International Energy Agency

Source Book for Energy Auditors

Volume 2

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 2

Source Book for Energy Auditors

Edited by M.D. Lyberg

IEA
Energy Conservation

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APPENDIX F AUDIT PROCEDURES

INTRODUCTION TO APP. F

The format of the Audit Procedures (AP) contained in this Appendix is described by means of an example below.

1. AUDIT PROCEDURE NUMBER: Each procedure is numbered identifying its area of application to aid its location and filing and to allow easy reference to specific procedures throughout the text. The first letter refers to the building component category classification (See Introduction p. 10) used in this Source Book. In the example, this is Lighting. The subsequent number identifies the AP number within a category.

2. APPLICATION AREA: Identifies the application area (for example the component category or a subcategory).

3. TITLE: Descriptive title of the procedure.

4. REFERENCED FROM: Indicates ECO, AP, MT, AT and RV where this Audit Procedure is referenced.

5. REFERENCES TO: Indicates ECO, AP, MT, AT or RV referenced in this Audit Procedure.

6. DESCRIPTION OF PROCEDURE: Provides a brief but complete description of, for example, the data collection and data evaluation methods.

   The "data collection" activity may demand the use of certain common measurement techniques and, rather than repeat such techniques in detail here and on other procedures, they are described in Appendix G. Measurement techniques are only described here where the technique is <u>unique</u> to the audit procedure.

   In the example shown, the measurements required involve the use of a light meter to measure illuminance. Since such measurements are common to other procedures, a description of illuminance measurement is in this case described as a measurement technique and only referenced here.

   Those auditors familiar with illuminance techniques need not reference the additional material, however, those unfamiliar with such techniques have a ready source of information.

   In a similar manner, the "data evaluation" activity may demand certain common analysis techniques. These are to be found in Appendix H instead of being described in detail in each procedure. Calculation techniques unique to the procedure are described directly as in the particular example chosen. In some cases a combination might be appropriate, i.e. a specific analysis method might be given to translate some site measured data to a design value, followed by guidance, with specific reference to an analysis technique, on how this might be used to generate annual energy information.
   Appropriate Reference Values (App. I) may also be given.

7. COSTS: Details of costs that can be expected in using the procedure are given here, if known. Costs are broken down into labor costs, expressed in manhours, equipment costs, and consumables which are given in U.S. dollars (1985).

8. EASE OF USE: Gives guidance on the complexity of the procedure which may be helpful in selecting appropriate audit personnel or using other alternative procedures where sufficiently qualified personnel are not available.

9. ACCURACY: Expected measurements and calculation accuracy are given where possible. This is given in order to
   i) That any subsequent calculation methods required may be selected on the basis of a similar degree of accuracy which, where procedures are not particularly accurate, may permit simple calculation methods to be utilised as opposed to carrying out a detailed, possibly hourly analysis.
   ii) Indicate the possible range of paybacks that might be expected, given the accuracy range of the procedure.

   Furthermore, uncertainty of the calculations of the expected accuracy can be used to give an indication of the energy savings or payback, thereby providing the building owner with some idea of the financial risk involved in proceeding with a particular retrofit.

10. REFERENCES: Publications giving greater details of the procedure or background information are identified. The actual references are listed in the reference list.

11. RECOMMENDED APPLICATION: Gives some guidance as to the area of applicability of the procedure.

12. ALTERNATIVE PROCEDURES: Gives alternative procedures which may be either of differing cost or differing accuracy allowing the energy auditor to choose whichever method most closely matches his budget, staff and instrumentation limitations.

13. ADDITIONAL INFORMATION: The space is used for additional information such as figures, photographs or tables and charts or to accomodate lengthy procedure descriptions.

All the above headings are contained in the Audit Procedure description even if there is no content. A list of all Audit Procedures is given below.

App. F Audit Procedures (L)

(1) **audit procedure:** L.3	(2) **application area:** LIGHTING	(4) **referenced from:** ECO L.10, L.5, L.16
(3) **title:** ESTIMATION OF DAYLIGHT POTENTIAL USING AN ILLUMINANCE METER	(5) **references to:** AP L.2, MTL.1	

(6) **description:**

The data collection consists of:

i) Choose a day with a relatively unchanging sky illuminance on which to carry out measurements. Choose type of sky "overcast" or "clear" depending on the preponderance of this type of sky in your area.

ii) Measure the outdoor and indoor illuminance simultaneously, as daylight levels vary very quickly. If this is not possible, measure the outside illuminance immediately prior to starting indoor measurements and at frequent intervals throughout the internal measuring procedure described in 3. below. If the measurement of outside illuminance shows significant variations, increase the frequency of outdoor measurement, repeat before and after <u>each room</u> measurement if significant variation noted. Outdoor measurements should be made for an unobstructed sky and no direct sunlight.

iii) For those areas thought to have some daylight potential, measure illuminance with the electric lights <u>OFF</u> at all those areas where critical visual tasks are performed, e.g., in an office, this would be a desk top, filing cabinet. Measurement locations should also be made cognizant of any potential lighting switching possibilities.

iv) If the room is provided with shades or drapes, repeat the indoor illuminance measurements with these devices closed and adjusted as they might be to minimise glare from the sky or to minimise unwanted solar gains.

v) Guidelines and precautions for carrying out illuminance measurements are given in MT L.1.

The data evaluation consists of

1. The daylight factor can be calculated using the formula:

   $$\text{Daylight Factor} = \frac{\text{(Inside Horizontal Illuminance)}}{\text{(Outside Horizontal Illuminance)}}$$

   Strictly speaking the measurement should be made at the same instant;hence the need to choose days with above mentioned sky conditions (no direct sunlight).

2. Construct average daily curves of inside daylight illuminance levels for a representative six months of the year (assuming approximately symmetrical throughout the year about June) from national or locally recorded outside illuminance levels (without direct sunlight) and site measured daylight factors - see Figure under "Additional Information".

3. Superimpose required illuminance level and lighting requirement profile on diagram (based on estimated or observed use of building or from lighting use survey, see AP L.2.

4. Make allowances for increases in heating energy and reductions in cooling energy brought about by a reduced lighting load. As a first approximation, assume that all the lighting reductions during the heating season must be made up from the heating plant - remember to add a boiler efficiency if fuel-fired plant and that savings during the cooling season divided by a refrigeration plant C.O.P. can be subtracted from the A/C load.

5. Where blinds or drapes are provided, some allowance for use of blinds should be made based on measured daylight factors and estimates of use.

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(7) **cost:** Equipment - $100+ for illuminance meter
Data Collection - 10 to 15 minutes per workplace

(8) **ease of use:** Data Collection simple, calculations more involved.

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(9) **accuracy:** Measurement accuracy 15%.

(10) **references:**

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(11) **recommended applications:**
- where daylight potential has been positively identified.

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(12) **alternative procedures:**
i) More accurate and expensive but time-saving -use daylight factor meter.
ii) Calculate daylight factor.
iii) Other calculation techniques are given in the references, alternatives, for more accuracy detailed hourly analysis methods such as DOE 2 could be used.

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(13) **additional information:**

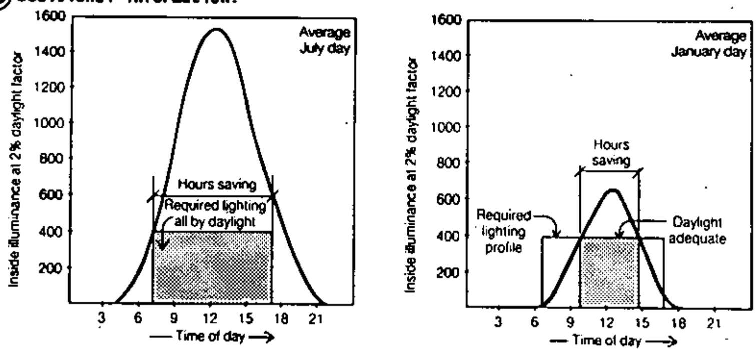


FIG. 1 Examples of daylight potential.

LIST OF AUDIT PROCEDURES (AP)

TITLE

ENVELOPE (E)

E.1 Global heat loss coefficient determined by the coheating method.
E.2 Global heat loss coefficient determined by the net energy input method.
E.3 Air infiltration rate using tracer gas.
E.4 Building envelope air infiltration and interzone air flow using the multiple tracer gas technique.
E.5 Overall building tightness using pressurization/depressurization techniques.
E.6 Building envelope air leakage using building mechanical systems for pressurization.
E.7 Building envelope air leakage using a special large fan brought to the site.
E.8 Air leakage in individual zones or apartments using fan pressurization.
E.9 Detection of leakage sites using infrared thermography/pressurization.
E.10 Detection of leakage sites using smoke pencils, or velocity measurement.
E.11 Detection of leakage sites using sound sources and receivers.
E.12 Component leakage using local pressurization methods.
E.13 Building component leakage using complete building pressurization.
E.14 Detection of thermal bridges and air leakage using IR-thermography.
E.15 Component U-value using heat flow meter.
E.16 Thermal resistance measurements using portable calorimeter and heat flow meters.
E.17 Wood moisture and mould growth audit for structural integrity.
E.18 Investigation of hidden parts of buildings using fibre optics.
E.19 Detection of moisture and mould growth.

REGULATION (R)

R.1 In situ thermostat checking.
R.2 Temperature setback and setup effects.
R.3 Pollutant concentration in exhaust air.
R.4 Evaluation of damper leakage.
R.5 Analysis of vertical temperature gradients.

HEATING (H)

H.1 Combustion efficiency.
H.2 Thermal losses and efficiencies for a boiler.
H.3 Electric boiler seasonal efficiency (total).
H.4 Evaluation of boiler oversizing.

HEATING/COOLING (H/C)

H/C.1 Performance of heat pumps and chillers.
H/C.2 Heat exchanger efficiency and output (without change of phase).

H/C.3 Air leakage of heat pumps and heat recovery units.
H/C.4 Heat pump expansion device.
H/C.5 Evaluation of defrost system.

DUCTWORK (D)

D.1 Evaluation of air leakage in distribution systems.
D.2 Evaluation of duct heat loss.
D.3 Evaluation of air flow balancing.

PIPEWORK (P)

P.1 Checking of balance of pipework system.
P.2 Pipework distribution efficiency.
P.3 Energy flow in heat distribution systems.
P.4 Steam trap inspection.
P.5 Heat emission from radiators.

SERVICE HOT WATER (S)

S.1 SHW requirements.
S.2 SHW storage capacity.
S.3 Evaluation of storage losses from SHW tank.
S.4 Performance check of a solar SHW system.
S.5 Use of heat pumps.

LIGHTING (L)

L.1 Overall lighting efficiency.
L.2 Lighting energy monitoring.
L.3 Estimation of daylight potential using an illuminance meter.

ELECTRICAL SYSTEMS (EL)

EL.1 Evaluation of power factor correction for charges based on measured power factor.
EL.2 Evaluation of power factor correction when reactive power is charged through kVa demand.
El.3 Evaluation of motor efficiency improvement.
EL.4 Evaluation of the potential for load shedding controls.

audit procedure:	application area:	referenced from:
E.1		ECO E.20, E.26, AP E.1.

title:	references to:
GLOBAL HEAT LOSS COEFFICIENT DETERMINED BY THE COHEATING METHOD	AP E.2., RV E.3

description:

Determine the wall global heat loss coefficient characterizing the building thermal losses due to transmission through the walls and ventilation losses.

i) Substitute electric radiators equipped with thermostats for the real heating system of the building, in all the heated rooms;

ii) Measure and record continuously all the radiator heat outputs at the same time as the other electricity consumptions in the house (if the house is occupied), and the corresponding inside and outside climatic data (indoor temperatures in all rooms, outdoor air temperature and solar radiation);

iii) Measure the data every minute and compute the hourly average values of the variables. The measurement period lasts 5 days, preferably in winter. The length of the period may be shortened if the temperature set point prevailing before the test is measured and maintained during the test period

iv) The global heat loss coefficient, K_w, is given by

$$K_w = (Q_h + Q_{el} + Q_m + Q_{sol} - L_{ir})/\Delta T$$

where

ΔT = average indoor-outdoor air temperature differences,

Q_h = total heat output from electric radiators,

Q_{el} = casual heat gains from lighting and electric equipments,

Q_m = metabolic heat gains from occupants,

Q_{sol} = solar heat gains calculated from recorded solar intensities.

If the global heat loss coefficient is much higher than design values, either the insulation level is too low or the ventilation rate too high: to make a choice between those two alternatives, a measurement of the infiltration losses is necessary in order to quantify the relative importance of transmission versus ventilation losses.

cost: Electric radiators: $35/unit. Thermostats: $10/unit. Electricity meters: $10/unit. Thermal probes: $20/unit. Data acquisition device: $800 min. Solarimeter: $650. Outdoor probe + fan: $90. Time to set up the equipment: one day, 2 persons per house.	**ease of use:** Complex.
accuracy: Increases with the length of the measurements.	**references:** Sonderegger, 1980

recommended applications:
The test is useful to control the quality of execution of a whole building.

alternative procedures: AP E.2.
Lower cost, lower accuracy: calculate the building transmission losses from standard data on material conductivities.

additional information:
The results are more accurate if the building is not occupied during the experiment, because the casual heat gains from occupants and equipments are difficult to estimate with accuracy.

