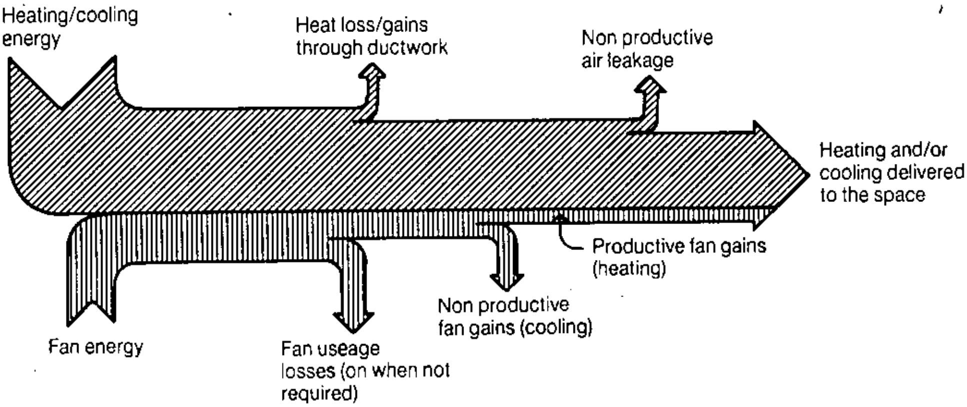


Fig. C.26 Energy flows in a ductwork system.

The first loss can be minimised 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 minimise the third type of loss, that of fan energy.

Fan energy consumption equals $\Delta p^* q_v^* t/(\eta_f^* \eta_t^* \eta_m)$ (C.6)

where Δp = ductwork pressure drop

q_v = volumetric flow rate
η_f, η_t, η_m = efficiency of fan, transmission and motor, respectively
t = operating time

The auditor should look to each parameter in the equation for possible energy savings.

The most promising areas are:

i) Ductwork resistance,
ii) Air volume flow rates; both of which affect the ductwork pressure drop and ultimately fan power requirements,
iii) Hours of operation, and
iv) Short circuiting of leakage air from supply ducts to return where supply and return share a common space, for example, supply ducts running in return plenum spaces.

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 outside ventilation air are discussed in section C.3.) Reductions in overall air flow may effect room air diffusion and will limit the amount of free cooling capacity. Increasing the room supply air temperature differentials (i.e. the difference between the room air and the supply air) can create discomfort through draughts.

Air flow rates can be reduced by throttling the air supply, i.e. 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 as discussed in section C.2.

Ductwork resistance can be lowered by looking for excessive pressure drops across components of the ductwork systems. 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. Areas of unnecessarily high pressure drops to look for are given on the ductwork data collection form, (see App. E). It is very important to remember, however, that reducing resistance alone will increase the flow rate and thereby the fan power and energy requirements (see Fig. C.27) and in the case of forward curved centrifugal fans it 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.

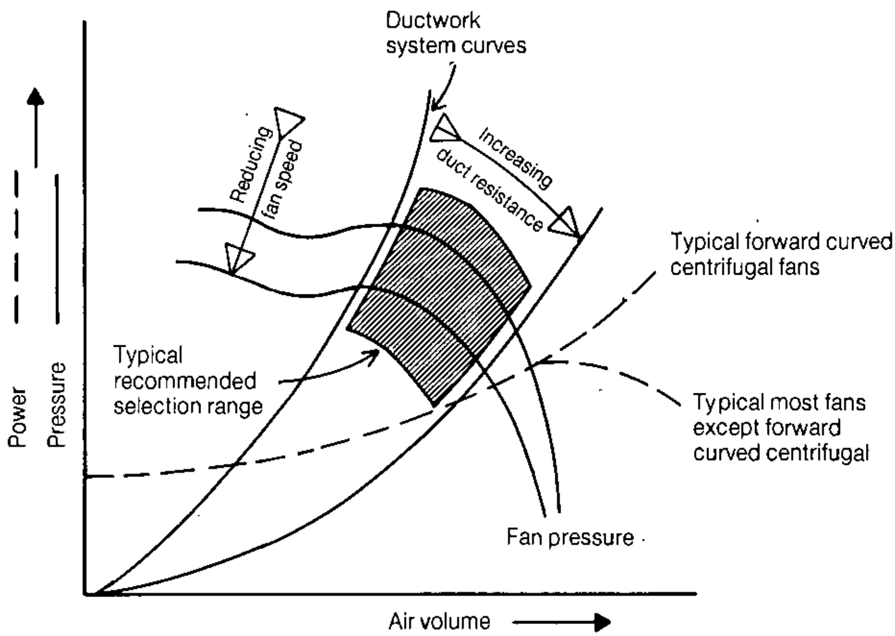


Fig. C.27 Typical fan and ductwork system characteristics.

Reduction in fan power requirements also may permit savings in electrical demand or a smaller motor to be fitted although no benefits are generally derived from replacement unless the motor is substantially oversized. Caution must also be exercised not to reduce the motor size to such an extent that it fails to provide sufficient torque to accelerate the fan wheel.

Perhaps the biggest auditing problems are those associated with the actual measurement of air flows and temperatures in order to get an accurate picture of energy transfer by the air. For an auditor inexperienced with air flow measurement, it may be wise to employ the services of an expert on air balancing and testing. Further difficulties arise in trying to locate in finished ductwork those components causing unnecessarily high pressure drops, e.g. large bends without turning vanes. The measurement of ductwork leakage is also a time consuming operation and should not be pursued unless there is very good reason to suspect major leakage.

C.5.2 Pipework Systems

Energy losses in pipework systems occur in two principal areas, namely pumping losses and losses caused by leaks and heat losses and gains from and to the pipework system. These losses are illustrated in Fig. C.28.

Unlike ductwork systems, piping system heat gains and losses are often of a significantly high enough value to warrant their consideration on an equal footing with pumping costs. These losses are discussed below for water systems and steam systems.

Pumping losses are normally of little interest in steam systems (see below) but in water systems pumping energy can often be significant. Pumping energy consumption equals $\Delta p^* \ q_v^* \ t/(\eta_f^* \ \eta_t^* \ \eta_m)$ [C.7]

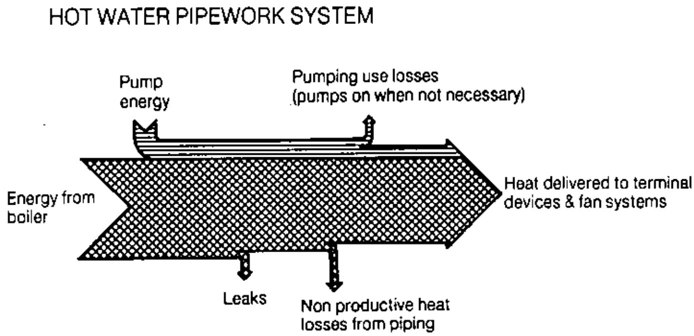
where: Δp = pipework pressure drop

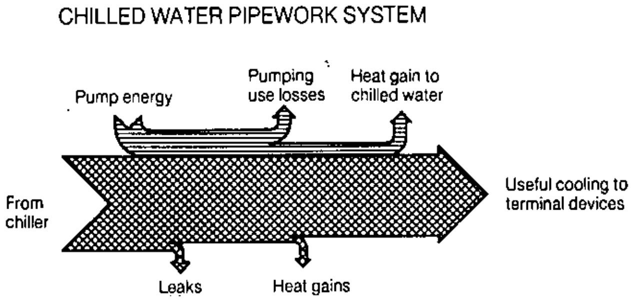
q_v = volumetric flow rate

η_p, η_t, η_m = efficiency of pump, transmission and motor, respectively

t = operating time

The auditor should look at each parameter in the equation for possible energy savings.





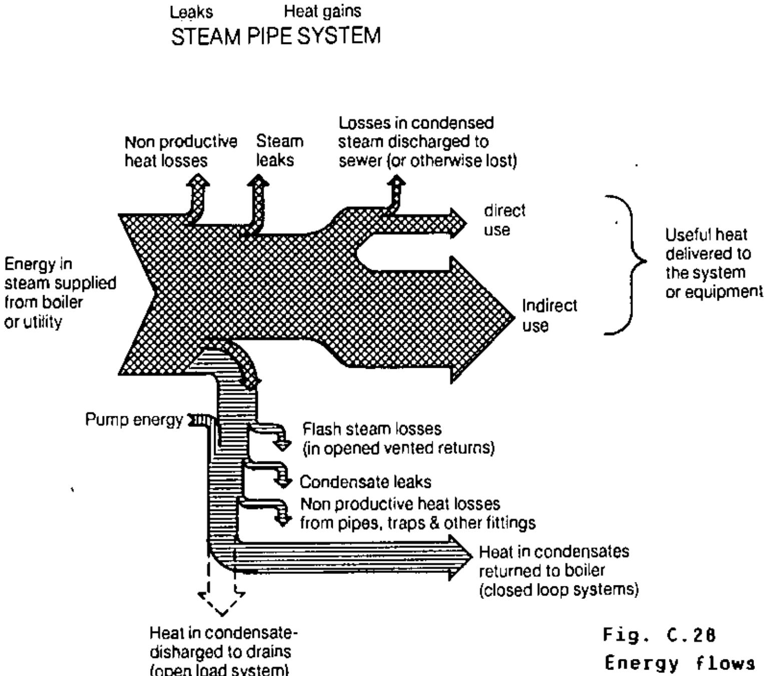


Fig. C.28
Energy flows in pipework systems.

Note that for heating systems, part of the pump energy will usually contribute to the heating of the building. 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.

Pumping energy losses can be reduced by:

i) Reducing Pressure Losses: The same kinds of relationships as detailed under ductwork are shared by piping systems. Any reduction in pressure drop in the circuit will provide an opposite and greater reaction in the flow rate and hence increase power consumption. This is not to say reducing pipe losses could 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. Again, as with ductwork systems, it is desirable to look primarily at the pipework index run.

ii) Reducing Pump Flow Rate: Reducing pump flow rate is often a particularly attractive ECO 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. Also, as an alternative to reducing temperature of the pumped fluid, which is sometimes practiced for temperature control, flow rate reductions could be considered using staged pumping or variable speed drives.

iii) Reducing Operating Hours: This is a particularly attractive and often cost effective action and efforts should be directed towards scheduling operation with the need for heating or cooling.

Pipework losses occur from conduction losses and from leaks which besides producing obvious direct losses, cause indirect losses by increasing pipework heat loss where insulation is wetted. Leakage at pump shaft seals, especially at packed gland type seal (as opposed to mechanical seals) is a common source of leakage. 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.

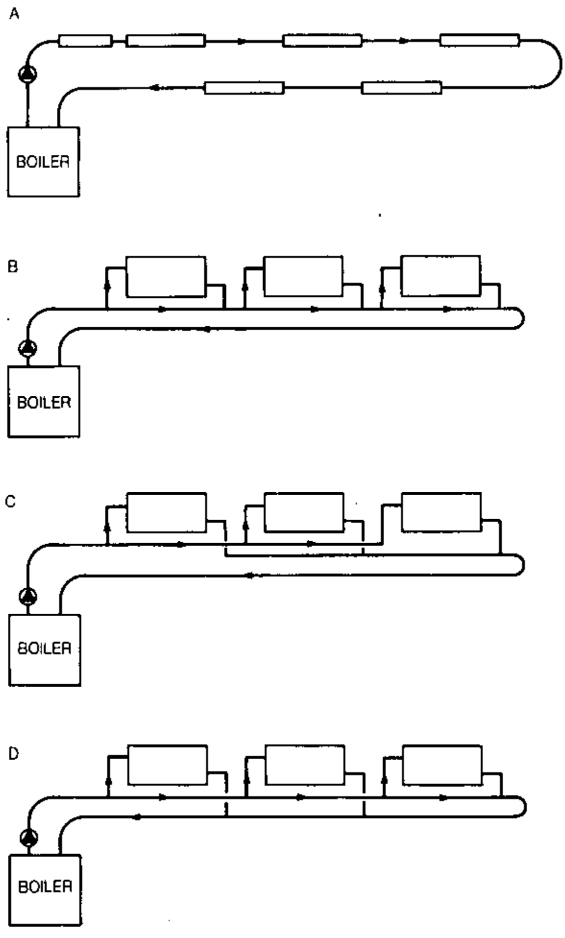


Fig. C.29 Examples of piping in hydronic heat distribution systems. A Series loop system, B One-pipe system, C Two-pipe reverse return system and D Two-pipe direct return system.

For hydronic heat distribution systems, an important energy conservation and comfort issue is the balancing of the system (see section C.3). The pressure drop across various elements such as piping and heat terminals has an impact on the flow rates and thereby on the balancing of the system. The way in which the balancing is carried out depends on the basic piping arrangement (see Fig. C.29).

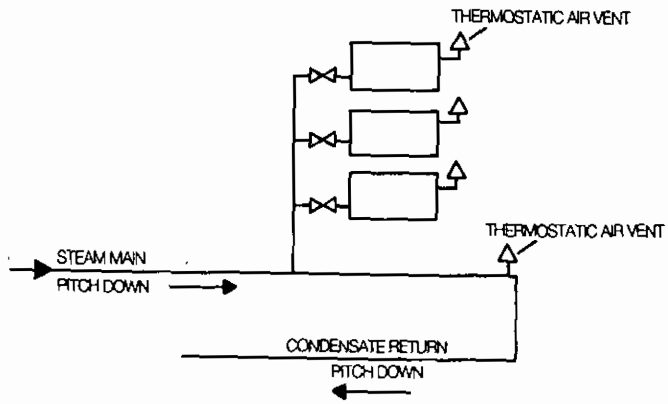
Unlike water, steam flows through the pipework systems unaided by pumps and as such energy used for pumping is not an issue (a small amount of energy is used where condensate is returned back to the boiler by the means of pumps but this is an order of magnitude smaller than would be required to circulate an equivalent amount of heat around a system using water).

Losses in steam distribution systems occur in two principal areas,heat loss from the piping system components and fluid losses.

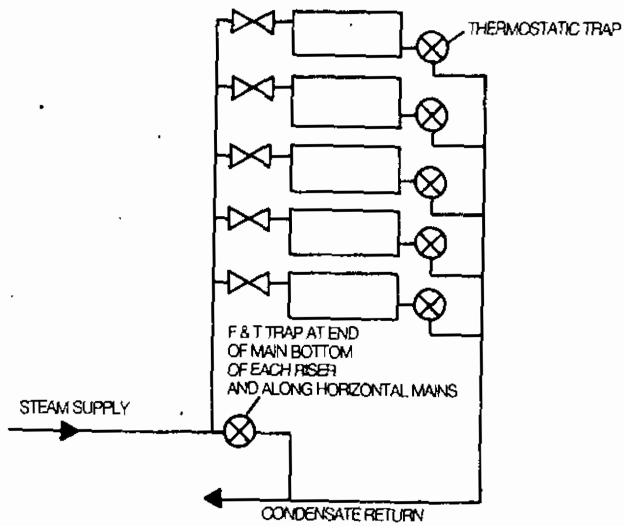
Pipework heat loss, because of the high operating temperature of steam systems, are potentially higher than in water pipework systems. Fluid losses occur in a number of areas, as indicated in Fig. C.29 where they are identified as either supply or return side losses.

A steam distribution system (see Fig. C.30) can be either an open loop system (condensate is not returned to the boiler; i.e. it is discharged to a building sewer) or a closed loop system (condensate is returned back to the boiler).

Indirect use of steam occurs when the steam and the heated medium do not freely mix (for example steam heating coils and radiators). Such a use permits the condensed steam (condensate) to be returned to the boiler. Direct use of steam occurs when the steam and the heated medium freely mix; for example fluid heating by direct injection of steam, steam baths, sterilisers and humidifiers. In such cases the condensed steam is normally discharged to the drain or atmosphere.

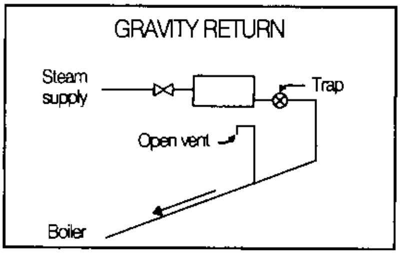


ONE-PIPE SYSTEM

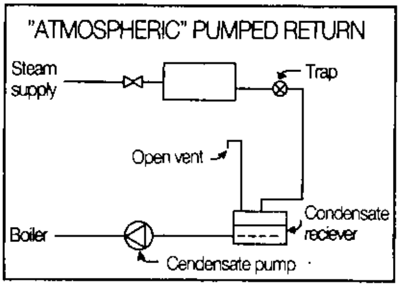


TWO-PIPE SYSTEM

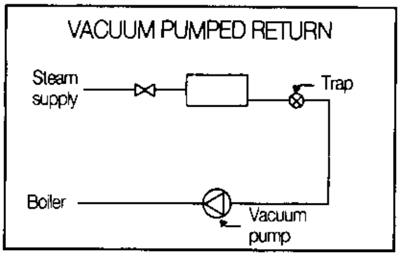
Fig. C.30 One and two pipe steam distribution systems. A F&T trap is a float and thermostatic trap.



. Restricted to small systems because slow to fill with steam & difficult to arrange gradients of pipework.
. Possibility of flash steam losses through open vent.



. Generally used on small to medium systems.
. Possibility of flash steam losses through open vent.



. Generally only used on large installations because systems fill quickly with steam.
. Steam supply pressure can be lower, resulting in more efficient operation.
. Systems may be variable or constant vacuum. In a variable vacuum, controlled vacuum is maintained on supply & return sides, and the vacuum varied with load. At low loads, lowest pressures are maintained & terminal units, which must be fitted with inlet orifices, are only partially filled with steam.

Fig. C.31 Simplified arrangement and primary characteristics of gravity, atmospheric and vacuum return steam systems.

Steam traps are required to drain the "supply" (steam) side of the system of condensate and gases to the return (condensate) side and to do so passing as little steam as possible. In one pipe systems (see Fig. C.30) where the steam and condensate share a common pipe, steam traps are not required.

The steam side of the system distribution system is always at a higher pressure than the condensate side which is normally at or below atmospheric pressure. Consequently the boiling point (temperature) of the steam side is higher than that of the condensate side meaning that the condensate passed through the trap to the condensate side has sufficient heat to revaporise or "flash" to steam at the lower pressure. For open vented condensate return systems (see Fig. C.31.), any flash steam not separated from the condensate will be lost through the vent pipe(s).

Energy savings can be addressed by condensing each aspect of the losses *identified (see Fig. C.28). In this regard* it is important to consider the steam supply source and condensate handling.

There are two possibilities for steam supply, one being purchased steam from a utility, the other being on site produced steam.

For utility delivered steam, it is of importance to extract as much heat out of the condensate as is economically possible where condensate return is not required, or where the utility gives no credit for its heat content. Heat recovery from the condensate is often a desirable ECO to pursue in such cases, and the minimisation of steam passage through traps is essential.

For on-site produced steam it makes no sense to pursue heat recovery since the heat extracted from the condensate will have to be replaced by the boiler, unless an open-loop steam distribution system is utilised. Reduction of the heat content of the condensate can, however, minimise return system losses occurring through pipe and equipment conduction, convection and radiation,and through condensate and flash steam leaks.

The major <u>auditing problem</u> is that of characterising the pipework performance. To do so, one needs to measure the fluid flow or the pressure drop across the pump. A pump characteristic is also needed in order to identify the operating point of the system. Fluid flow measurements are difficult to perform, unless the pipework is equipped with fittings on which a flow gauge can be installed. Alternatively, one can measure the pressure drop across some component (e.g. a valve) of which the pressure-flow rate characteristic is known. Further details of such methods are given in Appendices F and G. Conduction heat losses can be estimated by measuring the fluid temperature drop along the pipe. If a direct measurement of the fluid temperature is difficult to perform, one can measure the pipe surface temperature instead. The latter test is much easier to perform, but the results are obviously less accurate. A method for estimating pipe losses is given in AT P.1.

For steam systems, the principal auditing functions are those of:

i) Tracing down losses of steam and condensate;

ii) Surveying steam trap operation, and

iii) Review of the adequacy of thermal insulation.

C.6 SERVICE HOT WATER

C.6.1 Types of Systems

Service Hot Water (SHW) plants consist of the following major subsystems:

i) Boiler and/or heat exchanger,

ii) Storage tank (sometimes integrated in the boiler),

iii) Distribution system, including pipes and circulation pump,

iv) A number of delivery points (within kitchens, bathrooms, laboratories, laundry rooms, etc.), and

v) Waste water drain pipes.

The energy flows associated with each subsystem are visualized in Fig. C.32. The diagram represents the energy balance; the arrows pointing down indicate energy losses that the auditor is called on to identify and possibly reduce.

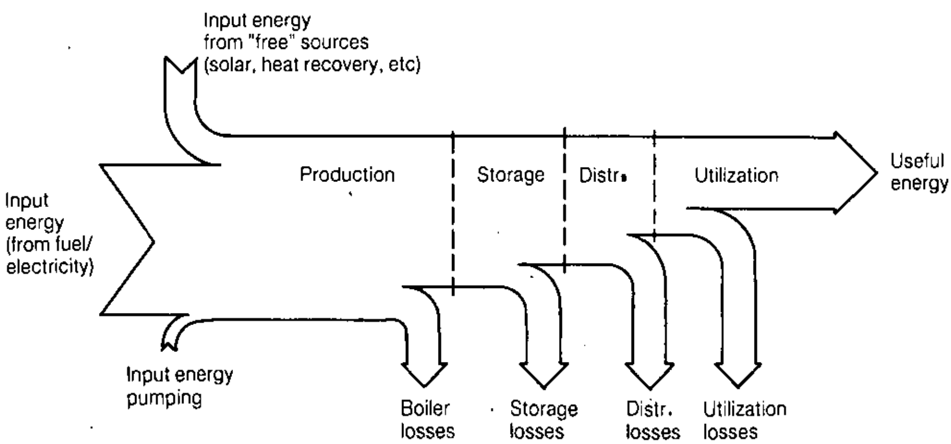


Fig. C.32 Energy flows in a SHW system.

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

i) Type of primary energy source employed:

- electricity (resistive heating),

- electricity (heat pump),
- fossil fuel,
- solar.

ii) Type of boiler, in particular:
- combined space heating/SHW production,
- separate SHW production.

iii) Type of SHW delivery:
- instantaneous type;
- storage type.

iv) Type of distribution:
- local production of SHW at each tap,
- distribution to taps from a central boiler,
- circulation loop with return of unused water,
- dead-leg distribution (no return).

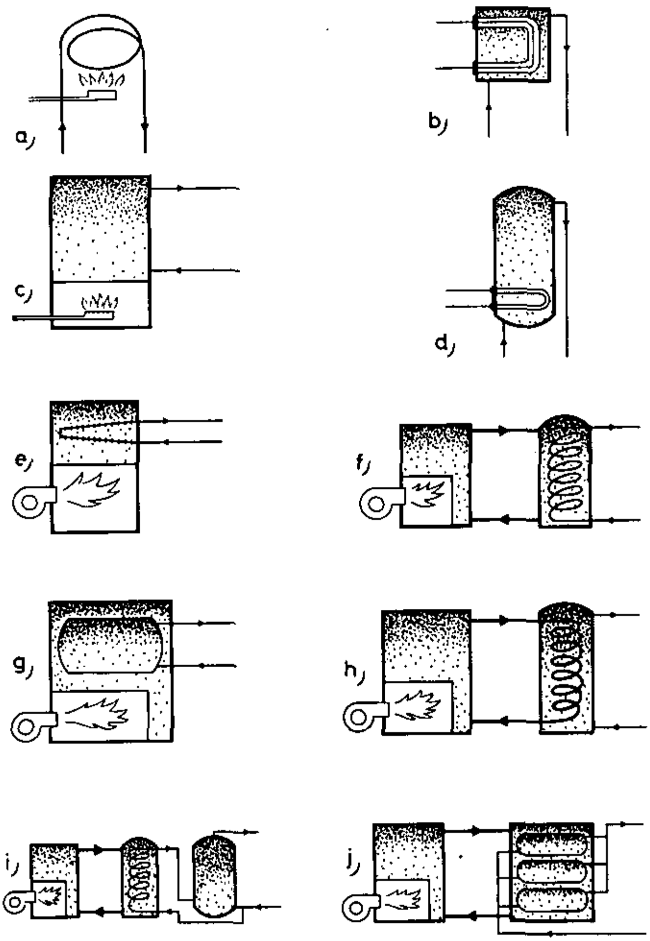
Most SHW systems belong to one of the following categories (Fracastoro-Lyberg, 1983):

i) Individual systems designed for service water heating, using electricity, oil or gas as the primary energy source:
- without storage (Fig. C.33 a and b),
- with storage (Fig. C.33 c and d).

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

ii) Central systems, normally oil- or gas-fired, or electrically heated:
- instantaneous units in which water is heated by means of a coiled tube built into the boiler, or in a separate heat exchanger (Fig. C.33 e and f),
- storage systems in which the storage tank may be either incorporated in the boiler or may be separate (Fig. C.33 g and h).

Central units are often part of combined space heating and SHW production units.



a) individual appliance using gas, no storage,
b) individual appliance using electricity, no storage,
c) individual appliance using gas, with storage,
d) individual appliance using electricity, with storage,
e) central heating with coiled tube in the main boiler, no storage,
f) central heating with coiled tube in a separate tank heated by the boiler, no storage,
g) central heating with storage tank incorporated in the main boiler,
h) central heating with separate storage tank heated by a coil from the boiler tank,
i) central heating with separate storage tank and heat exchanger,
j) *central heating with separate storage tank and cellular or modular* heat production.

Fig. C.33 Examples of SHW generation systems.

C.6.2 Production Losses

In SHW plants using conventional combustion heat generators, energy losses are of the same origin (i.e., incomplete combustion, stack losses, etc.) as in space heating systems (see App. C.4).

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, 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.

C.6.3 Storage Losses

The thermal power lost by conduction through the tank jacket, Q_j, can be estimated (see also AT P.1) from the expression:

$$Q_j = U^* A^* (T_w - T_e)$$ where

U = overall heat transfer coefficient,

A = surface area of the tank,

T_w = water temperature and

T_e = environmental temperature.

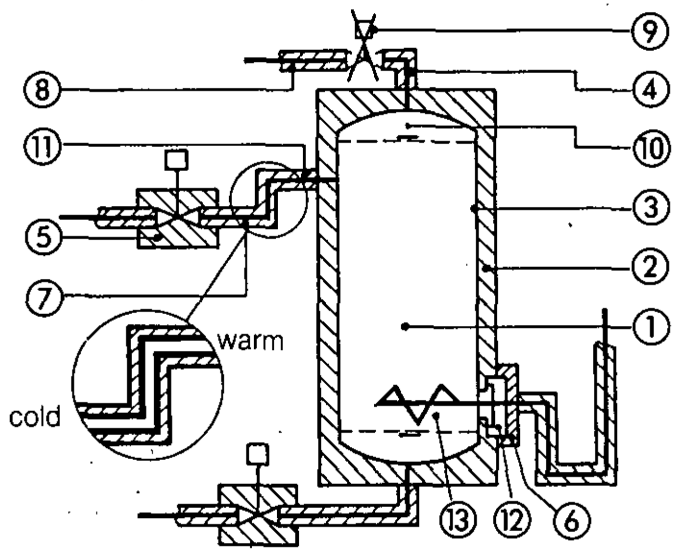
In addition, the following effects contribute much to losses:

i) pipe connections to the tank, especially if not insulated,

ii) poor stratification in the tank due to high flow velocity or mixing induced by the recirculated water,

iii) tank insulation ventilated between tank and insulation, and

iv) high output heating element inducing strong convective currents.



1. Tall, slender tank shape helps separate hot water from cold makeup water.
2. Completely insulate tank, avoid seams.
3. Avoid air between tank and insulation to minimise convective loss.
4. Pipe insulation should extend to tank.
5. Fittings and valves should be completely insulated.
6. Heating element and connection flange should be completely insulated with provisions for maintenance.
7. Prevent pipe circulation, convective loop flow, provide a piping offset.
8. If offset is not possible due to necessary air vent, connect piping horizontally.
9. Again to avoid convective loops, place fittings and valves away from critical location near tank.
10. To limit mixing space height, use baffle plates and perforated plates and low entry velocity.
11. Where welded or screw fittings can be used, choose those which are easier to insulate than flange fittings.
12. Flanges are necessary here for maintenance but retain insulation.
13. The heating element, or heat exchanger, acts as a stirring device -- keep this in mind.

Fig. C.34 Important points for selection of hot water storage vessels.

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 by addressing the losses indicated in Fig. C.34.

C.6.4 Distribution Losses

In the distribution subsystem two energy flows must be considered: heat transfer through the pipe wall, and pumping energy. The latter one is obviously zero if no circulation pump is provided, which is sometimes the case in individual systems, or if the pump is turned off. For the evaluation of these energy flows, see App. C.5.2.

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, in addition to those discussed in App.C.5, 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.

C.6.5 Utilisation Losses

These losses can be attributed to excessive SHW use and with usage 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 SHW is usually quite high: a heat exchanger could therefore be employed to recover some of the waste heat for cold water preheating.

C.6.6 Impact of SHW on the Energy Balance of the Building

Since the boiler, storage, pipework and users are located within the building, some of the energy through the mechanisms above described eventually appears as heat gains to the ambient air. In the heating season this reduces the space heating load, while the opposite occurs in the summer. However, the biggest heat loss is usually that associated with waste hot water.

C.6.7 Auditing Strategy

Auditing problems for SHW systems are common to other areas, since they concern components whose use is not restricted to SHW (e.g. heating plants, pipework systems, etc.).

Storage losses constitute an important problem in individual systems, the auditor should pay particular attention to thermostat setting and level of storage insulation. If peak rates are applied to primary energy, one should also consider the possibility of heating during off periods only.

Production losses are usually the major problem for instantaneous heaters, in individual systems using fossil fuel. If the boiler is not of the modulating type, *one should also look at temperature regulation problems.*

For collective systems, the full load boiler efficiency (see section C.4.1) is often not a good indicator of production efficiency. When combined systems are used for SHW production only, they operate at a very low load. For the distribution efficiency of collective systems, a trade off may exist between circulation pump use reduction and increasing pipe insulation.

When system replacement is advisable, the auditor should examine a whole set of alternative options, such as fuel substitution, modification of SHW supply (e.g. from storage to instantaneous, from central to individual installation of solar or heat pump heaters, etc).

C.7 LIGHTING

The auditor has two basic strategies for reducing energy use; the first entails efforts to reduce the electrical lighting load; the second to reduce the actual usage of the lights.

C.7.1 Installed Lighting Load

There are three principal ways in which lighting energy efficiency is reduced because of losses in the actual production of a visually acceptable environment:

i) Electric to light conversion losses (including ballast losses and light absorption by luminaires),
ii) Room losses, and
iii) Overilluminance and visibility losses.

Electric to light conversion losses occur at the actual conversion of electrical to light energy by the lamp.

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 "lamp luminous efficacy" is used and is defined as: The ratio of the light flux emitted by a light source to the power input to its electric circuitry. The common unit is lumen/watt.

Lamps used for interior lighting are basically of three types:
i) Incandescent filament lamps (tungsten filament or tungsten-halogen),
ii) Fluorescent lamps (tubes), and
iii) High intensity discharge (HID) lamps (mercury, metal halide lamps) and

In incandescent lamps, light is emitted by a tungsten filament heated to incandescence by an electric current, while in 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 sources in which light is absorbed and re-emitted at a different wavelength by the fluorescent coating of the glass envelope. In order to operate correctly, HID and fluorescent lamps require an auxiliary circuitry including a starting device and a current stabilizing device (ballast). When comparing the luminous efficacy and of light sources, it is important not to forget the auxiliary circuit losses.

HID lamps are usually more efficient than incandescent and fluorescent lamps. On the other hand, HID lamps modify the color appearance of objects less (in other words, they have a lower "color rendering index").

Typical values of luminous efficacy for a range of lamp types are given in RV L.2. Lamp luminous efficacy drops with the hours of burning, more for some lamps than others, because of physical changes within the lamp. Lighting designers take account of this by basing their designs on the lamp luminous efficacy at the end of the lamps expected lifetime. Typical deterioration curves are given in RV L.4.

The degree of dirt accumulation on the lamp depends on the room where the lamp is used. The dirt lowers the lamp luminous efficacy and the design is based on the reduction and cleaning intervals when dirt is removed.

A fraction of the light flux emitted by the lamp is absorbed by the (fixture) luminaire itself. Light output ratio is defined as the ratio of the lamp lumens output to the luminaire lumen output. Using this indicator only can be misleading, because the way the luminaire contributes to the illumination of the visual task is important. Hence it is necessary to consider a luminaire in the context of its use. 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.

As with lamps, dirt on the fixture surfaces will tend to reduce luminaire light output.

Room losses occur because a fraction of the light flux emitted by the luminaire is absorbed by the room walls and ceiling.

The lighting system performance (luminaire and room) can be expressed in terms of the installed efficacy, IE, defined as the ratio of the light flux reaching the working plane to the electric power input to the system.

The installed efficacy is always lower than the lamp efficacy for the reasons discussed above. For the purpose of lighting design, it is necessary to consider luminaire characteristics in the context of the room in which they are placed, consequently one will see tabulations of luminaire utilisation factors against "room index" (a measure of the geometry of the room) and room surface reflectances, for typical luminaires.

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 others. Clearly one can see, for instance, that a luminaire concentrating most of its light upwards onto the ceiling will perform much better if the ceiling is of a light, as opposed to a dark, color.

Overilluminance losses occur because more than the required illuminance is supplied at the task. This may result from the need:

i) To meet certain architectural grid layouts,
ii) To provide an overall high level of illuminance to cover the most critical task leaving much of the area with less critical task overilluminated, or
iii) To provide sufficient illuminance at the end of the lamp life.

Visibility losses result from glare and veiling reflections, because of which higher illuminance levels are sometimes provided.

Opportunities for reducing the installed lighting load include:

i) Maintaining the appropriate illuminance levels in all parts of the building, where critical tasks have to be carried out, by cleaning lamps and luminaires,
ii) Improving the efficiency of conversion of electricity into light through replacement of lighting components such as lamps, luminaires, and ballasts, with more efficient components, and
iii) Improving the light delivery process and visibility by affecting the workspace layout, luminaire location, and wall reflectances.

One should also be aware that some of the above actions (for example maintaining the luminaires) do not affect directly the energy consumption, but they rather increase the lighting quantity: energy savings are only achieved if other actions aiming at reducing installed power or time of operation, e.g. delamping, are carried out.

C.7.2 Lighting Usage

Significant savings and paybacks can be obtained by controlling lighting use. The major strategies possible are:

i) Use of daylight to replace or complement artificial lighting,
ii) The use of automatic dimming systems, and
iii) The use of devices (switches) to permit lights to be switched off when not required or to adjust luminance levels to changing visual tasks.

C.7.3 Impact of Lighting on Other Building Systems

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.

In general, the auditor should consider lighting as a significant energy user worth an auditing effort primarily in commercial and institutional buildings.

In residential buildings lighting energy is usually small compared with other end uses.

C.7.4 Auditing Strategy

As discussed in the previous sections, lighting ECOs are aimed at reducing either the operating time or the electric power used by the lighting system. In the former case, occupancy, switching/dimming capabilities, and daylight availability are the main factors to be considered. In the latter case, a number of factors should be examined, concerning the type and maintenance of luminaires, the spatial distribution of light sources and seeing tasks, the color rendering requirements, etc.

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/m^2 (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/m^2) 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 an insufficient installed efficacy of the lighting system.

A complete audit of a lighting system should include the following steps:

i) Assess the potential for operating time reductions from a comparison of occupancy and lighting schedules, with particular attention to off-hour occupancy, cleaning periods, security controls, etc. If possible, also compare actual electricity consumption with reference values,

ii) Estimate the daylighting potential; i.e. calculate the level and hours of outdoor daylight availability, and estimate or measure the daylight factor (ratio of indoor to outdoor illuminance) in several points of the working plane.

iii) Verify that the working plane illuminances comply with recommended levels; check that the luminaires are properly placed with respect to the seeing tasks; i.e. that light is directed primarily to areas where needed, and from the right direction to minimise glare and veiling reflections, and

iv) Evaluate the overall efficacy of the lighting system, by inspecting each component; particular attention should be devoted to the efficiency of the electric circuitry (ballasts) in HID or fluorescent sources; inspect the efficiency and cleanliness of reflectors and lenses; consider the potential for replacing the existing sources with more efficient ones, compatible with color rendering requirements; if the internal walls and ceiling are dark, consider repainting with light colors.

C.8 ELECTRICAL SYSTEMS

C.8.1 Electrical Systems

In practically all cases, electrical distribution systems in buildings will be Alternating Current (AC) systems in which the flow of current is constantly changing due to the alternating polarity of the generated voltage. Consequently, some knowledge of the basic relationships and physics of AC systems is essential in order to correctly apply measuring instruments and to carry out electrical systems related calculations.

Unless a system has purely resistive elements, the current in an AC system will not be in phase with the voltage (see Fig. C.35). In practice, equipment such as electric motors will tend to impede or delay the flow of current into the circuit and create what is termed a "lagging power factor" (see below). Conversely, capacitive elements will create a "leading power factor".

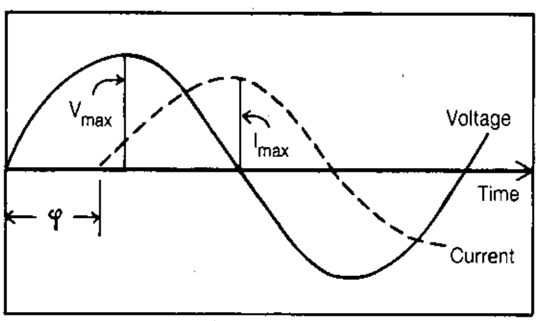
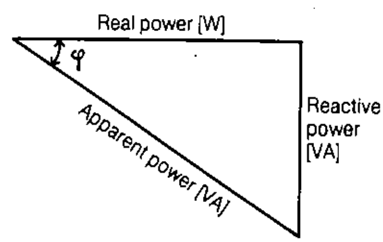


Fig. C.35 Voltage and Current values for a lagging power factor circuit.



$$\cos\varphi = \frac{\text{Real power}}{\text{Apparent power}} = \text{Power factor}$$

Fig. C.36 Vector representation of real, reactive and apparent power.

The power, P, (often referred to as "real power") in a single phase AC system is given in terms of the rms potential, V, the rms current, I, and the power factor, PF, by the relation

$$P = V * I * PF$$

For a sinusoidal voltage and current the power factor, PF, is equal to cos φ, where φ is the phase difference between the potential and the current.

V*I is often referred to as volt-ampére, 'VA' for short, or 'kVA' (1 kVA= 1000 VA) or "apparent power". Other relationships are shown in Fig. C.36.

In AC systems, work average values have very little importance since it is the 'power' produced by an electric current that matters. For an alternating current, we are interested in the "effective" value of the current. In the context of a current flowing through a resistance of R ohm, we are interested in the value of the alternating current that produces the same "heating effect" as a direct current of the same value. Suppose I is the value of the direct current, then the

$$\text{Heating Effect} = I^2 * R = \int_0^t R * i^2(t')\, dt'$$

where i(t) is the instantaneous value of the alternating current.

$$\text{Therefore } I = \sqrt{\left[\int_0^t i^2(t')\, dt' \right] / t}$$

= the square <u>root</u> of the <u>mean</u> of the <u>squares</u> of the current or
= the "root mean square" or (rms) value.

For a pure <u>sine wave</u> it can be shown that the <u>rms value</u> of the current or voltage is equal to 0.707 times the <u>peak value</u> and the average of the absolute value is equal to 0.637 of the peak value. For different waveforms this relationship, between 'average' and 'rms', will not be maintained and this may have implications on measurement accuracy of certain types of instruments when used for non-sinusoidal waveforms.

Although it is convenient to think of electrical systems in buildings as having voltages and currents that vary sinusoidally, this is in fact not usually the case. In practice, such equipment as motors, transformers, lighting ballast and dimmers can distort the waveform.

Such waveforms can be characterised by their peak or crest factor which is given by:

Crest factor = (Peak value)/(rms value)

These waveforms are normally composed of a mixture of a number of different waveforms of varying frequency and magnitude, although in most instances the most dominant waveform will be the 50 or 60 Hz supply system frequency. Other frequencies may be several times higher or lower than the dominant frequency, which can lead to measurement inaccuracies when digital (electronic) measuring devices are being used.

In a three phase AC system there are three (voltage) waveforms differing in phase by one third of a cycle (see Fig. C.37). Phases and phase conductors are usually identified by color; typically Red, Blue & Black; or Red, Yellow & Blue; or by letters, usually A, B & C.

In such a system loads can be connected in 'Δ' or in 'Y' (see Fig. C.38).

The Δ connection is usual for balanced 3 phase loads such as motors and, since the power is carried in 3 wires, it is often referred to as a "3 Phase-3 Wire" system.

The Y connected system is normal where the loads in each phase are not identical and where more than one voltage is desired since the system offers the possibility of two voltages. Since there are four wires with this method of connection, three phase conductors and one neutral, it is referred to as a "3 Phase-4 Wire" system. The neutral conductor carries the unbalanced component of the load and for the case where the phase loads are exactly equal there would be no current flow in this conductor.

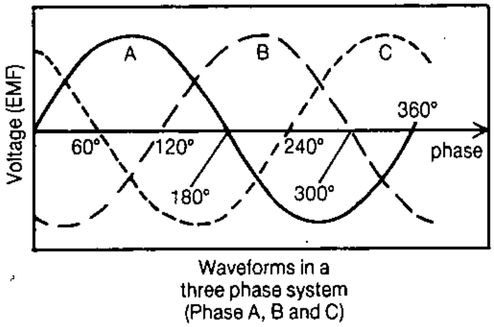


Fig. C.37 Waveforms in a three phase system.

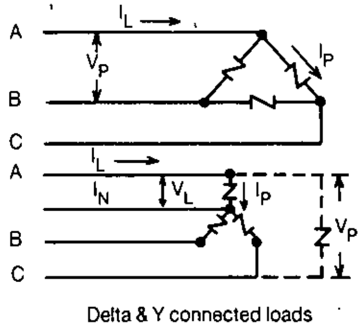


Fig. C.38 Δ and Y connected loads.

In a Δ connected system, Line Current (I_L) $=\surd 3$*Phase current (I_p) and $V_L=V_p$.

In a Star connected system: Phase Voltage (V_p)$=\surd 3$*Line Voltage (V_L), $I_L=I_p$.

The power, P, in an individual phase of a 3 phase system is given by:

$$P = I_p * V_p * PF$$

Total power in a 3 phase system is given by the arithmetic sum of the power in the individual phases; for a balanced system

$$P = \surd 3 * I_p * V_p * PF = 3 * V_L * I_L * PF$$

The <u>load factor</u>, LF, is a measure of how variable a load is. It is given by:

LF = (Energy consumption)/ (Maximal Demand * Time for Consumption)

Typically low load factors indicate a good potential for demand control, high load factors with intermittent occupancy suggests a potential for electrical equipment scheduling (applicable to both single and three phase systems.)

Because the voltage drops in electrical distribution systems will vary with the load being taken, the voltage at any point in the building distribution will be continuously varying. If this variation is large, the system is said to have "poor voltage regulation" and extreme variations can affect electrical equipment performance; e.g. low voltages can adversely affect motor efficiency. Variations can be considered to have two components:

i) Variations from the electrical utility - the utility company normally attempts to maintain a constant voltage with varying load by changing the voltage tappings on their distribution equipment.

ii) Variations within the building - voltage control is seldom practical except in very large installations. Voltage regulations are controlled to a large extent by the adequate sizing of cables. In old buildings with increased loading, voltage regulation can often be very poor.

Although electrical energy bills may be the only energy bill or represent a significant part of the total energy bill, most electrical energy savings will occur as a direct result of retrofit actions described under other component categories such as Lighting or Regulation. There are, however, a few instances that can be considered as uniquely or more closely related to the electrical system and these are discussed below.

C.8.2 Electric Motors

Because of the relative magnitude of energy consumed by electrical 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 RV EL.2 for typical values). The type, method of construction, and condition of the motor can be considered secondary but nevertheless influencing parameters on full load motor efficiency. The motor transmission, i.e. the connection to the driven piece of equipment, also is a source of energy loss.

Also, 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. Power factor, however, drops off more dramatically and consistently with load reduction (see RV EL.3).

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 ECOs are given in Appendix O.

i) 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 we will be trading a more efficient motor with increased transportation losses.

ii) Motor Construction. High efficiency motors, typically with improved efficiency ratings of up to 10% and improved power factors of up to 8%, can be substituted for standard construction motors (see RV EL.2).

iii) Power Factor Correction. This is normally justifiable where motors are running at part load and at low power factor and where the utility tariff includes a penalty for power factor (for an explanation of power factor, see AT EL.1). 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.

iv) Part Load Performance. Where the driven equipment does not have to meet a constant demand, opportunity can be excercised 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.

C.8.3 Auditing Strategy

The major focus of an audit of the electrical system in a building should be that of establishing the suitability of the tariff arrangement (see section C.10) and discovering ways in which the operation of equipment and systems might be operated to effect cost savings. This activity cannot be carried out totally in isolation of other system related activities and the auditor in auditing, for example, a cooling system should be very aware of the implications on, and possibilities for, additional savings associated with 'beating the tariff system', i.e. operation away from peak energy cost periods and possible use of cooling storage (see section C.10).

This need for consciousness of electric energy implications is also equally applicable where opportunities for savings through electric motor related ECOs are involved.

C.9 OCCUPANTS

For an understanding of the occupants influence on energy consumption, it may be useful to divide the complex of behavior, habits and activities of the occupant into (Fracastoro-Lyberg, 1983):

i) Operations involving consumption of energy in a direct form, and
ii Operations aiming at control of the indoor climate.

Operations of the first kind involve the consumption of energy in a direct form, which often means the use of domestic appliances. Energy will then be consumed directly in the form of electricity, gas, oil or hot tap water. If an occupant needs to perform an operation of this kind, he can only indirectly influence the amount of consumed energy.

Some appliances are used by the occupant to save time and to reduce the amount of manual work needed (e.g. the use of a dish-washer). Often this also means that the amount of required energy is reduced. Other appliances, such as illumination and TV, are not used to replace manual work. The use of these appliances will always increase the energy consumption.

The second kind of operations listed above do not directly require an energy source, but are operations performed in order to control the indoor environment. For some operations it is very difficult to determine the impact on energy consumption. The extent of operations of this kind is also directly influenced by social and cultural norms.

An example is the choice of, or demand for, a certain indoor temperature. The demand for a higher indoor temperature is probably linked to the tendency to wear lighter clothing. It is also common today that residents try to keep a comfortable temperature in all rooms.

If the occupant does not feel comfortable with the prevailing indoor climate, he will try to modify it in the desired direction. What action he takes will depend on the means at his disposal. The resulting behavior may be unpredictable. If it is too cold he might turn on an electric stove rather than change his clothing. If it is too warm he might open a window, which may easily offset any algorithms for the prediction of energy consumption.

A factor that should not be forgotten is the attitude of the occupant towards energy conservation. If the occupant can not understand the reason why a residential building is retrofitted, he may act in a way that the purpose of saving energy is not achieved. It is therefore important not to regard the occupant as a passive consumer of energy, but to take into account the interaction between environment, building and occupant.

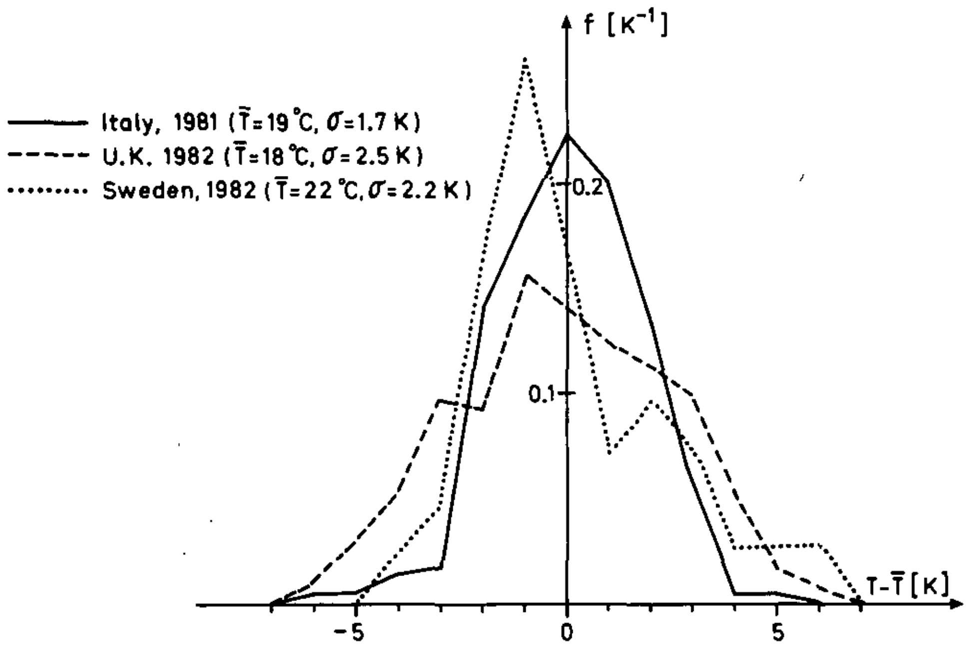


Fig. C.39 Distribution function of the variation in indoor temperature in dwellings, T, in three countries. $\bar{T}$ is the average indoor temperature, σ the standard deviation.

C.9.1 Energy Use Variations Due to Indoor Temperature and Use of Appliances.

In many discussions about the effect of occupancy on energy consumption it should be kept in mind that data refer to an "average behavior". The scatter around every such average is large. The cause of this scatter is complicated. Attempts to correlate energy consumption to different socioeconomic factors such as the size of dwelling, family size, income, education, occupation, or age have not been very successful. In most studies one has found that the standard deviation of the total energy consumption in a group of "identical" houses lies between 20 and 30 % of the average total energy consumption.

One major source of the variation in energy consumption is the variation in indoor temperature between dwellings. In studies of the indoor temperature one often finds that the standard deviation of the average temperature in a group of dwellings is close to 2 K, even if the average indoor temperature may vary from one country to another. Some examples are given in Fig. C.39. How much of the variation in total energy consumption that can be explained by this fact will of course depend on the average indoor- outdoor temperature difference and the degree of insulation.

The variation in the consumption of household energy is superimposed on the variation in the indoor temperature. Here one often finds that the standard deviation of a certain kind of household energy consumption is as large as 50 %. As an example we give in Fig. C.40 the distribution function of the use of hot tap water from investigations in some countries.

Very few studies have been performed where a disaggregation of energy use has been made in such a way that the variation in different energy uses can be studied. In Fig. C.41 we give an example where the standard deviation of the total energy consumption is rather small, while the variation in the energy consumption for different household activities is larger.

The cost of energy will of course also affect the energy consumed by the occupant. This can be of great importance when comparing energy consumption from different years.

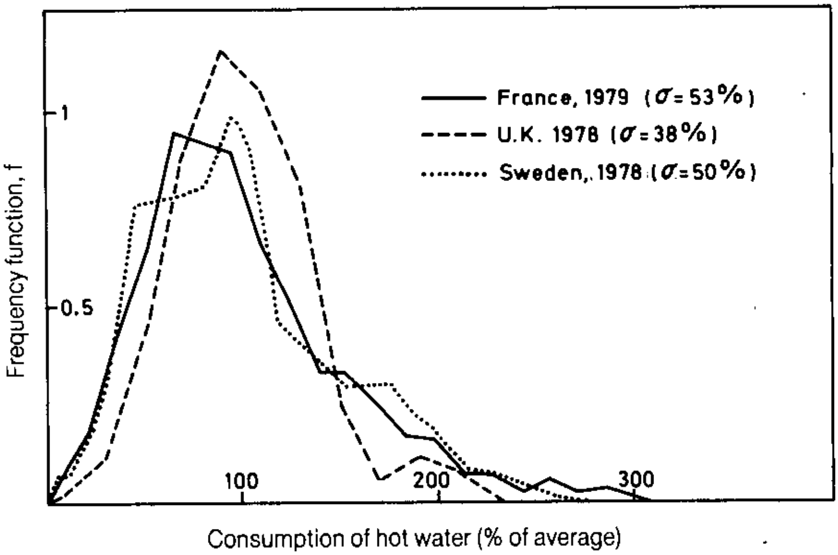


Fig. C.40 Distribution function of the hot tap water consumption relative to the average consumption for three countries. σ is the standard deviation.

C.9.2 Variations in Consumed Energy Due to Behavior and Attitudes

Much of the discussion on energy saving by retrofitting residential buildings has been about purely technical measures. However, it should be realized that more energy would be saved if the behavior of the occupants could be changed, or if every occupant was really motivated to save energy.

The behavior and attitudes of occupants may change with time. In many studies of the effects of retrofits it has been found that energy saving has been substantial at the beginning of a program, but then it has gradually faded away. One has, however, also noted the opposite effect. In retrofits, including the introduction of more complex systems into the building, sometimes no energy has been saved during the first heating season, but a substantial reduction in energy consumption has taken place during the second heating season. The probable explanation is that it has taken the occupants quite a long time to learn how to handle the new system.

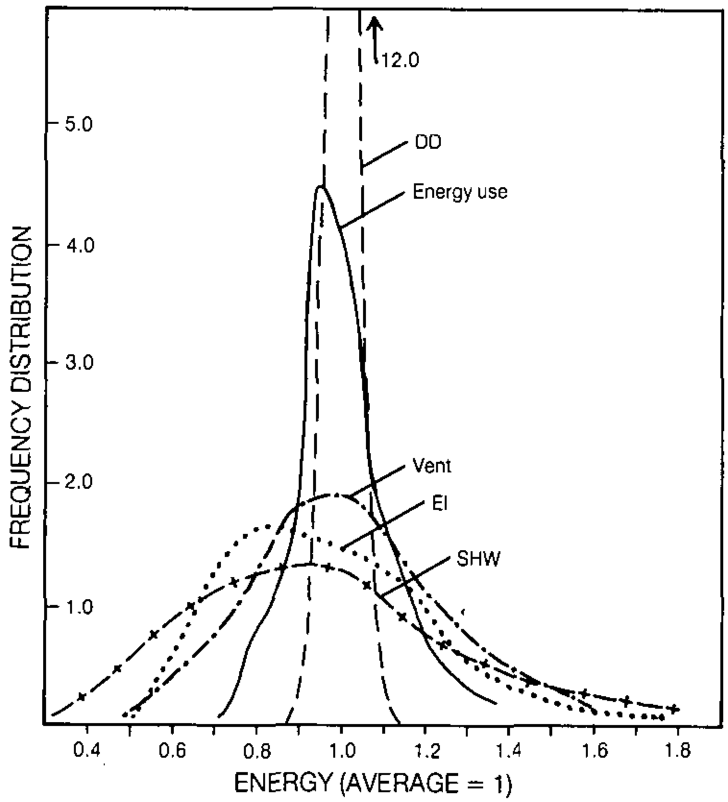


Fig. C.41 Frequency distributions for the end use of energy in 60 identical, all electric, town-houses. The items displayed are: Total Energy Use, DD (degree- days), Vent (mechanical ventilation losses), El (domestic electricity) and SHW.

The effects described in the previous paragraph will obviously be of special importance in cases where the PIPA measurement period (see Ch.5) is one year only. In this case it would be an advantage if one could follow at least the total energy consumption of the building during still another heating season to make sure that the effect described above is not at hand.

In retrofit actions involving residential buildings it is important that the occupants are informed in advance about the retrofit program, what measures are to be taken and what changes in the indoor climate can be expected. If possible, changes should be introduced gradually to give the occupants the possibility to adapt to the new environment. Otherwise the result may be complaints and a negative attitude of the occupants towards the retrofit project.

C.9.3 Auditing Strategy

A disaggregation of the direct energy use by occupants will not be necessary if one is interested only in the total consumption of domestic energy. It can usually be read off directly from a meter once a month or year. However, disaggregated data can be used in an evaluation of the energy balance of a residential building.

If one uses data collected from records, one will, in general, have information only about the consumption of energy by the average household. This may be sufficient if one is studying the effect of a retrofit on a large number of households. Otherwise, the energy consumption of a residential building will have to be monitored. It is necessary to disaggregate the end use of household energy if data are to be used in a simulation of the thermal building behavior or applied to other buildings. One will then, for the major energy consuming appliances, need information about:

i) The demand profile,
ii) The energy consumption by each appliance, and
iii) How much of the energy used by an appliance affects the heat balance.

It is in general difficult to relate energy consumption to socioeconomic factors. It is, therefore, not often meaningful to collect socioeconomic data unless one is working with a large statistical sample of buildings. It may be more relevant to collect data on the behavior and habits of occupants such as:

- the occupants' attitudes to and motivation for energy saving,
- when the occupant is at home,
- the use of set points,
- the use of ventilation system,
- the habits of airing, shielding windows, etc.
- the use of appliances,
- the use patterns of hot tap water, and
- the occupants experience of the indoor comfort.

Information of this kind can be obtained in several ways. One can apply survey techniques. Occupants are interviewed, or fill in a form.

Monitoring the occupant's choice of set- points is rather easy for some heating systems, for example electrical heating. For heating systems not allowing an easy monitoring, survey techniques can be used, for example in buildings equipped with indoor thermostats. In buildings with radiator controls the use of survey techniques is facilitated by the fact that many occupants prefer the extremes when choosing set points, either completely on or completely off, or at a rather low or a rather high temperature. Furthermore, many occupants seldom change the set points.

Monitoring of the occupant's use of building systems driven by electric motors, e.g. mechanical ventilation systems, is rather easy by simply recording the presence or absence of an electric current or a magnetic field (see MT EL.7).

C.10 FUEL TARIFFS

It is quite common in fuel tariff arrangements that energy consumption and energy costs are not directly equatable to one another. This is because the cost of production, delivery and accounting are not directly in relation to units of energy and most energy suppliers devise tariff arrangements that best reflect their cost. Consequently the auditor will sometimes be faced with 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 tariff arrangements under which energy is and could be purchased in the local of the building under consideration.

A general discussion of typical tariff arrangements is given below as background, but the auditor should obtain details of all applicable tariffs for those buildings he might be concerned with.

The actual fuel tariff may comprise of any one, or combinations of the following charges:

i) Flat Rate Charges: Where energy purchased is charged at a common per unit rate, $1 gallon oil, 3 cents kWh electric.

ii) Sliding Rate Charges: Where 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, e.g. in the case of electricity, the first 1,000 kWh at 3 cents, the next 2,000 at 2.5 cents and so on.

iii) Demand Charges: Where charges are made for the rate, usually the maximum rate, at which energy is consumed. These charges are normal for energy supply system without the capacity for energy storage; e.g. electricity and district heating, and reflect the cost of providing sufficient energy production systems to meet maximum demands.

iv) Time of Day Charges - in which 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 were recorded. Charges are based on similar considerations to those expressed in iii) above.

v) 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 tariffs obviously demand that the building be provided with its own fuel storage or alternative source of fuel.

vi) Minimum Billing Charges - Are sometimes levied to cover the administration cost of maintaining an account.

vii) Delivery Charges which may sometimes be billed as an item separate from the amount of fuel delivered.

Opportunities for cost savings can be pursued by looking for ways within the existing or alternative tariff arrangements to minimise those effects contributing to the cost. Examples would include:

i) Providing large storage facilities for solid and liquid fuels and making smaller number of bulk purchases, taking advantage where possible of seasonal fuel cost fluctuations.
ii) Providing alternate (dual fuel) sources to take benefits of lower unit energy costs.
iii) Restricting maximum demand purchasing cheaper off-peak energy by rescheduling equipment useage and/or providing secondary storage systems (e.g. hot and chilled water).

C.10.1 Electrical Tariff Arrangement

More so than any other fuel system, electrical energy use and energy cost are not normally directly equatable to one another. Often the choice of saving money will have to be made against the possibility of using more energy.

In addition to the above possibilities for tariff charges, electrical bills may include charges for Reactive Power charges - in which charges may be totally 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; or the total bill may be adjusted based on some power representative power factor as recorded at the building.

Charges may also vary depending on the voltage at which the electrical energy is purchased with high voltage power being cheaper than low voltage since the utility does not have to cover the cost of voltage transformation.

Demand charges also take on a special significance in electrical systems since in many instances they can form a significant percentage, as much as 50% of 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 tariff agreement - typical 20 or 30 minutes. It is not the instantaneous demand which is a misconception amongst many HVAC engineers. 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.

APPENDIX D ANNOTATED LIST OF ENERGY CONSERVATION OPPORTUNITIES (ECOs)

INTRODUCTION TO APP. D

The following list of Energy Conservation Opportunities (ECOs) for buildings such as: apartment buildings, commercial buildings and schools was compiled from a number of sources that address energy conservation in a variety of buildings. ECOs are presented here as concise statements of measures that can be taken to reduce energy use.

The ECOs are listed according to the component categories used in this Source Book (see Introduction, p. 10). The ECOs have been assigned a classification consisting of one letter, referring to the abbreviation of the building component category, and one numerical giving the ECO number within the component category. It is unavoidable that some ECOs are related to more than one building component. This is especially so for ECOs related to regulation and control of equipment. When looking for ECOs of this kind, one should check the R-category as well as other relevant component categories.

The ECOs are presented using the following format:

LEVEL:	Indicates the level of difficulty to carry out an ECO. The levels used are: O - Operations, M - Maintenance measures, I - Suggested Improvements involving relatively minor changes to the building components and equipment, and R - for measures involving Replacement of a system or installation of major new equipment.
DESCRIPTION:	Describes the ECO,
APPLICATION:	Indicates the ECO application,
SIDE BENEFITS:	Points out possible side benefits of the ECO,
CAUTIONS:	Indicates cautions that must be considered,
COST FACTORS:	Evaluates the Cost factors involved,
INTERACTIONS:	Looks at interactions with other ECOs,
EVALUATIONS:	Indicates how an evaluation of the ECO may take place and gives references to Audit Procedures (App. E), Measurement Techniques (App. G), Analysis Techniques (App. H) and Reference Values (App. I),
COMMENTS:	Adds appropriate comments,
REFERENCES:	Provides suitable references.

All the above headings can be found in the ECO description even if there may be no content. A list of the ECOs containing the ECO number, title, level and interactions can be found below.

LIST OF ENERGY CONSERVATION OPPORTUNITIES (ECOs)

	TITLE	LEVEL	INTERACTING ECOS
ENVELOPE (E)			
E.1	Close/open windows and doors to match climate.	D	E.3, E.19
E.2	Ensure proper ventilation of attic spaces	O	E.3, E.9, E.18
E.3	Operate shades, drapes and shutters.	O/I	E.1
E.4	Close convective paths in shafts and stairwells.	O/M	E.18
E.5	Repair broken glazing.	M	E.21, E.30
E.6	Maintain latches and other mechanisms.	M	E.7, E.29
E.7	Repair/upgrade seals, caulking and weatherstripping.	I/R/M	E.6, E.18, E.28
E.8	Upgrade insulation of flat roofs externally.	I	
E.9	Add attic insulation.	I	E.2
E.10	Add insulation to exterior walls by filling voids.	I	E.15-16, E.18, E.20
E.11	Add insulation to exterior wall externally	I	E.13,E.18,E.20,D.1,P.1
E.12	Add insulation to exterior wall internally	I	E.11, E.18, D.1, P.1
E.13	Add insulation to basement wall externally	I	E.13, E.15
E.14	Add insulation to basement wall internally	I	E.13, E.15
E.15	Add insulation to floors.	I	E.13, E.14
E.16	Upgrade insulation of ground floor above crawl space.	I	
E.17	Locate and minimize the effect of thermal bridges.	I	E.8-16, E.24
E.18	Correct excessive envelope air leakage.	I	E.2,E.4,E.7,E.10-12
E.19	Add automatic door closing system between heated and unheated space.	I	E.1, E.29
E.20	Cover, insulate or convert unnecessary windows and doors.	I	E.10-11
E.21	Install window film or tinted glass.	I/R	E.5, E.22
E.22	Install shutters, blinds, shades, screens or drapes.	I	E.21
E.23	Add insulation behind exterior radiators.	I	
E.24	Roll shutter cases - insulate and seal air leaks.	I	E.17
E.25	Modify vegetation to save energy.	I	
E.26	Reduce effective height of room.	I	
E.27	Use appropriate color exterior.	I	
E.28	Install storm windows and doors.	I/R	E.7, E.20, E.24
E.29	Replace doors with improved design.	R	E.6, E.19, E.28
E.30	Use double or triple glaze replacement.	R	E.5, E.28
E.31	Replace internal blinds with external systems.	R	
E.32	Employ evaporative cooling roof spray.	I	Cooling ECOs
E.33	Close off balconies to make sunspace/greenhouse.	I	Window ECOs

REGULATION (R)

R.1	Maintain proper space setpoints.	O/M	R.28, P.2, C.7
R.2	Setback, setup space temperatures.	O/I	R.4, R.28, H.24
R.3	Shut off humidification and ventilation equipment.	O/I	R.4-6,R.19,R.28,D.10
R.4	Preoccupancy cycle.	O/I	R.2-3,R.6,R.18,R.28
R.5	Install automatic ventilation control.	O/I	R.3-4, R.6, R.9, R.18, R.28, EL.6
R.6	Night flushing.	O/I	R.3-5, R.19
R.7	Sequence heating and cooling.	O/I	R.9, R.18, R.23, R.24, R.27,R.33,R.41-42,P.7
R.8	Shut off coil circulators when not required.	O/I	R.28
R.9	Maintain proper system control setpoints	M/I	R.7,R.11, R.13, R.24, R.31, D.2, D.8
R.10	Replace worn nozzles induction systems.	M/I	
R.11	Mixing damper replacement.	M/I	R.9
R.12	Special considerations, roof top air conditioning units.	M/I	
R.13	Shut down hot or cold duct in dual duct system.	O/I	R.9, R.22
R.14	Install radiator thermostatic valves.	R	
R.15	Humidistat control of swimming pool hall ventilation.	I	R.35,H/C.17,S.7,M.11
R.16	CO control of parking garage ventilation.	I	R.25, R.39
R.17	Minimise stratification in heating season	I/R	R.25
R.18	Air economiser.	I/R	R.4-5, R.7, H/C.17, C.13, D.2
R.19	Evaporative cooling.	I/R	R.3, R.6
R.20	Locate make-up air at exhaust hoods.	I/R	R.21, R.26, R.34, R.36, D.2
R.21	High velocity type exhaust hoods.	I/R	R.20, R.26, R.36
R.22	Conversion to VAV.	I/R	R.9, R.13, R.32, R.42
R.23	Deadband thermostats.	I/R	R.25, R.28, EL.6
R.24	Load reset (discriminator) control.	I/R	R.7, R.9 R.28, R.30, R.41-42
R.25	Air mixing between zones for utilising zone excess heat or exhaust make-up.	I/R	R.16-17, R.23, R.28, R.33, R.41, R.43
R.26	Install localised exhaust/make-up air systems.	I/R	R.9, R.21, R.26, R.36, D.2
R.27	Discontinue or relocate pre-heat coils.	I/R	R.7, R.18, D.8
R.28	Install EMS system.	I/R	R.1-2, R.4-5, R.7-8, R.23-25, R.43, P.3, D.2, C.3, L.17
R.29	Stratification splitters.	I/R	
R.30	Cycle air conditioning.	I/R	
R.31	Correct poor control valve selection.	I/R	R.9
R.32	VAV fan control in AC systems.	I/R	R.22, R.34, R.40,EL.6
R.33	Use cooling coil for both heating and cooling duties.	I/R	R.7
R.34	Variable volume controls for fume hoods.	I/R	R.20, R.32, H/C.17

R.35	Mechanical dehumidification in swimming pool halls.	I/R	R.25, H/C:17, M.10
R.36	Adsorption filters.	R	R.20-21, R.26
R.37	Local heating and cooling.	R	R.38
R.38	Radiant heating.	R	R.37
R.39	Direct gas fired make-up units.	R	R.16
R.40	Replace ceiling dump boxes.	R	R.32
R.41	Re-heat coils.	R	R.7, R.24-25
R.42	Individual coils in multi-zone system.	R	R.7, R.22, R.24, R.43
R.43	System replacement.	R	R.25, R.42

HEATING (H)

H.1	Shut boiler plant off when not required.	O	H.6,H.10,H.18,H.20,P.3
H.2	Turn pilot lights off in gas equipment when not required.	O	
H.3	Reduce number of on-line boilers as load reduces.	O	H.10, H.23
H.4	Control proper atomization of oil.	O/I	H.8, H.17, H.21-22
H.5	Reduce blowdown losses.	O/I	
H.6	Reset boiler aquastat with heat demand	O/1	H.1
H.7	Maintain correct system pressurization.	O	P.2, P.4, P.11
H.8	Service burner and adjust air-fuel ratio	O	H.9, H.16-17, H.19, H.21-22
H.9	Remove scale and soot.	M	H.8
H.10	Repair or upgrade insulation on boiler/ furnace.	M/I	H1, H3, P.6
H.11	Repair refractory.	R/I	H.24
H.12	Install air inlet at foot of chimney.	I	H.13
H.13	Install flue dampers.	I	H.12, H.17
H.14	Install turbulators.	I	H.15, H.19
H.15	Decrease firing rate of the burner or fit smaller burner.	I	H.8, H.14, H.16, H.24
H.16	Install dual fuel burner.	I	H.15, H.19, H.24
H.17	Install more efficient burner.	I	H.4, H.8
H.18	Install separate (summer) SHW heater.	I	H.1, H.20, P.3, P.6
H.19	Use flue gas heat exchanger.	I	H.8, H.14, H.16, H.24
H.20	Install heat storage	I/R	H.1, P.3, P.6, P.18
H.21	Use fuel additives.	I	H.8, H.14, H.17
H.22	Install automatic oxygen trim controller	M	H.4, H.8.
H.23	Sequence firing of multi-unit boiler plant.	I	H.3
H.24	Replace obsolete heating plant.	R	H.1-3, H.8, H.11, H.15-16, R.2, H/C.14
H.25	Use of exhaust air as heat source for heat pumps.	R/I	
H.26	Fireplace upgrade/replacement.	R/I	
H.27	Outside air for fireplace.	R/I	

HEATING/COOLING (H/C)

H/C.1	Sequence operation of multiple units.	O/I	H/C.13, H/C.15, C.10, O.5, O.7, EL.6

H/C.2	Reduce power consumption of heat pump ancillary equipment.	O/R	H/C.6-8, H/C.10
H/C.3	Maintain proper starting frequency and running time of heat pump.	O/I	H/C.6-7, H/C.13-14
H/C.4	Heat pump air leakage.	O	D.1
H/C.5	Maintain proper evaporating and condensing temperatures.	O	H/C.6-7, H/C.9
H/C.6	Check sensor functioning and placement for heat pumps.	O	H/C.2, H/C.5, H/C.7
H/C.7	Maintain efficient defrosting.	O/I	H/C.2-3, H/C.5-6,H/C.8
H/C.8	Maintain proper heat source/sink flow rates.	O/M	H/C.2, H/C.7
H/C.9	Maintain functioning of heat pump expansion device.	M/R	H/C.5
H/C.10	Check heat pump stand-by losses.	M/I	H/C.2
H/C.11	Clean and maintain cooling tower circuits and heat exchanger furnaces.	M	C.2, D.5, D.9, P.5
H/C.12	Maintain full charge of refrigerant.	M	
H/C.13	Improve capacity control.	I/R	H/C.1, H/C.14
H/C.14	Reduce compressor capacity or fit a smaller compressor.	I/R	H/C.13, H/C.16, H.24
H/C.15	Repipe/operate chillers or compressors in series or parallel.	I/R	H/C.1, C.1, C.10
H/C.16	Replace or upgrade cooling equipment and heat pumps.	R	H/C.11, H/C.14, C.2
H/C.17	Air to air heat recovery techniques.	R	R.18, R.34-35
H/C.18	Replace or upgrade heat pump supplementary heat supply	R/I	H.10,H.17,H.24,H/C.1 H/C.3,H/C.5,H/C.8

COOLING (C)

C.1	Raise chilled water temperature and suction gas pressure.	O/I	C.10, C.14, H/C.15
C.2	Lower condensing water temperature and headpressures.	O/I	C.4-5, C.7-8, C.10-12, H/C.11, H/C.16
C.3	Shut off auxiliaries when not required.	O/I	C.10, R.28
C.4	Clean condenser tubes.	M/I	C.2
C.5	Heat recovery of condenser heat.	I/R	C.2
C.6	Atmospheric cooling.	I/R	C.13
C.7	Exhaust (cool) conditioned air over condensers and through cooling towers.	I/R	C.2, C.12
C.8	Increase heat exchanger surface areas.	I/R	C.2, C.12, H/C.14
C.9	Use city water for cooling.	I/R	
C.10	Central chiller/refrigeration control.	I/R	C.1-3, H/C.1, H/C.15
C.11	Use natural water sources for condensing.	I/R	C.2, H/C.11
C.12	Minimise adverse external influences on cooling tower and air cooled condenser.	I	C.2, C.7-8, H/C.11
C.13	Free cooling chillers.	I/R	C.6, R.18
C.14	Use of desiccant for de-humidification.	I/R	C.1, C.6, C.9
C.15	Use "piggy back" absorption system.	I/R	
C.16	Chilled water and ice storage systems.	I/R	

DUCTWORK (D)

D.1	Adjust/balance ventilation system.	O/M	D.4, E.7, P.1
D.2	Reduce air flow rate.	M/I	D.8, R.18, R.28, R.34
D.3	Reduce pressure drops in ducts.	M/I	D.2
D.4	Reduce air leakage in ducts.	M/I	D.9
D.5	Clean fan blades.	M	H/C.1
D.6	Maintain drives.	M	
D.7	Clean or replace filters regularly.	M	H/C.1
D.8	Reduce motor size (fan power).	I	D.2, R.27
D.9	Duct insulation repair/upgrade.	I/R	D.4
D.10	Install back-draught or positive closure damper in ventilation exhaust system.	I	R.3
D.11	Relocate motor out of air stream.	I	
D.12	Install freeze laundry driers.	R	D.13
D.13	Automatic switch off of laundry driers.	R	D.12

PIPEWORK (P)

P.1	Adjust hydronic heat distribution system	M/R/I	P.5, P.10, P.14, R.14
P.2	Bleed air from system.	O	P.4, P.7, P.11, H.7
P.3	Switch off circulation pumps when not required.	O	P.10, R.28, H.1
P.4	Maintain proper water level in expansion tank.	O	P.2, P.11, H.7
P.5	Clean filters and screens.	M	P.1, P.9-10
P.6	Repair/upgrade insulation on pipes and tanks.	M/I	P.1, P.4, P.7, S.4, S.11, S.16
P.7	Repair leaks.	M	P.2, P.6, R.1, R.7
P.8	Maintain steam traps.	M	P.16, P.18
P.9	Reduce flow resistance.	I	P.5, P.10, E.23
P.10	Reduce flow rates.	I	P.1, P.3, P.5, P.9, P.15, EL.10
P.11	Ensure system operates above atmospheric pressure.	I	P.2, H.7
P.12	Convert 3-pipe system to 2-pipe or 4-pipe system.	R	
P.13	Convert single pipe steam system to condensate return system.	R	P.17
P.14	Install zone pumping.	R	P.1
P.15	Install varible volume pumping.	R	P.10
P.16	Replace steam traps.	R	P.8
P.17	Heat recovery from condensate.	R	P.13, P.18
P.18	Separate flash steam from condensate.	R	P.8, P.17

SERVICE HOT WATER (S)

S.1	Reduce water temperature.	O	S.2, S.11, P.6
S.2	Reduce use of circulation pumps.	O	S.11, S.15
S.3	Use cold water for laundry.	O	S.6
S.4	Heat during off-peak periods.	O	S.10, S.16, S.21, P.6
S.5	Install or improve water temperature regulation.	O/I	S.9

S.6	Use SHW in appliances.	O/I	S.3
S.7	Install heat pump water heater.	O/I	S.8. S.19-20
S.8	Heat recovery from waste SHW.	I/R	S.7, S.20
S.9	Install flow restrictors.	M	S.5, S.14, S.21
S.10	Shut off water heating when not required	M/O	S.4, S.18, S.21, P.6.
S.11	Install controls to reduce pump use.	M	S.2, P.6
S.12	Install a water softener.	I	
S.13	Replace pilots with electric ignition.	R	
S.14	Install pressure reducing valves.	I	S.9
S.15	Install trace heating on dead legs.	M	S.2
S.16	Optimize size of SHW storage tank.	I	S.4, S.12, S.18
S.17	Consider automatic SHW use.	R	
S.18	Add an instantaneous booster to storage system.	I	S.1, S.16
S.19	Install metering devices.	I	S.7, S.20, S.22
S.20	Install solar water heating.	I/R	S.7, S.8, S.19
S.21	Switch from storage to instantaneous SHW system.	R	S.4, S.9-10, S.19
S.22	Decentralize SHW production.	R	

LIGHTING (L)

L.1	Switch of unnecessary lights.	O	L.16-17, L.19
L.2	Limit lighting needs during cleaning periods.	O	L.17, L.19
L.3	Use low level lighting for security periods.	O	L.17, L.19
L.4	Reduce exterior, grounds, sign, display lighting.	O/I	L.16, L.17, L.19
L.5	Rearrange work space to make rest use of daylight.	O	L.6, L.16-17, L.19
L.6	Remove lamps.	O/I	
L.7	Luminaire maintenance.	M	
L.8	Clean interior wall surfaces, repaint with lighter colors.	M	
L.9	Improve luminaires geometric arrangement	I	L.5, L.10
L.10	Use task lighting.	I	L.9
L.11	Use efficient ballasts.	I/R	L.7, L.13, L.17-19
L.12	Replace low wattage lamps with fewer high wattage ones.	I/R	L.13, L.17, L.19
L.13	Install more efficient light source.	I/R	L.6-7
L.14	Install more efficient reflectors and lenses in luminaires.	I/R	L.6-7
L.15	Install automatic supply voltage control system.	I/R	L.7-8
L.16	Install control to enable better use of daylighting.	I/R	L.1, L.4-5
L.17	Add switches, timers, presence sensors, dimmers for better control.	I/R	L.11, R.28
L.18	Switch to a more efficient lighting system.	R	L.6-7, L.11-14
L.19	Install central light operation control.	R	

ELECTRICAL SYSTEMS (EL)

EL.1	Motor and drive maintenance.	M	El.3
El.2	Balance phase voltages.	M	
EL.3	Motor and drive alignment.	M	
EL.4	Load demand control through load shedding.	M	EL.5, EL.8, R.28
EL.5	*Power factor correction using capacitors*	I	EL.4, EL.7, EL.10
EL.6	Motor speed control.	I	R.5, R.22, R.32, H/C.1, P.15
EL.7	Power factor controllers.	I	EL.5, EL.9-10
EL.8	Peak shaving using on site generation.	I	EL.4
EL.9	High efficiency motors.	R	EL.10
EL.10	Correct matching of driven load and motor.	R	EL.5, EL.7, EL.9

MISCELLANEOUS (M)

M.1	Reduce elevator and escalator use.	0	
M.2	Keep refrigerators away from heat sources	0	
M.3	Reduce condensing temperatures.	0/M	
M.4	Perform airing efficiently.	0	
M.5	Inform and instruct occupants.	0	
M.6	Make displays legible.	0/I	
M.7	Make control manipulation easy.	0/I	
M.8	Equip tenants with indoor thermometer.	0	
M.9	Initiate bonus programs.	0	
M.10	Swimming pool covers.	I/R	R.1, R.35, R.36
M.11	Replace cold cabinet internal lights with external ones	R	M.12-13
M.12	Provide night covers for open cold cabinets	R/I	M.11, M.13
M.13	Reduce cooling losses from open refrigerated display cabinets	I	M.11-12

ECO E.1 CLOSE/OPEN WINDOWS AND OOORS TO MATCH CLIMATE
LEVEL: Operations.
DESCRIPTION: Adjustment of windows and doors in the building envelope to control ventilation rates to cool or heat the interior. The objective is to limit the use of space heating or cooling.
APPLICATION: All buildings with openable windows.
SIDE BENEFITS:
CAUTIONS: This is the simplest heating or 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 favorable. Also see ECO E.3, E.19.
EVALUATION: Use of on site inspection and possibly a questionnaire to determine prior behavior, may prove useful.
COMMENTS: Closely related to Regulation ECOs.
REFERENCES: ECM, 1982; Gatts, 1974; CIBSE Guide B2, 1986.