THE COHEATING TEST EQUIPMENT

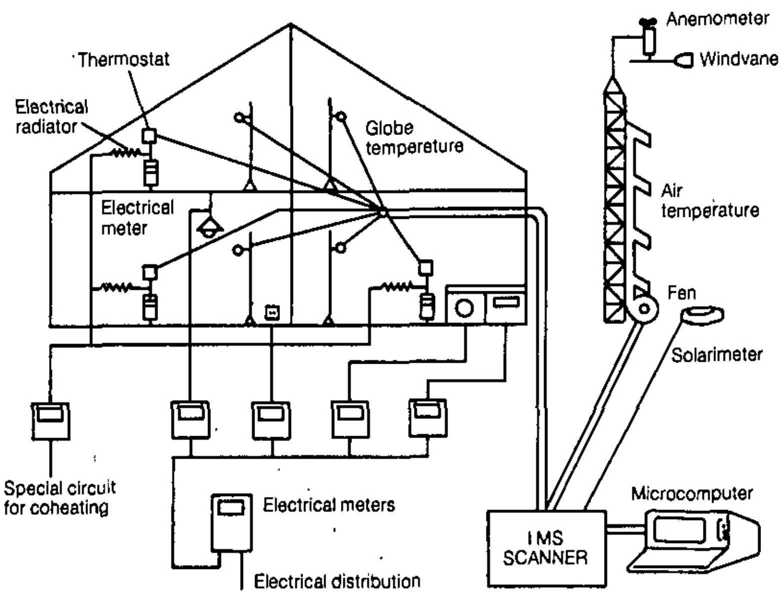


Fig. 1 Sketch of instrumentation arrangement for the co-heating measurement method.

audit procedure:	**application area:**	**referenced from:**
E.2	ENVELOPE - HEAT LOSSES	ECO E.20, E.26, AP E.1.

title: GLOBAL AND ENVELOPE HEAT LOSS COEFFICIENT DETERMINED BY THE NET ENERGY INPUT METHOD	**references to:** AP E.1.

description:
Determine the global heat loss coefficient characterizing the thermal losses due to conduction, convection, radiation and ventilation (note transmission losses through windows included.

i) Measure and record daily the accumulated net energy input to the building, E_{net}.

During the heating season, the net energy input to the building can be estimated from the sum of

- the energy output from the heat distribution system, Q_h,
- solar heat gains, Q_{sol},
- casual heat gains from lighting and appliances, Q_{el},
- metabolic heat gains from occupants, Q_m,

$$E_{net} = Q_h + Q_{sol} + Q_{el} + Q_m.$$

ii) Measure and record daily the accumulated indoor-outdoor temperature difference, ΔT.

iii) Plot the accumulated net energy input, E_{net}, versus the accumulated temperature difference, ΔT (see Fig. 1).

iv) The slope of the best linear fit through the measurement points and the origin is an estimate of the envelope global heat loss coefficient.

v) Compare this value to the corresponding design value calculated from the areas and U-values of the envelope components and from the design ventilation rate.

The measurement period should be 5 to 10 days.

cost:	**ease of use:**

accuracy:	**references:**
Depending on accuracy of measurements, temperature difference and length of measurement period. An accuracy of 10% is achievable.	

recommended applications:

Check of envelope performance.

alternative procedures: AP E.1.

additional information:

The greatest accuracy is obtained if the measurements are performed under conditions such that the major contribution to the net energy input comes from the heating system and electricity from lighting and appliances, i.e. in general when the temperature difference is rather large and solar and occupancy gains are small.

In buildings with mechanical ventilation this method can be used to calculate the coefficient characterizing transmission heat losses by subtracting the estimated ventilation losses, Q_{vent}, from the net energy input, i.e. $E_{net} - Q_{vent}$.

The slope is then an estimate of the heat losses through the envelope, the envelope heat loss coefficient.

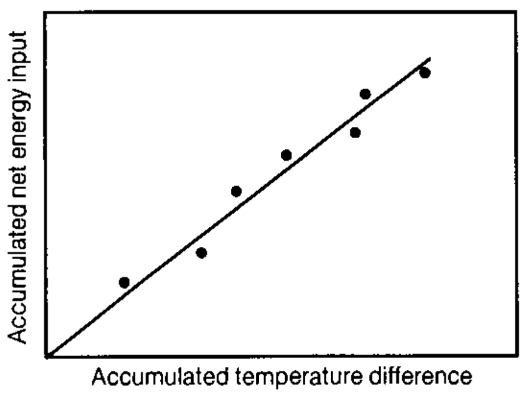


Fig. 1 Example of results using the net energy method.

audit procedure:	application area:	referenced from:
E.3	BUILDING ENVELOPE - AIR EXCHANGE	ECO E.2, E.4, E.18, AP E.5, E.6, E.10, E.12.

title:	references to:
AIR INFILTRATION RATE USING TRACER GAS	AT E.2.

description:

Quantify the air infiltration rate in the building under audit for the weather conditions at the time of the test. Use these data to estimate air infiltration component of energy use and indoor air quality.

i) Determine if building can be treated as a single cell, i.e., zones intercommunicate and the building behaves the same in all locations from and infiltration standpoint.

ii) Introduce (seed) tracer gas into the building in such a way as to ensure uniform concentration of the tracer gas. Good mixing is necessary for this to take place and may require fans to circulate the air.

iii)a(Decay Method) Measure the concentration of the tracer gas over time and determine the air exchange rate from the decay rate by plotting the tracer gas concentration versus time (see AT E.2).

iii)b(Constant Concentration Method) Measure the amount of tracer gas to maintain the same concentration. This allows individual zones to be monitored for individual air change rate. For determination of air change rate see AT E.2.

iii)c(Constant Injection Method) Measure concentration while maintaining constant injection of tracer gas.

iv) Calculate flow rates of air into building. Use guidelines (ASHRAE Standard 62 or the Nordic Standard) for appropriate flow rates needed for that building situation.

v) Air infiltration values can be compared to simple criterion such as achieving air exchange rates of 0.5 ACH.

vi) Data from testing periods representing weather periods of interest can be used to calculate a representative air infiltration pattern.

cost:	**ease of use:**
Highly dependent upon measurement choice. A portable gas chromatographic system for SF_6 measurement is $ 6600. Automated conc. systems start at $20000. Container or passive PFT sampling is $100-$200 per test. Consumables: Tracer and Carrier gas.	Again depending upon the measurement choice one can take container samples with little training (residents often take samples). Automated equipment can almost run itself. Because of the variability no time value is stated. Proper installation is important.

accuracy:	**references:**
Using approved techniques accuracy in the 10-15% range is normal.	ASHRAE Standard 62, 1981

recommended applications:

Best method for obtaining quantitative air exchange data provided measurement criteria are met. This means a uniform concentration of tracer gas brought about by proper mixing in the building.

alternative procedures:

Use of the pressurization/depressurization method also allows one to gather quantitative information on building tightness and related air exchange rates. Unlike the tracer gas method air exchange rates are calculated rather than measured. The pressurization method is less costly and less accurate.

additional information:

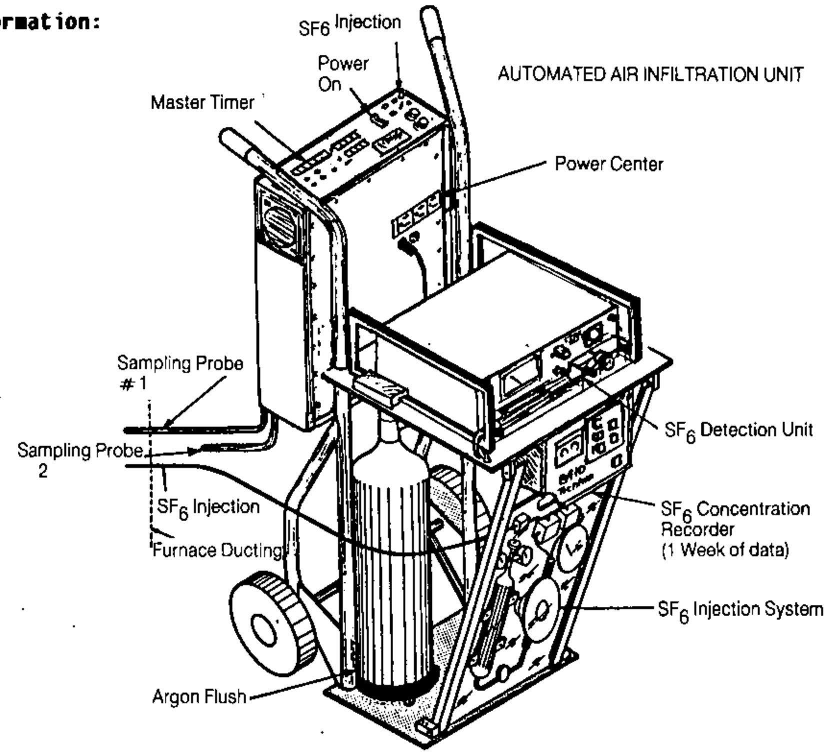


Fig. 1 Automated air infiltration unit.

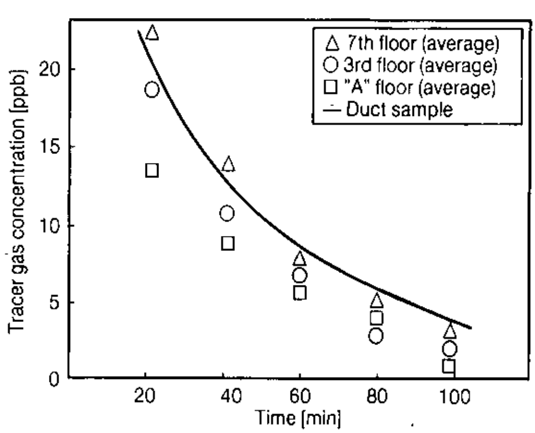


Fig. 2
Comparison of SF_6 concentration readings using decay method.

audit procedure:	application area:	referenced from:
E.4	BUILDING ENVELOPE - INFILTRATION'	AT E.5.

title:	references to:
BUILDING ENVELOPE AIR INFILTRATION AND INTERZONE AIR FLOW USING THE MULTIPLE TRACER GAS TECHNIQUE	AT E.2, AP E.3, E.B.

description:

Evaluate air infiltration through the building envelope as well as interzone air flows using multiple tracer gases. The evaluation will provide key information on energy use and possible indoor air quality problems. The data collection consists of:

i) Determine major zones to be measured.

ii) Place tracer gas source (either active or passive) in each zone, one tracer per zone. If using central system, tubes must be run to analyze recording unit.

iii) Place air sampling apparatus (either active or passive, see Fig. 2 and Ref.) in the zones.

iv) Continue to collect data over the desired test period.

v) Depending on constant output source, inject-decay, or constant concentration the data evaluation takes on a different character. The simplest arrangement is with constant concentration, where the makeup tracer gas to maintain each chosen zone at proper concentration is directly proportional to the outside air reaching that zone. (See AT E.2.) Evaluation using decay methods is limited by number of unknown and zone movement.

cost:	ease of use:
Multi-tracer analysis equipment is expensive with prices of $20000 or more the norm. Setup time for field equipment time can vary from a few hours of running tubing to less than one hour deploying passive sensors and sources.	Depending on whether passive system or tubing arrays difficulty of procedure vaies.

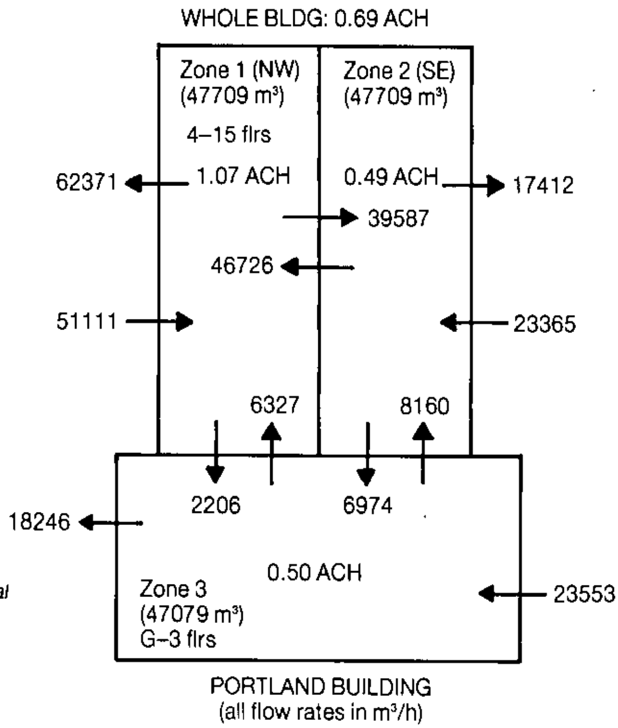
accuracy:	references:
10% accuracy is achievable.	Dietz, 1985

recommended applications:
This procedure should be reserved for those instances where interzone problems are suspected of raising energy use or causing comfort problems.

alternative procedures:
The detail provided by this procedure cannot be duplicated by other procedures. However, the detail on air infiltration to individual zones can be obtained from AP E.3 tracer gas using the constant concentration approach.

additional information:

Fig. 1
Example of results using multiple tracer gas techniques.