ECO E.2 ENSURE PROPER VENTILATION OF ATTIC SPACES
LEVEL: Operations.
DESCRIPTION: Ventilation under the roof system limits roof temperature and moisture build-up.
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 ECO E.9, E.18.
EVALUATION: Use AP E.17 (Moisture and mould growth) and inspect for improper venting of moist air into attic space, ventilation rates can be checked using AP E.3 (Tracer gas).
COMMENTS: This ECO is a high priority for ensuring material and building lifetime.
REFERENCES: BRE Digest 270, 1983.

ECO E.3 OPERATE SHAOES, DRAPES ANO SHUTTERS.
LEVEL: Operations/Improvement.
DESCRIPTION: Control of building envelope elements to regulate solar entry. Consider automatic equipment to perform function.
APPLICATION: All windows.
SIDE BENEFITS: Control of solar component can assist building heating and limit building cooling load.
CAUTIONS: Presence of such solar controls implies that they must be used properly, or glare, overheating, or excessive cooling loads can result. Care must be exercised to avoid damage associated with sunlight on materials.
COST FACTORS: No cost option if manually operated.

INTERACTIONS: Interactions with occupant comfort is a prime concern. Conditions resulting from solar entry can be local. See ECO E.1.
EVALUATION: Use MT E.4 (Integrated solar radiation). A questionnaire on occupant behavior would prove useful.
COMMENTS: Should be high priority item.
REFERENCES: Dubin, 1976; ECM, 1982.

ECO E.4 CLOSE CONVECTIVE PATHS IN SHAFTS AND STAIRWELLS
LEVEL: Operations/Maintenance.
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.
APPLICATION: All buildings.
SIDE BENEFITS: Improved comfort. Reduced air flow to upper part of building.
CAUTIONS: Sealing materials must be compatible with achieving appropriate indoor air quality (e.g. non-toxic and without strong odor).
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.
INTERACTIONS: Air movements from floor to floor can directly involve occupant comfort depending upon the degree of the air movement. See ECO E.18.
EVALUATION: Use AP E.10 (Smoke tracers) or AP E.3 (Tracer gas) deployed to measure flow rates.
COMMENTS: Should be ranked high in ECO priorities.
REFERENCES: Dubin, 1976; Harrje, 1983; Silvers and Tye, 1985.

ECO E.5 REPAIR BROKEN GLAZING
LEVEL: Maintenance.
DESCRIPTION: Repair broken glazing.
APPLICATION: All buildings with special attention to neglected buildings.
SIDE BENEFITS: Improved building security.
CAUTIONS: Glazing material should be carefully chosen in high breakage locations.
COST FACTORS: Cost benefit completely over-shadows cost.
INTERACTIONS: Possibly combine with other ECOs such as E.30 (Use double or triple glaze replacement), or E.21 (Install window films or tinted glass).
EVALUATION: Do without further evaluation.
COMMENTS: This is an absolutely first priority ECO.
REFERENCES: Gatts, 1974.

ECO E.6 MAINTAIN LATCHES AND OTHER MECHANISMS
LEVEL: Maintenance.
DESCRIPTION: Maintain openable hardware; windows, doors, vents, etc., to ensure tight closure. Repair doors/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: Interacts with function, energy use and building security. Combined inspection with other infiltration items especially ECO E.7 (Caulking and weatherstripping). See ECO E.29.
EVALUATION: Use AP E.10 (Smoke tracers).
COMMENTS: High priority ECO.
REFERENCES:

ECO E.7 REPAIR/UPGRADE SEALS, CAULKING AND WEATHER-STRIPPING
LEVEL: Improvement/Replacement/Maintenance.
DESCRIPTION: Repair or upgrade systems limiting convective and conductive losses through building envelope. Consider using superior caulking and weather-stripping for upgrading to trouble-free control of air leakage.
APPLICATION: All buildings.
SIDE BENEFITS: Occupant comfort improved.
CAUTIONS: Choose non-toxic and odor acceptable materials. Do not reduce ventilation in poorly ventilated massive buildings. Do not reduce ventilation when risk for 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, ECO E.6 (Door and window latches). See ECO E.28, and E.18.
EVALUATION: Use AP E.10, AP E.11, and AP E.12. See RV E.7.
COMMENTS: Priority should be high when normal maintenance is due.
REFERENCES: Dubin, 1976.

ECO E.8 UPGRADE INSULATION OF FLAT ROOFS EXTERNALLY
LEVEL: Improvement.
DESCRIPTION: Upgrade insulation of flat roofs by 1) adding batts or loose-fill insulation and by building a new sloping roof on top of the old one, or 2) by closing the air-gap between the old insulation and the (wood) construction carrying the old surface material, and then adding batts of high density mineral wool and covering by a new surface material.
APPLICATION: Buildings with flat roofs and a sub-standard insulation level. 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 damages. May increase cooling load.
COST FACTORS: A detailed economic evaluation is necessary.
INTERACTIONS:

EVALUATION: Use AP E.15 or E.16 to determine present U-value. Use AP E.14 to detect roof damage. Energy savings can be estimated by using AT E.4 and RV E.3.

COMMENTS:

REFERENCES:

ECO E.9 ADD ATTIC INSULATION

LEVEL: Improvement.

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 location.

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 electrical fixtures that could cause overheating and possible fire damage. Some of the insulation materials are composed of very small particles, therefore, care should be taken that the insulation material does not drift down in the living space. If insulation is covered by materials preventing diffusion, this may cause moisture damage.

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: ECO E.2 (Ensure proper ventilation of attic spaces).

EVALUATION: Use AP E.14 (IR Thermography). Calculate anticipated savings from AT E.4 and RV E.3.

COMMENTS: If insulation levels are low this is a very high priority ECO.

REFERENCES: Dubin, 1976; Jacobson, 1985; Beyea, 1977; ANSI/ASHRAE/ISA, 1981; BRE Digest 190, 1976.

ECO E.10 ADD INSULATION TO EXTERIOR WALLS BY FILLING VOIDS

LEVEL: Improvement.

DESCRIPTION: Add insulation to exterior walls by filling voids in cavity walls.

APPLICATION: Buildings with sub-standard insulation levels in exterior walls.

SIDE BENEFITS: Elimination of cold walls which cause discomfort and possible condensation and mould problems. Convective loop problems can also be eliminated through added insulation, air infiltration through walls may be markedly reduced by this retrofit.

CAUTIONS: Some of the insulation materials are composed of small particles, therefore, care should be taken so that insulation materials do not enter the living space. Materials that have odor or any toxic characteristics must be avoided in wall insulation (e.g., urea-formaldehyde insulation has experienced such problems). New condensation problems may occur if vapor diffusion is prevented or restricted.

COST FACTORS: Wall insulation can be expensive to install depending upon wall access (for cavity systems).
INTERACTIONS: May be combined with ECO E.20 (Unnecessary windows and doors). Can reduce air leakage and thus complement ECD E.18.
EVALUATION: AP E.15, E.16 or E.18 may be used to evaluate the U-value of the wall and/or the contents of the existing wall. Use AP E.14 (Infrared thermography) and MT E.2 (Envelope surface temperature). Savings are calculated from AT E.4 and RV E.3.
COMMENTS: This retrofit can prove to be very rewarding if little insulation is present in the existing wall. Additional benefits from reduced air infiltration can help to justify the expense.
REFERENCES: ANSI/ASHRAE/ISA, 1981; Dubin, 1976; Jacobson, 1985; Beyea, 1977; BRE Digest 236, 1980.

ECO E.11 ADD INSULATION TO EXTERIOR WALLS EXTERNALLY
LEVEL: Improvement.
DESCRIPTION: Upgrade insulation of exterior walls by adding batts or insulating boards carried by a framework or directly applied to the wall. Add new facade material.
APPLICATION: Buildings with sub-standard insulation levels or with facades due for maintenance or repair.
SIDE BENEFITS: Improved comfort and possibility to lower indoor temperature. Reduced infiltration.
CAUTIONS: Careful work required at joints. Look out for cracks in the insulating material. Check local or other regulations regarding exterior decor and looks and fire-safety. May increase cooling load.
COST FACTORS: May be expensive depending on access and decor concerns.
INTERACTIONS: Can be combined with ECO E.20 (Unnecessary windows and doors) or ECO E.18 (Air leaks). For optimal savings combine with distribution system adjustment (ECO D.1 and P.1). Heat plant seasonal efficiency may drop as a result of this ECO. See also ECO E.13.
EVALUATION: Use AP E.15 or E.16 to determine present U-value. Use AT E.4 and RV E.3 to estimate energy savings. Also consider using AP E.14 for detection of thermal bridges.
COMMENTS:
REFERENCES:

ECO E.12 ADD INSULATION TO EXTERIOR WALL INTERNALLY
LEVEL: Improvement.
DESCRIPTION: Upgrade insulation of external walls by adding interior insulation such as batts carried by a wood framework or prefabricated wall elements.
APPLICATION: Buildings with sub-standard insulation levels or due for interior refurbishment.
SIDE BENEFITS: Improved comfort. Possibility to lower indoor temperature. Increased comfort zone.
CAUTIONS: If a vapor barrier is installed, check for possible future moisture problems. Heat terminals, pipework and air ducts may

give rise to practical difficulties. May increase cooling load.

COST FACTORS: First choice is to insulate easily accessible surfaces. It may not be necessary to have the same insulation thickness everywhere.

INTERACTIONS: Can be combined with ECO E.18 (Air leaks). Adjustment of heating or ventilation system may be required for full effect of this ECO (see ECOs D.1, P.1). Heat plant efficiency may drop.

EVALUATION: Use AP E.15 or E.16 to determine U-value. Energy savings estimated by AT E.4 and RV E.3.

COMMENTS: This ECO may not reduce heat losses at thermal bridges to the same extent as does ECO E.11.

REFERENCES:

ECO E.13 ADD INSULATION TO BASEMENT WALL EXTERNALLY

LEVEL: Improvement.

DESCRIPTION: Upgrade insulation level of basement wall above or below grade on the external side. Different insulation materials in combination with several surface materials or prefabricated elements can be used.

APPLICATION: Buildings with basement walls having a sub-standard insulation level or in need of repair due to, for example, moisture damage.

SIDE BENEFITS: Improved comfort.

CAUTIONS: Diffusion tight insulation materials may obstruct drying of wall. Satisfactory drainage important after upgrading of insulation below grade.

COST FACTORS:

INTERACTIONS: Can be done in conjunction with ECO E.11 (Upgrading of exterior wall externally). In this case support of the wall insulation can be facilitated. Alternative to ECO E.14 (Internal insulation). See also ECO E.15.

EVALUATION: Upgrading above grade, see ECO E.14. Use AP E.14 or MT E.2 to detect possible moisture damage (cold surfaces). Use AT E.4 and RV E.3 to calculate energy savings.

COMMENTS:

REFERENCES:

ECO E.14 ADD INSULATION TO BASEMENT WALL INTERNALLY

LEVEL: Improvement.

DESCRIPTION: Upgrade insulation level of basement wall by adding insulation on the interior side, for example using mineral wool carried by a wood framework, or using prefabricated wall elements.

APPLICATION: Buildings with sub-standard insulation and no moisture damage.

SIDE BENEFITS: Increased comfort in basement.

CAUTIONS: Moisture damage to basement walls can become more severe if the ECO is implemented. Do not use vapor barriers because of risk for structural damage if there are cracks. Wood framework should not be in direct contact with the wall.

COST FACTORS: Presence of pipework and air ducts may present obstructions to this ECO.
INTERACTIONS: Alternative to ECO E.13 (External insulation of basement walls). See also ECO E.15.
EVALUATION: Use AP E.14 or MT E.2 to detect moisture damage. Use AT E.4 and RV E.3 to calculate energy savings.
COMMENTS:
REFERENCES:

ECO E.15 ADD INSULATION TO FLOORS
LEVEL: Improvement.
DESCRIPTION: Add insulation to those floors that constitute the thermal envelope.
APPLICATION: Buildings with sub-standard heat losses to the ground.
SIDE BENEFITS: Improve comfort by eliminating a cold floor situation. Can suppress sound from basement such as from furnace/boiler.
CAUTIONS: Increasing floor insulation levels to save winter heating energy may be partly compensated by loss of summer cooling potential.
COST FACTORS:
INTERACTIONS: This ECO separates heated from unheated space.
EVALUATION: AP E.15 and E.16 may be used to evaluate floor heat loss. Use AP E.14. Calculate savings using AT E.4 and RV E.3.
COMMENTS: A main concern with this retrofit action to make certain if there is a justifiable heat loss through the floor. Often insulation is better applied to basement walls rather than basement ceiling (living space floor), see ECO E.13 and E.14. For floor heating systems always add insulation to ceiling.
REFERENCES: BRE Digest 190, 1976.

ECO E.16 UPGRADE INSULATION OF GROUND FLOOR ABOVE CRAWL SPACE
LEVEL: Improvement.
DESCRIPTION: Add insulation below the ground floor by mounting batts of mineral wool between horizontal studs and cover by gypsum board, or by placing the insulation on the ground and inside the walls surrounding the crawl space.
APPLICATION: Buildings with crawl-space and substantial heat losses to the ground.
SIDE BENEFITS: Eliminates cold floors.
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.
COST FACTORS: Can be very cost-effective.
INTERACTIONS:
EVALUATION: Use AP E.15 or E.16 to determine U-value. Calculate energy savings from AT E.4 and RV E.3. Use AP E.17 or E.18 to detect mould growth.
COMMENTS:
REFERENCES:

ECO E.17 LOCATE AND MINIMIZE THE EFFECT OF THERMAL BRIDGES
LEVEL: Improvement.
DESCRIPTION: Locate thermal bridges, add appropriate 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).
CAUTIONS:
COST FACTORS: Cost directly dependent upon accessibility of thermal bridge.
INTERACTIONS: Heavily influenced by insulation ECOs E.8 through E.16. See also ECO E.24.
EVALUATION: Use AP E.14, E.15 and E.16 or MT E.2 for detection. Use AT E.4 and RV E.3 for energy savings.
COMMENTS: Basic architecture of building is cause of problem, hence it is characteristic of certain designs.
REFERENCES: Silvers and Tye, 1985; CIBSE Guide A3, 1980.

ECO E.18 CORRECT EXCESSIVE ENVELOPE AIR LEAKAGE
LEVEL: Improvement.
DESCRIPTION: Identify and improve seals and construction in problem areas associated with building envelope due to convective and infiltration paths (electrical and plumbing, chimneys, ventilation shafts, roll-up shutter cases and other air by-passes from conditioned space).
APPLICATION: Those buildings with common design efficiencies.
SIDE BENEFITS: Improved comfort through reduction of cold surfaces and drafts. Reduced exfiltration of moist air into attic areas (condensation problems).
CAUTIONS: Lack of infiltration unless supplemented by ventilation systems can reduce air space quality, create condensation problems and upset draught requirements for fireplaces and furnaces.
COST FACTORS: Cost is highly variable especially when problems are not easily accessible, e.g., leakage into roof cavity.
INTERACTIONS: Similaraities with E.4 (Close convective paths in stairwells) but degree of corrective measures is more costly. Also interacts with E.2 (Properly vent attic) and ECOs E.10, E.11, E.12 (Upgrade insulation) and E.7 (Upgrade seals).
EVALUATION: Use AP E.3. Also see RV E.5 and E.6 to assess need for tightening.
COMMENTS: High priority item governed by cost.
REFERENCES: Harrje, 1979, 1980, 1983; Silvers and Tye, 1985; Dutt, 1986; CIBSE Guide A4, 1986.

ECO E.19 ADD AUTOMATIC DOOR CLOSING SYSTEM BETWEEN HEATED AND UNHEATED SPACE
LEVEL: Improvement.
DESCRIPTION: Door between heated and unheated spaces must be kept closed - automated systems help this situation by limiting or

eliminating air movement between unconditioned and conditioned spaces.
APPLICATION: Any frequently used door system.
SIDE BENEFITS: Greatly improved comfort in the spaces, and reduced moisture problems in unheated basements.
CAUTIONS:
COST FACTORS: Cost of closure systems vary from <$10 to more than $50.
INTERACTIONS: Related to ECO E.1 but with automated feature. See ECO E.29.
EVALUATION: Use simple infiltration checks and local temperature measurements to check improvement, e.g. AP E.10.
COMMENTS: Priorities will depend on individual building situations.
REFERENCES:

ECO E.20 COVER, INSULATE OR CONVERT UNNECESSARY WINDOWS AND DOORS
LEVEL: Improvement.
DESCRIPTION: Cover, seal off and/or insulate window systems that are not necessary for ventilation or daylighting. Alternatively, consider converting windows or doors to wall system.
APPLICATION: Buildings where there are too many windows.
SIDE BENEFITS:
CAUTIONS: Lighting levels may be reduced. Occupant satisfaction may be diminished. Solar benefits will be eliminated.
COST FACTDRS: Converting windows to walls is more expensive than covering or insulating windows.
INTERACTIONS: Unless this retrofit is done properly it may encourage moisture condensation or overheating of materials in the window insulation sandwich. See also ECOs E.10 and E.11 (Upgrade insulation).
EVALUATION: Use theoretical calculations of window and wall values for justification, see AT E.4 and RV E.3 or use AP E.1 or E.2.
COMMENTS:
REFERENCES: Dubin, 1976.

ECO E.21 INSTALL WINDOW FILM OR TINTEO GLASS
LEVEL: Improvement/Replacement.
DESCRIPTION: ECO involves glass replacement at one end of scale to stickon films at the other end. Two types of films are available: summer solar reflective and winter internal heat retaining.
APPLICATION: Window systems with significant solar effects.
SIDE BENEFITS: Special films can markedly lower window U-value. Window film/tinting can limit local overheating, and glare from sky and sunlight.
CAUTIONS: Durability of stickons should be evaluated. Check for user acceptability before installation. Can reduce daylight contribution and useful solar gains.
COST FACTORS: Window stickon film cost is an order of magnitude less than glass replacement.
INTERACTIONS: Interacts with local comfort and daylighting, alternate to ECO E.22. Can be high priority if occupants are uncomfortable. See also ECO E.5.
EVALUATION: Use MT E.4.

COMMENTS:
REFERENCES: Dubin, 1976.

ECO E.22 INSTALL SHUTTERS, BLINDS, SHADES, SCREENS OR DRAPES
LEVEL: Improvement.
DESCRIPTION: Addition of heat control and light control elements over windows. Elements lower U-values of window system.
APPLICATION: All windows requiring heat and/or light control.
SIDE BENEFITS: Improved comfort.
CAUTIONS: Effective insulating internal shutters may cause window damage by raising window temperatures to high levels from trapped solar heating. Can be avoided by leaving unsealed the upper part of shutters.
COST FACTORS: Wide variety of cost factors.
INTERACTIONS: Interacts with all window functions and ECO E.21.
EVALUATION: Use MT E.4. For energy savings use.
COMMENTS: Priority item where windows are the dominant heat loss.
REFERENCES: Dubin, 1976; ECM, 1982.

ECO E.23 ADD INSULATION BEHIND EXTERIOR RADIATORS
LEVEL: Improvement.
DESCRIPTION: Add insulation, especially reflecting type, behind radiators on the building exterior. Remove obstructions to air flow around radiators that might excerberate heat loss through envelope.
APPLICATION: Buildings with radiators that are inadequately insulated.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS:
INTERACTIONS:
EVALUATION: Use AP E.15 or E.16 to evaluate heat loss. Use AP E.14 and MT E.2.
COMMENTS: The walls behind the radiators experience the highest temperatures of the building envelope and therefore, it is a key area to increase the insulation level.
REFERENCES:

ECO E.24 ROLL SHUTTER CASES - INSULATE AND SEAL AIR LEAKS
LEVEL: Improvement.
DESCRIPTION: Roll shutter case is source of local thermal bridge requiring insulation, possibly replace system to reduce losses.
APPLICATION:
SIDE BENEFITS: Possible condensation problems eliminated.
CAUTIONS:
COST FACTORS: Cost dependent on case configuration.
INTERACTIONS: Element of building envelope directly involves ECO E.17.
EVALUATION: Use AP E.14 finding problems and AT E.4 to determine possible savings.
COMMENTS:
REFERENCES:

ECO E.25 MODIFY VEGETATION TO SAVE ENERGY
LEVEL: Improvement.
DESCRIPTION: Vegetation on south side of building should allow solar energy to reach buildings in winter and shade building in summer and on the windward side should protect building.
APPLICATION: Buildings with flexibility in tree and shrub plantings.
SIDE BENEFITS: Enhanced appearance.
CAUTIONS: Planting too near 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 Lighting ECOs and local comfort. Regulation system must be able to accommodate heat gains without causing overheating.
EVALUATION: Calculate savings based on altered solar gain and air infiltration losses.
COMMENTS: Vegetation growth is slow, steps must be carefully planned. Priority must be based on local circumstances.
REFERENCES: Harrje, Buckley, Heissler, 1982; Mattingly, 1979.

ECO E.26 REDUCE EFFECTIVE HEIGHT OF ROOM
LEVEL: Improvement.
DESCRIPTION: Lowering ceiling in rooms can reduce conditioned volume. Reduced conditioning volume can save heating/cooling energy.
APPLICATION: Those rooms where excessive height serves no useful purpose.
SIDE BENEFITS: Reduces temperature stratification effect.
CAUTIONS: Esthetics of rooms may be changed. 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 through influence on ceiling U-value. Alternatively for spaces 4-5 meters or higher, consider destratification devices.
EVALUATION: Calculations that properly account for true benefits, e.g. changes in conditioned volume. True evaluation must be based on before/after energy records, building a data base. Also AP E.1 and E.2 could supply data.
COMMENTS: For high ceiling rooms this ECO can be very appropriate. It may not always save on cooling because of change in affected mass.
REFERENCES:

ECO E.27 USE APPROPRIATE COLOR EXTERIOR
LEVEL: Improvement.
DESCRIPTION: Color of exterior surface of building can influence heat absorption and heat rejection.
APPLICATION:
SIDE BENEFITS:
CAUTIONS: Radiation exchange at building surface goverened by emissivity and absorbtion of surface which are not directly related to color.

COST FACTORS: Cost is sufficient so that exterior maintenance should be factored into decision.
INTERACTIONS: Influence is dictated by U-value of building envelope. Low U-values reduce priority.
EVALUATION: Simple evaluation methods are probably not sensitive to this effect.
COMMENTS:
REFERENCES: BRE IP 26/81, 1981.

ECO E.28 INSTALL STORM WINDOWS AND DOORS
LEVEL: Improvement/Replacement.
DESCRIPTION: Add a window or 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.
CAUTIONS:
COST FACTORS: Cost factors important with this ECO, especially for doors. Sometimes $60/m^2$ or more.
INTERACTIONS: Interaction with ECO E.7 demands good seal to achieve performance. See ECO E.24, E.20.
EVALUATION: Use AP E.11, E.12, E.13 and M.1. Calculate conduction and convection savings from AT E.4 and RV E.3, E.6.
COMMENTS: Storm window added to original window can save more energy than double glazing if air gap is properly dimensioned.
REFERENCES: Dubin, 1976; BRE Digest 140, 1972.

ECO E.29 REPLACE DOORS WITH IMPROVED DESIGN
LEVEL: Replacement.
DESCRIPTION: Use of revolving doors, vestibules, insulated doors to replace poor entrance design and eliminate air curtains.
APPLICATION: Revolving doors can be considered in larger buildings.
SIDE BENEFITS: Both improved U-values and reduced air infiltration can result from proper entrance design.
CAUTIONS:
COST FACTORS: This can be an expensive ECO - shop competitive designs carefully.
INTERACTIONS: Competes with ECO E.6 (Maintain latches, etc.), ECO E.19 (Automatic door closures), ECO E.28 (Storm windows and doors).
EVALUATION: Use AP E.12, E.13 and M.1. Calculate conduction and convection savings from AT E.4 and RV E.6.
COMMENTS: Priority should depend on cost/benefit and exposure of the entrance to wind.
REFERENCES: Dubin, 1976; BRE IP 2/81, 1981.

ECO E.30 USE DOUBLE OR TRIPLE GLAZE REPLACEMENT
LEVEL: Replacement.
DESCRIPTION: Seek low U-values in glazing and frames in replacement windows.
APPLICATION: All buildings with single-pane windows but taking into account climate factors.

SIDE BENEFITS: More comfort (less radiant losses in heating season) and reduction or elimination of condensation on glass and frames.
CAUTIONS: 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: Interaction with ECO E.28 (Install storm windows and doors). See also ECO E.5. Especially attractive in extreme climates.
EVALUATION: Use calculation procedure to demonstrate economics.
COMMENTS: Energy and sound reduction may be better achieved with a two-pane, one-pane combination.
REFERENCES: Dubin, 1976.

ECO E.31 REPLACE INTERNAL BLINDS WITH EXTERNAL SYSTEMS
LEVEL: Replacement.
DESCRIPTION: Use external systems to replace internal blinds to reduce solar load. Intercepting solar load is much more efficient with external system.
APPLICATION: Air conditioned buildings for energy savings.
SIDE BENEFITS: Improved comfort particularly in non-air-conditioned buildings.
CAUTIONS: If used in winter may reduce the amount of useful solar gains released in the space.
COST FACTORS:
INTERACTIONS: May permit cooling system capacity reductions.
EVALUATION: Inspection and energy analysis.
COMMENTS: Weather resistant systems must be used outside and ease of use becomes more important. Automatic control is recommended to ensure correct use for greatest savings.
REFERENCES:

ECO E.32 EMPLOY EVAPORATIVE COOLING ROOF SPRAY
LEVEL: Improvement.
DESCRIPTION: Use an evaporative cooling roof spray to lower roof surface temperature. System dispels heat as it reaches roof.
APPLICATION: Generally employed on 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 by reduced heat load. Evaluate water cost and determine whether or not water use is allowed by local regulatory group.
INTERACTIONS: See Cooling ECOs - can be high priority item where conditions are favorable.
EVALUATION: Inspect building potential for system, then calculate possible energy savings from reduced temperature difference, see App.C.
COMMENTS: Original cooling equipment may prove to be greatly oversized and thus may operate with less efficiency when ECO is initiated.
REFERENCES: Dubin, 1976; Gatts, 1974.

ECO E.33 CLOSE OFF BALCONIES TO MAKE SUNSPACE/GREENHOUSE

LEVEL: Improvement.

DESCRIPTION: Open balconies are glassed in to trap solar and building heat. Adds semi-conditioned space.

APPLICATION: Southerly orientations only (Northern hemisphere).

SIDE BENEFITS: More useable room space. Reduced air infiltration.

CAUTIONS: Unless night insulation is used temperature variation can be extreme. Space may overheat even during heating season.

COST FACTORS: Cost for this conversion can be high since glass must be properly supported.

INTERACTIONS: Priority must address need for semi-conditioned space and orientation of building. Interacts with window ECOs. Calculate possible savings before taking action.

EVALUATION: Inspection and energy analysis before and after.

COMMENTS:

REFERENCES:

ECO R.1 MAINTAIN PROPER SPACE SETPOINTS
LEVEL: Operations/Management.
DESCRIPTION: Check setting and calibration of all space thermostats and humidistats. Adjust anticipator setting where thermostats have such devices.
APPLICATION: Buildings with individual space control devices.
SIDE BENEFITS: Improved comfort.
CAUTIONS:
COST FACTORS: Negligible cost unless sensors or controls need replacing.
INTERACTIONS: Because of poor control zoning, maintaining current temperatures throughout all areas of the building may be difficult. See ECO R.28, P.7, C.2.
EVALUATION: If thermostat setpoints or measured values (occupied period) are not equal to design values, reset to correct setting. If thermostat setpoint is OK 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, see RV R.1, a more thorough analysis of the thermal environment may be necessary, see AP R.1.
REFERENCES: ASHRAE Standard 55, 1981; Berglund, 1978.

ECO R.2 SETBACK, SETUP SPACE TEMPERATURES
LEVEL: Operations/Improvement.
DESCRIPTION: Adjust space thermostats or other space temperature controllers for energy saving set-points during unoccupied periods or for unoccupied spaces. Consider cycling heating and cooling plant and auxiliaries to minimize power costs. Consider earlier shut-down or setback (i.e. before occupants leave). Plant may be turned off in mild conditions when no danger of freezing. Auxiliaries should also be turned off where possible.
APPLICATION: 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: Condensation in boiler can reduce its life expectancy. Extreme humidity swings can result in condensation in winter, and mildew in summer. Possibility of plumbing freeze in vulnerable parts of the building. Shut down of steam systems can create problems such as might be caused by expansion and contraction cycles, boiler stress, water carry-over (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 minimised by using liquid expansion type steam traps or providing smaller control valve to limit flow of steam, and hence condensate forming during system warmup (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, particularly if *optimum start (variable preconditioning period) is adopted.* Can be expensive if large number of thermostats need to be changed to night setback type.
INTERACTIONS:	Consider ECO R.28 (EMS) and ECO R.4 (Preoccupancy cycle). Preconditioning period must be set with consideration of the ability of the heating and cooling plant to bring the building back to comfort. See also ECO H.24 (Replace heating plant).
EVALUATION:	*Check if equipment not 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 to plant load ratio. See RV R.3. Desirability of ECO often most influenced by cost of necessary control modifications. See AP *R.2 and H.4.*
COMMENTS:	Appendix C describes specific setback strategies for generic type HVAC systems. 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 warmup period is typically occuring at the coldest part of the day (thus lowering the COP).
REFERENCES:	*Levine, 1981; Johnson Controls Ltd., 1982; Berglund, 1978;* Spirax Sarco, 1985; Ellison, 1977; Backus, 1982; Bullock, 1978.

ECO R.3	SHUT OFF HUMIDIFICATION AND VENTILATION EQUIPMENT
LEVEL:	Operations/Improvement.
OESCRIPTION:	*Shut-down 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.
SIDE BENEFITS:	
CAUTIONS:	Not appropriate where ventilation required for safety or *cooling, or where humidity needs to be controlled, e.g.* museums.
CDST FACTORS:	No cost if manual, wide range of costs for automatic operation.
INTERACTIONS:	ECO R.6 (Night flushing), ECO R.28 (EMS), ECO R.19 (Evaporative cooling). ECO R.4 (Preoccupancy cycle). See also ECO R.5 and D.10.
EVALUATION:	*Where applicable shut off manually. Energy savings* proportional to fresh air infiltration and climatic severity, and the ratio of occupied to unoccupied hours (see AT R.1). Savings in most cases justifiable without further evaluation.
COMMENTS:	
REFERENCES:	

ECO R.4 PREOCCUPANCY CYCLE
LEVEL: Operations/Improvement.
DESCRIPTION: Carry out pre-heating and pre-cooling without introducing outside air where this would impose an additional load.
APPLICATION: All building with HVAC systems with economisers or separate ventilation systems.
SIDE BENEFITS: Can reduce peak demand on heating and cooling plant for quicker warm up or can reduce peak load electrical demand charges.
CAUTIONS: Care must be taken to avoid internal air quality problems when occupancy commences.
COST FACTORS:
INTERACTIONS: ECO R.28 (EMS system). Be careful not to eliminate the potential benefits of pre-cooling; see ECO R.18 and ECO R.6. Consider as complimentary to Night Setback/Setup (ECO R.2) and Ventilation and Humidification Scheduling (ECO R.3)
EVALUATION: See AT R.1.
COMMENTS: Note some controllers have self learning capability (e.g. pre-heat time automatically adjusts to system and building).
REFERENCES: Johnson Controls, 1982

ECO R.5 INSTALL AUTOMATIC VENTILATION CONTROL
LEVEL: Operations/Improvement.
DESCRIPTION: Vary ventilation rate by means of: a) Adjustment of outside air and mixing dampers; b) Throttle fan flow; c) Motor speed control; d) Mechanical speed control; e) Variable pitch blades (vane axial fans); f) Inlet guide vanes (centrifugal fans).
APPLICATION: Most potential in buildings with highly intermittent and variable occupancy, e.g. shops, theatres, auditoria.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Most benefit if automatic using CO_2 sensor. Time clock can be considered where the occupancy density pattern is predictable.
INTERACTIONS: Do not let control override economiser cycle (ECO R.18), or night flushing (ECO R.6). Cycling equipment EMS system (see ECO R.28). This ECO is complimentary to ECO R.3 (Shutting off ventilation and humidification) and ECO R.4 (Pre-occupancy cycle). See also ECO R.9 and EL.6.
EVALUATION: See AT R.1. RV E.4 and RV R.4 gives recommended ventilation needs. Occupancy profiles are given in RV R.10. Simple degree-day methods (AT E.1) 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.

ECO R.6 NIGHT FLUSHING
LEVEL: Operations/Improvement.
DESCRIPTION: Use cool outside night air to pre-cool the building.

APPLICATION: Most beneficial in heavy mass buildings and where night-time temperatures are much lower than daytime set-point.
SIDE BENEFITS: Improved comfort if mechanical cooling is not possible.
CAUTIONS: Be careful not to over-cool the space and create discomfort or a need for heating.
COST FACTORS: Low cost if ventilation equipment already installed.
INTERACTIONS: Evaporative cooling (ECO R.19) might be considered as an alternative or complimentary approach. See also ECO R.3, R.4, R.5.
EVALUATION: Fan power requirements need to be evaluated against mechanical cooling requirements. See AT R.2.
COMMENTS: High pressure fan systems can end up using more power than if fans run for shorter periods with mechanical cooling. VAV systems would require separate control of every damper and some form of central control would be necessary.

REFERENCES:

ECO R.7 SEQUENCE HEATING AND COOLING
LEVEL: Operations/Improvement.
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 economiser cycle with deck temperature control. Other possibilities where sequencing is important include systems with pre-heat or those utilising evaporative cooling.
SIDE BENEFITS:
CAUTIONS: Overlapping throttling ranges of controllers and loss of calibration can cause loss of sequencing when individual controllers are utilised.
COST FACTORS: Low cost if only system setpoint adjustment required. Sequencing by common controller more expensive but generally more satisfactory.
INTERACTIONS: In many instances sequencing should be coupled with reset control (ECO R.24). Loss of sequencing can occur when correct system setpoints are not maintained (see ECO R.9). See also ECO R.18, R.23, R.27, R.33, R.41, R.42, P.7.
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 is turned off. Make the comparison for 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, 1975; Haines, 1984; Albern,1983.

ECO R.8 SHUT OFF COIL CIRCULATORS WHEN NOT REQUIRED

LEVEL: Operations/Improvement.

DESCRIPTION: Schedule heating and cooling coil circulators off when no demand for heat or cool.

APPLICATION: Coils controlled by three-way mixing valve with circulator.

SIDE BENEFITS:

CAUTIONS:

COST FACTORS: Most benefit where or when a system operates with full coil flow and intermittent fan operation. Pump energy savings small but payback can be achieved where natural convection losses from coils are eliminated.

INTERACTIONS: EMS system (ECO R.28).

EVALUATION: See AT R.3.

COMMENTS: Avoid turning off where danger of freezing.

REFERENCES:

ECO R.9 MAINTAIN PROPER SYSTEM CONTROL SET-POINTS

LEVEL: Maintenance/Improvement.

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 short 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 <u>cooling load</u> (in winter the systems act like a reheat system and so doing minimises reheat energy). In summer, to minimise re-cool energy when the system functions as a re-cool system, the primary air temperature should be set as low as possible, consistent with not overcooling space with the <u>least cooling demand</u> (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.

For other examples see also ECO R.7, R.11, R.13, R.24, R.31.

APPLICATION: All systems with automatic controls, particularly those with heating and cooling.

SIDE BENEFITS:

CAUTIONS:

COST FACTORS: Minor.

INTERACTIONS: Very important where controls are not sequenced. Consider changing controls, see ECO R.7. Adjustment may be required where room load and/or air volumes have changed, ECO D.2, D.8, R.5.

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. Appropriateness of reset water schedule in systems with such a control system can be checked by analysing the results of co-incident inside, outside and heating flow water temperatures (Bloor, 1983).

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 utilised to sequence heating, cooling, mixing.

REFERENCES: Johnson Controls Ltd., 1982; Kao, 1983, 1985; CIBSE 811, 1985.

ECO R.10 REPLACE WORN NOZZLES INDUCTION SYSTEMS

LEVEL: Maintenance/Improvement.

DESCRIPTION: Replace worn nozzles.

APPLICATION:

SIDE BENEFITS: Improve induction of room air.

CAUTIONS:

COST FACTORS:

INTERACTIONS:

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 analyse savings.

COMMENTS:

REFERENCES:

ECO R.11 MIXING DAMPER REPLACEMENT

LEVEL: Maintenance/Improvement

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.

APPLICATION: Can be particularly effective when applied to dual duct mixing boxes. Applicable to air economisers, multizone and dual duct systems. Dampers on older type roof-top air conditioning units are prime examples for retrofit.

SIDE BENEFITS: Reduction of peak loads.

CAUTIONS:

COST FACTORS:

INTERACTIONS: See ECO R.9.

EVALUATION: See AP R.4. RV R.5 gives typical damper leakage data.

COMMENTS:

REFERENCES:

ECO R.12 SPECIAL CONSIDERATIONS, ROOF TOP AIR CONDITIONING UNITS

LEVEL: Maintenance/Improvement.

DESCRIPTION: The following list contains a number of maintenance and minor improvements specific to roof top units:

1. Clean air sides and straighten damaged fins of condenser evaporator.
2. Adjust fan belts.
3. Caulk leaking seams.
4. Repair and replace gaskets on inspection covers.
5. Secure loose covers, replace screw fixings with hinges and marine catches.
6. Repair or upgrade insulation.
7. Erect shade to keep direct sunlight off condenser.
8. Replace gas train and install electronic ignition.
10. 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.

CAUTIONS:

COST FACTORS: With exception of gas train replacement, all items are low to medium cost maintenance items.

INTERACTIONS: Since the roof top is a self-contained heating, cooling air distribution and regulation unit, many ECOs classified under Heating, Cooling, Ductwork and Regulation are applicable.

EVALUATION: No further evaluation required on maintenance items. Base gas train evaluation on current state of repair and measured combustion efficiency.

COMMENTS: RV R.9 gives typical effect of dirt on condensers and evaporating.

REFERENCES: Korte, 1976.

ECO R.13 SHUT DOWN HOT OR COLD DUCT IN DUAL DUCT SYSTEM OR MINIMISE TEMPERATURE DIFFERENCE

LEVEL: Operations/Improvement.

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.

SIDE BENEFITS:

CAUTIONS: Ensure comfort not compromised in some zones. Check for suitability of fan operating point.

COST FACTORS:

INTERACTIONS: For zones with very different requirements served by the same system, consider the installation of re-heat or re-cool coils or separate systems. Alternative option would be to convert to VAV operation (ECO R.22). See also ECO R.9.

EVALUATION: Operation in such a manner will eliminate mixing losses (mixing between hot and cold ducts) and reduce fan power.

COMMENTS:

REFERENCES: WECS, (undated).

ECO R.14 INSTALL RADIATOR THERMOSTATIC VALVES
LEVEL: Replacement.
DESCRIPTION: Replace radiator valves by radiator thermostatic valves.
APPLICATION: Buildings with hydronic heat distribution system, except series loop systems.
SIDE BENEFITS: Improved comfort.
CAUTIONS: Effect strongly dependent on positioning of sensors, equipment where sensor separate from thermostatic valve to be prefered. 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.
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: ECO P.1.
EVALUATION:
COMMENTS: Post-adjustment of system may be required.
REFERENCES:

ECO R.15 HUMIDISTAT CONTROL OF SWIMMING POOL HALL VENTILATION
LEVEL: Improvement.
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 excerbate material and surface deterioration.
COST FACTORS: Nominal.
INTERACTIONS: Alternatively use mechanical dehumidification, (ECO R.35), Air to Air Heat Recovery (ECO H/C.17) or Air to SHW Heat Recovery (ECO S.7). Pool cover (ECO M.10) can be considered as complementing this ECO.
EVALUATION: Consider alternatives before deciding to implement this ECO. See AT R.7, R.6 and RV R.12.
COMMENTS:
REFERENCES:

ECO R.16 CO CONTROL OF PARKING GARAGE VENTILATION
LEVEL: Improvement.
DESCRIPTION: Use carbon monoxide sensor to turn on garage ventilation equipment only when safe limits of CO concentration have been exceeded.
APPLICATION: Primarily mechanically heated and ventilated garages.
SIDE BENEFITS:

CAUTIONS: Check that variable ventilation can satisfy safe limits of CO concentration. Garage should be maintained under negative pressure at all times to minimise air flow to occupied zones. Air leakage to occupied areas should be eliminated.
COST FACTORS:
INTERACTIONS: ECO R.25 (Mixing between zones) can be considered complimentary. See also ECO R.39.
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: RV R.7 gives values for CO production and typical CO tolerance levels and recommended minimum ventilation rate. See also AP R.3 and AT R.4.
REFERENCES: Lloyd, 1985.

ECO R.17 MINIMISE STRATIFICATION DURING HEATING SEASON
LEVEL: Improvement/Replacement.
DESCRIPTION: Eliminate high temperatures during heating season at upper levels by use of fans, tubes, entrainment by air jets or drawing return air from high level. Make-up 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: Destratification in summer could increase cooling load.
COST FACTORS:
INTERACTIONS: May reduce peak demand on heating equipment and aggravate oversizing. See ECO R.25.
EVALUATION: AP R.5 gives details of technique for evaluating marginal cases or quantifying actual savings.
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 10 m and by 15 to 30 % for a height of more than 10 m. The corresponding numbers for forced air downward from high level are 5 to 10 % and 10 to 20 %, respectively.
REFERENCES: Fizzel, 1977.

ECO R.18 AIR ECONOMISER
LEVEL: Improvement/Replacement.
DESCRIPTION: Use air for free cooling by employing air economiser cycle. See text, App. C, Section 5.2, for discussion of principles involved.
APPLICATION:
SIDE BENEFITS: Enhanced air quality (as opposed to fixed minimum air system) during free cooling.
CAUTIONS:
COST FACTORS: Temperature controlled system less costly than enthalpy but theoretically less efficient. (Shavit, 1984.)

INTERACTIONS: Actual control of economiser should be such as to minimise heating and cooling. See ECO R.7 (Sequence Heating and Cooling). *Alternative* ECO: air to air recovery (ECO H/C.17). On dual duct or multizone air economiser can increase fuel cost if heating cost greater than cooling cost (See Comments). See also ECO R.4, R.5, R.27, D.2, C.13.

EVALUATION: Evaluation of savings normally requires the use of an hourly calculation technique or bin method (see AT M.1 and M.2). Where only control changes are required, cost most often justifies the change.

COMMENTS: Enthalpy economiser sensors are considered somewhat unreliable by some engineers. Careful selection of air temperature set-points can supply saving nearing those theoretically possible with enthalpy control.

Since the economiser cycle is basically a cooling energy saver, its direct application to multizone and dual duct system can in cases <u>not</u> 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; CIBSE B3, 1986.

ECO R.19 EVAPORATIVE COOLING

LEVEL: Improvement/Replacement.

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.

SIDE BENEFITS:

CAUTIONS:

COST FACTORS:

INTERACTIONS: See ECO R.3 and R.6.

EVALUATION: See AT R.5. RV R.8 gives design information on evaporative coolers.

COMMENTS: Will need to be sequenced carefully with deck temperature and economiser control.

REFERENCES: Eskra, 1980; Supple, 1982; Meyer, 1983; Pearson, 1982; and Dombroski, 1984.

ECO R.20 LOCATE MAKE-UP AIR AT EXHAUST HOODS

LEVEL: Improvement/Replacement.

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 (BSRIA, 1983) and other high exhaust zones.

SIDE BENEFITS: Supply of cool or fresh air at source of pollution can improve worker comfort.
CAUTIONS:
COST FACTORS:
INTERACTIONS: Consider replacement or modification along with ECO R.21 and with adjusting vent rate to varying requirement (ECO D.2). See ECO R.34 for fume hood applications. See also ECO R.26, R.36.
EVALUATION: See AT R.1. Often up to 70 to 85% of air can be supplied unconditioned or conditioned at a temperature other than room temperature. See also RV R.4.
COMMENTS:
REFERENCES: BSRIA, 1983; Dubin, 1975.

ECO R.21 HIGH VELOCITY TYPE EXHAUST HOODS
LEVEL: Improvement/Replacement.
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).
APPLICATION:
SIDE BENEFITS: Capture efficiency can be improved with lower air volumes with consequent saving in fan power and make-up air conditioning requirements.
CAUTIONS:
COST FACTORS:
INTERACTIONS: Consider replacement or modification along with ECO R.20. See also ECO R.26, R.36.
EVALUATION: See AT R.1 and RV R.4.
COMMENTS: Existing hoods can be modified by installing baffles inside the hood.
REFERENCES: Dubin, 1975.

ECO R.22 CONVERSION TO VAV
LEVEL: Improvement/Replacement.
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). Set setpoints as low as possible consistent with diffuser and air movement performance and ventilation requirements.
APPLICATION: Primarily applicable to terminal reheat and dual duct systems. Some applications for multizone systems.
SIDE BENEFITS:
CAUTIONS: Usually close control of space relative humudity is compromised. Low air volumes in direct expansion refrigerant systems may cause frosting at coils. Air diffusion quality in the space can be compromised at low air flow rates; fan driven terminals to maintain local circulation can minimise such effects.
COST FACTORS: Maximal savings with throttle type VAV boxes.
INTERACTIONS: Will need to add fan volume control to protect against duct over-pressurization and to maximise fan power saving. See ECO

R.32. This ECO is one particular option for improving zone control. See also ECO R.9, R.13, R.42.

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. Reheat may still be necessary in some zones.

REFERENCES: Wendes, 1983; Reed, 1983; Pannkoke, 1980; Pearson, 1985; Johnson, 1985; Haines, 1984; Honeywell, 1976.

ECO R.23 DEADBAND THERMOSTATS

LEVEL: Improvement/Replacement.

DESCRIPTION: Replace existing space thermostats with deadband type or set existing heat and cool set-points with deadband. NOTE: This is a specific form of sequencing (see ECO R.7)

APPLICATION: 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.

SIDE BENEFITS:

CAUTIONS: Wide deadband can compromise comfort.

COST FACTORS: Negligible cost if set-point adjustment is all that is required.

INTERACTIONS: Deadband control may not always be most desirable form in "building heat recovery/redistribution" schemes. (ECO R.25). See also ECO R.28 and EL.6.

EVALUATION: Reliable estimation of savings normally requires the use of an hourly energy analysis program.

COMMENTS:

REFERENCES: Fullman, 1981; Paoluccio, 1981; Haines, 1984.

ECO R.24 LOAD RESET (DISCRIMINATOR) CONTROL

LEVEL: Improvement/Replacement.

DESCRIPTION: Reset deck temperature in reheating 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 increased fan power may negate any chiller savings resulting from cooling or COP improvements. Main applications are Terminal Reheat, Multizone and Dual Duct Systems.

SIDE BENEFITS:

CAUTIONS:

COST FACTORS:
INTERACTIONS: Some chiller COP benefit can be obtained by resetting chilled water temperature up with cold deck temperature (ECO R.30). See also ECO R.7, R.9, R.28, R.41, R.42.
EVALUATION: Evaluation of savings normally requires the use of hourly analysis techniques.
COMMENTS: Some loss of humidity control can be expected. In dual duct and 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 minimise recool (3- and 4-pipe) and/or over-cooling(2-pipe) in summer. Check, however, secondary heating and cooling capacity adequate.
REFERENCES: Alexander, 1984; Spethmann, 1977; Haines, 1984.

ECO R.25 AIR MIXING BETWEEN ZONES FOR UTILISATION OF ZONE EXCESS HEAT OR EXHAUST MAKEUP
LEVEL: Improvement/Replacement.
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 or exhaust air from one zone can reduce use of fresh air for another zone. Examples include:
i) Circulating air between an attached sunspace at the main occupied space when the sunspace temperature is higher than the occupied space,
ii) 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,
iii) Discharge exhaust air into a parking garage space.
APPLICATION: Buildings where simultaneous needs for both heating and cooling can be identified or zones with less requirements for fresh air.
SIDE BENEFITS: Possibility of more even temperatures between different parts of the building.
CAUTIONS: Avoid mixing air between "dirty" and "clean" areas. It may be necessary to install smoke sensors to shut ventilation off or smoke dampers to prevent spreading smoke from one zone to another.
COST FACTORS:
INTERACTIONS: This ECO may be desirable as part of ECO E.33 (Close of balconies to make sunspace/greenhouse). An alternative strategy would be to install a heat pump heat recovery system (see ECO R.43). ECO R.17 (Minimise stratification) is a special case of this ECO where the two zones are not physically separated and are arranged one above the other. See also ECO R.16, R.23, R.28, R.41.
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 (Jones, 1985) if excess heat from internal and southerly exposed areas are utilised effectively.

COMMENTS:
REFERENCES: Jones, 1985.

ECO R.26 INSTALL LOCALISED EXHAUST/MAKEUP AIR SYSTEMS
LEVEL: Improvement/Replacement.
DESCRIPTION: Replace large central systems with small local and independently controlled exhaust systems or provide dampers in central systems at point of extract, e.g. garage (car exhaust), welding hoods, fume cupboards.
APPLICATION: Where large number of exhaust stations are provided requiring only intermittent use.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS:
INTERACTIONS: Consider along with ECO R.26 and R.21. See also ECO R.9, R.36, D.2.
EVALUATION: See AT R.1. Some idea of the frequency of use is required for an evaluation.
COMMENTS:
REFERENCES: Goldfield, 1985.

ECO R.27 DISCONTINUE OR RELOCATE PRE-HEAT COILS
LEVEL: Improvement/Replacement.
DESCRIPTION: Remove pre-heat coils or relocate after mixing box.
APPLICATION: 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.
COST FACTORS:
INTERACTIONS: If installed either before or after mixing box, ensure proper sequencing (see ECO R.7). ECO might be considered along with the installation/conversion to air economiser operation (ECO R.18). Removal may permit fan size reduction (see ECO D.8).
EVALUATION:
COMMENTS: Pre-heat coils usually installed to minimise risk of freezing but often can be eliminated by <u>proper mixing</u>, i.e. avoiding stratification. If this step is not ensured, freeze up may result.
REFERENCES: Haines, 1980.

ECO R.28 INSTALL EMS SYSTEM
LEVEL: Improvement/Replacement.
DESCRIPTION: Install energy management systems to schedule equipment operation. More sophisticated system also provide actual control capabilities, e.g.; Direct Digital Control Systems.
APPLICATION:

SIDE BENEFITS: Demand shedding to avoid high energy cost can be improved with EMS system.
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 increase with number of control points. Can be high cost.
INTERACTIONS: Basic EMS functions include ECO Numbers: R.1, R.2, R.4, R.5, and R.7. Advanced systems with control capabilities can be used for implementing ECO Numbers R.8, R.23, R.24, R.25, R.43, P.3, D.2, C.3 and L.17. EMS will have applications for central plant, HVAC lighting, distribution, ECOs and electrical systems.
EVALUATION: Desirability and type of system suitable will be most influenced by the number and type (binary or analog, input or output) of control functions (i.e. amount of equipment to be controlled and manner in which it is controlled).
COMMENTS:
REFERENCES: Haines, 1982; Birtles, 1984; Gardener, 1984; BRE Digest 289, 1984; BRE IP 2/85, 1985; BRE IP 3/83, 1983.

ECO R.29 STRATIFICATION SPLITTERS
LEVEL: Improvement/Replacement.
DESCRIPTION: Modify mixing section to direct warmer return air to hot deck and cooler outside air to cold deck.
APPLICATION: Applicable to some types of dual duct and multizone systems with built up central station plant.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS:
INTERACTIONS:
EVALUATION: Detailed hourly analysis methods are normally required for reliable estimates of savings.
COMMENTS:
REFERENCES: Dubin, 1975.

ECO R.30 CYCLE AIR CONDITIONING
LEVEL: Improvement/Replacement.
DESCRIPTION: Cycle compressor operation 10-15 minutes and run fan after compressor stops to re-evaporate condensation formed on the coil (benefit from evaporative cooling effect).
APPLICATION: Small central air conditioning installations with fan forced air circulation.
SIDE BENEFITS:
CAUTIONS: Increased space humidity value depending on cycle frequency.
COST FACTORS:
INTERACTIONS:
EVALUATION: See ref.
COMMENTS:
REFERENCES: Kinsey, 1979.

ECO R.31 CORRECT POOR CONTROL VALVE SELECTION
LEVEL: Improvement/Replacement.
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.
SIDE BENEFITS: Improved control stability. Prolonged life of steam coils.
CAUTIONS:
COST FACTORS:
INTERACTIONS: Load reductions can aggravate poor control valve selection problems by forcing operation more near to the valve closed position. See ECO R.9.
EVALUATION:
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; CIBSE B11, 1985.

ECO R.32 VAV FAN CONTROL IN AC SYSTEMS
LEVEL: Improvement/Replacement.
DESCRIPTION: Provide or improve fan flow/duct over pressure control by providing speed control or inlet guide vanes or variable pitch vane axial fans.
APPLICATION: VAV systems.
SIDE BENEFITS: Lower pressures will result in lower leakage from ductwork and past dampers.
CAUTIONS:
COST FACTORS: Usually high but generally good paybacks possible.
INTERACTIONS: ECO R.40 (Replacement of ceiling dump boxes). See also VAV Control for Fume Hoods (ECO R.34), ECO R.22 (Conversion to VAV), ECO EL.6 (Motor speed control).
EVALUATION: RV R.6 gives typical power/flow characteristics for a range of fan control means. A bin (see AT M.2) or hourly analysis method is normally required to estimate fan energy savings.
COMMENTS:
REFERENCES: Trane, 1979; Honeywell, 1976.

ECO R.33 USE COOLING COIL FOR BOTH HEATING AND COOLING DUTIES
LEVEL: Improvement/Replacement.
DESCRIPTION: When heating and cooling is not needed during some period, remove heating coil and pipe heating to cooling coil with appropriate control/isolating valves.
APPLICATION:
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:
COST FACTORS:

INTERACTIONS: This ECO is one way of sequencing heating and mechanical cooling (see ECO R.7)
EVALUATION:
COMMENTS:
REFERENCES:

ECO R.34 VARIABLE VOLUME CONTROLS FOR FUME HOODS
LEVEL: Improvement/Replacement.
DESCRIPTION: Add variable air volume controls to existing fume hoods to maintain nominally constant sash opening velocity over the range of such opening positions. Alternative - replace old hoods with new hoods with VAV controls.
APPLICATION: All fume hood applications, particularly those where the fume hoods operate continuously (hoods containing toxic equipment often have to operate continuously).
SIDE BENEFITS:
CAUTIONS: Some devices have proved to create operation problems and noted potential problems include: i) sensing devices interfere with access to hood, ii) low discharge velocity (at building exterior) can create re-entry problems, iii) relative pressures reversed between "clean" and "dirty" areas, and iv) incomplete scavaging of all parts of hood at the lower velocity.
Users must be trained to close the sashes, otherwise the savings will <u>not</u> be realized.
COST FACTORS: High payback potential, particularly in extreme climates.
INTERACTIONS: Air to air heat recovery (ECO H/C.17) can be considered as an alternative. Supplying partially conditioned make up air at the hood (ECO R.20) can be considered complimentary. See also ECO R.32.
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. See AT R.1.
COMMENTS:
REFERENCES: Bentson, 1985; Wiggin, 1985.

ECO R.35 MECHANICAL DEHUMIDIFICATION IN SWIMMING POOL HALLS
LEVEL: Replacement.
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.
APPLICATION: Swimming pools and spas.
SIDE BENEFITS: Possible to obtain lower pool hall humidity at <u>lower</u> energy costs than with ventilation. Water consumption 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.

COST FACTORS:

INTERACTIONS: Air to air heat exchanger (ECO H/C.17) or humidistat control of ventilation (ECO R.25) would be alternate or complimentary strategies, alternative if the same ventilation air charge rate is maintained or complimentary if the heat exchanger is applied to the reduced volume of outside air supplied. See also ECO M.10.

EVALUATION: See AT R.6 and R.7.

COMMENTS: In winter the heat from the compressor contributes to the space heating of the pool hall.

REFERENCES:

ECO R.36 ADSORPTION FILTERS

LEVEL: Replacement.

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.

APPLICATION: Kitchens in dwellings.

SIDE BENEFITS:

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: Alternative to R.20, R.21, R.26.

EVALUATION: See AT R.2.

COMMENTS: Check that such an option complies with building codes.

REFERENCES: Dubin, 1975; ASHRAE Equipment, Ch. 11, 1983.

ECO R.37 LOCAL HEATING AND COOLING

LEVEL: Replacement.

DESCRIPTION: Use local heating and cooling for comfort conditioning only in those locations where it is required in place of conditioning the complete building space.

APPLICATION: Most potential in large open spaces with low occupancy, e.g. warehouses.

SIDE BENEFITS: Can be adjusted to meet local needs.

CAUTIONS:

COST FACTORS:

INTERACTIONS: Consider radiant heating (ECO R.38).

EVALUATION:

COMMENTS: Local space design and freedom from drafts are important to achieve acceptable comfort levels.

REFERENCES: Azer, 1985.

ECO R.38 RADIANT HEATING
LEVEL: Replacement.
DESCRIPTION: Replace or supplement air heating with "High temperature small source" or "Low temperature large source" heating.
APPLICATION: Often found advantageous in large, high and open spaces such as factories. Response is rapid (immediate warm up, quick cool down) making application for intermittent 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 minimise infiltration and ventilation losses..
CAUTIONS: Not appropriate where atmosphere contains ignitable dust, gases or vapors.
COST FACTORS:
INTERACTIONS: Can be used as local heating (see ECO R.37).
EVALUATION: See AT R.8. Savings as high as 50% compared to "convection heating systems" are claimed to be possible.
COMMENTS:
REFERENCES: Fitzgerald, 1983; Burgess, 1984; Jones, 1985; CIBSE B1, 1986.

ECO R.39 DIRECT GAS FIRED MAKEUP UNITS
LEVEL: Replacement.
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, door entrance heaters and commercial kitchens.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Typically 20 to 40% more efficient than indirect units. Also cheaper capital cost than indirect.
INTERACTIONS: Consider along with ECO R.16 (CO controlled ventilation).
EVALUATION: See AT R.4.
COMMENTS:
REFERENCES:

ECO R.40 REPLACE CEILING DUMP BOXES
LEVEL: Replacement.
DESCRIPTION: Replace ceiling dump boxes (Bypass type) with throttle type volume control boxes.
APPLICATION: VAV systems.
SIDE BENEFITS:
CAUTIONS: Care must be exercised with direct expansion equipment where minimum air flow must be maintained over a coil to prevent ice formation.
COST FACTORS:
INTERACTIONS: See ECO R.32 for fan control options. Fan/duct pressure control may be required and in most cases is desirable.
EVALUATION: Evaluation of fan energy savings normally requires use of an hourly energy analysis program.

COMMENTS:
REFERENCES: Pannkoke, 1980.

ECO R.41 RE-COOL COILS
LEVEL: Replacement.
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:
COST FACTORS:
INTERACTIONS: Possible interference with ECOs R.7, R.25. Consider along with ECO R.24.
EVALUATION: Evaluation of energy savings normally requires the use of an hourly energy analysis program.
COMMENTS:
REFERENCES:

ECO R.42 INDIVIDUAL COILS IN MULTIZONE SYSTEM
LEVEL: Replacement.
DESCRIPTION: Replace systems with single pair (heat and cool) coils with systems having pair of coils per zone.
APPLICATION: Applicable to multizone systems only.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Normally only economical if the unit is nearing the end of its useful life.
INTERACTIONS: Alternative ECO R.22. Consider along with ECOs R.7, R.24 or consider replacement with an inherently more efficient system (ECO R.43).
EVALUATION: Evaluation of energy savings normally requires the use of an hourly energy analysis program.
COMMENTS:
REFERENCES: Dubin, 1975.

ECO R.43 SYSTEM REPLACEMENT
LEVEL: 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:
COST FACTORS: High cost.
INTERACTIONS: See also ECO R.25, R.42.

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. See RV R.11.

COMMENTS: More efficient HVAC systems will normally have variable volume air delivery, may utilise heat pumps for heat recovery and heat redistribution purposes, and may utilise 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 or all cooling it would be logical to have different heating and cooling set-points, e.g. 20°C heating; 26°C cooling. However, for the case where the building has coincident demands for both heating and cooling, it may be beneficial 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.

REFERENCES:

ECO H.1 SHUT BOILER PLANT OFF WHEN NOT REQUIRED
LEVEL: Operations.
DESCRIPTION: Close off boiler plant and auxiliaries when heat is not required, i.e. when building is unoccupied; when the need of heat is zero; or when heat storage may cover the heating need for several hours.
APPLICATION: All boiler plants.
SIDE BENEFITS: Reduced operation of system auxilaries, e.g., pumps, fans.
CAUTIONS: Condensation in boiler created by lower temperatures can reduce its life. Danger of freezing by low outdoor temperature. May affect comfort after the interruption.
COST FACTORS: Negligible cost, if done manually, although using automatic means (time clocks, energy management systems) give more reliable and greater saving, particularly if optimum start is adopted.
INTERACTIONS: Change of interior environment of the building influencing its use. See Regulation ECOs. Turn circulating pump off with boiler, see ECO P.3. Preconditioning period must be set with consideration of the ability of the heating plant to bring the building back to comfort level in time, see ECO H.20 (Install heat storage), ECO H.6 (Reset boiler aquastat), ECO H.10 (Repair boiler insulation), ECO H.18 (Install separate SHW heater).
EVALUATION: Cost of automatic control could be compared to savings from reduced stand-by losses (AP H.2 and RV H.2). See also AP H.4.
COMMENTS:
REFERENCES:

ECO H.2 TURN PILOT LIGHTS OFF IN GAS EQUIPMENT WHEN NOT REQUIRED
LEVEL: Operations.
DESCRIPTION: Turn gas pilot light off.
APPLICATION: Gas burners with pilot (as opposed to electric ignition systems).
SIDE BENEFITS: Can improve lifetime of equipment.
CAUTIONS:
COST FACTORS: Negligible cost if done manually.
INTERACTIONS:
EVALUATION: Energy saving proportional to the power of the gas pilot and to the period of the interruption.
COMMENTS:
REFERENCES:

ECO H.3 REDUCE NUMBER OF ON-LINE BOILERS AS LOAD REDUCES
LEVEL: Operations.
DESCRIPTION: Turn off the boilers as load reduces and isolate (separate) 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.
INTERACTIONS: Consider in conjunction with the sequencing of boiler firing (ECO H.23). Consider also isolating gas side. See also ECO H.10 (Upgrade boiler insulation).
EVALUATION: Energy saving determined from the reduction of the standby losses of the boilers (AP H.2 and RV H.2).
COMMENTS: With many oversized heating plants, additional boilers can be shut off semipermanently.
REFERENCES:

ECO H.4 CONTROL PROPER ATOMIZATION OF OIL
LEVEL: Operations/Improvement.
DESCRIPTION: Efficient combustion of oil depends greatly on the proper atomization of the oil and the correct air turbulence at the nozzle. Preheating of the oil may increase the combustion quality and the heat output.
APPLICATION: Heavy fuel oil burners.
SIDE BENEFITS: Decreased soot formation and deposit.
CAUTIONS:
COST FACTORS: Of most interest if the burner has to be changed.
INTERACTIONS: ECO H.8 (Service burner), ECO H.21 (Use fuel additives), ECO H.22 (Install oxygen trim), ECO H.17 (Install more efficient burner).
EVALUATION: Check if poor combustion justifies a change of burner. See AP H.1.
COMMENTS:
REFERENCES:

ECO H.5 REDUCE BLOWDOWN LOSSES
LEVEL: Operations/Improvement.
DESCRIPTION: Minimise blowdown losses by replacing regular (periodic) blowdown practices by: i) blowing down only when monitored suspended solids levels increase beyond that desirable and/or ii) recovering heat from blowdown to preheat make-up water.
APPLICATION: Steam boilers.
SIDE BENEFITS: Reduced water treatment costs if time between blowdowns increased.
CAUTIONS:
COST FACTORS: Automatic blowdown system based on solids monitoring must be weighted against time spent by maintenance personnel and costsinvolved with treating boiler water to reduce solids formation.
INTERACTIONS:
EVALUATION:
COMMENTS:
REFERENCES: Oven, 1983.

ECO H.6 RESET BOILER AQUASTAT WITH HEAT DEMAND

LEVEL: Operations/Improvement.

DESCRIPTION: Reduce boiler aquastat set-point as demand for heat drops (can be automated to adjust for climatic variations). For water systems water temperature can be regulated by resetting boiler aquastat. Outside air temperature reset can also be applied to the control of the primary air temperature in induction systems (an alternate is room temperature reset). For steam systems the same kind of control can be obtained by: i) "heat timers" which vary the amount of steam allowed into the distribution system as a function of outside temperature; ii) "zone control valves". These are usually ON/OFF type valves controlled by outdoor temperature sensors; iii) varying the vacuum pressure in variable vacuum distribution systems; iv) pressure differential control in which the steam supply pressure is varied. This system needs 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 ^{o}C for oil cast-iron boilers, 57 ^{o}C for oil welded boilers, 35-60 ^{o}C for natural gas.

COST FACTORS: Negligible cost if done manually. Higher cost if mautomatic, but prefered method of control.

INTERACTIONS: Alternative is to control temperature of heating fluid to spaces by a mixing valve. See also ECO H.1 (Shut boiler plant off when not required). Sophistications include solar and wind compensation.

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.

COMMENTS:

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

ECO H.7 MAINTAIN CORRECT SYSTEM PRESSURIZATION

LEVEL: Operations.

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.

SIDE BENEFITS:

CAUTIONS: Balance of the system is dynamic (see AP P.1) and therefore typical cycles of heating should be observed to guarantee no water is lost.
COST FACTORS: Provided original equipment is properly sized to adjust for system dynamics, not cost is involved.
INTERACTIONS: Interaction with Regulation and Piping items could alter volumes involved. See ECO P.2 (Bleed air), P.4 (Maintain proper water level), P.11 (Atmospheric pressure).
EVALUATION: See CAUTION.
COMMENTS: Low system pressurization can allow air to enter the system resulting in air traps and accelerated pipe scaling.
REFERENCES:

ECO H.8 SERVICE BURNER AND ADJUST AIR-FUEL RATIO
LEVEL: Operations.
DESCRIPTION: Service burner and adjust air-to-fuel ratio in oil or gas burners to achieve the highest combustion efficiency.
APPLICATION: Gas and oil boilers.
SIDE BENEFITS: Decrease of the air pollution and the production of soot.
CAUTIONS: Condensation in the chimney may cause damage. This occurs if the flue gas temperature or if the running time of the burner are too low.
COST FACTORS: Belongs in normal maintenance of the burner.
INTERACTIONS: ECO H.16 (Decrease firing rate of burner), see also ECO H.22 (Oxygen trim) and ECO H.9 (Remove scale and soot). ECO H.17 (Install more efficient burner), ECO H.19 (Flue gas heat exchanger), H.21 (Use fuel additives).
EVALUATION: Part of normal maintenance; carry out at same time as measuring combustion efficiency (AP H.1 and RV H.1).
COMMENTS: Function time of the burner by each run depends also on the thermostat setting and its differential.
REFERENCES:

ECO H.9 REMOVE SCALE AND SOOT
LEVEL: Maintenance.
DESCRIPTION: Removal of scale and soot to increase the heat transfer from combustion gases to the boiler and for lowering the flue temperature, i.e., improve efficiency.
APPLICATION: Fuel fired boilers.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Belongs as part of normal maintenance.
INTERACTIONS:
EVALUATION:
COMMENTS: ECO H.8. Soot formation can be minimized by correctly adjusted air-fuel ratio. Consider installation of soot blowers. Proper water treatment will minimise build-up on the water side.
REFERENCES:

ECO H.10 REPAIR OR UPGRADE INSULATION ON BOILER/FURNACE
LEVEL: Maintenance/Improvement.
DESCRIPTION: Repair or upgrade the insulation of boiler, furnace and piping to reduce radiation and convection heat losses.
APPLICATION:
SIDE BENEFITS: Reduced boiler room temperatures.
CAUTIONS: Do not block up the entrance for combustion air. Do not use inflammable insulation material.
COST FACTORS: Low cost.
INTERACTIONS: Reduces the effectiveness of ECO H.1 (Shut boiler plant off when not required) and ECO H.3 (Reduce number of on-line boilers). See also ECO P.6.
EVALUATION: Energy saving effectiveness increases with oversized boilers and high service temperature. See AP H.2 and AT P.1.
COMMENTS:
REFERENCES:

ECO H.11 REPAIR REFRACTORY
LEVEL: Replacement/Improvement.
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.
CAUTIONS:
COST FACTORS: Low if minor repairs are required. Replacement can be very expensive.
INTERACTIONS: ECO H.24 (Replace obsolete boiler).
EVALUATION: Measure combustion efficiency (AP H.1).
COMMENTS: Boiler innerchamber may benefit from size reduction by adding additional refractory where the burner has been derated.
REFERENCES:

ECO H.12 INSTALL AIR INLET AT FOOT OF CHIMNEY
LEVEL: Improvement.
DESCRIPTION: Install air inlet at foot of chimney. If chimney is under pressure during burner operation the inlet must be controlled by automatic damper.
APPLICATION: Small to medium sized boiler plants.
SIDE BENEFITS: Reduces heat loss of boiler by internal ventilation when burner is off (air flow through hot boiler is avoided as air passes directly into chimney). Helps to dry up chimneys with condensation problems. Lowers dew-point of flue gas and risk for condensation during burner operation; fuel flow rate might be lowered.
CAUTIONS: Possibility of flue gases passing into boiler room. Check local codes for acceptability.
COST FACTORS: No cost if inlet remains open (just remove explosion security flap).
INTERACTIONS: Alternative to flue dampers (ECO H.13).
EVALUATION:
COMMENTS:

REFERENCES:

ECO H.13 INSTALL FLUE DAMPERS
LEVEL: Improvement.
DESCRIPTION: Install flue dampers to limit off cycle heat loss up the chimney.
APPLICATION: All boiler plants without power burners or uncontrolled draught. Particularly beneficial on multi-unit plant where one boiler is kept warm. Less benefit with furnacees since retained furnace heat less than retained heat in the water system.
SIDE BENEFITS: Reduced air infiltration (closed flue decreases stack induced infiltration).
CAUTIONS:
COST FACTORS: Typical cost for small domestic boiler a few hundred dollars.
INTERACTIONS: ECO H.17 (Install more efficient burner) and ECO H.12 (Install air inlet).
EVALUATION: Evaluation must involve on and off cycles, therefore MT H.1 (Running time of boiler/furnace) or AT M.1 (Energy signature).
COMMENTS: Energy savings range from 1-2% to almost 10% in the ideal application.
REFERENCES:

ECO H.14 INSTALL TURBULATORS
LEVEL: Improvement.
DESCRIPTION: Install turbulator to increase heat transfer from combustion gases to the boiler and to decrease flue gas temperature.
APPLICATION: Fire tube boilers.
SIDE BENEFITS: Increased boiler capacity.
CAUTIONS:
COST FACTORS:
INTERACTIONS: Alternative or complimentary to ECO H.19 (Flue gas heat recovery) and ECO H.15 (Decrease firing rate of burner).
EVALUATION: Base potential on amount by which flue gas temperature exceeds 230°C. Energy saving can reach up to 18%, but can also be negative!
COMMENTS:
REFERENCES: STWA, 1983

ECO H.15 DECREASE FIRING RATE OF THE BURNER OR FIT SMALLER BURNER
LEVEL: Improvement.
DESCRIPTION: Change burner nozzles or orifices, adjust secondary flow flue restrictor, or replace burner with a smaller one.
APPLICATION: Oversized combustion equipment (high flue gas temperature).
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.