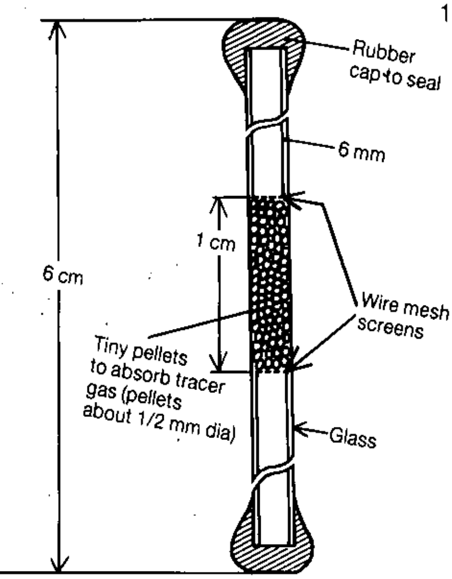


Fig. 2
Example of air sampling apparatus.

audit procedure: E.5	**application area:** BUILDING ENVELOPE - AIR TIGHTNESS	**referenced from:** ECO E.18, AP E.6, E.7, E.10, E.12, E.13.

title: OVERALL BUILDING TIGHTNESS USING PRESSURIZATION/ DEPRESSURIZATION TECHNIQUES	**references to:** AP E.3, E.4, E.8, E.9.

description:
Measure overall building tightness so that comparison with other buildings will serve as a guide for ECO implementation. The procedure is as follows:

i) Evaluation building as to possibilities for application of pressurization technique:
a) buildings with supply and exhaust ventilation systems which can be used to pressurize the building.
b) buildings where only portions of the building can be pressurized even to the point of individual apartment pressurization (recognizing there may be sizeable air leakage contributions from adjacent apartments). Representative apartments may be chosen for such tests.

ii) Use building fans or blowers (known flow rates or tracer gas calibrated) or dedicated equipment (whole building or smaller fan systems such as blower doors) to pressurize or depressurize the interior in steps, such as 10 Pa, to 50 Pa or higher. This will establish a pressure profile for the building. This procedure of pressurization is useful in AP E.3.

iii) In large buildings measure pressure difference (inside-to-outside) in several locations to take into account pressure variations at different floors or wings of the building.

iv) Use of Leakage per unit Envelope Area at a Reference Pressure is one method to rate building tightness. Extrapolation to air infiltration rates is in general not possible. Examples are given in Table 1 (Shaw, 1981).

cost: Equipment dedicated to building pressurization such as a calibrated blower door (see Fig. 1) is approximately \$4000. Large building pressurization equipment may easily reach \$20000. Use of building supply and exhaust costs nothing. Time: One hour up to a day depending on building size.	**ease of use:** This depends on whether blower door or building equipment is used. Single house test take less than one hour installation time. Training is needed for proper data interpretation.
accuracy: Calibration of the pressurization equipment is the key but 5% can be achieved.	**references:**

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recommended. applications: Fundamental test to place air infiltration in proper perspective with other building energy losses. Procedure may be used on a variety of housing.

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alternative procedures: Use of the Tracer Gas Technique: AP E.3 and E.4. The tracer gas method will tend to be more expensive, more accurate and weather sensitive (contrasted to pressurization tests which except for wind velocities >5 m/s can be accomplished year round).

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additional information: TABLE 1. Examples of wall leakage at 50 Pa [l/s,m^2]

Building category	Low	Average	High
Supermarket and Shopping Mall	3	13	20
Schools	5	7	10
High Rise Office Building	1	3	5

Fig. 1 Sketch of instrumentation arrangement for pressurisation test.

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audit procedure:	application area:	referenced from:
E.6	BUILDING ENVELOPE - AIR LEAKAGE	ECO E.18, AP E.10.

title:	references to:
BUILDING ENVELOPE AIR LEAKAGE USING BUILDING MECHANICAL SYSTEMS FOR PRESSURIZATION	AP E.5, E.3, E.7, RV E.5, MT D.5.

description:

Evaluate air leakage through the building envelope using the central ventilation system of the building to supply the required pressurization so that comparisons with desired performance can be made and energy use evaluated. The procedure is as follows:

i) Alter the central ventilation system so that the building may be pressurized/depressurized. This means closing exhaust vents or supply vents and operating the system to provide pressure imbalance.

ii) Open interior doors to allow for pressure equalization to the best degree possible.

iii) Measure the volumetric flow rates. If the air flow rate is small, use tracer gas procedure (MT D.5).

iv) Following AP E.5, the building would be pressurized/depressurized in steps, fan control permitting.

v) Results can be compared against standards for airtightness where applicable (RV E.5).

vi) Depending on evaluation from (5) will determine that (a) little or no benefit would be available from pursuing building tightness ECOs or (b) that such ECOs hold promise for energy reduction and possible comfort improvement.

cost:	ease of use:
Instruments:Accurate differential pressure gauges <$100 each. Must also account for tracer gas instrumentation and consumption.Time: Preparation 2-4 hours, test time, 3 hours.	Availability of tracer gas test apparatus.

accuracy:	references:
10%, similar to other pressurization tests.	

recommended applications:

alternative procedures:

(i) Higher cost, similar accuracy, complete building test performed by separate mechanical fan system, see AP E.7 that could incorporate flow measurement and thus not require tracer gas method.
(ii) Same cost, determines air infiltration rates under normal building operation using tracer gas methods, see AP E.3.

additional information:

Larger buildings often rely upon central ventilating systems to move air through the buildings. These same fan systems can be used to pressurize the building to determine building envelope tightness. The technique relies upon knowledge of how to effectively control supply and exhaust vents. The technique can use supply fans to pressurize the building by closing all but the air supply vents louvers. Exhaust systems may be used depressurize the building by allowing only exhaust vents to be open.

Details of the method include knowing where supply vents are located in the building and making certain they are functioning in a way to allow the pressurization, depressurization test. This may mean disabling linkages which automatically open or close the vents. Central fan systems are then operated to provide one or more (de)pressurization steps with flows measured using tracer gas techniques (see AP E.3). The tracer gas techniques require equipment described in AP E.3.

audit procedure:	application area:	referenced from:
E.7	BUILDING ENVELOPE - AIR LEAKAGE	ECO E.18, AP E.6, E.10.

title:	references to:
BUILDING ENVELOPE AIR LEAKAGE USING A SPECIAL LARGE FAN BROUGHT TO THE SITE	AP E.5, RV E.5.

description:

Evaluate air leakage through the building envelope using a special large fan brough to the site to supply pressurization/depressurization.

i) Transport special large fan to building site - depending upon size of fan this may require a flatbed truck.

ii) Provide power access from building or dedicated power supply and attach fan to buiilding interior through an appropriate size opening, e.g. large double doors to central hallway.

iii) Open interior doors to allow for pressure equalization to the best degree possible.

iv) Measure the volumetric flow rate from the precalibrated fan system rpm or use tracer gas procedures to make measurements.

v) Following AP E.5 the building would be pressurized/depressurized in steps by adjusting air flow within the limits of the fan capacity.

vi) Results can be compared against standards for airtightness where applicable (RV E.5).

vii) Depending on evaluation from (vi) will determine that (a) little or no benefit would be available from pursuing building tightness ECOs or (b) that such ECOs hold promise for energy reduction and possible comfort improvement.

cost:	ease of use:
Special large fans have cost up to $20000. Consumables: (Tracer-gas if that flow measurement is required). Time: Up to a one day preparation. Transportation cost can be considerable.	Difficult - this is a task for a dedicated crew to attach the system to the building and operate the fan properly

accuracy:	references:
Previous measurements have shown 10% accuracy.	

recommended applications:

Designed for buildings where no central ventilation exists and total building air leakage values using pressurization/depressurization are desired. Fan size is clearly dependent on size of the building as well as the leakiness of the building. It is desired that several pressure steps can be achieved to better define the envelope air leakage.

alternative procedures:

Lower cost, determines air leakage under normal building operation using tracer gas methods.

additional information:

audit procedure:	**application area:**	**referenced from:**
E.8	BUILDING ENVELOPE - AIR LEAKAGE	ECO E.18, AP E.10.

title:	**references to:**
AIR LEAKAGE IN INDIVIDUAL ZONES OR APARTMENTS USING FAN PRESSURIZATION	AP E.4, E.5.

description:

The purpose can be to 1) quantify air leakage through all components with a given zone or apartment, or to 2) evaluate air leakage interaction with adjacent zones or apartments.

i) Provide additional fan pressurization to adjacent zones or apartments so that those volumes can be adjusted to the same pressures to avoid interzone leakage. For the second purpose adjacent zone or apartment fan pressurization systems would be turned off sequentially to evaluate severity of interzone leakage. Test data would be collected as in AP E.5 with the added requirement that each pressure step would be simultaneously achieved in adjacent zones/apartments. Communication must be maintained via "walkie-talkie", telephone, etc. to achieve this goal.

ii) Procedures identical to AP E.5 would be employed for the first purpose.

iii) With non-zero pressure differentials between adjacent zones (other pressurization equipment turned off or operated at a different pressure level) qualitative evaluation of interzone leakage can be made (see second purpose). Quantitative evaluation under natural conditions should use multiple tracer gases, see AP E.4.

cost: Depending on building complexity 3 to 6 blower doors would be required at $4000 each. Personnel are needed for each. Time: 1-2 hours per zone is estimated.	**ease of use:**
accuracy: Measurements would be in the 15% range because of summing blower door accuracies.	**references:**

---

recommended applications:

Carry out test only when simpler procedures prove inadequate.

---

alternative procedures:

(i) Possibly lower cost, improved accuracy in that it measures actual apartment and interzone leakage use AP E.4, multi-tracer.

(ii) Lower equipment cost, fewer operators on site, lower accuracy: evaluate interzone leakage using differential pressure readings between test zone/apartment and adjacent zones while following AP E.5.

---

additional information:

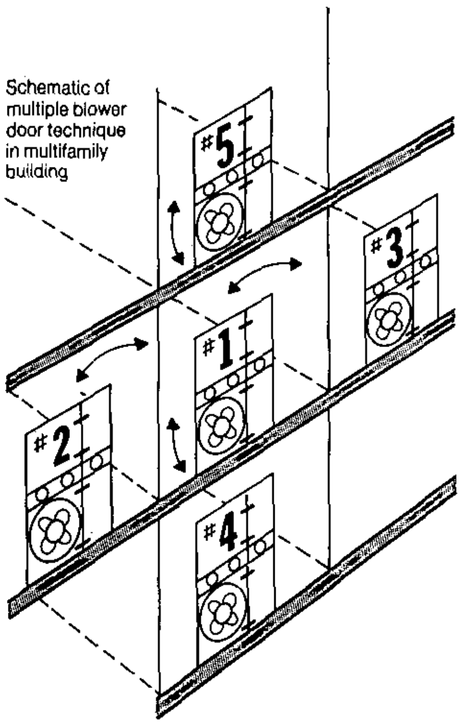

Fig. 1 Schematics of multiple blower door techniques in multi-family building.

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audit procedure:	application area:	referenced from:
E.9	BUILDING ENVELOPE - AIR LEAKAGE SITES	ECO E.18, AP E.10.

title:	references to:
DETECTION OF LEAKAGE SITES USING INFRARED THERMOGRAPHY/PRESSURIZATION	AP E.5, E.10, E.11.

description:

Locate leakage sites to evaluate requirements for ECO implementation.

i) Determine areas of building to be surveyed for leakage sites and ensure visual access to surfaces of interest.

ii) Preferred method is to use the overall building pressurization methods employed in AP E.5 to depressurize the building so that outside air will flow in through leakage site thereby cooling or heating adjacent surfaces allowing infrared equipment to evaluate such temperature differences.

iii) For the infrared method to work effectively the temperature difference inside to outside should be 5 K or greater.

iv) Data on leakage sites is obtained from the surface temperature patterns observed with infrared scanning equipment when outside air of different temperature reaches the interior of the building. records may be in the form of notes as to location or thermal pictures, thermograms, of the wall surfaces and leakage sites.

v) Results may be compared to standard thermograms which represent air leakage versus thermal patterns due to heat conduction variations in the wall materials.

cost:	ease of use:
Instrument: $10000-$50000. Comsumables: Depending on IR Scanner, unit may work on electricity, high pressure gas or liquid nitrogen. Time: Two minutes per room.	Method requires well-trained personnel and appropriate choice of equipment and techniques.

accuracy:	references:
Surface temperature measurements are 0.2^{o}C for good equipment, however, used as a leakage site locator accuracy is good but qualitative.	

---

recommended applications:

AP E.5 (Measurement of overall building tightness) should be used as the criterion for using E.9. Also to be considered is comfort of occupants who may be experiencing drafts which suggests leakage site documentations.

This method is very effective in searching out leakage sites over building surfaces without prior knowledge of where these sites are likely to be located. Quickness of the method allows immediate movement to regions of interest. Documentation via thermograms permits after visit analysis.

---

alternative procedures:

1. Lower equipment cost, similar accuracy, AP E.10, smoke tracers or velocity probes.
2. Low cost, less accurate: use sound source and sound detection system to evaluate leakage sites (see AP E.11).
3. Lowest cost, less accurate, use wool tuft of paper streamer on wire wand to test for leakage sites (same general method as using candle flame).

---

additional information:

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audit procedure:	application area:	referenced from:
E.10	BUILDING ENVELOPE - AIR LEAKAGE SITES	ECO E.4, E.6, E.7, E.18, AP E.9, E.11, E.12.

title:	references to:
DETECTION OF LEAKAGE SITES USING SMOKE PENCILS, OR VELOCITY MEASUREMENT	AP E.3, E.5, E.6, E.7, E.8, E.9, E.11

description:

Locate leakage sites to evaluate requirements for ECO implementation.

i) Determine areas of building to be surveyed for leakage sites and ensure access to surfaces of interest.

ii) Select method of leak detection, e.g. smoke pencils, smoke gun, or velocity measurement, e.g. a heated wire or thermistor.

iii) Move detection device over those surface areas of interest looking for incoming air (infiltration) or outgoing air (exfiltration).

iv) Preferred method is to use the overall building pressurization methods employed in AP E.5 through E.8 to aid in leak site detection outlined in this procedure. This is achieved by pressurizing the building so that all air leakage is from inside-to-outside, causing the smoke to be drawn to the leakage site. For best results the smoke source should be close to the leakage site (order 15 cm or less). If the building is depressurized, air jets will be present at the leakage sites allowing for easy detection by the velocity probe. Smoke will be blown away by the jets.

v) Where the building is not pressurized/depressurized or where the pressurization is not large, condiserations of the naturally induced pressure across the envelope should be made, e.g. consider wind and stach effects when choosing test locations.

This procedure yields qualitative data in the case of the smoke tracer, and somewhat quantitative for the velocity probes. Judgement on the part of the auditor is necessary to determine what constitutes an air leakage site that is excessive and requires retrofit action; what is marginal and may require action; and what is acceptable and requires no action. Proximity of the air leakage sites to the location of building occupants may also influence the auditor's judgement.

cost:	ease of use:
Instruments: Smoke sticks $10; smoke gun $50; velocity probe $50-500 Consumables: smoke generation materials. Time: depends on building size, approx. 10 minutes or less per room could be used as a guide.	Simple to use but can be time consuming based upon previous knowledge of what building surfaces and components be surveyed.

accuracy:	references:

---

recommended applications:

Conduct tests if there are complaints of drafts, or if there are questions as to where ECO actions should be focused to control envelope leakage. Suggest using AP E.3 to justify this procedure.

---

alternative procedures:

1. Lowest cost, less accurate: use wool tuft of paper streamer on a wire wand to test for leakage sites (same general method as using candle flame).
2. Lower auditor cost (personnel), comparable accuracy; use AP E.9 for detection of leakage sites using infrared thermography. This method involves only one or two minutes per room but equipment costs are high. Requires proper inside-outside temperature difference (order 5 K or more) for method to work.
3. Low cost, less accurate: use sound source and sound detection system to evaluate leakage sites, AP E.11.

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additional information:

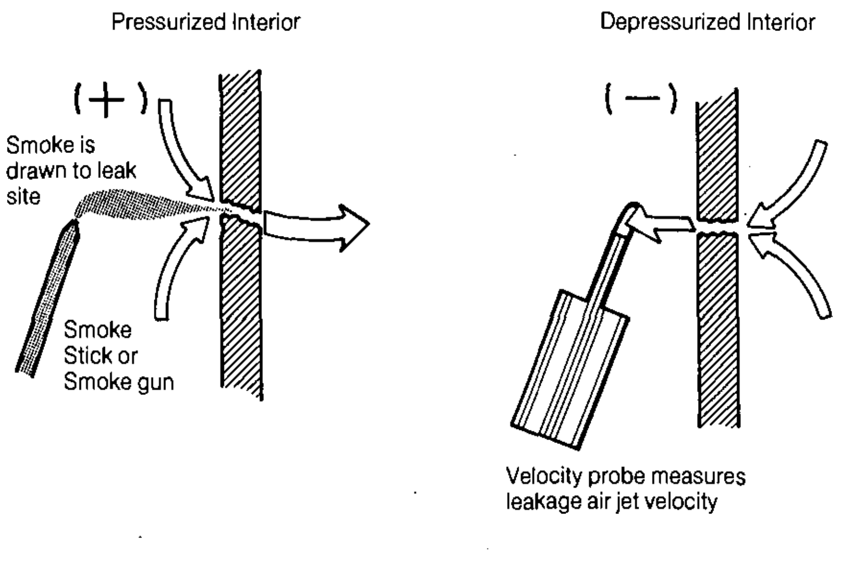

Fig. 1 Sketch of use of smoke pencils.

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audit procedure:	**application area:**	**referenced from:**
E.11	BUILDING ENVELOPE - LEAK SITES	ECO E.7, E.28, AP E.9, E.10.

title:	**references to:**
DETECTION OF LEAKAGE SITES USING SOUND SOURCES AND RECEIVERS	AP E.10.

description:

Locate leakage sites to evaluate requirements for ECO implementation.

i) Method requires use of sound source on one side of building envelope and sound detection system on the other. Sound source can be a tape cassette of white noise or a rising and falling tone. Sound detection can be as simple as a stethoscope or earphones attached to a microphone and inline amplifier.

ii) Low-rise buildings can employ sound sources inside or outside. High-rise buildings would require exterior sound unless access to the outside surface of the building could be achieved economically.

iii) Sound is generated and intensity detected on the opposite side of the envelope and is directly related to the air leakage potential. Detection is achieved by moving the stethoscope or microphone across the wall surface.

iv) Complex air paths through the structure may result in sound decay making detection less certain.

This procedure yields qualitative data which is useful for leak site detection. Experience on the part of the auditor is necessary to evaluate what constitutes excessive leakage. Used to evaluate a door seal it is immediately evident applying this technique which portions of the seal have not been properly fitted.

cost:	**ease of use:**
The cost of the sound source can easily be less than $50 using a portable tape player and sound tape. Stethescope is $10 whereas the better electronic sensing could be assembled for $75.	Method is extremely easy to use but can be time consuming unless sites to be investigated and limited.

accuracy:	**references:**

recommended applications:

This method is useful to evaluate seals around doors and windows. As with AP E.10 leak site location of a more general nature is also achieved using this process.

alternative procedures:

1. Low cost, more accurate: use smoke pencils or velocity probes to evaluate leak sites (see AP E.10).
2. Lower auditor cost (personnel), more accurate: use AP E.9 (Detection of leakage sites using infrared thermography). This method involves only one or two minutes per room but equipment costs are high. Requires proper inside-outside temperature difference (order 5 K or more) for method to work.
3. Lowest cost, less accurate: use wool tuft of paper streamer on a wire wand to test for leakage sites (same general method as using candle flame).

additional information:

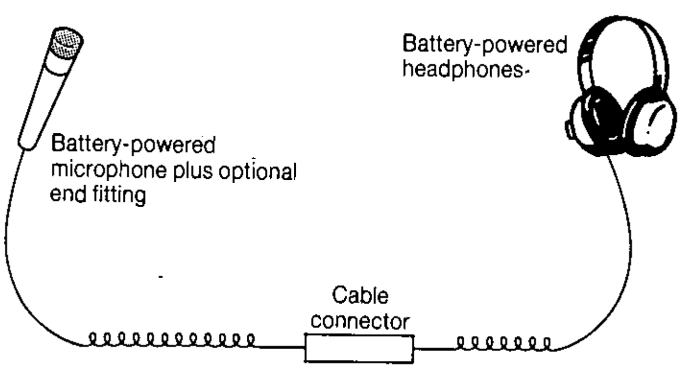

Fig. 1 Listening system used for most field investigations.

audit procedure:	**application area:**	**referenced from:**
E.12	BUILDING ENVELOPE - AIR LEAKAGE	ECO E.7, E.28, E.29, AP E.13.

title:	**references to:**
COMPONENT LEAKAGE USING LOCAL PRESSURIZATION METHODS	RV E.6, AP E.3, E.5, E.10.

description:
Quantify air leakage through components such as windows, doors, vents, moldings, etc.

i) Isolate area to be tested using plastic sheeting.

ii) Connect test equipment and develop air flow versus pressure relationship (see standard measurement and instrumentation techniques App. G, see also next page).

iii) Measurements are best carried out when there is little natural pressure difference across component. To minimize this effect, testing should be done over a range of pressure differences significantly higher than the natural one.

iv) Flow is given by: $Q = C(\Delta p)^n$ where C is the air flow coefficient, Δp is the pressure difference and n is the flow exponent (e.g. n=0.65).
Equivalent Leakage Area, A, is given by:
$A = C * (\Delta p)^n / \sqrt{2 \Delta p/\rho}$
where ρ is the air density and Δp is the reference pressure, e.g., 4 Pa

v) Results can be compared against standards for air tightness (RV E.6). If component meets desired standard, retrofit is probably <u>not</u> justified and no further action recommended.

vi) If components are much leakier than standards, a cost benefit analysis is required.

vii) If ECO is relatively low cost, do simple analysis.

viii) If ECO is relatively high cost, careful cost benefit is required.

cost: Instrument: approx. $500. Consumables: negligible (tape). Time: less than one hour per component (e.g., window).	**ease of use:** Average. Sealing component if not a flat surface can be tricky, perfect air seal is necessary.

accuracy: Measurement 5%. Measurement inherently more accurate than calculation of cost benefit owing to difficulty of predicting annual infiltration effect.	**references:**

---

recommended applications:

First Priority: Carry out test only if noticeable leakage (see AP E.10) complaints of draughts or if overall leakage testing AP E.5, and AP E.2 reveal need for retrofitting.
Second Priority: Conduct test to supply background information to determine what are the best component choices thereby aiding future projects.

---

alternative procedures:

(i) Lower cost, lower accuracy: If a complete building pressurization test is being carried out use AP E.13.
(ii) Lower cost, low accuracy: Estimate or measure crack size. This approach has limited applicability.

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additional information:

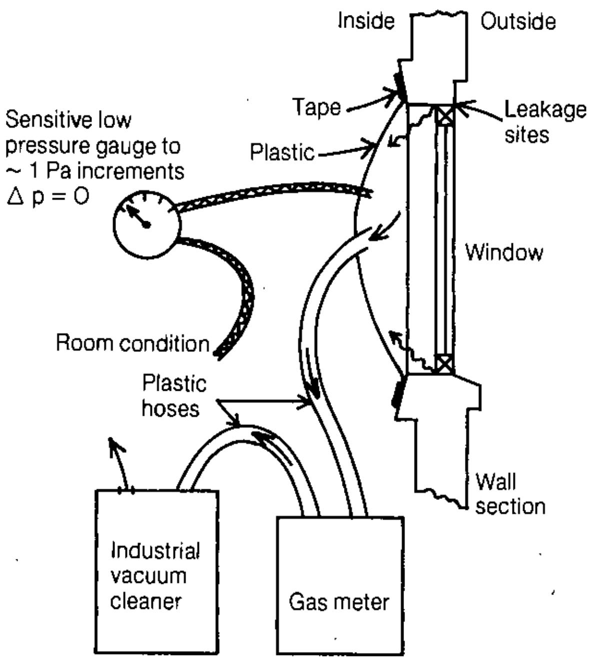

Fig. 1 Sketch of instrumentation arrangement for component leakage tests.

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audit procedure:	application area:	referenced from:
E.13	ENVELOPE - AIR LEAKAGE	ECO E.28, E.29, AP E.12.

title:	references to:
BUILDING COMPONENT LEAKAGE USING COMPLETE BUILDING PRESSURIZATION	

description:

Quantify air leakage through components such as windows, doors, vents, mouldings, etc.

i) Using the method outlined in AP E.5, conduct individual component tests as in AP E.12.

ii) Isolate area or component to be tested with plastic sheeting or comparable arrangement.

iii) Record whole building (or apartment) pressurization data with and without sheeting in place. The air leakage associated with the component or area is the difference of the two readings.

iv) Observe the same cautions and make use of the same flow relationships as in AP E.12.

v) As stated, leakage is the difference between two flow readings, therefore, calibration is critical and the difference in two large numbers always presents problems.

vi) Follow items v)-viii) in AP E.12.

cost:	ease of use:
Since whole building pressurization is involved, costs may include blower doors ($4000) etc., or may use building ventilation systems at no cost (see AP E.5). May be very time-consuming for instance if it is required to seal off all windows.	Difficulty may be encountered in sealing off certain components and in remote readout of resulting pressure changes.

accuracy:	references:
It is doubtful that accuracy better than 10% can be achieved for even larger air leakage values.	