INTERACTIONS: ECO H.8 (Service burner). Consider upgrading to quality of the burner (ECO H.24). ECO H.14 (Install turbulators), H.16 (Install dual fuel burner).
EVALUATION: Potential benefit proportional to amount by which flue gas *temperature exceeds 230°C. Short cycling indicative of* oversized burner (see MT H.1 and MT H.2). See also AP H.4.
COMMENTS:
REFERENCES: Macriss, 1985.

ECO H.16 INSTALL DUAL FUEL BURNER
LEVEL: Improvement.
DESCRIPTION: Install burner for both oil and gas combustion, or solid-liquid solid-gas combination.
APPLICATION: Where better fuel tariff is available with interrupt clause.
SIDE BENEFITS: More secure energy supply.
CAUTIONS: Does not normally result in energy saving unless more efficient burner is selected.
COST FACTORS:
INTERACTIONS: ECO H.15 (Fit smaller burner), ECO H.24 (Replace plant), ECO H.19 (Flue gas heat recovery).
EVALUATION: Savings can be estimated based on differences in the fuel tariff cost.
COMMENTS:
REFERENCES:

ECO H.17 INSTALL MORE EFFICIENT BURNER
LEVEL: Improvement.
DESCRIPTION: Install multi-stage burner or modulating burner. Electronic ignition. Air rather than steam atomization.
APPLICATION: All boilers except modular boiler systems.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS:
INTERACTIONS: Alternatives are ECO H.8 (Adjust air-fuel ratio) and ECO H.4 (Proper atomization).
EVALUATION: Estimate of improved seasonal efficiency will be required (see AT H.1).
COMMENTS:
REFERENCES:

ECO H.18 INSTALL SEPARATE (SUMMER) SHW HEATER
LEVEL: Improvement.
DESCRIPTION: Install separate heater for SHW, for constant use alternatively only to be used during summer.
APPLICATION: Combined space heat and SHW system (ECO eliminates high summer stand-by losses), primarily large systems.
SIDE BENEFITS:
CAUTIONS: May not be cost effective, depending on individual system. Shutting off boiler plant when not required may be more efficient, i.e., if SHW storage exists.

COST FACTORS: Effectiveness of summer use only increases with i) oversizing of system with respect to summer demands, ii) decreasing distribution efficiency, iii) length of nonheating season and iv) increasing SHW consumption.
INTERACTIONS: ECO H.1 (Shut boiler off), ECO P.6 (Repair or improve storage insulation), ECO P.3 (Turn circulation equipment off), ECO H.20 (Install heat storage).
EVALUATION: Cost-efficiency depends on local tariff structure among oil, gas and electricity. Estimation of differences in stand-by losses for heating plant and separate SHW heater required (AP H.2).
COMMENTS:
REFERENCES: Dubin, 1976; BRE CP 44/78, 1978.

ECO H.19 USE FLUE GAS HEAT EXCHANGER
LEVEL: Improvement.
DESCRIPTION: Install flue gas heat exchanger (economiser).
APPLICATION: 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.
SIDE BENEFITS:
CAUTIONS: Condensation in chimney.
COST FACTORS:
INTERACTIONS: ECO H.8 (Adjust air-fuel ratio), ECO H.14 (Install turbulators), ECO H.16 (Decrease flow rate of burner), ECO H.24 (Replace obsolete heating plant).
EVALUATION: Generally worthwhile if flue gas temperature cannot be brought lower than 230^{o}C, by other means. See MT H.2.
COMMENTS:
REFERENCES:

ECO H.20 INSTALL HEAT STORAGE
LEVEL: Improvement/Replacement.
DESCRIPTION: Install heat storage for heating or for SHW with high insulation of the connecting pipes and of the storage tank.
APPLICATION: General.
SIDE BENEFITS: Charging heat storage can often be carried out at peak boiler efficiency.
CAUTIONS:
COST FACTORS:
INTERACTIONS: ECO H.1 (Shut boiler plant off when not required), ECO P.3 (Switch off circulation equipment), ECO P.6 (Repair/upgrade damage insulation), ECO H.18 (Install separate SHW heater).
EVALUATION: Energy saving corresponds to stand-by losses of the boiler which can be shut off for longer periods, less storage losses (AP H.2, AT P.1).
COMMENTS:
REFERENCES:

ECO H.21 USE FUEL ADDITIVES
LEVEL: Improvement.
DESCRIPTION: Use fuel additives with regular fuel oil for (possible) improved combustion efficiency and less soot formation.
APPLICATION: Large oil heating plants.
SIDE BENEFITS:
CAUTION: Many fuel additives have been found to be totally ineffective.
COST FACTORS:
INTERACTIONS: ECO H.8 (Adjust air-fuel ratio), ECO H.14 (Control proper atomization), ECO H.17 (Install more efficient burner).
EVALUATION: Measure combustion efficiency (AP H.1) with and without fuel additive.
COMMENTS: Consider fuel-water emulsions as having most potential.
REFERENCES:

ECO H.22 INSTALL AUTOMATIC OXYGEN TRIM CONTROLLER
LEVEL: Maintenance.
DESCRIPTION: Install automatic oxygen trim controller (combustion optimisation system) to maintain safe excess air level over varying fuel and air conditions.
APPLICATION: Commercial and institutional size boilers burning fossil fuels with jack-shaft or pneumatic controls.
SIDE BENEFITS:
CAUTION:
COST FACTORS: Paybacks of the order of less than one year have been claimed for large boiler applications.
INTERACTIONS: Eliminates need for ECO H.4 (system compensates for changing fuel viscosity) and manual adjustment of fuel air ratio (ECO H.8).
EVALUATION:
COMMENTS:
REFERENCES:

ECO H.23 SEQUENCE FIRING OF MULTI-UNIT BOILER PLANT
LEVEL: Improvement.
DESCRIPTION: Fire no more boilers at any one time than is sufficient 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.
SIDE BENEFITS:
CAUTION: The sequence should be verified through field measurements or monitoring.
COST FACTORS:
INTERACTIONS: Complimentary to ECO H.3 (On-line boiler control).
EVALUATION: Measure running time and starting frequency of individual boiler (MT EL.7) for different loads.
COMMENTS: The most efficient boiler should be used as the lead boiler.
REFERENCES:

ECO H.24 REPLACE OBSOLETE HEATING PLANT

LEVEL: Replacement.

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

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

SIDE BENEFITS:

CAUTION:

COST FACTORS: High cost retrofit.

INTERACTIONS: ECO H.1 to H.3 (Boiler control); ECO H.8 (Boiler and heat plant improvements), ECO H.11 (Repair refractory),ECO H.15 (Decrease firing rate), ECO H.16 (Install dual fuel burner), ECO H/C.14 (Compressor capacity), ECO R.2 (Setback temperatures.)

EVALUATION: Desirability of retrofit influenced by boiler and burner age, combustion efficiency, extent of outstanding maintenance, compatibility with the installation of a more efficient burner. (See AP H.1, AP H.3 and RV H.3.)

COMMENTS:

REFERENCES: Kelly, 1975.

ECO H.25 USE OF EXHAUST AIR AS HEAT SOURCE FOR HEAT PUMPS

LEVEL: Improvement/Replacement.

DESCRIPTION: Install heat pump to utilize exhaust air as heat source. Check for potential external customers if excess energy can be produced.

APPLICATION: Buildings with heating or SHW demand, equipped with mechanical ventilation.

SIDE BENEFITS: Ventilation systems will be checked.

CAUTION: SHW demand is often over-estimated. Check flow/pressure capacity of existing fans to cope with increased pressure drop. Consider noise problems. Direct expansion systems can have problems with long refrigerant tubes in large buildings (oil return, pressure drop). Check duct tightness (AP D.1).

COST FACTORS: New installation is costly, especially if conversion to mechanical ventilation is needed. Mostly cost-effective. Savings are normally much greater than by use of heat exchangers, especially if there is a demand for SHW.

INTERACTIONS: ECOs on SHW, ventilation and central heating plant.

EVALUATION: To establish the potential savings measure the exhaust air flow rate (MT D.2 through D.5), temperature and humidity (MT D.7). Also determine the SHW consumption (AP S.5, RV S.1) and calculate the heat load and the seasonal performance factor of heat pumps (AT H/C.1). This will make it possible to estimate the profitability of the ECO. Exhaust air should be cooled as much as possible.

COMMENTS: Dependent on relation between cost for different energy sources.

REFERENCES: Bergstrom, 1985.

ECO H.26 FIREPLACE UPGRADE/REPLACEMENT
LEVEL: Replacement/Improvement/Maintenance.
DESCRIPTION: i) Replace existing fireplaces with airtight stoves of fix glass firescreen doors or heat recovery devices, ii) close fireplace dampers when not in use, make sure dampers are not distorted by heat, if so replace with heavier gauge steel.
APPLICATION: Homes with open hearth fireplaces that are used on a regular basis.
SIDE BENEFITS: Improved security against fire hazard from flying sparks etc. can be provided but not assumed. Comfort improvement.
CAUTIONS: There is a danger of creosote collection causing fires in the flue pipe with some units.
COST FACTORS: Minor for damper replacement.
INTERACTIONS: Consider separate outside air supply as complimentary ECO.
EVALUATION: RV H.4 gives typical fireplace efficiency figures. Desirability will depend upon extent of use and to a large extent would be strongly influenced by owners preference. Damper replacement without further evaluation.
COMMENTS:
REFERENCES: ASHRAE, Ch. 26, 1983.

ECO H.27 OUTSIDE AIR FOR FIREPLACE
LEVEL: Replacement/Improvement.
DESCRIPTION: Supply combustion air for fireplace directly from outside using insulated duct with damper. Close damper when fireplace not used.
APPLICATION:
SIDE BENEFITS:
CAUTIONS:
COST FACTORS:
INTERACTIONS: This ECO is considered complementary to fireplace management. Tightening of the envelope to minimise air infiltration may result in insufficient draught.
EVALUATION:
COMMENTS: If a fuel fired furnace is installed without a combustion air duct there is a danger of the fireplace draught interfering with furnace operation and danger of toxic gases being drawn into the occupied space, and in very tight houses, fireplaces may not be able to draw sufficient draught without such a measure.
REFERENCES: OFAC, 1983.

ECO H/C.1 SEQUENCE OPERATION OF MULTIPLE UNITS
LEVEL: Operations/Improvement.
DESCRIPTION: Sequence operation of multiple chillers and refrigerators or heat pump compressors with load variations to achieve optimal overall plant performance. Isolate off line chillers when not required and reduce water flow rate and pumping costs.
APPLICATION: Multiple chiller plant installations.
SIDE BENEFITS: Return of chilled water through 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.
CAUTIONS:
COST FACTORS: Isolation of off-line chillers is a negligible cost item 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.
INTERACTIONS: For variable pump flow control see ECO EL.6. This ECO can be implemented through a central chiller/refrigeration control (ECO C.10. Complimentary ECO - Improve capacity control ECO H/C.13). See also ECO H/C.15 (Repipe/operate chillers or compressors in series or in parallel) and ECOs D.5 and D.7.
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 (MT EL.7,) for individual compressors as a function of load. Measure supply heating or cooling temperatures (MT D.7, P.5, P.6) and compare with values required by heating or cooling system demand. A difference will result in decreased compressor performance which can be estimated from compressor diagrams.
COMMENTS:
REFERENCES: Dubin, 1975

ECO H/C.2 REDUCE POWER CONSUMPTION OF HEAT PUMP ANCILLARY EQUIPMENT
LEVEL: Operations/Replacement.
DESCRIPTION: Check power consumption of ancillary equipment such as i) pumps or fans, ii) crank case heaters, iii) supplementary heat sources, iv) defrost equipment.
APPLICATION: Heat pumps or cooling units.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Normally cheap, can be more expensive if large pumps or fans have to be changed.
INTERACTIONS: ECOs on heat pump flow rates (ECO H/C.8), stand by losses (ECO H/C.10), sensor functioning (ECO H/C.6) and efficient defrosting (ECO H/C.7).
EVALUATION: Measure the power consumption of the heat pump system (MT EL.6) with everything running except for the compressor. This consumption should not be more than maximum 10% of the total consumption.
COMMENTS:

REFERENCES:

ECO H/C.3 MAINTAIN PROPER STARTING FREQUENCY AND RUNNING TIME OF HEAT PUMP

LEVEL: Operations/Improvement.

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.

APPLICATION: Heat pumps or cooling units.

SIDE BENEFITS: Less noise and better life expectancy.

CAUTIONS: Increasing storage capacity can cause larger heat losses.

COST FACTORS: Checks and adjustments of controllers are cheap. Changes in size of heat pump or storage capacity are costly.

INTERACTIONS: ECO H/C.13 (Capacity control), H/C.14 (Reduce compressor capacity), H/C.7 (Efficient defrosting) and H/C.6 (sensor functioning).

EVALUATION: Use measurement techniques on starting frequency and running times (MT EL.7) to ensure that recommended values from the compressor manufacturer are kept.

COMMENTS:

REFERENCES:

ECO H/C.4 HEAT PUMP AIR LEAKAGE

LEVEL: Operations.

DESCRIPTION: Check tightness of ducts or cabinets on heat pumps using air as heat source or heat sink. Tighten leaks with e.g. woven tape or silicon rubber.

APPLICATION: Heat pumps with ducted air handling systems.

SIDE BENEFITS: Decrease of unnecessary air transport.

CAUTIONS: In integrated heating/ventilating systems balancing of the systems can be affected (ECO D.1).

COST FACTORS: Very cheap.

INTERACTIONS: See CAUTIONS. Also depending on where leaks are situated HVAC control may be affected.

EVALUATION: Check duct leakage by AP D.1 and cabinet external leakage by AP H/C.3. A first check can be made by comparing the temperature difference over the condensor or evaporator with the estimated difference from power - flow rate considerations. Leak flow and temperature difference between room air and outdoor air will give the power savings.

COMMENTS:

REFERENCES: SS 2095, 1986.

ECO H/C.5 MAINTAIN PROPER EVAPORATING AND CONDENSING TEMPERATURES

LEVEL: Operations.

DESCRIPTION: Maintain correct evaporating and condensing temperatures.

APPLICATION: Heat pumps and air conditioners.

SIDE BENEFITS: Lowers the absolute pressure ratio, thereby reducing discharge temperatures, increases service life of compressor. Unnecessary shut off will be avoided.

CAUTIONS: Improper temperatures may result in too small pressure differences for proper functioning of expansion devices. Too low condensing temperatures may overload compressor motor.
COST FACTORS: Cheap for adjustments. Work on refrigerant circuit expensive.
INTERACTIONS: ECO H/C.6 (Sensor functioning), ECO H/C.7 (Efficient defrosting), ECO H/C.9 (Expansion device).
EVALUATION: Measure temperatures by MT P.5 or MT P.6. Compare the evaporating temperature to the cooling agent temperature by measurement of evaporating pressure (MT P.1). For chilled water systems compare water temperature to required supply temperature. Compare condensing temperature to required supply temperature or external air temperature. Estimate effect of lowered condensing temperature from compressor diagrams.
COMMENTS: For chillers with condensors connected to cooling towers savings from lowered condensing temperatures should be compared to increased losses in the cooling tower.
REFERENCES: See Section C.4.

ECO H/C.6 CHECK SENSOR FUNCTIONING AND PLACEMENT FOR HEAT PUMPS
LEVEL: Operations.
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.
APPLICATION: Heat pump and cooling systems.
SIDE BENEFITS: Correct sensor operation improves heat pump life.
CAUTIONS: Observe sensors in positions behind valves that can be shut off.
COST FACTORS: Work can be time consuming and therefore costly.
INTERACTIONS: ECO H/C.2 (Ancillary equipment), H/C.5 (Proper temperatures), H/C.7 (Efficient defrosting).
EVALUATION: Evaluate sensor functioning by measuring the respective temperatures (MT D.7, P.5, P.6), pressures (MT P.1 and D.6) and flow rates (MT 0.2 through D.5 and P.2 through P.4) and compare then with the set values and also compare set values with calculated optimal settings.
COMMENTS:
REFERENCES:

ECO H/C.7 MAINTAIN EFFICIENT DEFROSTING
LEVEL: Operations/Improvement.
DESCRIPTION: Check functioning of defrosting devices. Timer initiation causes unnecessary defrosts and should be changed to a more sophisticated system using demand control.
APPLICATION: Air source heat pumps, air conditioners and heat exchangers.
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.
INTERACTIONS: ECOs on proper temperatures (ECO H/C.5), proper flow rates (ECO H/C.8), starting frequency (ECO H/C.3), sensor functioning (ECO H/C.6) and power consumption of ancillary equipment (ECO H/C.2).
EVALUATION: Use AP H/C.5 to check defrost functioning. By measuring running time and number of starts (MT EL.7) at full load the energy delivery lost during defrosting periods can be calculated. By measuring electricity consumption (MT EL.6) during defrosting the extra power required for defrosting can be determined.
COMMENTS:
REFERENCES: Merril, 1981.

ECO H/C.8 MAINTAIN PROPER HEAT SOURCE/SINK FLOW RATES
LEVEL: Operations/Maintenance.
DESCRIPTION: Check the flow rates to the evaporator and the condenser.
APPLICATION: Heat pumps or air conditioners.
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: ECOs on ancillary equipment (ECO H/C.2), ECO H/C.7 (Efficient defrosting).
EVALUATION: Use measurement techniques on flow rates (MT D.2 through D.5 and P.2 through P.4). If these are not correct first check for leaks, clogged filters incorrectly set valves and faulty pumps or fans. If nothing is found to be wrong readjust 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 (MT EL.6). Compare measured values with calculated optimum values.
COMMENTS:
REFERENCES:

ECO H/C.9 MAINTAIN FUNCTIONING OF HEAT PUMP EXPANSION DEVICE
LEVEL: Maintenance/Replacement.
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.
APPLICATION: Heat pumps or cooling units.
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.
INTERACTIONS: ECOs on correct temperatures (ECO H/C.5).
EVALUATION: Use audit procedure on expansion device (AP H/C.4) to evaluate expansion device performance.
COMMENTS:
REFERENCES:

ECO H/C.10 CHECK HEAT PUMP STAND BY LOSSES
LEVEL: Maintenance/Improvement.
DESCRIPTION: Measure electric or thermal energy consumption of heat pump when it is in a stand by mode. In particular check the following items: i) do circulating pumps/fans continue to operate, ii) are crank case heaters required to operate, iii) losses through insufficient insulation, iv) losses from compressors placed outdoors, v) are water-cooled condensors placed outside of building (requiring warm water circulation at sub-zero temperatures).
APPLICATION: All heat pumps and cooling units.
SIDE BENEFITS:
CAUTIONS: Never shut off circulation of water in outdoor condensors if risk for 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.
INTERACTIONS: ECO H/C.2 (ancillary equipment).
EVALUATION: Stand by losses are easily estimated by measuring power consumption during off duty periods (MT EL.6). Estimate savings by multiplying seasonal number of hours in off duty mode with stand by losses.
COMMENTS:
REFERENCES: See Appendix C.4.

ECO H/C.11 CLEAN AND MAINTAIN COOLING TOWER CIRCUITS AND HEAT EXCHANGER SURFACES
LEVEL: Maintenance.
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 for undue stops because of clogging or early shutdown on safety equipment. Enhanced heat transfer.
CAUTIONS: Use of chemicals for cleaning should be exercised with care.
COST FACTORS: In air systems cleaning is cheap. Liquid systems will normally have to be shut down.
INTERACTIONS: This ECO will provide lower condensing water temperatures (see ECO C.2) in air circuits. See also ECO D.5, D.9, P.5.

Alternative ECO: Use natural water sources for condensing (ECO C.11),replacement (ECO H/C.16). See also ECO C:12 (Minimise adverse external influences)..

EVALUATION:

COMMENTS: Compare cost of manual and automatic cleaning.

REFERENCES: Burger, 1980.

ECO H/C.12 MAINTAIN FULL CHARGE OF REFRIGERANT

LEVEL: Maintenance.

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

APPLICATION: Cooling or heating systems using compressor operated chillers, air conditioners or heat pumps.

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.

INTERACTIONS:

EVALUATION: Measure refrigerant condensing and evaporating pressures and temperatures (MT P.1) and compare with outgoing temperatures of condenser and evaporator flows. Use refrigerant detector to locate leaks.

COMMENTS:

REFERENCES: Stamm, 1978.

ECO H/C.13 IMPROVE CAPACITY CONTROL

LEVEL: Improvement/Replacement.

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

APPLICATION: All compressor driven equipment and absorption chillers.

SIDE BENEFITS: Prolonged equipment life.

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

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

INTERACTIONS: Correct sequencing operation of multiple units (ECO H/C.1) enhances capacity control. ECO H/C.14 (Reduce compressor capacity).

EVALUATION: RV C.6 gives comparative performance of various types of capacity control for different systems. Hourly analysis methods may be required to justify capital expenditures of providing improved capacity control means. Measure running time and number of starts (MT EL.7), and electric power consumption (MT EL.6). If running times are short, unit is too large. For heat pumps, compressor power consumption and using supplied compressor diagrams will give an estimate of the output, knowing the condensing and evaporating temperatures. This can be compared with calculated heat loads to see if the heat pump is too large.

COMMENTS: Centrifugal machines normally operate most efficiently between 40 and 70% loaded. Maximum savings are obtained when cylinder unloading (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.

ECO H/C.14 REDUCE COMPRESSOR CAPACITY OR FIT A SMALLER COMPRESSOR

LEVEL: Improvement/Replacement.

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.

CAUTIONS:

COST FACTORS:

INTERACTIONS: Alternative or complimentary ECOs are H/C.13 (Improve capacity control, C.8 (Increase heat exchanger surface areas), H/C.16 (Replacement) and, for heating systems, boiler replacement (ECO H.24).

EVALUATION: Measure running time and number of starts (MT EL.7) and electric power consumption (MT EL.6). If running times are short, compare estimated output from heating/cooling unit to estimated demand.

COMMENTS:

REFERENCES:

ECO H/C.15 REPIPE/OPERATE CHILLERS OR COMPRESSORS IN SERIES OR PARALLEL

LEVEL: Improvement/Replacement.

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

APPLICATION: Central cooling systems with multiple chillers and heating/cooling systems with heat pumps.

SIDE BENEFITS: Reduced starting currents.

CAUTIONS: Caution required in Direct Expansion systems.

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

INTERACTIONS: Consideration should be given to ensuring correct sequencing. see ECO H/C.1 and ECO C.10. See also ECO C.1 (Chilled water temperature).
EVALUATION: It is necessary to evaluate both COP 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 rates or high temperature difference (i.e. supply-return temperature).
COMMENTS:
REFERENCES: Tao, 1985.

ECO H/C.16 REPLACE OR UPGRADE COOLING EQUIPMENT AND HEAT PUMPS
LEVEL: Replacement.
DESCRIPTION: Replace old and inefficient equipment (condensors, cooling towers, compressors, heat pumps etc.) with new more efficient types.
APPLICATION: Prime targets are change of: i) heat pumps, ii) air cooled condensors to cooling towers (particularly in locations with fewer than 15 000 wet bulb degree hours.), iii) single unit to multiple plant, iv) upgrade wood filled towers to ceramic towers, or replace fill, v) absorption to vapor compression systems, vi) single stage absorption chillers to two stage, vii) hermetic with open compressors (Stamm, 1984), and viii) high lift single stage compressors with two stage with flash intercooling (Prasad, 1981; Klinger, 1980).
SIDE BENEFITS:
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 condensors in critical situations such as hospitals might be reviewed carefully.
COST FACTORS:
INTERACTIONS: ECO H/C.11 (Clean and maintain), ECO H/C.14 (Reduce compressor capacity), ECO C.2 (Lower condensing water temperature).
EVALUATION: See Checklist for Cooling, App. E, AT C.1 (Seasonal performance of cooling systems), RV H/C.1 (Performance indices of heating and cooling equipment), and AP H/C.1 (Performance of heat pumps and chillers). For check of oversizing measure running time and number of starts (MR EL.7) and electric consumption (MT EL.6). If running times are short, unit is probably oversized. Compare estimated output from unit to estimated demand.
COMMENTS:
REFERENCES: Stamm, 1984; Prasad, 1981; Baltimore Air Coil, 1984; Klinger, 1980; and Hill, 1984.

ECO H/C.17 AIR TO AIR HEAT RECOVERY TECHNIQUES
LEVEL: Replacement.
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 stop off ventilation air under certain weather conditions. If possible put heat recovery after preheating coil.
COST FACTORS:	
INTERACTIONS:	In some instances, air economisers may be an alternative (ECO R.18). See also ECO R.34, R.35. May require larger fans or fan motors owing to increased static pressure drop introduced by exchanger equipment.
EVALUATION:	See AP H/C.2. RV H/C.2 gives typical characteristics.
COMMENTS:	
REFERENCES:	Sun, 1979, Reay, 1980, Hamgtong, 1984, Chauhan, 1985, Kary, 1984, Wright, 1984.

ECO H/C.18	REPLACE OR UPGRADE HEAT PUMP SUPPLEMENTARY HEAT SUPPLY
LEVEL:	Replacement/Improvement
DESCRIPTION:	Replace existing supplementary heating/cooling supply with more economic and/or energy efficient type. Upgrade installation to run heat pump as base load and change criteria for starting of supplementary heating/cooling supplies.
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 dimensioning of existing net work.
COST FACTORS:	Replacement is expensive. Upgrading can be expensive if existing pipework has to be changed. Changing starting criteria is normally cheap.
INTERACTIONS:	ECO H.10 (Upgrade boiler insulation). H.17 (More efficient burner), H.24 (Replace obsolete boiler), H/C.1 (Sequence operation), H/C.3 (Proper starting frequency), H/C.5 (Proper temperatures), H/C.8 (Proper flows).
EVALUATION:	Use AP H.1, H.2 or H.3 to evaluate efficiency of existing burner or boiler. Check oversizing and starting criteria by measuring running time and number of starts (MT EL.6) or comparing installed power and peak load (AP H.4).
COMMENTS:	
REFERENCES:	

ECO C.1 RAISE CHILLED WATER TEMPERATURE AND SUCTION GAS PRESSURE
LEVEL: Operations/Improvement.
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: Raising chilled water temperature lowers capacity for latent cooling causing space humidity levels to rise. Too high an evaporator temperature may compromise proper functioning of expansion devices.
COST FACTORS: No cost unless automatic water reset controls are added.
INTERACTIONS: ECO H/C.15 (Chiller piping arrangement) could complement or interfere with this ECO. See ECO C.10, Central chiller/refrigeration control, C.14 (Use of desicant).
EVALUATION: RV C.1 gives typical effect of evaporating temperature on chiller performance.
COMMENTS:
REFERENCES:

ECO C.2 LOWER CONDENSING WATER TEMPERATURE AND HEADPRESSURES
LEVEL: Operations/Improvement.
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 (ECO R.1). Lower temperatures can be achieved by: i) increasing tower or air cooled condenser fan volumes, ii) increasing tower water flow rate, iii) where installation operates at constant condenser water temperature, modify controls for more continuous tower/condenser operation and, iv) move condenser closer to the compressor to minimise pumping energy.
APPLICATION: Air conditioning chillers and direct expansion (DX) equipment and industrial refrigeration systems. Not applicable when 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 may occur if increased tower energy is higher than COP improvements. Undercompression 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.
COST FACTORS:
INTERACTIONS: An alternative ECO is ECO C.11 (Use natural water sources for condensing). Complementary ECOs are ECO C.4 (Clean condenser tubes); ECO H/C.11 (Clean and maintain cooling tower curcuit); C.7 (Exhaust (cool) conditioned air over condensers and through cooling towers); ECO C.10 (Central

chiller/refrigeration control); C.12 (Minimise adverse external influences on cooling tower performance); ECO C.8 (Increase heat exchange surface areas) and ECO H/C.16 (Replace or upgrade obsolete, oversized and/or inefficient equipment). Lower condensing temperature may not be compatible with heat recovery option (ECO C.5).

EVALUATION: RV C.2 gives typical effect of condensing temperature on chiller performance.

COMMENTS:

REFERENCES: Cole, 1985; Dubin, 1975.

ECO C.3 SHUT OFF AUXILIARIES WHEN NOT REQUIRED

LEVEL: Operations/Improvement.

DESCRIPTION: Shut off all auxiliaries where chilling/refrigerant 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.

SIDE BENEFITS:

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.

INTERACTIONS: This ECO can be achieved through Central chiller or refrigeration control (ECO C.10) or through general energy management systems (see ECO R.28).

EVALUATION:

COMMENTS:

REFERENCES:

ECO C.4 CLEAN CONDENSER TUBES

LEVEL: Maintenance/Improvement.

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.

CAUTIONS:

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

INTERACTIONS: This ECO allows for lower condensing water temperatures (ECO C.2).

EVALUATION: RV C.4 provides information on the effect of condenser fouling and the impact of automatic tube cleaning brushes.

COMMENTS:

REFERENCES: Leitner, 1980.

ECO C.5 HEAT RECOVERY OF CONDENSER HEAT
LEVEL: Improvement/Replacement.
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 ECO is attractive where there is year round need for cooling operation and a co-incident need for space or SHW heating.
SIDE BENEFITS: Less use of water.
CAUTIONS:
COST FACTORS:
INTERACTIONS: A trade off is required between high grade reclaimed heat and its impact on lowering refrigeration COP. (COP falls with increasing condensing temperature, ECO C.2).
EVALUATION: Measure flow and temperature of cooling water to calculate possible heat recovery.
COMMENTS: Heat storage can increase savings.
REFERENCES: Stamm, 1978.

ECO C.6 ATMOSPHERIC COOLING
LEVEL: Improvement/Replacement.
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. economiser cycle).
ALTERNATIVE: Any application unsuitable for heat pump, especially when chiller and air handling units are remotely located.
SIDE BENEFITS:
CAUTIONS: Risk for freezing.
COST FACTORS: Can be a relatively low cost item compared with other means of generating winter chilled water.
INTERACTIONS: Free cooling chillers are on alternative strategy (ECO C.13).
EVALUATION: Hourly analysis normally required to estimate savings.
COMMENTS:
REFERENCES: Winger, 1983; Albern, 1984.

ECO C.7 EXHAUST (COOL) CONDITIONED AIR OVER CONDENSERS AND THROUGH COOLING TOWERS
LEVEL: Improvement/Replacement.
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.
SIDE BENEFITS:
CAUTIONS:

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 data from RV C.2 and local weather conditions using, as a minimum, a bin method type analysis (AT M.2).
INTERACTIONS: Allows lower condensing temperature (see ECO C.2). See also ECO C.12 (Minimise adverse external influences).
EVALUATION:
COMMENTS:
REFERENCES:

ECO C.8 INCREASE HEAT EXCHANGER SURFACE AREAS
LEVEL: Improvement/Replacement.
DESCRIPTION: Increase condenser surface areas for lower condensing temperatures; e.g. larger cooler tower or condenser or additional unit(s).
APPLICATION:
SIDE BENEFITS:
CAUTIONS:
COST FACTORS:
INTERACTIONS: Consider also steps to minimise adverse external influences on cooling tower (ECO C.12). Where installed cooling capacity is more than required, an alternative is to fit a smaller compressor (ECO H/C.14). Increasing condenser heat exchanger area will permit lower condensing temperatures (ECO C.2).
EVALUATION:
COMMENTS:
REFERENCES:

ECO C.9 USE CITY WATER FOR COOLING
LEVEL: Improvement/Replcement.
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 being used for some other purpose.
COST FACTORS: Can be quite low.
INTERACTIONS:
EVALUATION:
COMMENTS: This ECO is not to be confused with the common practice of using city water for cooling condensers.
REFERENCES:

ECO C.10 CENTRAL CHILLER/REFRIGERATION CONTROL
LEVEL: Improvement/Replacement.
DESCRIPTION: Install central controller to optimise 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.
COST FACTORS:
INTERACTIONS: Complementary ECOs: ECO C.1 (Raise chilled water temperature, ECO C.2 (Lower condensing water temperature), ECO H/C.1 (Sequence operation of multiple units) and ECO C.3 (Shut off auxiliaries when not required). See also H/C.15 (Operate in series or parallel).
EVALUATION: Small percentage savings can often justify the cost of the central controller. Hourly analysis is desirable.
COMMENTS:
REFERENCES: Stoecher, 1980; Baillie, 1985; and Thielman, 1983.

ECO C.11 USE NATURAL WATER SOURCES FOR CONDENSING
LEVEL: Improvement/Replacement.
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: i) Use of natural water source may cause fouling of heat transfer equipment resulting in loss of performance and requiring additional maintenance. ii) Increase of temperature, due to rejected heat, in small, nonflowing water bodies can upset water eco system.
COST FACTORS:
INTERACTIONS: ECOs aimed at improving efficiency of heat regulation are alternatives to this ECO. ECO H/C.11 (Clean and maintain), ECO C.2 (Lower condensing water temperature).
EVALUATION:
COMMENTS:
REFERENCES:

ECO C.12 MINIMISE ADVERSE EXTERNAL INFLUENCES ON COOLING TOWER AND AIR COOLED CONDENSER
LEVEL: Improvement.
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.
CAUTIONS:

COST FACTORS: General low cost except where relocation is required.
INTERACTIONS: Complementary ECO to ECO H/C.11 (Clean and maintain cooling tower circuit) and ECO C.7 (Exhaust conditioned air over condensers and cooling towers). Effect of ECO will be lower possible condensing temperatures (ECO C.2). See also ECO C.8 (Increase heat exchanger surface areas).
EVALUATION:
COMMENTS:
REFERENCES: Hensley, 1983.

ECO C.13 FREE COOLING CHILLERS
LEVEL: Improvement/Replacement.
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 $7.5^{\circ}C$ and more than 2,000 (heating) degree-days ($^{\circ}C$) per year, and which have low outdoor wet bulb temperatures.
SIDE BENEFITS:
CAUTIONS: 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.
INTERACTIONS: Atmospheric cooling (ECO C.6) or Air economiser (ECO R.18).
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 (ECO R.18).
REFERENCES: Welsh, 1984 and Kallen, 1982.

ECO C.14 USE OF DESICCANT FOR DE-HUMIDIFICATION
LEVEL: Improvement/Replacement.
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.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS:
INTERACTIONS: Where the cooling medium is chilled water the setpoint can be raised to make use of higher COPs (ECO C.1). See also ECO C.6 (Atmospheric cooling) and C.9 (Use of city water for cooling).
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.

COMMENTS:

REFERENCES: Dubin, 1975.

ECO C.15 USE "PIGGY BACK" ABSORPTION SYSTEM

LEVEL: Improvement/Replacement.

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

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

SIDE BENEFITS:

CAUTIONS:

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

INTERACTIONS:

EVALUATION:

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.

ECO C.16 CHILLED WATER AND ICE STORAGE SYSTEMS

LEVEL: Improvement/Replacement.

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.

SIDE BENEFITS:

CAUTIONS:

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.

INTERACTIONS:

EVALUATION: Detailed hourly evaluations are almost always required.

COMMENTS:

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

ECO D.1 AOJUST/BALANCE VENTILATION SYSTEM

LEVEL: Operational/Maintenance.

DESCRIPTION: Adjust ventilation system for proper air flows to different building zones.

APPLICATION: All buildings with mechanical ventilation systems, supply air systems, supply and exhaust air systems and supply and exhaust air systems with heat exchangers.

SIDE BENEFITS: Increased comfort.

CAUTIONS: Should be preceded by cleaning of air ducts, louvers, dampers, grills, etc. Air tightness of ducts should be checked (see AP D.1).

COST FACTORS: Normally cost-effective.

INTERACTIONS: Should be carried out before adjustments of the heat distribution system (ECO P.1) and after improvement of the air tightness of the building envelope (ECO E.7). See also ECO D.4.

EVALUATION: Evaluation of air flow balancing (AP D.3).

COMMENTS: Should be part of ordinary maintenance (every 5 years).

REFERENCES:

ECO D.2 REDUCE AIR FLOW RATE

LEVEL: Maintenance/Improvement.

DESCRIPTION: Flow rate may be reduced by: i) throttling air flow, ii) fitting new fan-motor sheaves, iii) motor speed control or iv) cycling fan.

APPLICATION: Buildings with mechanical ventilation systems where: 1) original system is oversized, 2) load reduction is carried out or planned, 3) ventilation rates are relaxed or 4) room supply air/room-air temperature difference is increased. Desirability increases with climate severity and period of occupancy.

SIDE BENEFITS: Reduces draughts, reduced noise. Fan power saving.

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. Cycling equipment can reduce life. 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.

INTERACTIONS: Fan motor size reduction may be possible, ECO D.8. Possible loss of free cooling (ECO R.18), cycling possible with EMS system (ECO R.28). Consider upgrading damper seals and replacing backdraft dampers with motorised ones. See also ECO R.34 (control of fume hoods).

EVALUATION: Easy when air flow is known/measured (see MT D.2 through D.5, D.8 through D.11 and AT R.1). Compare against design values and take measurements only if values significantly different or if there is a suspicion that ventilation rates not as designed. For calculation of savings, see AT R.1.

COMMENTS: Often a possibility in buildings/rooms with low occupancy or low process load. Design flow rates are often overestimated.

REFERENCES:

ECO D.3 REDUCE PRESSURE DROPS IN DUCTS
LEVEL: Maintenance/Improvement.
DESCRIPTION: i) Remove obstacles, dirt clogged filters, comb damaged coil fins, open dampers on the index run, ii) install turning vanes in sharp bends, expand narrow passages, eliminate long lengths of flexible ductwork or replacing with solid, or iii) reduce air flow rates.
APPLICATION: Ventilation plants with working pressure >200 Pa.
SIDE BENEFITS: Noise reduction.
CAUTIONS: Rebalancing may be needed.
COST FACTORS: For the cases listed above: 1) cheap, 2) high and 3) moderate.
INTERACTIONS: ECO D.2 (Reduce air flow rates).
EVALUATION: See MT D.6.
COMMENTS: Energy use will increase unless fan speed is reduced (see ECO D.7).
REFERENCES: ASHRAE Standard 62.81, 1981.

ECO D.4 REDUCE AIR LEAKAGE IN DUCTS
LEVEL: Maintenance/Improvement.
DESCRIPTION: Repair all possible leaks in existings ducts.
APPLICATION: All ventilation ducts, especially high pressure systems.
SIDE BENEFITS:
CAUTIONS: If the leakage has been considerable, hydronic heating systemsmay need new balancing (see ECO P.1).
COST FACTORS: In structural ducts (esp. brickwork) the leakage can be considerable, but the ECO can be expensive.
INTERACTIONS: ECO D.9 (Duct insulation repair/upgrade).
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 (see AP D.1, MT D.1 through D.5, MT D.8 through D.11, AT R.1 and RV D.1).
COMMENTS:
REFERENCES:

ECO D.5 CLEAN FAN BLADES
LEVEL: Maintenance.
DESCRIPTION: Clean fan blades (for reduced fan power).
APPLICATION: Large fan wheels. Particularly of the forward curved centrifugal type in dirty environments.
SIDE BENEFITS: Uneven dirt collection can unbalance 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: Normal energy savings.
INTERACTIONS: See ECO H/C.1 (Clean and maintain)
EVALUATION: Part of regular maintenance.
COMMENTS:
REFERENCES:

ECO D.6 MAINTAIN DRIVES
LEVEL: Maintenance.
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.
CAUTIONS:
COST FACTORS: Low cost.
INTERACTIONS:
EVALUATION: Part of regular maintenance.
COMMENTS: Nominal energy savings.
REFERENCES:

ECO D.7 CLEAN OR REPLACE FILTERS REGULARLY
LEVEL: Maintenance.
OESCRIPTION: Clean or replace filters regularly.
APPLICATION: All ventilation systems.
SIDE BENEFITS: Other installations which depend on proper ventilation standard will work under right conditions.
CAUTIONS:
COST FACTORS:
INTERACTIONS: See ECO H/C.1 (Clean and maintain).
EVALUATION: Maintenance (see RV D.2).
COMMENTS: Seen independently, a ventilation system with clogged filter will cause reduced 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:

ECO D.8 REDUCE MOTOR SIZE (FAN POWER)
LEVEL: Improvement.
DESCRIPTION: Install smaller motor on present fan. This may be possible after air flow and ductwork resistance reduction (ECO D.2 and D.3). 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 (100%), or more. Oversized motors give high reactive effect.
SIDE BENEFITS: Less noise. Increasing room/supply air temperature difference can permit lower air flows.
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: ECO D.2 (Reduce air flow rates), ECO R.27 (Discontinue or relocate preheat coils).
EVALUATION: For the calculation of fan power, see App C.5.
COMMENTS:
REFERENCES:

ECO D.9 DUCT INSULATION REPAIR/UPGRADE

LEVEL: Improvement/Replacement.

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 low temperatures.

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 labor cost involved. Complete upgrading of insulation can be very costly. With high labor cost, the cost-effectiveness may not be sufficient. Replacement is preferably to be done when renewing the duct system.

INTERACTIONS: Reduce air leakage in ducts (ECO D.4).

EVALUATION: Check for ample space around ducts for working, repair or replacement. Estimate duct heating/cooling loss and energy saving on bases of temperature differential, level of air conditioning, flow rate (see AP D.2, MT D.7, AT D.1 and RV D.1). On large jobs, measure temperatures in ducts and rooms and air flow rate..

COMMENTS: A few degrees temperature drift in the extremes of the heating/cooling season has a heavy influence on the performance of the heating/cooling plant.

REFERENCES:

ECO D.10 INSTALL BACK-DRAUGHT OR POSITIVE CLOSURE DAMPER IN VENTILATION EXHAUST SYSTEM

LEVEL: Improvement.

DESCRIPTION: Install dampers to prevent unwanted leakage of conditioned room air out of the building or cold 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 having stack ventilating systems and fan shut-down periods.

SIDE BENEFITS: Air pollution from other exhaust systems will not enter the system during off periods.

CAUTIONS: Dependable operation of back-draught dampers is important. Signal lamps showing open/closed are desirable. Fire safety may require back-draught dampers to open for smoke ventilation.

COST FACTORS: Back-draught dampers usually a low cost ECO. 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. See ECO R.3.

EVALUATION: The back flow of room air depends on back flow resistance, the chimney and wind effect i.e., the temperature differential inside/ouside duct, system height, and the length of the fan off period.

COMMENTS: Very often underestimated in less sophisticated plants.
REFERENCES:

ECO D.11 RELOCATE MOTOR OUT OF AIR STREAM
LEVEL: Improvement.
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.
CAUTIONS:
COST FACTORS:
INTERACTIONS:
EVALUATION:
COMMENTS:
REFERENCES:

ECO D.12 INSTALL FREEZE LAUNDRY DRIERS
LEVEL: Replacement.
DESCRIPTION: Replace existing laundry driers of the hot-air type by freeze laundry driers.
APPLICATION: Laundries and multi-family residences with common laundry area.
SIDE BENEFITS: If existing hot-air driers are heated by hydronic system, the supply water temperature of the building can be lowered.
CAUTIONS: Space heating should be switched off during operation for maximal savings.
COST FACTORS:
INTERACTIONS: ECO D.13.
EVALUATION: Mostly cost-effective.
COMMENTS: Provide residents with manual of operation.
REFERENCES: Hansson, 1984

ECO D.13 AUTOMATIC SWITCH OFF OF LAUNDRY DRIERS
LEVEL: Replacement/Operation.
DESCRIPTION: Install timers for automatic switch-off of fans and heat supply for laundry driers.
APPLICATION: Laundries and multi-family residences with common laundry area.
SIDE BENEFITS:
CAUTIONS: Space heating should be switched off during operation of driers for maximal savings.
COST FACTORS:
INTERACTIONS: ECO D.12.
EVALUATION: Mostly cost-effective.
COMMENTS: Provide residents with manual of operation.
REFERENCES:

ECO P.1 ADJUST HYDRONIC HEAT DISTRIBUTION SYSTEM

LEVEL: Maintenance/Replacement/Improvement.

DESCRIPTION: Correct hydronic imbalances in systems by replacing or adjusting valves on main pipes and adjusting radiator valves. Savings are achieved after balancing by adjusting the heat control see App. C.3.2).

APPLICATION: Medium to large buildings with hydronic heat distribution. Often this ECO is necessary to make maximal savings from Envelope and Regulation ECOs.

SIDE BENEFITS: Improves comfort.

CAUTIONS: Should be carried out after implementation of other ECOs. Upgrading of distribution pipe insulation (ECO P.6) may be required after other ECOs 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 ECOs and many Regulation ECOs. Incorrect pump sizing may be part of the problem, see ECO P.14 (Install zone pumping), P.10 (Reduce flow rates), ECO P.5 (Clean filters and screens). See also ECO R.14.

EVALUATION: Should only be considered in buildings where indoor temperatures on the average deviate more than 1 K from desired temperatures. See AP P.1, P.5 and MT R.2.

COMMENTS: If heat terminals are oversized the number of elements in radiators may be reduced or thermostatic valves installed (ECO R.14). If terminals are undersized, the number of elements should be increased. Carry out adjustments at a high flow rate if the system is considered for conversion to a low-temperature system.

REFERENCES: CIBSE Guide B11, 1985.

ECO P.2 BLEED AIR FROM SYSTEM

LEVEL: Operational.

DESCRIPTION: Check all pipework is under positive pressure (with respect to atmospheric) at all times. Check especially upper floor radiators.

APPLICATION: Hot water systems with forced circulation and pump on return pipe.

SIDE BENEFITS: Even distribution of water flowrate. Improved heat transfer. Helps prevent oxidation of radiators.

CAUTIONS: Verify that bleeding can be done.

COST FACTORS: Negligible.

INTERACTIONS: Presence of air in the piping may be due to bad operation of expansion tank (ECO P.4) or to leaks in the pipes (ECO P.7). It may also depend on pressure (ECD P.11). See also ECO H.7 (System pressurization) and Regulation ECOs.

EVALUATION: A partially or completely cold radiator may indicate presence of air in the pipes. No specific audit procedure required.

COMMENTS: Radiators may be cold due to other factors (closed valves, obstructions in the network).

REFERENCES:

ECO P.3 SWITCH OFF CIRCULATION PUMPS WHEN NOT REQUIRED

LEVEL: Operational.

DESCRIPTION: Switch off pumps to save on distribution losses and pumping energy. This may be done manually or automatically.

APPLICATION: Where there is regular variation in demand and/or where reduced pumping is sufficient to cope.

SIDE BENEFITS: Increases the life-time of the pump. May reduce mixing losses.

CAUTIONS: Ensure the pump operates when the boiler is on.

COST FACTORS: Low for manual control. Moderate for automatic control.

INTERACTIONS: Particularly effective if not coupled with reduced flow rates (ECO P.10). If an energy management system is in use consider to switch the pumps with it (ECO R.28). See also ECO H.1 (Shut boiler plant off).

EVALUATION: Energy savings are dependent on pump size and distribution losses (AP P.3, MT P.2 through P.6, AT P.1, P.2, RV P.1).

COMMENTS:

REFERENCES:

ECO P.4 MAINTAIN PROPER WATER LEVEL IN EXPANSION TANK

LEVEL: Operational.

DESCRIPTION: Check that water auto-feed equipment of expansion tank operates correctly. Proper water levels will help avoid air infiltration in pipework and terminals.

APPLICATION: Open expansion tank hot water system.

SIDE BENEFITS: See ECO P.2.

CAUTIONS: If open expansion tanks are undersized, there may be hot water losses from the circuit. Water in noninsulated expansion tanks installed in cold rooms may freeze, thus preventing regular circulation (see ECO P.6).

COST FACTORS: Negligible (ordinary maintenance).

INTERACTIONS: ECO P.2 (Bleed air from system), H.7 (System pressurization), P.11 (Atmospheric pressure).

EVALUATION: With proper water levels in the expansion tank, all radiators will operate correctly, thus allowing to maintain a lower average temperature in centrally heated buildings.

COMMENTS: Check size and position of tank.

REFERENCES: CIBS, Guide B1, 1986.

ECO P.5 CLEAN FILTERS AND SCREENS

LEVEL: Maintenance.

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: ECO P.1 (Adjust distribution system). For energy savings, pump delivery needs to be reduced, see ECO P.10. See also ECO P.9 (Reduce flow resistance).
EVALUATION: Do only if filters or screens really need cleaning.
COMMENTS:
REFERENCES:

ECO P.6 REPAIR/UPGRADE INSULATION ON PIPES AND TANKS
LEVEL: Maintenance/Improvement.
DESCRIPTION: Repair faulty insulation or increase thermal resistance 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: Do not exceed optimal thickness (RV P.1). Consider possible moisture problems on cold pipes.
COST FACTORS: Depends on labor cost and material cost.
INTERACTIONS: ECO P.7 (Repair leaks), ECO P.1 (Adjust distribution system), ECO P.4 (Maintain proper water level). See also ECO S.4, S.11 and S.16.
EVALUATION: Should always be performed if pipes run out of the conditioned area. Savings from upgrading, see AT P.1, RV P.1. See also AP P.2. For SHW evaluations see also AT S.2 and RV S.2.
COMMENTS:
REFERENCES: Energy Efficiency Office Booklet 8.

ECO P.7 REPAIR LEAKS
LEVEL: Maintenance.
DESCRIPTION: Check if there are leaks in pipes, tanks, or other pipework components. Check for and eliminate fluid leakage past closed control valves. This ECO will prevent deterioration and loss of thermal resistance of insulants.
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 damage, mould formation, etc. May reduce system cycling improviding occupant comfort.
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 and where heating and cooling fluids available together and where fluid not reset according to outside conditions or otherwise overall load variations.
INTERACTIONS: ECO P.6 (Repair/upgrade insulation) and ECO P.2 (Bleed air from system). If pipes are leaky, consider changing the

pipework layout as a complementary ECO. Leaks from control valves may cause loss of space temperature control (ECO R.1) or loss of sequencing of heat and cool processes (ECO R.7).
EVALUATION: Benefit difficult to estimate.
COMMENTS:
REFERENCES:

ECO P.8 MAINTAIN STEAM TRAPS
LEVEL: Maintenance.
DESCRIPTION: Check that steam traps passing condensate, venting gases and restricting steam passage. Also check that bypass around traps are not passing steam.
APPLICATION: 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) and 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; coil freeze up in extreme climates; reduce steam temperature and pressure (see AT P.2).
COST FACTORS: Negligible. Maintain all faulty traps as part of required maintenance.
INTERACTIONS: ECO P.16 (Replace steam traps) and P.18 (Separate flash steam).
EVALUATION: Most benefit obtained in open loop systems where condensate is discharged to drain or lost, or where steam is purchased and discharged with no or little account given for the condensate heat content. AP P.4 describes methods by which faulty steam trap operation can be identified. See also AT P.2 and RV P.2.
COMMENTS: Steam issuing from open vents usually indicates that one or more traps in the installation is passing steam.
REFERENCES: Spirax-Sarco, 1985; Batherman, 1982; CIBS Guide B16, 1986.

ECO P.9 REDUCE FLOW RESISTANCE IN PIPES AND HEAT TERMINALS
LEVEL: Improvement.
DESCRIPTION: This ECO includes cleaning fouled piping, water treatment, removing unnecessary equipment, and opening all valves on index run. Reduction of flow resistance may allow use of smaller pumps, smaller impellers (in same pump body) or same pumps running at lower speeds.
APPLICATION: All systems.
SIDE BENEFITS: Cleaning heat terminals improves heat transfer.
CAUTIONS: If pump is not replaced after this ECO is implemented there will be a higher pumping energy consumption.
COST FACTORS: Depends highly on which of the above actions is selected.
INTERACTIONS: ECO P.5 (Clean filters and screens). If pump substitutions not feasible (e.g., for cost reasons) consider the possibility to reduce flow rates (ECO P.10). See also ECO E.23.
EVALUATION: Check first that all valves are open on index run. Benefit obtained only if flow resistance reduced on index run, or pump

changed with one of small size (ECO EL.19). RV S.6 (Water quality analysis) may be required. Pressure drop measurements may also be required (MT P.1).

COMMENTS:
REFERENCES:

ECO P.10 REDUCE FLOW RATES

LEVEL: Improvement.

DESCRIPTION: Flow may be reduced by throttling output, automatic flow control valves, reducing impeller size (turn original or fit new of smaller size), 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, increased temperature difference between feed and return.

SIDE BENEFITS: Lower flow rates imply lower flow velocities: noise problems reduced.

CAUTIONS:

COST FACTORS: Throttle is negligible cost but least savings, pump replacement high cost.

INTERACTIONS: ECO P.9 (Reduce flow resistances), ECO EL.10 (Replace motor); may be necessary to balance the distribution system (ECO P.1), ECO P.3 (Switch off circulation pumps), ECO P.5 (Clean filters and screens). See ECO P.15.

EVALUATION: Do if previous ECOs on the building envelope have reduced the thermal loads. May require measurement of temperature drop across radiators (MT P.5 and P.6, AP P.3).

COMMENTS:
REFERENCES:

ECO P.11 ENSURE SYSTEM OPERATES ABOVE ATMOSPHERIC PRESSURE

LEVEL: Improvement.

DESCRIPTION: Where possible ensure that the highest terminal in the pipework operates above atmospheric pressure. This will help avoid air infiltration. Alternatively, move the pump from the return to the feed pipe or move the expansion tank.

APPLICATION: Applies to forced hot water systems with the pump on the return side.

SIDE BENEFITS:

CAUTIONS: Implementation may require plant emptying. If the pump is moved to the feed line its life will be shortened due to higher operating temperatures. The effect of pressure changes on the boiler should be investigated if the pump remains on the return side.

COST FACTORS: Depends on action taken.

INTERACTIONS: Bleed air from system (ECO P.2), Maintain proper water level (P.4), System pressurization (H.7)

EVALUATION: Do only if air infiltration takes place. May require pressure measurements in pipes (MT P.1).

COMMENTS:
REFERENCES: CIBSE Guide B16, 1986.

ECO P.12 CONVERT 3-PIPE SYSTEM TO 2-PIPE OR 4-PIPE SYSTEM
LEVEL: Replacement.
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.
SIDE BENEFITS:
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.
INTERACTIONS:
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.

ECO P.13 CONVERT SINGLE PIPE STEAM SYSTEM TO CONDENSATE RETURN SYSTEM
LEVEL: Replacement.
DESCRIPTION: Do not discharge condensate to drain, return to boiler; replace steam injection heating systems (where the condensate is essentially lost) with heat exchangers.
APPLICATION: Open loop steam system.
SIDE BENEFITS: Reduced make up water consumption and water treatment costs. Possibility of flash steam heat recovery.
CAUTIONS:
COST FACTORS: Dependent on distance of return and accessibility.
INTERACTIONS: Heat recovery is an alternative (ECO P.17). See also AT P.2.
EVALUATION:
COMMENTS:
REFERENCES: Spirax-Sarco, 1985; Energy Efficiency Office Booklet 9.

ECO P.14 INSTALL ZONE PUMPING
LEVEL: Replacement.
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.
CAUTIONS:
COST FACTORS: Depends on number of pumps to be installed.
INTERACTIONS: ECO P.1 (Adjust distribution system).
EVALUATION: Do only if pumping costs are very high. Requires procedures aiming at determination of flow rates and pressure drops in different circuits.
COMMENTS:
REFERENCES: CIBSE Guide B11, 1985.

ECO P.15 — INSTALL VARIABLE VOLUME PUMPING
LEVEL: Replacement.
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 advantages in larger distribution schemes with variable load.
SIDE BENEFITS: Prolonged pump life.
CAUTIONS: Lower flow rates increases susceptibility to freeze up.
COST FACTORS: High.
INTERACTIONS: Regulation ECOs. Alternative to fixed flow variable temperature distribution systems (ECO P.10).
EVALUATION:
COMMENTS: Typical power-flow relationships are given in RV EL.1.
REFERENCES: CIBSE Guide B16, 1986.

ECO P.16 — REPLACE STEAM TRAPS
LEVEL: Replacement.
DESCRIPTION: Replace existing steam traps with different (more suitable) trap type and/or correctly sized trap.
APPLICATION: Steam systems.
SIDE BENEFITS: Improves system performance (see ECO P.8) plus: i) Undersized traps can cause condensate back-up at times of peak loads, particularly at plant start up, and can increase the frequency of cycling, causing premature failure. ii) Oversized traps result in excessive steam loss when trap fails and can result in malfunctioning of some traps (inverted bucket type).
CAUTIONS:
COST FACTORS: Cost benefit greatest for open loop systems or where steam is purchased and discharged, or little or no account is given for heat content of the condensate.
INTERACTIONS: Poor trap performance might be the result of lack of or poor maintenance (see ECO P.8).
EVALUATION: Correctly installed trapping devices are neccessary for proper system operation and all necessary changes should be made regardless of direct steam savings. Justification may, however, be required where the only malfunction is some steam leakage - obviously wide open traps need to be replaced. See AP P.2 for inspection of trap losses.
COMMENTS: No single trap is ideal for all applications and it is not uncommon to have a number of different trap types in a single installation. RV P.2 gives some guidance of trap application.
REFERENCES: EMC, 1983; Spirax-Sarco, 1985; CIBSE Guide B16, 1986.

ECO P.17 — HEAT RECOVERY FROM CONDENSATE
LEVEL: Replacement.
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.

SIDE BENEFITS:
CAUTIONS:
COST FACTORS:
INTERACTIONS: ECO P.13 (Condensate return system) would be an alternative in open loop systems or sub-systems. See also regulation and SHW ECOs where the recovered heat could be utilized, as well as ECO P.18.
EVALUATION:
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; Energy Efficiency Office Booklet 9.

ECO P.18 SEPARATE FLASH STEAM FROM CONDENSATE
LEVEL: Replacement.
DESCRIPTION: Ensure that sufficient heat is removed from the steam/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.
CAUTIONS:
COST FACTORS:
INTERACTIONS: Ensure correct steam trap operation (ECO P.8) before considering this ECO. See also P.17 (Heat recovery from condensate).
EVALUATION: This ECO 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.
COMMENTS:
REFERENCES: Spirax-Sarco, 1985; Energy Efficiency Office Booklet 6.

ECO S.1 REOUCE WATER TEMPERATURE.
LEVEL: Operational.
DESCRIPTION: Reduce setting storage aquastat 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: 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 intermediate temperatures (40 to 55°C). Check for local regulations.
COST FACTORS: No cost.
INTERACTIONS: In central storage systems, consider adding a booster heater (ECO S.2) as a complementary ECO; alternatively, maintain the same storage temperature and add more insulation to storage tank (ECO P.6). Also interacts with ECO S.11. (Install controls, timers to reduce pump use.)
EVALUATION: Lower temperature without further evaluation. See RV S.3 for suggested setpoint. Reduce 5°C at a time to check if lower temperatures are satisfactory. See also AT S.2.
COMMENTS:
REFERENCES: Dubin, 1974; Gatts, 1974.

ECO S.2 REDUCE USE OF CIRCULATION PUMPS.
LEVEL: Operational.
DESCRIPTION: Turn off circulating pump during periods of no demand to save electricity and pipe 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, i.e., more cool water must be run off before water becomes hot.
COST FACTORS: Negligible.
INTERACTIONS: Consider installing automatic controls/timers (ECO S.11). Alternative is to replace pump circulation with single pipe and heat tracing (ECO S.15).
EVALUATION: Check users' habits and pump running time. Evaluate reduction of pumps running time; to evaluate energy saving potential, refer to RV S.2. See also AT S.2.
COMMENTS:
REFERENCES:

ECO S.3 USE COLD WATER FOR LAUNDRY.
LEVEL: Operational.
DESCRIPTION: Select appropriate washing and rinsing programs (if possible) to use coldest water that is still suitable.
APPLICATION: Laundry machines and dishwasher having reduced temperature washing programs.
SIDE BENEFITS:
CAUTIONS: Use appropriate detergents for lowered temperatures.

COST FACTORS: Negligible.
INTERACTIONS: As an alternative, consider connecting appliance to SHW supply (ECO S.6), if feasible.
EVALUATION: Check appliance for possibility of selecting appropriate washing and rinsing programs. Evaluate savings on the basis of average frequency of use. See also AT S.2.
COMMENTS:
REFERENCES:

ECO S.4 HEAT DURING OFF-PEAK PERIODS.
LEVEL: Operational.
DESCRIPTION: SHW heating is performed at lower energy cost in off-peak hours.
APPLICATION: Applicable to electric heaters with storage and where fuel tariff provides for low cost electricity during certain hours of the day, or where charge made for demand: turn of heater during low-demand periods only (e.g., at night).
SIDE BENEFITS:
CAUTIONS: Make sure storage insulation is sufficient to prevent cooling of SHW and that storage is adequate for needs between reheating times.
COST FACTORS: Negligible. Energy <u>use</u> may increase although energy <u>cost</u> should fall.
INTERACTIONS: ECO S.10. (Install water heater timers.), ECO P.6. (Upgrade insulation of tanks and piping.) If storage capacity does not match daily needs, consider modifying storage tank (ECO S.16). See ELECTRICAL ECOs. Alternatively, consider energy source substitution (ECO S.21).
EVALUATION: Savings will be evident in electrical demand charge reduction.
COMMENTS:
REFERENCES: Gatts, 1974; CIBSE Guide B1, 1986.

ECO S.5 INSTALL OR IMPROVE WATER TEMPERATURE REGULATION.
LEVEL: Operation/Improvement.
DESCRIPTION: To improve temperature control: 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 within 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: If necessary, install a pressure stabilizing valve. It may be advisable to install a flow restrictor (ECO S.9) in conjunction with a flow mixer.
EVALUATION: Check mixing problems in individual and central systems. See also AT S.2.

COMMENTS:
REFERENCES:

ECO S.6 USE SHW IN APPLIANCES.
LEVEL: Operation/Improvement.
OESCRIPTION: Consider using service hot water instead of cold water in domestic appliances.
APPLICATION: Laundry and dishwashing machines that can be fed with SHW. Only applicable if central SHW system uses cheaper fuel source.
SIDE BENEFITS:
CAUTIONS: Make sure appliance is equiped for accepting SHW input, or if it can be modified.
COST FACTORS: Negligible if appliances are equiped to accept SHW.
INTERACTIONS: ECO S.3. (Use cold water for laundry.)
EVALUATION: Check average duty cycle water consumption.
COMMENTS:
REFERENCES:

ECO S.7 INSTALL HEAT PUMP WATER HEATER.
LEVEL: Operational/Improvement.
DESCRIPTION: Install heat pump for heating of SHW. Also investigate possibility of using heat pump for heating or cooling.
APPLICATION: Installations producing SHW.
SIDE BENEFITS:
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.
INTERACTIONS: ECO S.8 (Heat recovery from waste SHW), S.20 (Install solar water heating), S.19 (Install metering devices).
EVALUATION: See AP S.5.
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.
REFERENCES: Bergstrom, 1985.

ECO S.8 HEAT RECOVERY FROM WASTE SHW.
LEVEL: Improvement/Replacement.
DESCRIPTION: If the waste SHW 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 pre-heat cold water feeding either the storage tank or an instantaneous water heater.
APPLICATION:
SIDE BENEFITS:

CAUTIONS: Leakage between water systems must not occur. There may be legal problems.
COST FACTORS: May be high. Skilled manpower required.
INTERACTIONS: ECO S.7 (Install heat pump), S.20 (Install solar water heating).
EVALUATION: Approximately 25% of the useful heat content of the water is recoverable. Applying a factor of 0.25 to the useful SHW energy demand (see AP S.1) provides a measurement of the prospective energy saving. Check that distance between heat exchanger and heater compatible with supply pressure. See also AT S.2 and AP S.5.
COMMENTS:
REFERENCES:

ECO S.9 INSTALL FLOW RESTRICTORS.
LEVEL: Maintenance.
DESCRIPTION: Install flow restrictors in suitable points of piping, low-flow shower heads, aerated faucets, etc., to conserve use of SHW.
APPLICATION:
SIDE BENEFITS:
CAUTIONS: Make sure supply flow rate is not reduced below minimum accepted by occupants.
COST FACTORS: Low cost but can result in substantial savings.
INTERACTIONS: Pressure stabilizing valves may be required. Consider adding a temperature regulation device (ECO S.5) as a complementary ECO. Interacts with benefits of reducing energy costs by energy source substitution (ECO S.21). Alternative to providing pressure reducing valve (ECO S.14).
EVALUATION: Compare water usage with RV S.1; if excessive usage appears to be caused by high flow rates, consider implementation of this ECO: estimate water usage reduction based on manufacturer data. See also AT S.2.
COMMENTS:
REFERENCES: Dubin, 1974.

ECO S.10 SHUT OFF WATER HEATING WHEN NOT REQUIRED
LEVEL: Maintenance/Operations.
DESCRIPTION: Shut off water heating when not required, e.g. when building not occupied. Control heater operation (boiler or resistive heater) to match SHW demand, thereby saving on standby losses.
APPLICATION:
SIDE BENEFITS:
CAUTIONS: See ECO S.4. (Heat during off-peak periods.)
COST FACTORS: Moderate.
INTERACTIONS: See ECO S.4. (Heat during off-peak periods.) Consider adding storage insulation (ECO P.6) as an alternative ECO, particularly if SHW use is evenly distributed during the day. Switching energy source could be a complementary ECO, when off-peak rates are applied (ECO S.18 and S.21).

EVALUATION: Inspect water usage profiles and look for high and low usage periods. Evaluate standby losses (see AP H.2, AP S.3 and AT P.1) and estimate energy savings associated with heating time reduction.
COMMENTS:
REFERENCES: Dubin, 1976.

ECO S.11 INSTALL CONTROLS TO REDUCE PUMP USE.
LEVEL: Maintenance.
DESCRIPTION: Same as ECO S.2 (reduce use of circulating pumps) but done automatically. Generally requires magnetic valves to stop gravity circulation.
APPLICATION: All systems using pumps for water circulation.
SIDE BENEFITS: See ECO S.2. (Reduce use of circulating pumps.)
CAUTIONS: Make sure ECO is compatible with water use patterns (increased time lag in SHW delivery).
COST FACTORS: Variable, highly dependent upon installation.
INTERACTIONS: Reduces benefit of ECO P.6, (Upgrade insulation). ECO S.2, (Circulation pumps).
EVALUATION: Estimate distribution losses from MT P.2 through P.6 or AT P.1 and compare with RV S.2. Calculate energy savings from pump operating time reduction (two benefits: reduced distribution losses and pumping energy consumption). See also AT S.2.
COMMENTS:
REFERENCES: Dubin, 1976; Harrje, 1983.

ECO S.12 INSTALL A WATER SOFTENER.
LEVEL: Improvement.
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 officiency).
APPLICATION:
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.
INTERACTIONS:
EVALUATION: Look for chalky deposits on pipes and taps; if necessarry, perform a water quality analysis (RV S.6).
COMMENTS:
REFERENCES: CIBSE Guide B7, 1986.

ECO S.13 REPLACE PILOTS WITH ELECTRIC IGNITION.
LEVEL: Replacement.
DESCRIPTION: Replace pilot flame with automatic electronic ignition system.
APPLICATION: Gas units.
SIDE BENEFITS: Possibly safer operation.
CAUTIONS:
COST FACTORS: Moderate.

INTERACTIONS: Consider particularly if SHW system replacement is advisable.
EVALUATION: Estimate time in which pilot is on and associated fuel savings.
COMMENTS:
REFERENCES: Dubin, 1976.

ECO S.14 INSTALL PRESSURE REDUCING VALVES.
LEVEL: Improvement.
DESCRIPTION: Install pressure reducing valves in main SHW outlets to regulate flow.
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: ECO S.9 (Install flow restrictors).
EVALUATION: Measure flow rate from outlet and compare with the recommended value (RV S.3). Estimate saving due to reduced consumption.
COMMENTS: This ECO will not reduce the amount of energy used to heat the water to "fill" baths etc.
REFERENCES:

ECO S.15 INSTALL TRACE HEATING ON DEAD LEGS.
LEVEL: Maintenance.
DESCRIPTION: Use trace heating to keep hot water at temperature in pipework rather than circulating pumps. This reduces pumping losses and pumping energy, also shorter pipe runs (no return pipe required) reduces distribution losses.
APPLICATION: SHW 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: ECO S.2 (Circulation pumps).
EVALUATION: Saving in distribution losses (MT P.2 through P.6 and AT P.1) and pumping energy should be compared against trace heating energy.
COMMENTS: Modern trace heating cable is available that is self (temperature) regulating.
REFERENCES:

ECO S.16 OPTIMIZE SIZE OF SHW STORAGE TANK.
LEVEL: Improvement.
DESCRIPTION: Modify size of storage tank to adjust to storage needs.
APPLICATION:
SIDE BENEFITS:
CAUTIONS: Check compatibility with SHW demand.
COST FACTORS: Comparable with replacement costs.
INTERACTIONS: All ECOs implying radical modifications to system. If storage undersized (and storage size cannot be modified), consider adding a booster heater. If modular storage oversized eliminate one or more modules. This ECO interferes or is an alternative to other ECOs aimed at standby losses reduction (Upgrade insulation), S.18 (Add booster heater), S.4 (Heat during off-peak periods), S.12 (Decentralize SHW production).
EVALUATION: Compare actual storage size with optimal value based on AP S.2. Estimate savings due to standby loss reduction (AP H.2 or AT P.1). See also AT S.2.
COMMENTS:
REFERENCES: CIBSE Guide B4, 1986.

ECO S.17 CONSIDER AUTOMATIC SHW TAPS.
LEVEL: Replacement.
DESCRIPTION: Substitute ordinary taps with taps automatically operated by photocells, infrared sensors, or mechanical means to minimize SHW 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.
CAUTIONS:
COST FACTORS:
INTERACTIONS:
EVALUATION: Compare actual water consumption with RV S.1. Calculate energy savings based on estimated water savings.
COMMENTS:
REFERENCES:

ECO S.18 ADD AN INSTANTANEOUS BOOSTER TO STORAGE SYSTEM.
LEVEL: Improvement.
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.
CAUTIONS:
COST FACTORS: Moderate with respect to modifications of storage capacity.
INTERACTIONS: Consider this ECO as a complement to ECO S.1 (Reduce water temperatures) and an alternative to ECO S.16 (Optimize size of storage tank). If storage is insufficient, consider the following options: Add a booster heater. Increase storage

capacity. Install additional heater at point of use. Increase storage temperature and add more insulation. If storage excessive, reduce thermostat setting and add booster heater.

EVALUATION: Estimate energy savings based on annual SHW requirements (AP S.1) and storage loss reduction. See AT S.2.

COMMENTS:

REFERENCES:

ECO S.19 INSTALL METERING DEVICES.

LEVEL: Improvement.

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

APPLICATION: Building where additional metering is permitted (check plant layout).

SIDE BENEFITS: Occupants are informed about actual SHW 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.

INTERACTIONS: Complementary to ECOs related to system substitution (ECO S.7, S.20, S.21).

EVALUATION: Should be applied if water consumption is high (see RV S.1). See also AT S.2.

COMMENTS:

REFERENCES:

ECO S.20 INSTALL SOLAR WATER HEATING.

LEVEL: Improvement/Replacement.

DESCRIPTION: Possible combinations that may be used to lower heating SHW costs are: i) solar only ii) solar-assisted heat pump.

APPLICATION: Especially electrical SHW system.

SIDE BENEFITS:

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.

INTERACTIONS: Most Replacement level ECOs. ECOs related to heat recovery (ECO S.8). Alternative: ECO S.7 (Install heat pump), S.19 (Install metering devices).

EVALUATION: Evaluate solar energy availability and daily SHW production (RV S.5). Calculate SHW energy demand before the retrofit (AP S.1) and estimate the savings based on system performance figures (AT S.1).

COMMENTS:

REFERENCES: Dubin, 1976; BRE Digest 205, 1977; BRE Digest 253, 1981; BRE IP 14/81, 1981.

ECO S.21 SWITCH FROM STORAGE TO INSTANTANEOUS SHW SYSTEM.

LEVEL: Replacement.

DESCRIPTION: Replace existing storage system with instantaneous system.

APPLICATION: Most applicable to highly intermittent use and/or widely distributed points of use.
SIDE BENEFITS: SHW supply not constrained by storage size.
CAUTIONS:
COST FACTORS: Particularly effective if existing system needs replacement. The convenience of this ECO will increase with: i) Decreasing distribution efficiency of the storage system, and ii) Decreasing average amount of water drawn at one time.
INTERACTIONS: Most Replacement level ECOs and ECO S.4 (Heat during off-peak periods), ECO S.9 (Install flow restrictors), S.10 (Shut off water heater), S.19 (Install metering devices).
EVALUATION: Estimate storage losses with AP S.3 or AT P.1. Calculate energy savings associated with reduced distribution/storage losses and (possibly) increased production efficiency (AT S.2).
COMMENTS: Instantaneous systems are mostly indicated when there is infrequent and light use of SHW.
REFERENCES:

ECO S.22 DECENTRALIZE SHW PRODUCTION.
LEVEL: Replacement.
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:
CAUTIONS:
COST FACTORS: Mostly effective if existing system has low distribution efficiency.
INTERACTIONS: Most Replacement level ECOs.
EVALUATION: Evaluate feasibility of this ECO by inspecting plant layout; estimate potential savings by calculating distribution efficiency.
COMMENTS:
REFERENCES:

ECO L.1 SWITCH OFF UNNECESSARY LIGHTS

LEVEL: Operational.