---

recommended applications:

When whole building pressurization is already part of the audit procedure, adding information on major component leakage rates is easily justified. The leakage breakdown may be started by merely closing off parts of the building, closing doors, etc.

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alternative procedures:

(i) Higher cost, higher accuracy: Use AP E.12.
(ii) Low cost, low accuracy: Estimate or measure crack size. This approach has limited applicability.

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additional information:

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audit procedure: E.14	**application area:** ENVELOPE - CONDUCTION, AIR LEAKAGE, MOISTURE	**referenced from:** ECO E.8, E.10, E.11, E.13, E.14, E.17, E.23, E.24, AP E.17, E.18, E.19.

title: DETECTION OF THERMAL BRIDGES AND AIR LEAKAGE USING IR-THERMOGRAPHY	**references to:**

description:

An infrared camera that is sensitive to radiation from building surfaces gives the information in two types of pictures - so called thermograms.

i) Grey scale thermograms where the picture shading is due to the relative difference in infrared radiation density which is related to the surface temperature. Normally dark areas are colder than light areas.

ii) Thermograms with isotherms indicating points, lines or areas leaving the same infrared radiation density (i.e. the same temperature for the same material).

The emissivity of the surface material covering the object influencies the radiation density as well as the surface-temperature itself and therefore, for proper interpretation, emissivity values are needed. Many building surface materials fall in a narrow emissivity range.

By using an infrared camera Grey scale thermograms and thermograms with isotherms are produced. The following measurements are made:

1. outdoor climatic conditions (defined limits for IR-sensing),
2. ambient and reference surface temperatures,
3. pressure drop across the envelope,
4. air velocity (in case air leakage is suspected),
5. *estimation of emissivity.*

The evaluations should be carried out according to standards or manuals (see ISO 6781 and Pettersson-Axén, 1982).

cost:	**ease of use:**
Equipment $20000-$40000. *Methods involving significantly* cheaper instrumentation are usually unsatisfactory.	Special thermal conditions are required. Special training for the operator is needed.

accuracy:	**references:**
10% or 0.5 K whichever is the greater for a high resolution system.	ISO 6781 Pettersson-Axén, 1982

recommended applications:

Detection of insulation voids in the envelope.
Detection of thermal bridges, where heat flows are abnormally high.
Detection of air leakage in joints and junctions.
Identification of parts influenced by moisture.

alternative procedures:

Infrared thermography covers large areas but is qualitative. A second technique, giving a quantitative information but for very small areas, is the measurement of wall U-values and resistances using temperatures and heat flux sensors (AP E.15). Measure surface temperature variations, many measurements are required to insure that e.g. small thermal bridges are not lost.

This method is complementary to the thermography technique.

additional information:

The data collection can be done either from the inside or from the outside of the building. For complex view high quality envelopes it is recommended that the IR-sensing is done from the inside.

The method is qualitative and includes interpretation based on personal knowledge and experience.

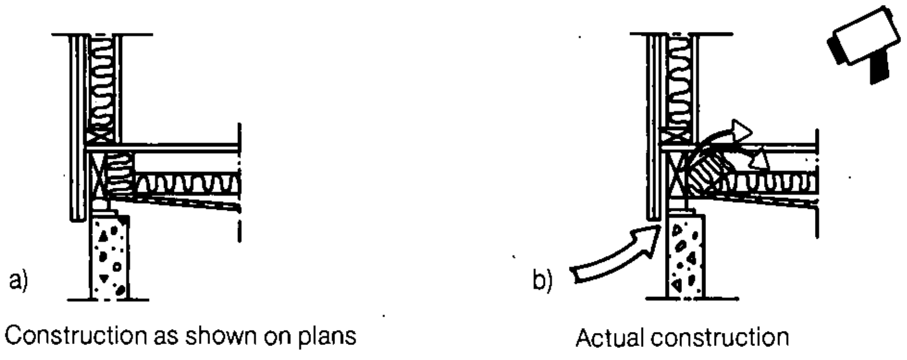

Fig. 1 Example of envelope performance detectable by IR-thermography.

audit procedure: E.15	**application area:** ENVELOPE - CONDUCTION	**referenced from:** ECO E.8, E.10, E.11, E.12, E.15, E.16, E.17, E.23.
title: COMPONENT U-VALUE USING HEAT FLOW METER		**references to:** AP E.16, E.18

description:

A heat flow meter consists of a thermo-electrical circuit embedded in an insulating layer (typically 3 mm thick, 100 mm in diameter). The principle is based on detecting and amplifying the temperature difference across the heat flow meter.

i) Locate a place where the heat flow is one dimensional (for example, the middle of the wall surface and away from thermal bridges);
ii) To measure the wall U-value, install two thermal probes on both sides of the wall and a heat-flow meter on the wall outdoor surface and connect those equipments to a data logger;
iii) Measure the temperatures and the heat flow through the wall every 1, 2 or 5 minutes, and compute the hourly average values of the three variables. The measurement period is 3 to 20 days depending on the wall thermal inertia;
iv) The U-value is given by:

$$U = q/\Delta T$$

where
q = average heat flow,
U = U-value,
ΔT = average indoor-outdoor temperature difference;

v) Results can be compared against standard for U-values. If the wall meets desired standard, retrofit is probably not justified;
vi) If the wall is much less insulated than standards, an improvement of the wall insulation must be evaluated (cost/benefit analysis). Use a careful cost benefit analysis, as the envelope insulation is generally a high investment ECO, which may lead to a significant oversizing of the existing heating equipment.

cost: Datalogger: \$1700-\$9200. Thermal probes: \$20 per unit. Heat flow meter: \$170-\$360. Time to set up the equipment is 1-3 hours for several walls in a house.	**ease of use:** In general easy, but dynamic effects can make this kind of measurement quite difficult.
accuracy: The accuracy is improved for long measurement periods, large temperature differences and stable conditions.	**references:**

recommended applications:

alternative procedures: AP E.16.
Lower cost, lower accuracy: Calculate U-values from the knowledge of the wall composition (AP E.18) (thicknesses and materials of the layers) and with standard values of material conductivities.

additional information:

The use of heat flow sensors involves some specific problems, such as:
- additional thermal resistance of the sensor itself;
- alteration of the wall thermal field;
- unsteady-state conditions occurring during the measurements, while the sensor has been calibrated in steady-state conditions;
- difference between radiative properties of the sensor and the wall;
- response depends on the properties of the wall.

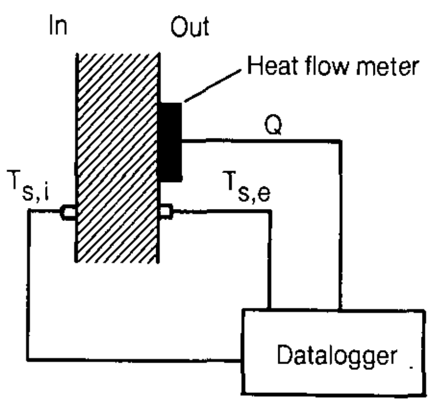

Fig. 1 Measurement of component U- value using heat flow meter.

audit procedure:	application area:	referenced from:
E.16	BUILDING ENVELOPE - CONOUCTION	ECO E.8, E.10, E.11, E.12, E.15, E.16, E.17, E.23.

title:	references to:
THERMAL RESISTANCE MEASUREMENT USING A PORTABLE CALORIMETER AND HEAT FLOW METERS	AP E.15.

description:

The purpose is to quantify thermal resistance of the building envelope.

i) Representative location on the interior side of the building envelope are chosen.

ii) A metal stud finder is used to ensure that measurements are over insulation-filled cavities. A measurement system is used to monitor the signals from the portable calorimeter, the electric use meter and the thermistors.

iii) The portable calorimeter is suitably installed.

iv) The calorimeter is operated so that all the heat generated within the calorimeter is forced to flow through the wall to be measured, i.e., internal calorimeter temperatures are matched to room temperature. Temperatures of interior and exterior air are measured by thermistors.

v) *Microcomputer-based data acquistion is used to average data over a 24-*hour period to limit thermal effects. Cumulative averages of daily thermal resistance values are calculated for representative wall section. Measurements up to 15 days have been found useful.

vi) The thermal resistance, R, is defined as the ratio of the average air-to-air temperature difference across a section of exterior wall to the average heat flow rate and is calculated from $R = \Delta T/q$ where ΔT is the average interior-exterior temperature difference, and q is the average heat flow rate.

cost:	ease of use:
Portable calorimeter: $1000-$1500. Micro-computer: $3000-$4000. Setup-time: 2-4 hours. Consumables: Negligible.	Dynamic effects may make this kind of measurement quite difficult.

accuracy:	references:
10%.	

recommended applications:

Desirable test for determining the thermal resistance of building envelopes where there is question as to wall component thermal contributions.
Verification of new building specifications.

alternative procedures: AP E.15

Spot radiometer survey method, however, has low accuracy (40%). Thermography with systematic measurements over 24-hours, less accurate but covers more surface area, in development stage at present time.

additional information:

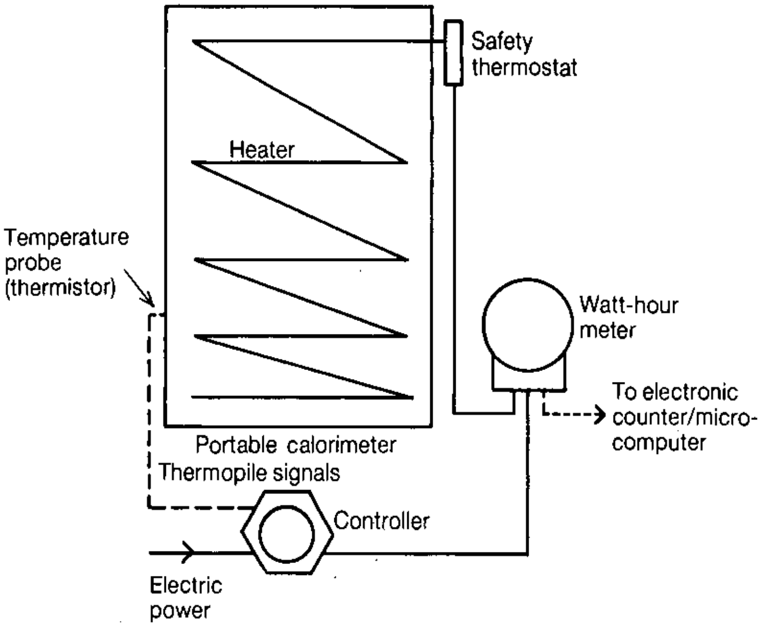

Fig. 1 Sketch of measurement/control system for portable calorimeter.

audit procedure:	application area:	referenced from:
E.17	ENVELOPE - MOISTURE	ECO E.2.

title:	references to:
WOOD MOISTURE AND MOULD GROWTH AUDIT FOR STRUCTURAL INTEGRITY	AP E.14, E.19.

description:

The following steps are made to identify the cause of moisture damage:

i) The theoretical moisture condition must be determined. This can be done by theoretical calculations or by using experience from similar building constructions.

ii) The relative humidity and temperature should be measured in the in- and outdoor air and in several points on different levels in the building element.

iii) If the building has severe mould growth or smells of mould, samples for mycologic analysis should be taken from organic materials in damp surroundings.

iv) Calculate the absolute humidity from the relative humidity and temperature for each measuring point and determine in which direction the moisture is moving.

v) Compare the measured moisture condition with the theoretical moisture condition. By this comparison and by knowing the direction of the moisture transfer, one can assess the cause of damage and recommend measures.

cost:	ease of use:
Equipment: $5000. Investigations: $500.	Special training is needed for operator.

accuracy:	references:
2% RH (Relative Humidity). 0.2 K (Temperature).	

recommended applications:

All kinds of moisture damage in buildings and building parts.

alternative procedures:

- Low cost, less accurate use walk through audit AP E.11.
- IR sensing procedures (AP E.14) are an alternate way to observe moisture damage and water leaks on flat roof buildings.

additional information:

The importance of moisture problems can be directly related to ECO actions. Upgraded ceiling insulation can result in reduced roof deck temperatures with moisture condensation. Moisture sources include inside air carrying moisture upwards. Depending upon the material involved serious damage can take place, such as the corrosion of metal supports or wood rot or plywood delamination (because of repeated moisture cycling). In the upper parts of the building moisture levels peak in winter with rapid drying occurring during warm, sunny weather. Lower parts of the building tend to have moisture peaks according to local climate and ground moisture condition. Floor joists, floor materials and sill plates are subject to moisture damage.