DESCRIPTION: Switch off lights in unoccupied areas (manually).

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: ECOs dealing with lighting control (L.16, L.17, L.19).

EVALUATION: Check lighting use during non-working periods: estimate possible reductions in operating time (refer to AT L.1 for computing energy savings).

COMMENTS:

REFERENCES: BRE Digest 232, 1979 and BRE Digest 272, 1983.

ECO L.2 LIMIT LIGHTING NEEDS DURING CLEANING PERIODS

LEVEL: Operational.

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.

SIDE BENEFITS:

CAUTIONS: Respect minimum safety illumination levels in other spaces.

COST FACTORS: Negligible.

INTERACTIONS: ECO L.17 (add switches), L.19 (central light operation).

EVALUATION: Examine cleaning schedules and building layout. Estimate energy savings with AT L.1.

COMMENTS:

REFERENCES: IES, 1981 and BRE Digest 232, 1979.

ECO L.3 USE LOW LEVEL LIGHTING FOR SECURITY PERIODS

LEVEL: Operational.

DESCRIPTION: Use low level lighting (e.g. emergency lighting) during security controls.

APPLICATION: All buildings which require security controls.

SIDE BENEFITS:

CAUTIONS: Care must be taken so that safety is not compromised.

COST FACTORS: Negligible.

INTERACTIONS: ECO L.17 (add switches), L.19 (central light operation).

EVALUATION: Estimate energy savings with AT L.1.

COMMENTS:

REFERENCES: IES, 1981.

ECO L.4 REDUCE EXTERIOR, GROUNDS, SIGN, DISPLAY LIGHTING

LEVEL: Operational/Improvement.

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.

SIDE BENEFITS:

CAUTIONS: Respect minimum safety illumination levels.
COST FACTORS: Negligible to low.
INTERACTIONS: ECOs dealing with lighting control (L.16, L.17 and L.19).
EVALUATION: Compare installed power and lighting usage with reference values (RV L.1); estimate savings with AT L.1.
COMMENTS:
REFERENCES:

ECO L.5 REARRANGE WORK SPACE TO MAKE BEST USE OF DAYLIGHT
LEVEL: Operational.
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 may be needed to avoid glare.
COST FACTORS: Negligible.
INTERACTIONS: ECOs related to lighting control (L.16, L.17). Delamping (L.6). Improve fixtures arrangement (L.19). See also ENVELOPE ECOs dealing with fenestration.
EVALUATION: Estimate daylighting potential with AP L.3. Evaluate reduction in artificial light use with AT L.1 and L.2.
COMMENTS:
REFERENCES: CIBSE, 1984.

ECO L.6 REMOVE LAMPS
LEVEL: Operational/Improvement.
DESCRIPTION: i) If lighting is above required level, consider removing some of the lamps from fixtures, ii) 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 in i) above.
INTERACTIONS: Removing lamps may increase heating load. See also HVAC system INTERACTIONS. Could be applied in conjunctioon with ECOs increasing the lighting level (e.g., maintenance, most Improvement and Replacement ECOs).
EVALUATION: Check illuminance levels on working plane (MT L.1). Alternatively, refer to reference values for installed lighting power (see RV L.1) to estimate potential for delamping. Estimate energy savings with AT L.1.
COMMENTS:
REFERENCES:

ECO L.7 LUMINAIRE MAINTENANCE
LEVEL: 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.
CAUTIONS:
COST FACTORS: Should be part of ordinary maintenance.
INTERACTIONS: This ECO 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 components replacement (most I/R ECOs).
EVALUATION: Refer to RV L.4 for lamp depreciation curves.
COMMENTS: Cleaning required after approximately 1000 operating hours (bulbs) or 2500 hours (tubes).
REFERENCES: IES, 1981, BRE Digest 232., 1979 and BRE Digest 272, 1983.

ECO L.8 CLEAN INTERIOR WALL SURFACES. REPAINT WITH LIGHTER COLORS
LEVEL: Maintenance.
DESCRIPTION: In order to make better use of emitted light flux, use high reflectance matte paints for walls and ceilings.
APPLICATION: All lighting, especially when reflected light is a significant part of the overall lighting level; e.g. indirect lighting, small rooms, luminaires with wide angle distribution.
SIDE BENEFITS:
CAUTIONS: Avoid excessive reflectances which may cause veiling reflections and glare.
COST FACTORS: May be part of ordinary maintenance.
INTERACTIONS: This ECO does not save energy unless coupled with actions aimed at lighting power reduction (e.g. delamping, permanent power reduction, etc.).
EVALUATION: To estimate potential energy savings, refer to RV L.2 (Installed efficacy of luminaires).
COMMENTS:
REFERENCES: BRE Digest 232, 1979.

ECO L.9 IMPROVE LUMINAIRES GEOMETRIC ARRANGEMENT
LEVEL: Improvement.
DESCRIPTION: Modify position of lighting fixtures, according to work station location: i) Rearrange luminaires horizontally, without modifying height; ii) Lower luminaire mounting height.
APPLICATION: All buildings.
SIDE BENEFITS:
CAUTIONS: Control veiling reflections and glare.
COST FACTORS: ECO most approriate where lighting renovation work is needed.

INTERACTIONS: ECO L.5: Rearrange work areas to utilize daylight. Should be coupled with delamping or power reduction to achieve energy savings. Alternatively consider task lighting (ECO L.10).
EVALUATION: Auditor should first check if it is possible to rearrange the space layout before displacing the luminaires. Refer to AP L.1 to assess the overall efficiency of the lighting system.
COMMENTS:
REFERENCES: BRE Digest 232, 1979.

ECO L.10 USE TASK LIGHTING
LEVEL: Improvement.
DESCRIPTION: Locate work stations and provide required illuminances, while maintaining lower values in surrounding non-critical areas.
APPLICATION:
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.
COST FACTORS:
INTERACTIONS: Should be coupled with delamping to achieve energy savings. Alternatively consider ECO L.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 and calculate energy savings with AT L.1.
COMMENTS:
REFERENCES: IES, 1981, BRE Digest 232, 1979 and BRE Digest 256, 1981.

ECO L.11 USE EFFICIENT BALLASTS
LEVEL: Improvement/Replacement.
DESCRIPTION: Substitute existing ballasts with more efficient ones: i) install multi-level ballasts if lighting level control is desirable; ii) install high frequency ballasts.
APPLICATION: Fluorescent systems.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Ballast replacement only may not be cost-effective. Consider also complete luminaire replacement.
INTERACTIONS: Luminaire maintenance (ECO L.7). Multi-level ballasts may be an alternative to other lighting control ECOs (L.16, L.17). Alternatively, consider lighting replacement (ECO L.13, L.19).
EVALUATION: Usually a simple visual inspection of the ballast type is sufficient to assess replacement; alternatively detect high temperature as an indicator of poor performance.
COMMENTS:
REFERENCES: BRE Digest 232, 1979, BRE Digest 272, 1983, BRE IP 14/84, 1984 and BRE CP 44/78, 1978.

ECO L.12 REPLACE LOW WATTAGE LAMPS WITH FEWER HIGH WATTAGE ONES
LEVEL: Improvement/Replacement.

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.
SIDE BENEFITS:
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 (ECO L.7). Alternatively, consider lighting replacement (ECO L.13, L.19).
EVALUATION: Refer to RV L.3 for lamp efficacy data; estimate energy savings with AT L.1.
COMMENTS:
REFERENCES:

ECO L.13 INSTALL MORE EFFICIENT LIGHT SOURCE
LEVEL: Improvement/Replacement.
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.
SIDE BENEFITS:
CAUTIONS: Respect color rendering requirements. Most fixtures have limited lamp possibilities: this ECO may imply substituting the whole fixture. Also notice that not all lamps have equal dimming capability.
COST FACTORS: Moderate.
INTERACTIONS: Consider as a complement/alternative to component or lighting system replacement. May be coupled to ECOs L.6, L.7.
EVALUATION: Refer to target values for installed power (RV L.1) to evaluate feasibility of lamp substitution. Estimate energy savings from installed efficacy data (RV L.2).
COMMENTS: Miniature fluorescent lamps are available as a direct replacement for incandescent lamps.
REFERENCES: IES, 1981.

ECO L.14 INSTALL MORE EFFICIENT REFLECTORS AND LENSES IN LUMINAIRES
LEVEL: Improvement/Replacement.
DESCRIPTION: Install reflectors and lenses achieving the desired light distribution with minimum light loss.
APPLICATION: Older lighting systems and components.
SIDE BENEFITS:
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 (ECO L.6, L.7).
EVALUATION: Use AP L.1 and MT L.1 to evaluate potential improvements in lighting efficacy (see also RV L.2 for typical installed efficacy values.

COMMENTS: Many older type lenses were subject to yellowing with age and consequent reduction in light transmission.
REFERENCES:

ECO L.15 INSTALL AUTOMATIC CONTROL SYSTEM TO MAINTAIN CONSTANT ILLUMINANCE
LEVEL: Improvement/Replacement.
DESCRIPTION: Install a control system which adjusts the luminaire light output to maintain a constant illuminance.
APPLICATION: Only for lighting systems that allow dimming.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Moderate.
INTERACTIONS: Luminaire maintenance (ECO L.7); Wall repainting (ECO L.8).
EVALUATION:
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.
REFERENCES: BRE Digest 232, 1979, BRE Digest 272, 1983 and BRE CP 44/78, 1978.

ECO L.16 INSTALL CONTROL TO ENABLE BETTER USE OF DAYLIGHTING
LEVEL: Improvement/Replacement.
DESCRIPTION: i) install controls which automatically reduce artificial lighting when daylight is available; ii) install separate switches for inner and peripheral area.
APPLICATION: Spaces within about 7 m from windows.
SIDE BENEFITS:
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: ECO L.5: rearrange work areas to utilize daylight. Switch off lights (ECOs L.1, L.4).
EVALUATION: Estimate daylight potential using AP L.3; estimate energy savings using AT L.1 and L.2.
COMMENTS:
REFERENCES:

ECO L.17 ADD SWITCHES, TIMERS, PRESENCE SENSORS, DIMMERS FOR BETTER CONTROL
LEVEL: Improvement/Replacement.
DESCRIPTION: i) Add switches to enable better local lighting control; ii) install time clocks to reduce lighting in public spaces during unoccupied periods; iii) install photo-electric cells to control outdoor lighting; iv) install timer switches on local circuits in intermittently occupied areas; v) install movement-sensitive switches to turn out lights in intermittently occupied areas; vi) install dimmers for

adjusting illuminance level; vii) install pull switches in offices.

APPLICATION:
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Usually cost effective only when major interior renovation or rewiring is planned.
INTERACTIONS: All ECOs related to lighting control and occupancy. Consider multi-level ballasts as an alternative control technique (ECO L.11). Consider switching functions along with other EMS functions (ECO R.28).
EVALUATION: Preliminary evaluation requires comparison of actual energy use with reference/target values; alternatively, simply evaluate occupancy habits. For more detailed assessments, refer to AP L.2 (lighting use monitoring).
COMMENTS:
REFERENCES:

ECO L.18 SWITCH TO A MORE EFFICIENT LIGHTING SYSTEM
LEVEL: Replacement.
DESCRIPTION: Replace existing lighting system with one using more efficient light sources and/or more efficient luminaires.
APPLICATION: Older systems and buildings.
SIDE BENEFITS:
CAUTIONS: Respect color rendering requirements.
COST FACTORS: Consider if major renovation work is planned.
INTERACTIONS: Consider as an alternative to delamping (ECO L.6), luminaire maintenance (L.7) or components replacement (L.11, L.12, L.13 and L.14).
EVALUATION: Estimate energy savings using AT L.1; evaluate replacement feasibility from power budget analysis (RV L.1), or from energy consumption data (RV L.5); refer also to RV L.3 for lamp efficacies.
COMMENTS: Typically fluorescent sodium or mercury vapor metal halide lamps installed in place of incandescent.
REFERENCES: BRE Digest 232, 1979.

ECO L.19 INSTALL CENTRAL LIGHT OPERATION CONTROL
LEVEL: Replacement.
DESCRIPTION: Install a central, computer based lighting management system.
APPLICATION:
SIDE BENEFITS: System may perform other control tasks (e.g. HVAC, security, fire safety).
CAUTIONS:
COST FACTORS: High: cost-effective only if full capability of management system is actually needed.
INTERACTIONS: Occupancy related ECOs.
EVALUATION:
COMMENTS:
REFERENCES:

ECO EL.1 MOTOR AND DRIVE MAINTENANCE
LEVEL: Maintenance.
DESCRIPTION: Carry out preventive maintenance procedures including:
i) Clean - especially around ventilation openings.
ii) Lubrication do not overgrease.
iii) Tighten terminals.
iv) Inspect drives for signs of wear and belt tension.
v) Measure motor insulation resistance.
APPLICATION: All motors.
SIDE BENEFITS: Greater reliability, longer life.
CAUTIONS:
COST FACTORS:
INTERACTIONS: See also ECO EL.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.

ECO EL.2 BALANCE PHASE VOLTAGES
LEVEL: Maintenance.
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.
SIDE BENEFITS:
CAUTIONS: Electrical Codes may demand that loads be balanced irrespective of cost benefits of doing so where large motor loads are concerned.
COST FACTORS: Low cost.
INTERACTIONS:
EVALUATION: Measure phases voltages (see MT EL.3); rebalance if voltages differ by more than 1% of one another.
COMMENTS: Source of imbalance could result from building load or from the utility.
REFERENCES:

ECO EL.3 MOTOR AND DRIVE ALIGNMENT
LEVEL: Maintenance.
DESCRIPTION: Align motor and motor drive.
APPLICATION: Belt driven and close coupled equipment.
SIDE BENEFITS: Longer bearing and belt life.
CAUTIONS:
COST FACTORS: Low cost.
INTERACTIONS:
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.

ECO EL.4 LOAD DEMAND CONTROL THROUGH LOAD SHEDDING

LEVEL: Maintenance.

DESCRIPTION: Provide means of reducing peak demand in a building by either turning off non-essential loads over period of peak demand or by installing storage systems to shift demands of elecctric heating and cooling systems.

APPLICATION: Buildings in which electricity tariff includes maximal demand or time of day charges.

SIDE BENEFITS:

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 maximal 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 ECOs under Other Categories, particularly Energy Management Systems (ECO R.28). Note that improving power factor (ECO EL.5) can reduce kVA demand. See also ECO EL.8.

EVALUATION: Potential savings generally increase with lower Load Factors (see Section C.10 for definition) and large Secondary Loads (i.e. loads that can be switched off at times of peak loads). See AP EL.4 and AT EL.1.

COMMENTS:

REFERENCES: NECA, 1975; Spethmann, 1981; Berutti, 1984.

ECO EL.5 POWER FACTOR CORRECTION USING CAPACITORS

LEVEL: Improvement.

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 energy tariff penalises poor power factor. Typically building 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 realised 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 (ECO EL.4), correct matching of motor and drive load (ECO EL.10) and installing a power factor controller, (ECO EL.7).

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. (Refer to AP EL.1 and EL.2.) A knowledge of the type of electrical equipment would permit calculatioon but site measurement is invariably cheaper and more reliable.

COMMENTS: Check Wiring Regulations for requirements concerning the installation of capacitors and synchronous motors/condensers. Typical maximum sizes of capacitors for installation at individual motors are given in RV EL.6.

REFERENCES: Freeborn, 1980; Bell and Hester, 1980.

ECO EL.6 MOTOR SPEED CONTROL

LEVEL: Improvement.

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.

CAUTIONS:

COST FACTORS: Usually a relatively high cost item, desirability of the retrofit improves with the variability of the driven load.

INTERACTIONS: see those ECOs in other categories requiring variable speed drives; i.e. P.15, R.32, R.22, R.5 and H/C.1

EVALUATION: Refer to ECOs listed above to determine the potential for speed control. AT EL.1 indicates how actual motor savings can be calculated. RV EL.1 gives typical speed control performance for a range of control options.

COMMENTS:

REFERENCES: Electrical Construction and Maintenance, 1983.

ECO EL.7 POWER FACTOR CONTROLLERS
LEVEL: Improvement.
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 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 unsatisfactory.
COST FACTORS:
INTERACTIONS: Alternative to the installation of high efficiency motors (ECO EL.9) matching of motor and drive load (ECO EL.10) and power factor correction (ECO EL.5).
EVALUATION: Motors operating at less than 50% of their full load or operating on idle for a significant part of their operating life are prime applications. AP EL.3 gives guidance on evaluating savings associated with motor operating efficiency improvements.
COMMENTS:
REFERENCES: Freud, 1981; Holmes, 1982.

ECO EL.8 PEAK SHAVING USING ON SITE GENERATION
LEVEL: Improvement.
DESCRIPTION: Reduce the maximum demand of a system by supplying part of the load at the time(s) of peak demand from on site fuel driven generators.
APPLICATION: Buildings in which electricity tariff includes demand component and primarily buildings with existing emergency generation equipment.
SIDE BENEFITS: Emergency generating equipment needs to be "exercised" regularly to ensure that it will start when required.
CAUTIONS:
COST FACTORS: The installation of generating equipment solely for peak sharing 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 ECO EL.4.
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.
COMMENTS:
REFERENCES: Choi, 1982; PME, 1984.

ECO EL.9 HIGH EFFICIENCY MOTORS
LEVEL: Replacement.
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.
CAUTIONS:
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 (ECO EL.10).
EVALUATION: AP EL.3 gives basis for determining benefit of Motor Efficiency Improvement. RV EL.2 gives typical efficiency improvement for range of motor sizes.
COMMENTS:
REFERENCES: ECM, 1984; Dautovich, 1980.

ECO EL.10 CORRECT MATCHING OF DRIVEN LOAD AND MOTOR
LEVEL: Replacement.
DESCRIPTION: Replace motors that are significantly oversized with units closer matching the driven load.
APPLICATION: Motor driven equipment utilising standard motor drives.
SIDE BENEFITS:
CAUTIONS: Ensure smaller motor has sufficient torque to accelerate the piece of equipment being driven. This can be a problem with large fans. Refer to RV EL.6 for information.
COST FACTORS: Most potential benefit where driven loads are a fraction (less than one half) of motor size, RV EL.3, gives part load efficiency relationships - and/or where tariff includes penalty for poor power factor. In carrying out significant retrofitting in large buildings with many different motors the possibility of switching motors offer 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 (ECO EL.7) to improve part load performance, or alternatively consider power factor correction (ECO EL.5) although this last measure will not improve efficiency.
EVALUATION: The estimation of motor efficiency improvement can be made using AP EL.3.
COMMENTS:
REFERENCES:

ECO M.1 REDUCE ELEVATOR AND ESCALATOR USE
LEVEL: Operational.
DESCRIPTION: Convince people to make less use of elevators and escalators.
APPLICATION:
SIDE BENEFITS:
CAUTIONS: Adequate stair lighting must be provided to avoid accidents.
COST FACTORS: Low cost.
INTERACTIONS:
EVALUATION:
COMMENTS: Escalators must have switch-off feature if energy is to be saved.
REFERENCES: Dubin, 1976.

ECO M.2 KEEP REFRIGERATORS AWAY FROM HEAT SOURCES
LEVEL: Operational.
DESCRIPTION: Keeping refrigerators away from heat sources. Placement in cold area also saves energy.
APPLICATION:
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Low cost.
INTERACTIONS:
EVALUATION:
COMMENTS:
REFERENCES:

ECO M.3 REDUCE CONDENSING TEMPERATURES
LEVEL: Operational/Maintenance.
DESCRIPTION: Reduce condensing temperatures of refrigerators, freezers, coolers, etc., by cleaning and ventilating coils.
APPLICATION: All refrigerating equipments.
SIDE BENEFITS: Increased equipment life.
CAUTIONS:
COST FACTORS: Low cost.
INTERACTIONS:
EVALUATION:
COMMENTS:
REFERENCES:

ECO M.4 PERFORM AIRING EFFICIENTLY
LEVEL: Operational.
DESCRIPTION: Do not leave windows and doors open for more than a short period of time. Open more than one window to get cross-flow when airing.
APPLICATION: Improves air quality and limits moisture build-up.
SIDE BENEFITS:
CAUTIONS:
COST FACTORS:
INTERACTIONS:
EVALUATION:

COMMENTS:
REFERENCES: OFAC, 1983.

ECO M.5 INFORM AND INSTRUCT OCCUPANTS
LEVEL: Operational.
DESCRIPTION: Inform and instruct occupants on the optimal use of thermostats, radiator set points, window blinds and shutters, ventilation system, etc. Supply short instructive manual.
APPLICATION:
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Often cost-effective.
INTERACTIONS:
EVALUATION:
COMMENTS: Needs to be repeated at regular intervals.
REFERENCES:

ECO M.6 MAKE DISPLAYS LEGIBLE
LEVEL: Operational/Improvement.
DESCRIPTION: Make displayed settings of controls (thermostats, programmers, time-switches, valves, etc.) legible. Particularly important for persons with impaired vision.
APPLICATION:
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Low cost.
INTERACTIONS: Interacts with Regulation ECOs.
EVALUATION:
COMMENTS: In practice displays are often illegible.
REFERENCES:

ECO M.7 MAKE CONTROL MANIPULATION EASY
LEVEL: Operational/Improvement.
DESCRIPTION: Make the physical manipulation of controls easy. Particularly important for elderly or disabled persons.
APPLICATION:
SIDE BENEFITS:
CAUTIONS:
COST FACTORS: Low cost.
INTERACTIONS: Interacts with Regulation ECOs.
EVALUATION:
COMMENTS: In practice controls are often difficult to manipulate.
REFERENCES:

ECO M.8 EQUIP TENANTS WITH INDOOR THERMOMETER
LEVEL: Operational/Improvement.
DESCRIPTION: Equip tenants with a reliable indoor thermometer with a good display for more efficient control of temperature setting etc.
APPLICATION:

SIDE BENEFITS: Often results in less complaints.
CAUTIONS: Placement of thermometer is critical to supplying accurate indication of interior conditioning.
COST FACTORS: Low cost.
INTERACTIONS:
EVALUATION:
COMMENTS:
REFERENCES:

ECO M.9 INITIATE BONUS PROGRAMS
LEVEL: Operational.
DESCRIPTION: Bonus programs initiated with operator/manager and with occupants to encourage energy conservation.
APPLICATION:
SIDE BENEFITS:
CAUTIONS: At least short-term effective.
COST FACTORS:
INTERACTIONS:
EVALUATION:
COMMENTS:
REFERENCES:

ECO M.10 SWIMMING POOL COVERS
LEVEL: Improvement/Replacement.
DESCRIPTION: Control heat and evaporation losses in swimming pools by using pool covers when pool is not in use.
APPLICATION: Indoor and outdoor pools. More applicable to smaller pools because of handling problems.
SIDE BENEFITS: Lower pool hall humidity. Water and water treatment savings.
CAUTIONS:
COST FACTORS:
INTERACTIONS: ECO R.1, R.35, R.36 are complementary or alternatives to consider for internal pools.
EVALUATION: See AT R.6, R.7. Best paybacks where high ratio of non-use to use hours.
COMMENTS:
REFERENCES:

ECO M.11 REPLACE COLD CABINET INTERVAL LIGHTS WITH EXTERNAL ONES
LEVEL: Replacement
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.
SIDE BENEFITS:
CAUTIONS: May reduce display effectiveness.
COST FACTORS:
INTERACTIONS: ECO M.12 and M.13 can be considered complimentary to this ECO.

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

COMMENTS:

REFERENCES: Dubin, 1975.

ECO M.12 PROVIDE NIGHT COVERS FOR OPEN COLD CABINETS

LEVEL: Replacement/Improvement

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.

SIDE BENEFITS:

CAUTIONS:

COST FACTORS:

INTERACTIONS: ECO M.11 can be a complimentary ECO. Alternative is to replace with closed cabinets (ECO M.13).

EVALUATION: In addition to refrigeration savings effects of reduced space heating and possibly increased 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.

COMMENTS:

REFERENCES: Dubin, 1975.

ECO M.13 REDUCE COOLING LOSSES FROM OPEN REFRIGERATED DISPLAY CABINETS

LEVEL: Improvement

DESCRIPTION: Replace open cold cabinets with closed type of retrofit existing with doors or strip covers.

APPLICATION: Refrigerated food display units with open front. Primarily applicable to stores and restaurants.

SIDE BENEFITS:

CAUTIONS: Some retails 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 (ECO M.12).

EVALUATION: Evaluation can be complex if heat from refrigeration compressors is reclaimed for space heating.

COMMENTS:

REFERENCES: Dubin, 1975.

APPENDIX E DATA COLLECTION SHEETS

E.1 CHECKLIST CRITERIA

Checklists have and still are being developed and used by many organisations and individuals involved in energy auditing. While some professionals argue that the uniqueness of each building precludes the possibility of developing such a standard approach, the checklist serves a useful purpose for many auditors.

Checklists dealing with energy auditing and with energy conservation potential in buildings are both numerous and varied in their approach, content, and detail. The simplest forms of checklists are those which present a list of ECOs to serve as an "aide-memoire" to the auditor or those which provide a format for collecting what might be considered pertinent data from the site. The most useful ones are considered to be those that combine both functions and provide a methodology for using the collected data directly in the evaluation of ECOs.

Because of the number of possible ECOs in large buildings and the relationships and interactions with one another, the process previously described is often too complex to be carried out intuitively or without a formal framework. Further, because of the extreme variations in the way buildings are designed and used, the kind of experience required to make good intuitive decisions demands a high level of expertise which is often incompatible with cost effective auditing and/or may be beyond the experience of available audit personnel.

To minimise these problems, a checklist type of approach is suggested which provides a formal framework for carrying out the identification and preliminary evaluation of ECOs. Such an approach, it is felt, would offer the following advantages:

i) The minimisation of the risk of omitting potentially valuable ECOs.
ii) The possibility of using less experienced auditors while still maintaining a standard auditing service (forms can be easily checked by more experienced auditors or supervisory staff).
iii) The minimisation of time on repeated trips to the building site to collect data missed on earlier trips.

In order to meet these criteria, a checklist needs to:

i) Serve as an aide-memoire on all the possible ECOs that may be appropriate to any specific building.
ii) Provide a means for orderly and cost effective collection and recording of building data that is necessary for the identification and sorting of ECOs.
iii) Provide a means of sorting the ECOs based on their projected value with as a minimum level of detail as is possible.

The use of computerised audit checklists in which the computer prompts the auditor for information, searches data bases and arrives at the logic of identification and sorting internally might also be considered.

The intent of this appendix is to describe a methodology by which such (manual) audit checklists might be developed.

E.2 CHECKLIST FORMAT

The suggested format for a checklist has two principal parts; a "data collection form" and a "worksheet".

The data collection form serves as a guide to what data should be collected in order to carry out the ECO sorting process, and as a medium for the actual recording of the data.

The worksheet primarily provides working area for sorting ECOs in a number of groups according to their desirability.

Data collection forms have been prepared corresponding with the component category systems used throughout the Source Book with a General data collection form covering common aspects that may be useful in more than one category.

A single worksheet has been prepared for the electrical category (see Table 1) to illustrate the complete proposed methodology. The particular worksheet prepared:

i) Identifies all possible ECOs within the category of "Electrical Systems",
ii) Identifies all interaction between the various ECOs in the category and where there is interaction outside of the category, and
iii) Leaves a space for adding notes and comments for future reference and as an aid to the sorting process.

For the interaction part of the work sheet:

C is used to denote complementary ECOs. These ECOs should be considered for implementation together.
A is used to denote alternative ECOs. These ECOs should be considered as alternatives to one another, i.e. only one or the other should be implemented.
I is used to denote interference. These ECOs interfere with one another, for instance if both ECOs are implemented the resultant saving may not be the sum of the individual savings.

For the actual sorting of ECOs, seven alternate classifications are used:

"DO". ECO should be implemented without further evaluation.

"DO (PRIOR TO POSSIBLE AUTOMATION)". ECO should be implemented manually and considered for automation for enhanced savings.

"DO IF". ECO should be implemented subject to some condition being satisfied. E.g. '<u>DO</u>' service burner '<u>IF</u>' boiler is not to be replaced. The 'Comments' column provide a space for defining such conditions.

"MOST DESIRABLE". ECO should be considered for further evaluation.

"NEUTRAL". ECO may be worth considering for further evaluation.

"LEAST DESIRABLE". ECO probably not worth considering further.

"NOT APPLICABLE". ECO not appropriate. Space is provided on the worksheet to identify which of the first six of these categories is most appropriate for a given situation in a building; for the seventh, "NOT APPLICABLE", the ECO can be crossed off the form.

E.3 CHECKLIST USE

The use of the forms parallels the philosophy for the ECO identification and evaluation process as described earlier.

The process is an iterative one where ECOs are progressively ranked or 'discarded' according to their desirability or lack of applicability, using progressively more detailed and/or less readily available data.

To summarise the previous discussion in the context of the use of checklists:

Only those checklists should be selected for processing that cover those areas of the building that have been identified as requiring auditing either on the basis of disaggregation analysis, or specific client directives. Of course, checklists that cover component categories for which there is no corresponding equipment in the building being audited need not be considered.

Individual ECOs or groups of ECOs should be discarded on the basis of:

i) Clearly unfavourable economics, i.e. paybacks and capital cost very much greater than client's criteria,
ii) Instruction from client not to pursue certain specific ECOs or ECO types,
iii) ECO has already been implemented, and
iv) Type of system, process or occupancy specific to the ECO not present in the building.

Work on a copy of the worksheet, cross out ECOs that are considered inappropriate and add notes to aid further evaluation.

Individual ECOs should then be classified according to their perceived or judged energy saving and economic potential. Such decisions should include technical and economical considerations as well as considerations of useful remaining life of a piece of equipment and considerations such as a client's desire to favor visible as opposed to nonvisible retrofit actions. These client directives should have been previously recorded on the 'General Building Data Collection Sheet and used in this process.

In addition, any interactions that this ECO may have with other ECOs within the same component category or within other category groups, or any adverse or side benefits that the ECO may have, should form part of the consideration.

These processes are not carried out quantitatively and rely to a great deal on the experience of the auditor. The process should be carried out first using information at hand followed by information collected at the site. As ECOs are discarded, the requirement to collect certain data should be reviewed. Where data are clearly not required to be collected, because the ECO has been discarded, the relevent sections of the data collection forms should be crossed out. The process of ECO sorting can be given some formality by working through the annotated ECO list as illustrated in the following example. In this regard it is most desirable that auditors add their own particular knowledge to the ECO annotations on an ongoing basis.

Let us consider the case of ECO R.17 "Minimise Stratification". A copy of the annotated ECO description is given below.

ECO R.17	MINIMISE STRATIFICATION
LEVEL:	Improvement/Replacement.
DESCRIPTION:	Eliminate high temperatures at upper levels by use of fans, tubes, entrainment by air jets or drawing return air from high level. Make-up 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:	Destratification in summer could increase cooling load.
COST FACTORS:	
INTERACTIONS:	May reduce peak demand on heating equipment and aggravate oversizing. See ECO R.25.
EVALUATION:	AP R.5 gives details of technique for evaluating marginal cases or quantifying actual savings.
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 10 m and by 15 to 30 % for a height of more than 10 m. The corresponding numbers for forced air downward from high level are 5 to 10 % and 10 to 20 %, respectively.
REFERENCES:	Fizzel, 1977; Beier, 1978.

Information relating to possible limitations in the use or application of the ECO can usually be found under the sub heading "APPLICATIONS", i.e. the information provided can often be used to discard ECOs as inappropriate. In this case we note that the ECO is only applicable to large open spaces, generally in excess of 5 metres high.

If our building is say 4 metres or more in height we might wish to consider it for possible implementation and information found under the subheading "EVALUATION" can prove useful in this regard.

Based on the above information a tentative decision can be made as to whether the ECO is applicable and technically viable. The sub heading 'COST FACTORS' should then be checked to see if there is information regarding the economics of this particular ECO which might help ascertain whether or not it would fall within the range of the client's budget limitation. This budget information, along with consideration of 'SIDE BENEFITS', 'CAUTIONS', and 'COMMENTS', annotated on the ECO sheet, should be used to finally discard or rank the ECO.

Any relevant comments, or questions to be raised during the detailed evaluation of this particular ECO, could be noted under the comments section of the Worksheet. Conversely, overriding or prime reasons for rejecting an ECO could be noted for future reference where this is felt worthwhile.

E.4 DEVELOPING YOUR OWN WORKSHEETS

Worksheets can be developed for categories not covered in this text using the format and philosophy adopted and presented in this publication. The development process is described below:

i) Using the list of ECOs for the category in question, set up the framework of an "ECO interaction matrix" using the list of ECOs to define both the rows and columns of the matrix. Set up additional columns to cover the remaining component categories (see Table E.1).

   The list of ECOs should be reviewed for relevance to the location and type of usual auditing requirements. In this way simple, shorter worksheets and corresponding data collection forms can be formulated; very simple forms can result, for instance, where the audit checklist is customised to deal with non air conditioning dwellings.

ii) Using the Annotated ECO sheets (App. D), identify and mark on the matrix all interactions between individual ECOs and between individual ECOs and other categories.

iii) Finally, additional columns plus a space for comments should be added to the matrix to permit the classification of ECOs.

TABLE E.1 WORKSHEET FOR ELECTRICAL SYSTEMS

ECO	EL	INTERACTION (OTHER ECOs) .1	.2	.3	.4	.5	.6	.7	.8	.9	.10
.1	MOTOR & DRIVE MAINTENANCE	x		C							
.2	BALANCE PHASE VOLTAGES		x								
.3	MOTOR & MOTOR DRIVE ALIGNMENT	C		x							
.4	LOAD DEMAND CONTROL THROUGH LOAD SHEDDING				x				C		
.5	POWER FACTOR CORRECTION USING CAPACITORS					x		A		I	I
.6	MOTOR SPEED CONTROL						x				
.7	POWER FACTOR CONTROLLERS					A		x		A	A
.8	PEAK SHAVING USING ON SITE GENERATION				C				x		
.9	HIGH EFFICIENCY MOTORS					I		A		x	C
.10	CORRECT MATCHING OF DRIVEN LOAD & MOTORS					I		A		C	x

INTERACTION (OTHER CATEGORIES)	.1	.2	.3	.4	.5	.6	.7	.8	.9	.10
ENVELOPE (E)				*						
REGULATION (R)				*		*		*		*
HEATING (H)				*		*		*		
HEATING AND COOLING (H/C)										
COOLING (C)				*		*		*		*
DUCTWORK (D)				*		*		*		*
PIPEWORK (P)				*		*		*		*
SERVICE HOT WATER (S)				*				*		
LIGHTING (L)				*				*		
MISCELLANEOUS (M)										

FOR EVALUATION (FOR AUDITORS USE)	.1	.2	.3	.4	.5	.6	.7	.8	.9	.10
1. DO										
2. DO (PRIOR TO POSSIBLE AUTOMATION)										
3. DO IF										
4. MOST FAVOURABLE										
5. NEUTRAL										
6. LEAST FAVOURABLE										

COMMENTS

GENERAL BUILDING DATA COLLECTION SHEET
(Audit Briefing Checklist)

0. ADMINISTRATIVE GENERAL DATA

0.1 Building Address ZIP ________ Town ______________________________
Street ______________________ Nr ________

0.2 Ownership type ____
Owner/manager's name ____________________________________
Address ______________________________________ Tel. ______________
Private owner ( ) Public ( )
Building tenants: owner ( ) fully rented ( ) mixed ( )

0.3 Person responsable for administration
Name ____
Address ______________________________________ Tel. ______________

0.4 Person responsable for technical matters
Name ____
Address ______________________________________ Tel. ______________

0.5 Building Category (Building functional use)
(Specify the percentage of the total conditioned floor area)

Residential	________	Offices	________	Commercial	________
School	________	Hospital	________	Sport Centre	________
Swimming Pool	________	Catering	________	Tourism	________
Cultural Bldg	________	Military	________	Industrial	________

0.6 Building Type
Detached ( ) Semidetached ( ) Midterrace ( ) Highrise ( ) Low rise ( )
Number of storeys _____ Number of conditioned zones _____
if residential: _____ Number of dwelling units _____

0.7 Building Year of construction ________
Date of last major modification of the envelope, if any ________

0.8 Gross Building Vol. _______ m^3 Gross Conditioned Vol. _______ m^3

0.9 Total conditioned floor area ________ m^2

0.10 Building Position
Town Centre ( ) Suburb ( ) Open country ( )

0.11 Windy Site High ( ) Medium ( ) Low ( )

0.12 Conventional HDD ___________ CDD ___________

1. OVERALL BUILDING

1.1 Remaining life of:

Building structure _____yrs.
Envelope system _____yrs.
HVAC systems _____yrs.
Interior (partitioning) systems _____yrs.

1.2 Detail of planned changes, major refurbishments, etc.________________

____

____

____

____

1.3 Possibility of Audit recommendations being applied to other building
yes ( )   no ( )

Details____

____

2. ECONOMIC RESTRAINTS

2.1 Capital - very limited ( )
(O&M changes must be implemented to generate savings to find retrofits)
Capital available $ ________
(give details)

2.2 Investment criteria - method of evaluation and values

simple payback ( )   time period ____ yrs.
internal rate of return ( )   %

Other ( )   describe ________________________________

____

____

2.3 Current fuel tariffs (give details) ________________________

____

____

Specific Details (describe interest rates, discount periods, tax, etc.)