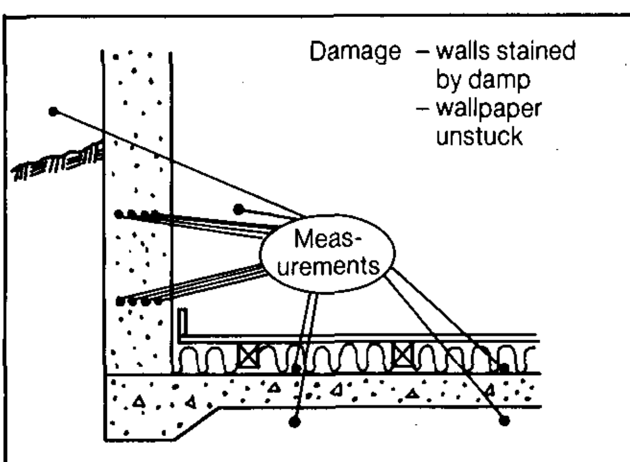

Fig. 1 Example of measurement of wood moisture.

audit procedure: E.18	**application area:** ENVELOPE	**referenced from:** ECO E.10, E.16, AP E.15

title: INVESTIGATION OF HIDDEN PARTS OF BUILDINGS USING FIBRE OPTICS	**references to:** AP E.14.

description:

To get information about the existence, quality, amount, location of materials and their conditions inside a building component or a part of the construction a boroscope can be used. It consists of fibre optics with cold light supply to which can be connected a camera or a TV-camera.

i) Drill a hole, diameter 12 mm (if the boroscope has the size 10 mm) at the spot of interest. Use the type of drill that gives you a sample from the hole and which is normally used in order to find out about material quality.

ii) Examine the sample.

iii) Choose fibre optic mirror top depending on desired viewing-angle.

iv) Insert the boroscope and switch on the cold light supply.

v) Connect camera if documentation is required.

cost:	**ease of use:**
Equipment: $2000 or more	Very easy to use.

accuracy:	**references:**

recommended applications:

All types of buildings except those which are of a solid construction.

alternative procedures:

IR sensing procedures (AP E.11) can give some information about differencies in material, quality or thickness if there is a temperature drop over the construction.

additional information:

audit procedure:	application area:	referenced from:
E.19	ENVELOPE - MOISTURE	AP E.17.

title:	references to:
DETECTION OF MOISTURE AND MOULD GROWTH	AP E.14, E.17.

description:

A walk through audit to observe mould growth, odor, moisture damaged wood, staining of facades, efflorence etc.

i) Concentrate on attic and basement/crawl space areas with secondary interest in wall systems.

ii) Take into account seasonal aspect of moisture damage; mid-winter problem in attics and mid-summer problems in basement/crawl spaces.

iii) Instrumentation for direct moisture measurement in wood uses the principle of electrical resistance changes between two metal prongs driven into the wood (Delmhorst probe). Readout is immediate and expressed in % moisture.

iv) At 40% moisture content the water is running on the wood surface. At 20% moisture content one is at the marginal moisture level for wood damage and mould growth. Wood moisture >20% and temperatures above freezing, mould will grow. At moisture levels above 30% rot fungi will grow attacking the inside of wood structure. Moisture cycling can damage plywood at the 20% moisture level.

cost:	ease of use:
Probe is of the order of $500 and is completely portable and rugged.	Very easy.

accuracy:	references:
Wood moisture x2%.	

recommended applications:

Recommended as part of the energy audit to make sure roof members or supporting wood members are not experiencing moisture problems and possible major building damage.

alternative procedures:

For a better accuracy AP E.17.
IR sensing procedures (AP E.14) are an alternate way to observe moisture damage, and water leaks on flat roof buildings.

additional information:

The importance of moisture problems can be directly related to ECO actions. Upgraded ceiling insulation can result in reduced roof deck temperatures with moisture condensation. Moisture sources include inside air carrying moisture upwards. Depending upon the material involved serious damage can take place, such as the corrosion of metal supports or wood rot or plywood delamination (because of repeated moisture cycling). In the upper parts of the building moisture levels peak in winter with rapid drying occurring during warm, sunny weather. Lower parts of the building tend to have moisture peaks according to local climate and ground moisture condition. Floor joists, floor materials and sill plates are subject to moisture damage.

audit procedure:	application area:	referenced from: ECO R.1
R.1	HVAC-CONTROL	

title:	references to:
IN SITU THERMOSTAT CHECKING	MT H.1, R.2.

description:

Record indoor air temperature in the room under consideration for several days (one full week) e.g., with a thermograph (see MT R.2).

Ensure that:

i) The outdoor climate is cold enough, that there is a significant amount of heat delivered by the heating system,
ii) There is no influence from occupancy behavior (e.g. window opening).

Evaluate from the time-temperature diagram the average indoor temperature in steady-state conditions (no over-heating by the sun). This temperature should be close to the thermostat set-point. The range of oscillations should be reviewed to see if the maintained temperatures are within the acceptable comfort range.

If a simultaneous recording of burner on-off time is available (see MT H.1) check further that the burner is stopped and started at the appropriate time, e.g. started before the thermal inertia of the space and heating system allows the space temperature to drop below the minimum acceptable comfort temperature.

cost:	ease of use:

accuracy:	references:

recommended applications:

In all buildings with feedback control on indoor air whenever there is some doubt about the thermostat capability to inform the heating system about the dynamic behavior of the building.

alternative procedures:

additional information:

audit procedure: R.2	**application area:** REGULATION	**referenced from:** ECO R.2

title: TEMPERATURE SETBACK SETUP EFFECTS	**references to:** MT R.1, R.2, E.1, AT M.1, R.1.

description:

Energy savings and cost savings are derived from:

i) Temperature setback for one or more periods each day (heating),
ii) Temperature setup for one or more periods each day (cooling), and
iii) Precooling building (cooling).

Energy flow across the building envelope is directly proportional to the inside-outside temperature difference under steady-state conditions (see section C.3.2). If the conditioned periods are brief compared to the thermal inertia of the structure (see MT R.1), the building envelope will be in a dynamic state, i.e., the typical linear change in temperature from inside to outside will be altered. This can be advantageous from an energy savings standpoint and is the reason to setback the temperature of the conditioned spaces for one or more periods during the 24 hour cycle, and/or setup the temperature for cooling situations.

Determination of the energy saving effect from temperature setback/setup, can be made by making a comparison of the energy consumption during periods when the temperature setback/setup is operating (on-periods) and when it is not (off-periods). One has to measure energy consumption, average indoor temperature (MT R.2) and average outdoor temperature (MT E.1).

The energy consumption for the on-periods and the off-periods, respectively, are plotted versus the indoor-outdoor temperature difference or the outdoor temperature, and the energy signatures (see AT M.1) for the two periods are determined.

In the case of cooling, this relation may not be valid if significant amounts of moisture are transferred to the interior during the off cooling cycle.

cost:	**ease of use:**
accuracy:	**references:**

---

recommended applications:

Post retrofit evaluation of the installation of setback/setup controls.

---

alternative procedures:

---

additional information:

The accuracy of this procedure depends on what variation in temperature difference is obtained in the measurements.

One can use weekly averages and let on- and off-periods alternate. To determine the energy signature one will in general need 5-10 on-off periods, which means that the measurements have to go on for 10-20 weeks.

An alternative is to use daily averages. This will increase the scatter in data due to dynamic effects, but instead one may obtain a larger span of temperature differences. One can still use alternating on-off periods of one week, but exclude from the data set the first one or two days of each period to reduce dynamic effects resulting from the building time constant.

An example of the results one may obtain in the case of night setback is shown below.

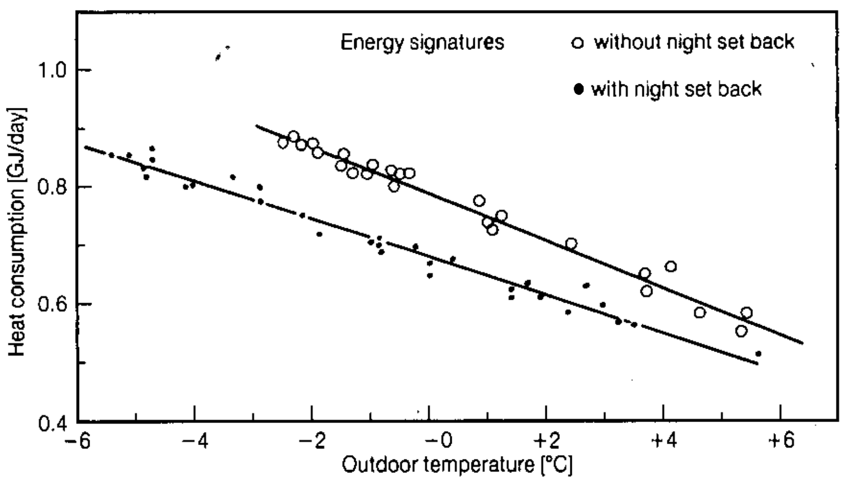

Fig. 1 Example of energy signatures with and without night set-back.

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audit procedure:	application area:	referenced from:
R.3	REGULATION, SPECIFICALLY, VENTILATION SYSTEMS	ECO R.16.

title:	references to:
POLLUTANT CONCENTRATION IN EXHAUST AIR	AT R.4, RV E.4.

description:

i) Measurement of volatile organic compounds.
Air from the duct is sucked by a low-flow pump through an impinger containing a chemical solution or through a passive sampler containing a chemical collector (e.g. charcoal). The details and the exposure time, up to one week, will vary with the compound being evaluated.
The content of the sampler then has to be analyzed at a laboratory using, e.g. chromatographic methods. These measurements cannot be performed without specific expertise and equipment.

ii) Measurement of respirable suspendid particulates.

For this measurement there are available portable instruments. The exposure time is of the order of minutes.

iii) Radon, not radon progeny, are normally measured either in the occupied building zones or in the exhaust air. Control of radon controls the progeny which are the actual cause of the health hazard. Passive measurement methods include charcoal canisters (4-5 day periods), alpha track average measurements (several weeks duration) or continuous radon monitors for seven-day averages. Averages higher than national guidelines mean action should be taken immediately or during a prescribed period depending on the radon levels measured.

iv) Measurement of carbon monoxide (CO) content can be made with dedicated instruments which directly read parts per million. These are low cost instruments.

cost:	ease of use:
Expensive.	1. Complex. 2. Easy.

accuracy:	references:
Good.	

---

recommended applications:

Buildings where contaminant level can be expected to be high.

---

alternative procedures:

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additional information:

The measurement of respirable suspended particles is relatively easy to perform, even though the instruments are expensive.

The measurement of volatile organic compounds is not too complex or expensive in itself, but costly all the same as there may be several hundreds of compounds to search for, if one does not know what to look for, and the final analysis has to be carried out at a laboratory.

Typical recommended minimum ventilation rates and maximum tolerable levels for various pollutants are given in RV E.4.

Methods of calculating time weighted average values are described in AT R.4.

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audit procedure:	application area:	referenced from:
R.4	VENTILATION SYSTEMS	ECO R.11.

title:	references to:
EVALUATION OF DAMPER LEAKAGE	

description:

The purpose is to evaluate air leakage through dampers in ventilation systems with connection to outside air in order to determine the amount of unwanted ventilation in shut off periods.

Check the ventilation system for dampers. There should be a shut-off damper for each fan, also in systems with common intake- or exhaust-chamber. Check that the dampers really close when the fans are turned off.

Note if any fan rotates when it is turned off due to draught through the system. Check also the normal running time per day and week, preferably checking the time controller.

If the ventilation system is OK, further investigation is normally not needed if the building height is lower than 8-10 storeys and the building is not highly exposed to wind.

If pressure measurements have to be carried out, stop the fan and check that the shut-off damper closes. Measure the pressure difference across the closed damper (see AT D.6.). Wait 1/2 hour to establish stable temperatures before measuring. This should preferably be done on a day with outside temperature near the average for the heating season. Measure the indoor and outdoor temperature and the damper gross area.

Find a suitable part of the main duct and measure the air flow with a hot-wire anemometer (see MT D.3). Expected velocity is less than 1 m/s with closed damper.

It is not recommended to measure on intake- or exhaust grilles.

A first estimate of the leakage during the heating season can be calculated from

$$q_s = A* \sqrt{[\Delta p + 0.045*(T_e - T_{e,s})*h]} / \sqrt{(2/\rho)}$$

where

q_s = average seasonal leakage [m^3/s],

A = damper area [m^2],

Δp = measured pressure difference across damper [Pa],

$T_{e,s}$ = average seasonal outdoor temperature [^oC],

T_e = measured outdoor temperature [^oC],
h = height difference between intake and exhaust opening [m],
ρ = density of air (= 1.2 kg/m^3).

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cost:	**ease of use:**
Liquid filled inclined manometer: From $50. Hot-wire anemometer: From $500. Data collection: 1/2-1 h/damper.	Data collection simple, for measurement of air flow more training is necessary.

accuracy:	**references:**
About 50%, *air flow measurement* about 25%.	

recommended applications:

Where damper leakage may be part of the overall building leakage.

---

alternative procedures:

More accurate and more expensive: use AP D.1. The procedure has to be adjusted for the actual use. The duct on one side of the damper must be sealed off near the damper. The main problem is to make a complete airtight sealing barrier.

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additional information:

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audit procedure:	**application area:**	**referenced from:**
R.5	REGULATION	ECO R.17

title:	**references to:**
ANALYSIS OF VERTICAL TEMPERATURE GRADIENTS	AT M.2.

description:
Use, e.g., a portable pyrometer with air measuring probe to measure air temperatures (see MT R.2) 200 mm below the ceiling and 1 metre above the floor and midway between ceiling and floor. Record temperature differences, ΔT, on a floor plan sketch at various locations. In large open unpartitioned spaces a small number of measurements will normally be sufficient. More measurements should be made where there are high partitions formed by walls, storage or equipment, in order to check uniformity.

Take measurements on or near design day conditions and if possible in addition over a range of outside conditions. Avoid measurements near open doors and near air supply or exhaust locations.

If ΔT is greater than 6 K, retrofit will almost always be justified, between 2 and 6 K an analysis should be required as laid out below; below 2 K there is little opportunity for savings.

If ΔT measurements are available for one outside temperature only, use degree day method to estimate potential heating savings. Estimate heating energy use before retrofit by dividing building horizontally in 2 or 3 zones and calculating energy consumption through these zones on the basis of the different inside air temperatures measured. Ventilation losses should be accommodated in a similar way, i.e. air exhausted or leaving at the roof will be at a higher temperature than air leaving at the flow level. The after retrofit situation can be estimated in a similar manner using reduced temperature gradients.

If temperature gradients were measured at various outside conditions, a bin method (see AT M.2) can be used (in a similar way to explaned above) for a better estimate. (This is because the temperature gradient will be affected by outside conditions).

cost: Low cost	**ease of use:** Simple
accuracy: Good	**references:** Fizzel, 1977; Beyeay, 1978

recommended applications:

alternative procedures:

additional information:
When estimating average room temperatures, it should be noted that the room temperature gradient is highly dependent on the heating system (see App. C.2)

audit procedure:	**application area:**	**referenced from:**
H.1	HEATING PLANT	ECO H.4, H.8, H.11, H.21 H.24, AP H.2, AT H.1

title:	**references to:**
COMBUSTION EFFICIENCY	AP P.1.

description:

The data collection is carried out in three steps:

i) Measure the flue gas temperature T_f (MT H.2).

ii) Measure the CO_2 (or O_2) content [%] of the flue gases (MT H.3).

iii) Measure the temperature of the combustion air T_a.

Repeat the steps i)-iii) for every burning mode (hi/low fire).

The combustion efficiency (or dry combustion efficiency, see App. C.4) of the burner η_c [%] is given by

$$\eta_c = 100 - c_s * (T_f - T_a)/CO_2$$

where c_s = Siegert constant = 0.58 for oil
= 0.48 for natural gas
= 0.67-0.75 for coal
= 0.53 for coke.

cost:	**ease of use:**
$1000-$1500 automatic efficiency meter. Labor: 15 minutes (5 min. automatic).	Easy.

accuracy:	**references:**
High.	

recommended applications:

Repeat measurement 1 or 2 times per year.

alternative procedures:

Several automatic instruments are available which allow to carry out steps 1-3 above by inserting a probe into the exhaust gas pipe. A display and/or a print-off of the efficiency parameters is provided. This makes an on-line readjustment of the burner in order to improve the efficiency easier. The time for carrying out this AP is considerably reduced.

additional information:

The duration of the prepurging (gas burners) must be short for minimizing the off-cycle stack losses, but it cannot be reduced beyond a certain minimum value for safety reasons. Prepurging time should not exceed 10% of the average running time of the burner.
The number of start-ups should be kept as low as possible. Each start of an oil boiler produces soot, which decreases the heat transfer to the heating fluid. The Bacharach soot number has to be 0 or 1.
It may be advisable to measure also the CO content in the exhaust gases to check not only the completeness of the combustion but also the air pollution.
Compare the combustion efficiency value with standards and with target efficiency values of advanced burners.
Compare the stack draft with reference depressurisation value of the specific boiler and burner type.

audit procedure:	**application area:**	**referenced from:** ECO H.1
H.2		H.3, H.16, H.20, H.4, H.18, AT H.1, RV H.2

title:	**references to:**
THERMAL LOSSES AND EFFICIENCIES FOR A BOILER	AP H.1, RV H.1

description:

Boiler stand-by losses include jacket and off-cycle stack losses. Storage losses are heat losses from a storage between the boiler and the distribution network (see Fig. 1). The boiler thermal efficiency is defined as the fraction of the heat content of the fuel received by the heated fluid when the burner is on. The heat plant thermal efficiency is the fraction of the heat content of the fuel delivered to the heat distribution network.

For oil and gas-fired boilers, four measurements are required:

i) The boiler operating temperature, T_b,
ii) The fractional burner on-cycle time, w_1, when the distribution network valves are closed,
iii) The fractional burner on-cycle time, w_o, when the valve at the boiler outlet is closed, and
iv) The combustion efficiency, η_c [%] (see AP H.1).

The losses, given in per cent of the heat content of the fuel, are then given by:

- the fractional stand-by losses $L_{sb}(T_b) = \eta_c * w_o(T_b)$,
- the fractional storage losses $L_s(T_b) = \eta_c * (w_1 - w_o)$
- the fractional jacket losses, L_j, and fractional off cycle losses, L_{oc}, by $L_j + L_{oc} = L_{sb}$.

The boiler full load thermal efficiency, η_b [%], is given by

$$\eta_b = \eta_c * (1 - L_j/100).$$

As a rule of thumb, the jacket losses are 2/3 of the total stand-by losses. We then have

$$\eta_b = \eta_c * (1 - 2w_o/3).$$

The heat plant (boiler and storage) thermal efficiency, η_p [%], is given by

$$\eta_p = \eta_c * (1 - w_1).$$

All losses [%] can be converted to power [kW] by multiplying by the fuel mass flow rate [kg/s] (see MT H.4) and by the heat content of the fuel [kJ/kg] (see RV H.1).

For solid fuels one has to measure the energy flow from the boiler or from the tank (see AP P.3) and then divide by the heat content of the fuel to obtain η_b and η_p respectively.

cost: See AP H.1 for cost of combustion efficiency measurement. Small cost for recorder.	**ease of use:** Simple.
accuracy:	**references:**

recommended applications:

alternative procedures:
If no recorder is available, use a simple clock in well defined test periods. Alternative procedures for measuring stand-by losses can be to measure the temperature, the area of wet and dry boiler surfaces and the room temperature to calculate the heat losses (see AT P.1).

additional information:
- Compare with stand-by losses standards for new boilers (see RV H.1).
- Analyze the oversizing of the boiler.
- Also take into account distribution losses (AT P.1) and regulation losses.

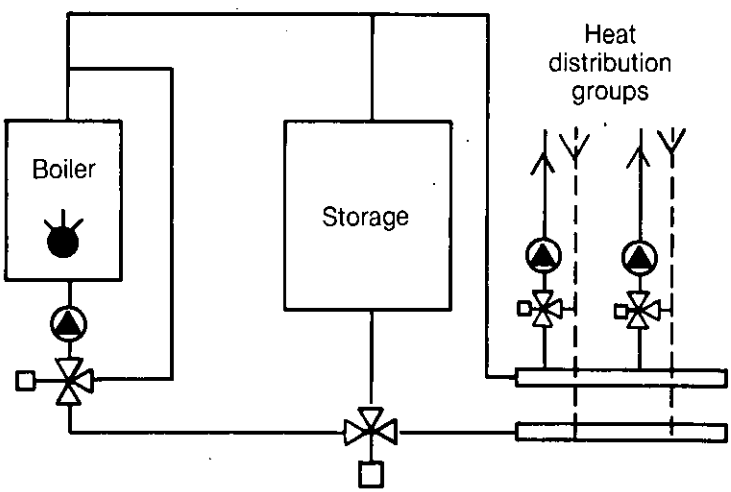

Fig. 1 Schematics of heating plant and heat distribution.

audit procedure:	**application area:**	**referenced from:**
H.3	HEATING PLANT	ECO H.24.

title:	**references to:**
ELECTRIC BOILER SEASONAL EFFICIENCY	AP P.3, MT P.5, P.6, AT P.1.

description: This AP can be applied to systems utilising off peak electricity and thermal storage.
The measurements are carried out in three steps:

i) Measure the temperature of the boiler, storage and pipes in the heating plant, (see MT P.5 and P.6),
ii) Measure the energy consumption during a few hours, without delivering any heat to the building (stand-by losses). This measurement should be repeated once with storage, once without storage,
iii) Measure the energy consumption for each period during which the tariff for the price of the kWh is different.

The measurement is carried out by reading the electricity counter or by measuring the on-off time.

The seasonal efficiency can be obtained in the following manner:

1. Calculate the stand-by losses with and without storage and compare with the full power of the boiler (see AT P.1 and AP S.3).
2. Determine the stand-by losses of the storage alone and compare with the storage capacity (see AT P.1 and AP P.3).
3. The seasonal efficiency, η, is given by

$$\eta = (P_{el} - Q_{sb})/P_{el}$$

where
P_{el} [kW] = average electric energy consumption in one heating season,
Q_{sb} [kW] = stand-by losses (at the average heating plant temperature).

4. Compare the obtained values with target values and evaluate the energy saving potential.

cost:	**ease of use:** Easy

accuracy: Good	**references:**

recommended applications:

alternative procedures:

additional information:

audit procedure:	application area:	referenced from:
H.4	HEATING PLANT	ECO H.15, H.1, R.2, AP S.5

title:	references to:
EVALUATION OF BOILER OVERSIZING	AT M.1

description:

i) Determine the energy signature of the building, see AT M.1 and plot the results - average boiler load versus outdoor temperature. The average boiler load is given by the energy consumption divided by the time period for which the energy consumption was recorded (for a burner it is suitable to record the fractional power on time) for a range of outdoor temperatures.

ii) Extrapolate the relationship back to the value of the design temperature appropriate to the location to find the actual steady state design heating demand.

iii) Compare the value obtained in ii) with the installed boiler capacity to determine the degree of oversizing.

iv) For intermittant heating or setback the required boiler size will be higher than that required to meet the steady state load and there is a trade off between shortness of pre-heating time and boiler oversizing.

v) To determine the suitability of the present pre-heating period with respect to installed boiler power, it is necessary to track the interior temperature or heating demand during the pre-heating period under conditions as close as possible to the design point. If the inside air temperature reaches comfort level before the end of the pre-heating period or if the boiler does not operate at 100 per cent output over the pre-heating period, then the pre-heating period has been set too long.

vi) Note ideal setback strategies include an optimum start sequence in which the pre-heat time is shortened as outside conditions become milder.

cost:	ease of use:
$50 to $200 for the measurements.	
accuracy: -	**references:**

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recommended applications:

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alternative procedures:

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additional information:

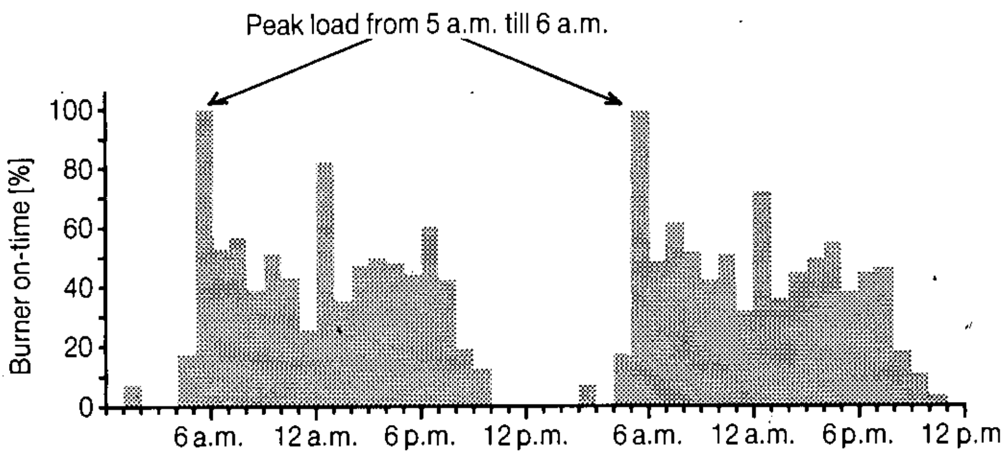

Fig. 1 Example of variations in load for a house during two days.