____

____

____

____

____

2.4 Investment and operational needs/desires

to save energy ( )
to save specific fuel type ( ) details____________
to save maximum demand ( )
accommodate increased load in the building ( )
pass energy cost directly to tenants ( )
limit manual operation ( )
other (describe) ____
____
____
____
____

2.5 Applicable Grants, subsidies and tax advantages ______________________
____
____
____
____

3. BUILDING CONOITION

Note all problems

comfort ( )
breakdowns ( )
lack of capacity ( )
appearance ( )
noise ( )
other ( )

Describe problems ____
____
____
____
____

4. ECO IMPLEMENTATION PLAN

		Preferred	Essential
4.1	In order of loads, distribution then systems & central plant	( )	( )
4.2	In ascending order of payback, internal rate of return or other life-cycle cost	( )	( )
4.3	Energy savings used to generate retrofit capital fund	( )	( )

4.4 Items capitalized ( ) ( )

4.5 In conjunction with planned retrofit ( ) ( )
& refurbishment - give details

4.6 To be assessed ( ) ( )

Additional Comments and Details: ______________________________
____
____
____
____

5. SPECIFIC REQUEST BY OWNER/MANAGER

Note details of general requirements, e.g. desirability of visible ECO's and specific ECO requests from owner, manager______________________
____
____
____
____
____

6. OCCUPANCY AND MISC. EMS System ( ) type ______________________

Normal Occupancy Period: hours per day ( ) days per week ( )
weeks per year ( )
Cleaning and Maintenance (outside of normal hours): hours per day ( )
days per week ( ) weeks per year ( )
Security (outside of normal and cleaning hours): hours per day ( )
days per week ( ) weeks per year ( )
Occupancy Pattern : steady ( ) intermittent, e.g. restaurant ( )
(density)
uniform ( ) isolated ( )
e.g. office e.g. warehouse

Building/Space Thermal Inertia : light weight ( ) medium weight ( )
heavy weight ( )

7. UTILITY AND OTHER RECORDS

7.1 Annual data

	Value	Cost
Consumption		
Maximum demand		
Power factor (electricity)		
Load factor		
Other		

7.2 Monthly data (or seasonal)

Use to plot consumption, demand, costs, etc.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

7.3 Hourly data

Use to plot demand, consumption etc.

Day 1=.........		Day 2=..........		Day 3=..........	

Midnight Noon Midnight Noon Midnight Noon Midnight

ENVELOPE DATA COLLECTION SHEET

1. WINDOWS

Materials used:

Wall surface covered by glass ....%
Number of glass panes ....%
....%
Estimate total glass area ....m^2
Note: missing or cracked glass ....

No of windows ....
Are there windows that can be covered over? .....
Storm windows ......%

....
Special treatments applied, coatings, etc.
....
Can improvements be made, how? ....
....

Thermal/solar factors:

Are there shades, shutters, drapes, roller blinds, etc.? ....
....
....
Note solar shading environment ....
....
Can improvements be made, how? ....
....

Ventilation and air leakage factors:

Windows able to be opened (describe) ....
....
Level of weather stripping: none ( ) partial ( ) well done ( )
....
Conditions of latches ....
Recommendations ....

Water problems

Evidence of water problems, windows & mouldings none ( ) yes ( )
List details ....
Vents: ....
....
Recommendations ....
....

2. DOORS

Exterior doors:

Surface covered by exterior doors ....% Thermal resistance ....
Are some unnecessary and could they be covered over? ....
What exterior door construction has been used?
doors .... seals .... latches ....
storm doors .... closure apparatus ....

Can exterior door systems be upgraded, how? ....
....
....

Interior doors:
Are they present at each floor to prevent floor-to-floor vertical air flow, details? ....
....
....
Recommendations: ....
....

3. WALLS

Material used (describe):
Exterior color ....
Exterior surface treatment ....
Interior treatment ....
Estimate of thermal resistance ....
Estimate of wall surface area ....
Are radiators located along exterior walls? ....
Can insulation be added, how? ....
....

State of repair: poor ( ) average ( ) good ( )
Evidence of air leakage sites (gaps, cracks, etc.) ....
....
....
Evidence of thermal bridges (discoloration, etc.) ....
....
....
Evidence of moisture problems (stains, rot, etc.) ....
....
....

Interior Space
Average room height ....m
Is it feasible to lower room heights to reduce conditioned volume?
....

Notes on existing conditions and possible improvements:
....
....
....

4. ROOFS/ATTICS

Type/Size of roof system .... m^2 ....
....
Type/Size of attic ....

Materials used, roof/attic:
Water barrier ....
Insulation level & type ....
Support material ....
Estimate of thermal resistance ....
Can insulation be added? Specify choices ....
....

Vents/ventilation size and location):
Penetrations through roof ....
Under roof ventilation ....
Are vents sized properly and unblocked? ....
....

Water/weather problems:
Inside water leaks ....
Deterioration of roof surface ....
Water puddling on roof/ice dams ....
Wet insulation ....
Air penetration under insulation ....

Wood product decay/discoloration roof/attic ....
Roof cooling: Can roof/building benefit from and support an
evaporative spray system? ....
....

5. FOUNDATIONS/LOWER FLOOR

Type of foundation, floor construction ....
....
....

Materials used:
Structural ....
Insulation (inside, outside, describe) ....
....
Surface treatments ....
Estimate of thermal resistance ....
Can insulation be added, how?

Coupling with main portion of building
Shafts and stair system ....
Isolated from building?..

Floor immediately above foundation.
Materials ....
Insulation level/method ....
Should additional insulation be added, how? ....

Vents and other connections to outside
Vent description ....
Openings at service pipes, wiring ....
....

Notes on possible improvements: ....
....
....

6. AIR MOVEMENT AND EXCHANGE

Air exchange level (all components):
Is there evidence of building draftiness, open vents, leak sites, etc.?
....
What is needed in terms of sealants and/or construction to limit air exchange? ....

Vertical air movement:
Is there evidence of plumbing and electrical shafts extending upward through the building? ....
....
Possible solutions ....

REGULATION DATA COLLECTION SHEET

1. HEATING DISTRIBUTION (see also PIPES checklist) — not provided ( )

Zones : single ( ) multiple ( )

Control : fixed temperature ( )

variable temperature with
- i) indoor master stat. ( )
- ii) outside air stat. ( )
- iii) solar compensation ( )
- iv) night changeover ( )

temperature control by: mixing valve ( ) resetting boiler aquastat ( )
additional room controls : ( )

2. SPACE HEAT CONTROL

Zones : individual room ( ) zone ( ) building ( )

Setpoints : OK ( ) COMMENTS: ______________________________

____

Comfort Problems : overshoot

too hot : always ( ) spring/fall ( ) sunny weather ( )
too cold: always ( ) spring/fall ( ) early morning ( )

windows opened for temperature control ( )

when ______________________________

Control : setback ( )

Thermostat Types: ON/OFF ( ) anticipator ( ) proportional ( )
thermostatic radiator valves ( )

Heating Terminals :
static: electric ( ) hydronic ( )
warm air: electric and gas or oil ( ) (e.g. furnace) hydronic ( )

demand change in tariff ( )
(electrical systems only)

mainly radiant ( ) (low temperature) radiant ( ) (high temperature)

Water and Steam Coils : throttle valve ( ) 3-way mixing with circulator ( )
single control valve on large coil ( )

3. SPACE COOL CONTROL not provided ( )

Zones : individual room ( ) zone ( ) building ( )

Setpoints : OK ( ) deadband or otherwise sequenced with heating ( )
(check results from disaggregation analysis) ( )

Comfort Problems:

too hot : always ( ) sunny weather ( ) time of day ________
too cold : always ( ) dull days ( ) time of day ________

Thermostat Type : ON/OFF ( ) proportional ( ) deadband ( )

Control : temperature setup or shut off ( )

Main System Type(s): ____

____

Cooling Medium : chilled water ( ) refrigerant (Dx, systems) ( )

4. MECHANICAL VENTILATION SYSTEMS not provided ( )
(Systems supplying conditioned air - see also GARAGES).

Current Operation : continuous ( ) only when occupied ( )
on during pre-conditioning period ( )

Required Operation : continuous ( ) only when occupied ( )

Type : 100% (outside air) ( ) mixing system ( )
air economiser ( ) heat exchanger ( )
evaporative cooling ( ) preheat coils ( )

Control : constant ( ) varied by time clock ( )
varied by CO monitor ( ) (during occupancy)
varied by CO_2 monitor ( ) (during occupancy)
varied by humidity monitor
night ventilation ( ) (for cooling)

Heating : direct (gas) ( ) indirect or electric ( )

Volumes : excessive ( ) about right ( ) lower than required( )
not known ( )

Notes: ____

5. MECHANICAL EXHAUST SYSTEMS not provided ( )
(Systems exhausting air from the space, see also GARAGES).

Current Operation : continuous ( ) only when occupied ( )
as required (localised systems only) ( )

Required Operation : continuous ( ) only when occupied ( )
as required (localised systems only) ( )

Makeup : infiltration ( ) general ventilation ( )
local ventilation ( ) from other zones ( )
directly at exhaust using partially or
unconditioned air ( )

Type : general exhaust ( ) local exhaust ( )

Exhaust Hoods: low velocity ( ) high velocity ( ) activated carbon ( )

6. HUMIDIFICATION not provided ( )

Current Operation : continuous ( ) only when occupied ( )

Required Operation : continuous ( ) only when occupied ( )

Setpoint : ( ) %
Open space: ( ) %

7. SWIMMING POOL HALLS (Additional Information)

Size : very large (e.g. Olympic) ( ) large( )
small (private) ( )

Type : indoor ( ) outdoor ( )
Temperature: hall ( ) pool ( )

Humidity Control : none ( ) humidistat controlled ventilation ( )
mechanical dehumidification ( ) pool blanket ( )

8. INDOOR GARAGES (Additional Information)

Type : ventilation only ( ) heating and ventilation ( )

Makeup Air : outside ( ) from other zones ( )

Control : constant rate ( ) manual( ) CO monitor ( )

Comments : ____
____
____

9. HIGH SPACES (Additional Information)

Space Height : 5-10 m ( ) 10 m ( )

Terminal Heating Location : low level ( ) high level ( )

10. INDUCTION SYSTEMS not provided ( )

nozzle age ( )
temperature reset of primary air ( )
load reset controller ( )

11. DUAL DUCT, MULTIZONE AND REHEAT SYSTEMS

load reset controller ( )
stratification splitters ( ) (dual duct and multizone only)
individual coils ( ) common coils ( ) (multizone only)
recool coils ( )

12. VAV SYSTEMS not provided ( )

Terminal Types : bypass ( ) throttle ( )

Fan Control : throttle ( ) inlet or outlet dampers ( )
variable pitch or speed control ( )

13. ROOFTOP HVAC (PACKAGED) SYSTEMS

Coils: dirty ( ) clean ( )

Fan Belts: slack ( ) damaged ( ) ok ( )

Leaking Seals: yes ( ) no ( )

Gaskets (Access Doors) damaged ( ) missing ( ) ok ( )

Covers: marine hatch ( ) of screwed fasteners ( )
secure ( ) loose ( )

Insulation: damaged ( ) OK ( )
thickness mm _________

Condenser: shaded ( ) in direct sunlight ( )

Cooling Coil Trap: blown ( ) OK ( )
(air escaping)

HEATING PLANT DATA COLLECTION SHEET

1. GENERAL

Type of heating system:
heating only ( ) combined heating & cooling ( )
combined production of space heating and SHW ( )
combined with supplementary heating system Yes ( ) No ( )
if Yes: solar ( ) heat pump ( ) wood ( ) oil ( )
LPG ( ) natl. gas ( ) elect ( ) others ( )

Central heating building ( ) more than 1 bldg. ( )

Main fuel used:
natl. gas ( ) gas-oil ( ) heavy oil ( ) electricity ( )
heat content high .... low ....
pressure (gas only) .... kPa/bar/mm H_2O ....

Number of heat generators .... of which .... for reserve

Heating period .... days
starting date .../... ending date .../...
Operating schedule of the heating plant

	total hrs/day	from	to	from	to
working days	.....	.....	.....	.....	.....
pre-holidays	.....	.....	.....	.....	.....
holidays	.....	.....	.....	.....	.....

Person responsible for the operation ....

Maintenance frequency
burner on request ( ) start/end season ( ) ..... times/year
boiler on request ( ) start/end season ( ) ..... times/year
chimney on request ( ) start/end season ( ) ..... times/year
treatment of heating fluid ....

Person responsible of the maintenance ....

There are heat recovery devices installed on the flue gas exhaust? Yes ( ) No ( ).

Boiler room pipe insulation
none ( ) damaged or insufficient ( ) OK ( )
thickness ( ) mm type: ....

Has the central heating a water storage tank? Yes ( ) No ( )
storage tank capacity .....m^3 storage temperature .....^oC
storage tank insulation:
none ( ) damaged or insufficient ( ) OK ( )
thickness ( ) mm type: ....

Expansion tank volume .....m^3 open ( ) closed ( )

Primary circuit transfer fluid
hot water ( ) superheated water ( ) steam ( ) oil ( )

Circulation pump total electric power .....hp*0.74 = ...kW

Is there a fuel oil pre-heater Yes ( ) No ( )

Boiler room ambient temperature (^{o}C) .....

Energy meters in the plant room:
nat.gas/oil flow-meter Yes ( ) No ( )
electricity meter Yes ( ) No ( )
oil tank level gauge Yes ( ) No ( )
others (specify) ....

2. BURNER

Burner-boiler system no.	1	2	3	4
trade mark	....	....	....	....
model	....	....	....	....

type: Air Pressure jet, Steam Pressure jet, High Pressure Gas, Rotary cup, Atmospheric Gas, Electric Resist., Electrode

type	....	....	....	....
thermal rating (kW) input	....	....	....	....
fuel flow rate range	....	....	....	....
measured fuel flow rate (kg/hr or m^3/hr)	....	....	....	....
nozzle charact. (GPH-mm)	....	....	....	....
fuel pressure at the nozzle (if applicable) .....Pa	....	....	....	....

Compressor electric power (if applicable) .... hp*0.74 = ...kW

Burning mode Single fire ( ) High ( ), Low ( ), Fully Modulating ( )

	....	....	....	....
dual fuel (No/Yes)	....	....	....	....
if Yes, what other fuel	....	....	....	....
Air flow adjustable	....	....	....	....
Emulsifier installed (only heavy oil) (Yes/No)	....	....	....	....
Is fuel injection angle and position adjustable (Yes/No)	....	....	....	....
Pre-purging time (seconds)	....	....	....	....

3. BOILER

Trade mark ....
Model ....
Year of installation ....
Type: Cast-Iron ( ) Steel ( ) Condensing ( ) Pulsating ( ) Water-Tube ( )
Fire-Tubes ( )

....
Rated output capacity (kW) ....
Boiler jacket insulation ....
None, Insufficient, OK
thickness ( ) mm type: ....
Jacket surface temp. (^oC) ....
Are turbulators or baffles installed in the boiler? (Fire tube boilers only)
Yes/No ....
Flue damper installed? ....
None ( ) Gravity ( ) Electromech. ( )
Boiler draft to chimney (Pa) ....
Aquastat temp. (^oC) ....
Aquastat control (constant or variable)

....
Means of (Manual, Automatic with outside air)

4. CHIMNEY

diameter .... height ....
material brick ( ) concrete ( ) tubed ( )
trace of moisture: Yes ( ) No ( ) soot layer: small ( ) thick ( )

5. EFFICIENCY

<u>Boiler combustion efficiency data</u>

CO_2 content (%) high/low fire	.../...	.../...	.../...	.../...
O_2 content (%) " "	.../...	.../...	.../...	.../...
CO content (ppm)	.../...	.../...	.../...	.../...
flue gas temp. (^oC)	.../...	.../...	.../...	.../...
soot (Bacharach) no.	.../...	.../...	.../...	.../...
combustion efficiency (%)	.../...	.../...	.../...	.../...
stand-by losses (% rated kW)	....	....	....	....
boiler full load eff. (%)	....	....	....	....

Total heating plant stand-by losses: ....% ....kW
Boiler sheduling (if applicable)
No ( ) Yes: manual ( ) automatic ( )
if Yes, setting of boiler cascade .../.../.../.../.../
ext. temp. of starting the cascade .....^oC

No. of working hours/season ....

Remarks ....

CENTRAL ELECTRIC HEATING
Trade mark .... model .... year ....
Rated thermal capacity .... storage vol.........m^3
Supply: single phase ( ) 3-phases ( )
type of tariff ....

SOLAR SPACE HEATING SYSTEMS
Trade mark of collectors .... year ....
use: space heating ( ) heating & SHW ( ) other ( ) ....
collector type: plane ( ) vacuum tube ( ) concentration ( )
other ( ) ....
collector fluid: water ( ) air ( ) anti freeze solution ( )
other ( ) ....
collector surface area gross ....m^2 net ....m^2
material: Al ( ) s.steel ( ) Cu ( ) plastic ( )
other ( ) ....
selective treatment Yes ( ) No ( )
storage type: water ( ) pebble bed ( )
other ( ) ....
capacity (volume) ....m^3
thermal capacity ....kJ/K
possibility to get a solar system installed Yes ( ) No ( )

HEAT PUMP FOR SPACE HEATING
Trade mark .... model .... year ....
type: air/air ( ) water/water ( ) air/water ( ) water/air ( )
use: heating ( ) heating and cooling ( ) heating and SHW ( )
other ( ) ....
engine: electric ( ) internal combustion ( )
internal combustion with heat recovery ( )
other ( ) ....
rated HP thermal output capacity ....kW
rated HP input power ....kW
COP at nominal working temperature (....°C) ....
Bivalent ( ) Parallel ( ) Alternative ( ) Parallell/Alternative ( )
Direct heating ( ) Storage heating ( )

DISTRICT HEATING
rated thermal capacity to the load ....kW
type of heat exchanger ....
type of tariff ....

REGULATION - See Regulation checklist

FIREPLACES
Estimated thermal capacity ....kW
location external wall ( ) internal wall ( )
type: open hearth ( ) heatilator ( )
semi-airtight ( ) airtight stove ( )
does it have glass doors Yes ( ) No ( )
does the damper fit properly Yes ( ) No ( )
if no glass doors, is it plugged when not in use Yes ( ) No ( )
frequency of use: occasional ( ) frequent ( ) main heating ( )
does it have air distribution to other rooms Yes ( ) No ( )
does it have fresh air supply Yes ( ) No ( ) with damper Yes ( ) No ( )

COOLING PLANT DATA COLLECTION SHEET

1. COOLING EQUIPMENT

PURCHASED CHILLED WATER ( )

CENTRAL CHILLERS (CHILLED WATER DISTRIBUTION)

No. of units: single ( ) multiple ( ) give number of units .....
Type: reciprocating ( ) single cylinder ( ) multi cylinder ( )
centrifugal ( )
screw ( )
absorption ( )

Free cooling types: Yes ( ) No ( )
Compressors: open ( ) closed (hermetic) ( )

Fuel/Motive power

Electricity ( )			
Turbine ( )	gas ( )	steam ( )	
Engine ( )	gas ( )	oil ( )	
Hot water ( )	site generated ( )	purchased ( )	
Steam	by product steam ( )	condensate returned ( ) to boiler or utility	

INDUSTRIAL REFRIGERATION (REFRIGERANT DISTRIBUTION) ( )

UNITARY AND SPLIT SYSTEMS

Split ( ) Distance between evaporator & condenser............
Single package ( )
Type of compressor ....

ATMOSPHERIC COOLING ( )

Details...
....

CONTROL

Current setpoint: ....Reset manually Yes ( ) No ( )
Auto reset control: Yes ( ) No ( ) setpoints........................
Critical humidity control Yes ( ) No ( )
Number (cooling stages) Flash intercooling: Yes ( ) No ( )

Capacity control: Variable speed ( )
Solution control ( )
Condenser control ( ) Absorption Only
Throttle control ( )
Hot gas bypass ( )
Back pressure valve ( ) Reciprocating only
Cylinder unloading ( )
Suction damper ( )
Inlet guide vanes ( ) Centrifugal only
Other (describe):..

SEQUENCING OF MULTIPLE UNITS

Series ( ) Parallel ( ) connection
Automatic sequencing Yes ( ) No ( )
Details ....
Manual sequencing Yes ( ) No ( )
Details ....

MISCELLANEOUS

Reasons to believe equipment oversized Yes ( ) No ( )
E.g. units of multiple plant not used, equipment cycles on hot days, etc.
Details ....
....

CHILLED WATER/ICE STORAGE PROVIDED Yes ( ) No ( )
Details ....
Estimated demand charges (if any)
Associated with chiller operation ( ) very significant
( ) could be significant
( ) none

Need for winter time cooling Yes ( ) No ( )
If Yes, by outside air or chilled water? ....
Details ....

2. HEAT REJECTION EQUIPMENT

Type: air cooled condensers ( ) city water cooled ( )
evaporative coolers ( )
cooling tower ( )
type of fill: wood ( ) ceramic ( )
natural water source ( )
describe ....
....

Is nearby natural water body available suitable for cooling Yes ( ) No ( )

CONTROL

Current setpoint: .... Reset manually Yes ( ) No ( )
Auto reset control: Yes ( ) No ( ) setpoints ....

MAINTENANCE RELATED

Condenser age ..... years

Service water quality problem Yes ( ) No ( )
Time since last cleaning ..... months
Auto tube cleaning installed Yes ( ) No ( )

Cooling towers age ..... years

Visible evidence of lack of maintenance Yes ( ) No ( )
Details ....
Time since last cleaning ..... months

TOWER/CONDENSER LOCATION good ( ) OK ( ) bad ( )

Give details below
1. stagnant air ( )
2. full sunlight ( )
3. other ....

MISCELLANEOUS

Existing heat recovery equipment: Yes ( ) No ( )
Details ....
Potential use for recovered heat: (Describe) ....
....
....

EXHAUST AIR PASSED OVER CONDENSERS Yes ( ) No ( )

Changes to exhaust air over condensers would be:
EASY (worth pursuing further) ( )
MODERATE (worth consideration) ( )
DIFFICULT (not worth pursuing) ( )

COINCIDENT DEMAND FOR COOLING & PROCESS WATER Yes ( ) No ( )

EXISTING EMS SYSTEM Yes ( ) No ( )

System serves cooling plant Yes ( ) No ( )

System provides: 1. Chilled water reset ( )
2. Condenser water reset ( )
3. Chiller sequencing ( )
4. Scheduling of auxiliaries ( )

IS DESICCANT DE-HUMIDIFICATION PROVIDED Yes ( ) No ( )

3. GENERAL

OPERATION OF AUXILIARIES	ITEM	OPERATION
	1. Chilled water pumps	....
	2. Condenser water pumps	....
	3. Oil heaters	....
	4. Cooling tower pan and trace heating	....
	5. Compressor Age ...Years Low level of refrigerant Yes ( ) No ( ) (Check sight glass)	....
	6.	....
	7.	....

Are pumps and fans controlled such that their power consumption is reduced in part-load condition (reduced rpm or other adequate control mechanisms)?

Are mixing losses possible between heated and chilled water? If yes, what has been done to avoid them.

Planned changes, major refurbishment etc. associated with or possibly affecting cooling plant ....
....

DUCTWORK DATA COLLECTION SHEETS

AIR DISTR. SYSTEM NO ... NAME ....

System type: Ventilation ( ) Heating ( ) Cooling ( )

Air flow: Design air flow: .... Measured air flow: ....

System size: Main duct dimensions: ....

Operation: Continuous ( ) when occupied ( ) ....
When needed for temp. control ( )

Supply air: Fan: manufacturer.................. type: ....
Drive: direct ( ) belt drive ( ) motor in air stream ( )
Motor: mult. speed ( ) speed(s): .... voltage: ....
Amperes: .... power: .... power factor: ....
Fan static pressure: ....

Exhaust air: Fan: manufacturer .... type: ....
Drive: direct ( ) belt drive ( ) motor in air stream ( )
Motor: mult. speed ( ) speed(s): .... voltage: ....
Amperes: .... power: .... power factor: ....
Fan static pressure: ....

Accessories: Intake backdraught damper ( ) function test ( )
Intake filter ( ) press. drop ....
Mixing unit ( ) function test ( )
Heat exchanger ( ) function test ( )
Exhaust backdraught damper ( ) function test ( )

Instruments: Thermometer for intake air (unconditioned air)
( ) reading ....
Thermometer for supply air (after plant)( ) reading ....
Thermometer for exhaust air ( ) reading ....
Manometer for filter ( ) reading ....
Other: .... ( ) reading ....
Other: .... ( ) reading ....
Other: .... ( ) reading ....

Ducts: Design pressure class: .... air-speed (avrg.) ....
Structural ( ) galvanized ( ) fibreglass ( )

Bends: made on site ( ) pre-fab. ( ) turning vanes ( )
Dampers: for balancing ( ) pres. outlets for air flow meas.( )
Insulation: type: none ( ) inside ( ) outside ( )

Supply air temp. (inside duct): summer: ..... winter: .....
Surrounding temp: (outside duct): summer: ..... winter: .....

<u>Observations</u>:	(poor, fair, good, excellent)
General maintenance	....
Intake screen	....
Intake backdraught damper	....
Air filter	....
Supply fan casing cleanliness	....
Supply fan belt alignment	....
Supply fan belt tightness	....
Supply fan rotor cleanliness	....
Supply fan rotor balance	....
Supply fan rotor noise	....
Supply fan motor temperature	....
Supply fan motor noise	....
Supply fan motor cleanliness	....
Exhaust fan casing cleanliness	....
Exhaust fan belt alignment	....
Exhaust fan belt tightness	....
Exhaust fan rotor cleanliness	....
Exhaust fan rotor balance	....
Exhaust fan rotor noise	....
Exhaust fan motor temperature	....
Exhaust fan motor noise	....
Exhaust fan motor cleanliness	....
Duct tightness	....
Duct cleanliness	....
Duct insulation	....

PIPEWORK SYSTEM DATA COLLECTION SHEET

1. DISTRIBUTION

Type of system:	hot water pipework system	( )	
	chilled water pipework system	( )	
	steam pipework system	( )	
Type of fluid:	hot water	( )	max. temp. .....
	chilled water	( )	min. temp. .....
	superheated water	( )	max. temp. .....
	steam	( )	pressure .....
	other	( )	....
	open loop system	( )	
	closed loop system	( )	
	single-pipe	( )	
	series	( )	
	diverting	( )	
	two-pipe	( )	
	direct-return	( )	
	reverse-return	( )	
	distr. from top	( )	
	distr. from bottom	( )	

2. WATER TREATMENT & FILTERING

Type of treatment: chemical conditioning ( )
mixed ( )

Chemical analysis of feedwater: yes ( ) no ( ) date ......
Boiler water hardness analysis: yes ( ) no ( ) date ....

Type of filter: ....

Pressure-flow characteristics available? yes ( ) no ( )

Time since last filter replacement ....

Dirty filters? yes ( ) no ( )

3. EXPANSION TANK

Location:	indoor ( )	outdoor ( )	
	open ( )	closed ( )	
Insulation:	yes ( )	no ( )	material ....
			thickness ....
			conductivity ....
			condition ....
Type:	open ( )	closed ( )	capacity ....
			....
			....
Air separator:	type		

4. PUMPS

Type:
1 - centrifugal direct-drive ( )
2 - centrifugal indirect-drive ( )
3 - reciprocating ( )

No.	Type	Manufacturer and model	Pressure drop	Flow rate	Motor speed	Motor power	Notes

Maintenance:	fan	good ( )	problems ....
	bearings	good ( )	problems ....
	fan belt	good ( )	problems ....
	piston	good ( )	problems ....
	brushes	good ( )	problems ....
Noises		no ( )	yes ( ) ....
Leakage		no ( )	yes ( ) ....
Fouling		no ( )	yes ( ) ....
Misalignment		no ( )	yes ( ) ....
Pump position		....	

5. PIPES

Material steel ( )
copper ( )
other ( ) ....

Location of vertical piping
outdoor ( )
in wall space (insulation on ext. side) ( )
in wall space uninsulated ( )
in solid wall ( )
indoor ( )

Accessibility: good ( ) problems ....
Visible leakage: yes ( ) no ( )
Noise: yes ( ) no ( )

Condition of		good	medium	bad
	pipes	( )	( )	( )
	expansion joints	( )	( )	( )
	flanges	( )	( )	( )

6. PIPE INSULATION no ( ) yes ( )

pipe external diameter .... mm

material ______________________
thickness ______________________
conductivity ______________________
condition ______________________

7. HEATING/COOLING TERMINALS

Type:
radiators ( ) material ....
low-temp. panels ( ) floor ( ) ceiling ( )
convector heaters( ) with fan yes ( ) no ( )
fan-coil units ( )
other ( ) ....

Position: adjacent to external wall ( )
adjacent to internal wall ( )
back screens no ( ) yes ( )

Leaks: no ( ) yes ( )
Noise: no ( ) yes ( )
Unnecessary terminals: no ( ) yes ( ) where ? ....

8. VALVES

Are valves insulated? no ( ) yes ( )

Indicate valves that do not operate correctly:

Location	Reason of malfunctioning (*)

(*) e.g.: leaks, noise, stem does not turn easily, excessive pressure

9. STEAM SYSTEMS

Source of steam:

UTILITY ( ) SITE GENERATED ( )

Give details below

Condensate return yes ( ) no ( ) all closed loop ( )

Credit for heat content of condensate yes ( ) no ( ) predominantly closed loop ( )

predominantly open loop ( )

completely open loop ( )

Type of distribution:

Gravity ( )

Atmospheric ( )
(pumped return) ( )

Constant vacuum ( )

Variable vacuum ( )

System features:

Condensate heat recovery ( )

Flash steam generators ( )

Visible leaks from vents: yes ( ) no ( )

EQUIPMENT INVENTORY

It is not necessary to complete all parts of this inventory during the initial audit stages unless the information is readily available.

		EQUIPMENT	
		DESCRIPTION	
		RATING	
		PRESSURE	
		DIRECT STEAM USEAGE	
		INDIRECT STEAM USEAGE	
		TYPE	TRAP DETAILS
		SIZE	
		AGE	
		CORRECT SIZE	TRAP CONDITION
		CORRECT TYPE	
		HOLDING CONDENSATE	
		STUCK OPEN	
		LEAKING STEAM	
		TIME SINCE MAINTAINED	
		COMMENTS	

SHW DATA COLLECTION SHEET

Number of users served by system: ....

Estimated total SHW consumption: ....(m^3)

Type of SHW accounting:
- based on number of users ( )
- individual metering ( )
- whole building metering ( )

1. DOMESTIC APPLIANCES/SHW USERS

Specify number and type of domestic appliances which may use SHW directly:

number	type
......	....
......	....
......	....
......	....

Indicate if any of the following devices are installed or if their adoption would be advisable:

type	present	absent	advisable
Flow restrictors	( )	( )	( )
Mixing devices	( )	( )	( )
Automatic shut-off	( )	( )	( )
....	( )	( )	( )
....	( )	( )	( )

Do all taps/faucets seal well? Yes ( ) No ( )

2. SHW DISTRIBUTION LAYOUT

Type of distribution:
- Local production ( )
- From central unit (dead leg) ( )
- From central unit (circulation loop) ( )

3. PIPES

Characteristics of SHW distribution piping:

Location	Length	Diameter	Pipe material
....	......	....	....
....	......	....	....
....	......	....	....

4. PUMPS

Type of circulation:
Gravity ( ) With pump ( )
Can circulation pump be turned off? Yes ( ) No ( )

Rated power of circulation pump ..... (kW)

Circulation pump operating time ..... (h/day)

5. STORAGE

Storage type:
- Individual electric heater ( )
- Central with separate tank ( )
- Central with storage integrated in the boiler ( )

Storage capacity ..... (liters) number of tanks .....

Type of heat exchanger...

6. CONTROLS/TIMERS

Type of SHW temperature control (specify):
....

Temperature setpoint in storage tank: ..... (^{o}C)
Boiler time control: Yes ( ) No ( )
If yes, time on ..... time off .....(h/day)

7. INSULATION

Pipework insulation:
Material .... Thickness .....(mm) Length ..... (m)
Maintenance state ..... Can insulation be upgraded? ......

Tank insulation:
Material .... Thickness ..... (mm) Area ..... (m^2)
Maintenance state ..... Can insulation be upgraded? .....

8. WATER TREATMENT

Type of treatment: .... None ( )
Results of water chemical analysis (if any)
.... Date ....
Is there any sign of pipe fouling? ....

9. SHW PROOUCTION SYSTEM

Source of energy employed:
electricity ( ) oil ( ) gas ( ) other ( ) ....

Type of SHW production:
SHW only ( ) Combined SHW-space heating ( )
Other All-year ( ) Winter only ( )

Type of boiler:
....

Rated heating capacity:
Unit 1 ..... (kW) Unit 2 ..... (kW) Unit 3 ..... (kW)

Maximum total rated supply of SHW to the system: .... (l/h)

Is there any form of energy metering? Yes ( ) No ( )

Is there any possibility of installing heat exchanger for waste heat recovering? Yes ( ) No ( )

LIGHTING DATA COLLECTION SHEET

N.B. Complete one form for each area in the building with similar lighting requirements.

Description of space: ....

Floor area: .... m^2

Exterior lighting: Yes ( ) No ( )

Interior lighting: Yes ( ) No ( )

Is there any possibility of installing:
heat exchanger for waste heat recovery Yes ( ) No ( )
switching to a cheaper fuel heater Yes ( ) No ( )
solar heater Yes ( ) No ( )

1. LIGHTING QUALITY

Minimum illuminance:
horizontal plane: .... (lux)
vertical plane: .... (lux)
tilted plane (tilt angle ...^{o}): .... (lux)

Color rendering requirements:
Color rendering index: .... (if available)
or none ( ) average ( ) special ( )

Glare:
from natural lighting: Yes ( ) No ( )
from artificial lighting: Yes ( ) No ( )
from reflecting surfaces: Yes ( ) No ( )

2. LIGHTING SYSTEMS

	Type	Maintenance condition			
		Good	Fair	Poor	Replace
Lamps					
Luminaires					
Circuitry					
Controls					

Maintenance schedule	Cleaning	Replacement
Lamps	....	....
Luminaires	....	....

3. DAYLIGHTING

External obstructions: Yes ( ) No ( )

Per cent of workspace surface which can be effectively illuminated by daylight: .....%

4. SWITCHING/CONTROLS

Switching arrangement:

Individual luminaire:	Yes ( )	No ( )
Zone/room:	Yes ( )	No ( )
Entire space/floor:	Yes ( )	No ( )

Control capabilities:

Manual dimming:	Yes ( )	No ( )
Daylight dimming:	Yes ( )	No ( )
Occupancy sensors:	Yes ( )	No ( )

5. BUILDING/STRUCTURAL

Wall color: Light ( ) Medium ( ) Dark ( )
Repainting needs: Yes ( ) No ( )
Major refurbishing needs (specify):

....
....

ELECTRICAL DATA COLLECTION SHEETS

1. GENERAL

Is there a need for additional load capacity	Yes ( )	No ( )
Is there a problem with 'voltage regulation'	Yes ( )	No ( )
Has power factor equipment been installed	Yes ( )	No ( )

2. TARIFF DETAILS

	Yes	No	Details
kWh consumption	( )	( )	....
Time of day	( )	( )	....
Flat rate	( )	( )	....
kW demand	( )	( )	....
Power factor	( )	( )	....
Other	( )	( )	....
Other	( )	( )	....

3. EMERGENCY GENERATING EQUIPMENT

Capacity .... kVA (kW)

Connected load .... kVA (kW)

Manual ( ) or automatic ( ) operation ....
....

Fuel: ....

Any possible reason not to permit use for peak shaving? ....
....

4. EQUIPMENT INVENTORY (FOR EVALUATION ELECTRICAL DEMAND CONTROL)
It is not necessary to complete all parts of this inventory during preliminary stages of the audit unless information is readily available.

DESCRIPTION	EQUIPMENT REFERENCE
	1. Voltage
	2. 1 or 3 phase
	3. Size (kW or kVA)
	4. Motor or stationary load
OPERATION	5. Hours per week
	6. On during peak demand
	7. Control by (1)
LOAD SCHEDULE	8. Primary or secondary load (2)
	9. Deferred or lost load (3)
	10. Effect on conditioned space (Y/N) (4)
	11. On emergency power
MOTORS	12. Power factor controller
	13. Power factor correction
	14. Speed control
	15. High efficiency motor
	16. Oversized motor
MAINTENANCE	17. Age
	18. Dirty or clean
	19. Wear on drives
	20. Noisey
	21. Evidence of overlubrication
	22. Misalignment of drives

- COMMENTS

NOTES: (1) E.G. Time clock, thermostat, photocell.
(2) Primary loads are loads that cannot or should not be interrupted.
(3) Deferred loads are loads which are not 'lost' when switched of, merely deferred, e.g. storage type water heaters.
(4) Load which contributes to the internal gain of a conditioned space, e.g. lighting, fan motors, where installed in the space or in the air supply stream.

Analytical Index

C

D

Analytical Index

This Source Book for Energy Auditors is the result of a collaboration of 9 countries and the Commission of the European Communities within the International Energy Agency. Knowledge in these countries of energy conservation measures in existing buildings has been combined, and it is presented in a way that should make it easy to apply. The work is directed towards larger buildings with a certain complexity of systems for energy use and supply, such as multifamily buildings, offices, commercial buildings etc., but it is of course also applicable on other buildings.

In the first volume the process of energy auditing is discussed, and general guidelines are given on how to select buildings for auditing, how to evaluate present energy consumption and to select what energy conservation measures to recommend. Approximately 250 energy conservation opportunities (ECOs) are described, and references are given to auditing procedures, measurement techniques, common values on consumption and technique to analyze measured data and judge the cost-effictiveness.

In the second volume these procedures and methods to collect and analyze data are presented, as well as reference values and other back-ground material.

The Source Book contains numerous references to literature giving more detailed information.

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