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audit procedure: H/C.1	application area: HEATING AND COOLING	referenced from: ECO H/C.16.
title: PERFORMANCE OF HEAT PUMPS AND CHILLERS		**references to:** MT EL.4

description:
Carry out the following measurements:

i) Operate the unit with a stable load for half an hour.

ii) Measure the electric power for the compressor, P_k, and if possible for the whole unit, P_t. See MT EL.4

iii) Measure condensing and evaporating pressures with built-in manometer or with test manometers if pressure tappings are fitted. Read the corresponding saturated condensing and evaporating temperatures, T_{co} and T_{ev}, of the refrigerant from tables, or measure these temperatures.

iv) Measure the volumetric flow rates and temperatures of the heated and the cooled fluid at the inlets and the outlets (for notation, see Fig. 1). Use MT from categories D and P. For liquids the flow rate can also be obtained by measuring the pressure drop across the pump and the rpm and reading the volume flow from the pump characteristic. For gases the volume flow can also be obtained from the rpm and the fan characteristics.

v) Calculate the difference in energy flow between the inlet and the outlet for the heated, P_h, and the cooled, P_c, fluid from

$$P_h = q_{v,h} * (T_{h,o} - T_{h,i}) * \rho_h * c_{p,h}$$

$$P_c = q_{v,c} * (T_{c,o} - T_{c,i}) * \rho_c * c_{p,c}$$

where ρ is the density and c_p the specific heat at constant pressure of the fluids. The indices o and i refer to outlet and inlet, respectively.

vi) Calculate the two entities $COP_h = P_h/P_k$, which is equal to the compressor coefficient of performance in the case of heating, and $COP_c = P_c/P_k$, which is equal to the compressor coefficient of performance in the case of cooling.

vii) For consistency, compare COP_h to COP_c+1. These should be identical. If they deviate by more than 20%, use more accurate measuring equipment.

viii) Compare the relevant COP to target values for the measured working pressure range.

cost: \$100-\$500 depending on presence of prepared measurement facilities. 2 to 4 hours for data

ease of use:
Equipment is simple to handle, but requires experienced staff if accurate results are required.

accuracy:
15%.

references:
ASHRAE, 1984; SP MET, 1985

recommended applications:
Performance check of heat pumps and chillers.

alternative procedures:
Implicit deductions of performance from measurement of surface temperatures and refrigerant pressures. This is not recommended practice.

additional information:
As a further check, calculate the Carnot COP given by
$T_{co}/(T_{co}-T_{ev})$.

The ratio of COP_h to the Carnot COP should lie between 0.4 and 0.7, depending on compressor type and operating conditions. As a check of the operating conditions:

1. Compare the flow rates of the heated and cooled fluids to design values.
2. Typical temperature differences are:
   $T_{co} - T_{h,o}$ 0-5 K; $T_{h,o} - T_{h,i}$ 5-15 K; $T_{c,i} - T_{c,o}$ 5 K; $T_{c,o} - T_{ev}$ 5-10 K.

   These values will greatly depend on type of unit and application, and should always be checked against design data. If there are deviations for a circuit, check for fouling.
3. Compare refrigerant temperatures with design values.

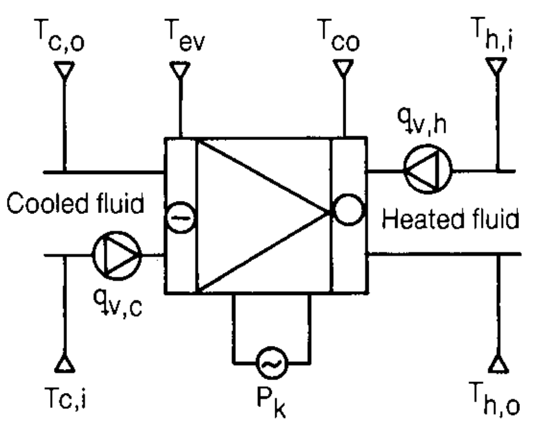

Fig. 1
Notation used for heat pumps.

audit procedure:	**application area:**	**referenced from:**
H/C.2	HEATING PLANT, DISTRIBUTION SYSTEM	ECO H/C.17

title:	**references to:**
HEAT EXCHANGER EFFICIENCY AND OUTPUT (WITHOUT CHANGE OF PHASE)	AP H/C.3.

description: The procedure consists of:

i) Operate heat exchanger until stable conditions have been maintained for 0.5 hours.

ii) Measure at least 2 parameters on each side of the heat exchanger (see diagram under additional information), for example. T_{h1}, T_{h2} or T_{h2}, q_h and T_{c1}, T_{c2} or T_{c1}, q_c.

Preferably all 3 parameters are determined on both sides.

iii) Measure pressure drop and working pressure on both sides.

iv) For air/air heat exchangers determine external leakage and cross over leakage (AP H/C.3).

v) Calculate the heat input (P_c) and the heat output (P_h)

$$P_h = (T_{h1} - T_{h2}) * q_h * \varrho_h * c_{p,h}$$

$$P_c = (T_{c1} - T_{c2}) * q_c * \varrho_c * c_{p,c}$$

where ϱ is the density and c_p the specific heat at constant pressure.

vi) Depending on heat exchanger use calculate the efficiency $\eta = P_h / P_c$. If the volumetric flow rate is the same and the fluids are the same, the efficiency is given by $(T_{h2} - T_{h1})/(T_{c1} - T_{c2})$.

This is often used as a definition of efficiency, temperature efficiency, even if the flow rates are not the same.

vii) Compare pressure drop with design values and calculate required pump or fan power.

viii) For air/air heat exchangers check that external leakage is less than 4% and cross over leakage less than 8%.

ix) Estimate the heat loss $\Delta P = P_h - P_c$

cost:	**ease of use:**
$100-$2000 depending on size of exchanger and level of testing.	Expert required.

accuracy:	**references:**
Depends greatly on operating conditions, but typically 0.05 for temperature efficiency.	Nordtest, 1983; Eurovent, 1977.

recommended applications:

Guarantee tests of large heat exchangers or whenever degradation of performance is suspected.

alternative procedures:

additional information:

Higher than design pressure drops suggests clogging or fouling. Correct this by cleaning.
Leakage tests should always be performed on air to air heat exchangers before performance tests are carried out. Excessive leakage will render performance measurements meaningless.

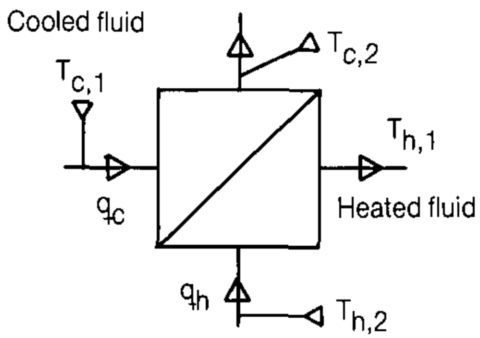

Fig. 1
Notation used for heat exchanger.

audit procedure: H/C.3	**application area:** HEATING AND COOLING PLANTS, HEAT RECOVERY UNITS	**referenced from:** ECO H/C.4, AP H/C.2.

title: AIR LEAKAGE OF HEAT PUMPS AND HEAT RECOVERY UNITS	**references to:**

description:

The cabinet exterior air leakage of a heat pump or heat recovery unit to the atmosphere is determined by creating a difference in pressure. Units with two air systems in the same cabinet (e.g. outdoor air and circulated indoor air or exhaust air and fresh air) are tested with two fans. The heat recovery unit and the measuring equipment are set up as shown in Fig. 1. The static pressures are set with the adjustable fan(s) in the normal pressure range of the tested unit. If two fans are used, the two pressures should be the same. The pressures are measured with a differential pressure gauge.

The total leakage at each test point is calculated as the sum of the measured flows. The leakage should not exceed 4% of the nominal operating flow rate of the unit.

The cross-over air leakage between two air systems of a heat pump or heat recovery unit is determined by putting one air system of the unit under pressure. The pressure in the other systeem of the unit is brought to zero. Two fans have to be used (see Fig. 2). For each pressure in the first system, the flow which passes the second system with zero pressure is measured with an air flow measuring tube. This air flow is of the same magnitude as the air leakage between the two systems. It is compared with the nominal flow rates of the air systems. The leakage should not exceed 8% of the nominal flow rate.

cost: $50-$200 depending on size and number of duct connections.	**ease of use:** Easy to use.
accuracy: Depends on method of measurement used for pressure and flow rate.	**references:** Nordtest VVS 021-022.

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recommended applications:

Heat pumps, air conditioning units or heat recovery units with duct connections where external air leakage or cross-over leakage is suspected.

---

alternative procedures:

Tracer gas techniques (more complex and expensive equipment).

For air/air heat recovery units one fan is sufficient in the case of exterior leakage if the heat exchanger element can be removed.

---

additional information:

The duct between the fans and the unit should have a hydraulic diameter D corresponding to that of the coupling of the unit and this duct should have a length of at least 10 D. Static pressures should be measured at a distance from the unit exceeding 5 D. Not used couplings are closed with covers. Passages for drainage are sealed with airtight tape.

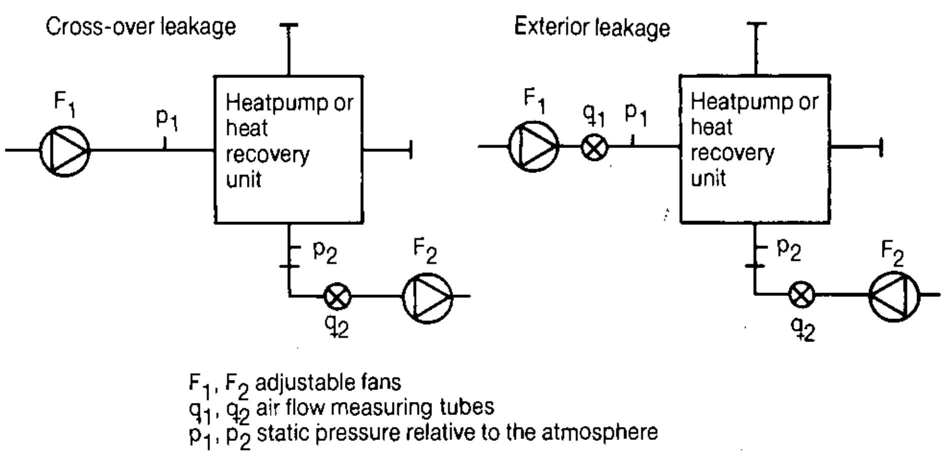

Fig. 1 Arrangement for test of cabinet exterior air leakage (right) and cross-over leakage (left).

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audit procedure:	**application area:**	**referenced from:**
H/C.4	HEATING AND COOLING	ECO H/C.9.

title:	**references to:**
HEAT PUMP EXPANSION DEVICE	MT P.5, P.6.

description:
Operate the heat pump at different conditions and capacities:

i) Determine the amount of refrigerant superheat, after the evaporator by measuring the refrigerant temperature (see MT P.5 and P.6), at the location of the TEV (thermostatic expansion valve) bulb.
ii) Determine the length of the cycle period if the refrigerant temperature is oscillating.
iii) Compare measured values with design values. Normal values of superheat are between 4 and 8 K.
iv) If the refrigerant temperature is oscillating with a period of a few minutes, this is probably due to too little superheat for stable control of the TEV.

Use the MSS (Minimum Stable Signal) procedure to check sizing and operation of TEVs.

- If there are no oscillations, decrease the static superheat (SS) until oscillations appear. If this is not possible increase the size of the TEV nozzle. If oscillations cannot be prevented with minimum SS then decrease the size of the TEV nozzle.
- If TEV does not seem to operate at all this may be caused by lost bulb charge, poor contact between bulb and refrigerant pipe, damaged membrane or frozen water droplets in the refrigerant.
- Check that the amount of refrigerant superheat does not vary for different operating conditions. If it does, this may be due to an unsuitable type of bulb charge, improper sizing or incorrect adjustment of the TEV.

cost: $20-$100.	**ease of use:** Measurements are easily performed but care and skill is needed in the application of transducers and in analyzing results.

accuracy: If care is exercised and accurate measuring equipment is used, superheat can be determined within 1K	**references:** ASHRAE,1979 (Ch. 43); ASHRAE, 17-75; ASHRAE, 1983 (Ch. 20).

recommended applications:
Heat pumps, air conditioning units, chillers with refrigerant flow control by means of thermostatic expansion valves or capillary tubes.

alternative procedures:

additional information:

audit procedure:	**application area:**	**referenced from:**
H/C.5	Heating and cooling plant	ECO H/C.7

title:	**references to:**
EVALUATION OF DEFROST SYSTEM	MT EL.6, EL.7

description:
For optimum performance of air source heat pumps or air conditioners, efficient defrost systems are needed for evaporating temperatures below 0 °C. The procedure consists of:

i) Measure the number of defrosts per hour at ambient temperatures of about +7, +2 and -7 °C (MT EL.7). Compare with manufacturers recommendations.

ii) Measure duration of defrost period (MT EL.7).
iii) Measure energy consumption during defrost (MT EL.6). Estimate savings if more efficient defrost system is used.
iv) Visually inspect evaporator surface for frost accumulation and location just before and just after defrosting. It should be free from frost.
v) Note set points for controllers or software programs if defrost initiation and duration are operator adjustable. Compare with manufacturers recommendations.
vi) Check that sufficient frost has accumulated to warrant initiation of a defrost (visually and by recording a significant decrease in evaporating temperature).
vii) Check that water from thawed ice is disposed of through the proper drains (no ice should accumulate in the drain pan).
viii) For reversing units estimate the power lost for defrosting by calculating power taken from the heating system, electric power absorbed during defrost and heat that could have been produced if a defrost was not needed. For other types of systems only the last two items apply. For temperatures below the balance point cost of the supplementary heat used during the defrosting period must be considered.

cost:	**ease of use:**
$100-1000 dependending on complexity of the evaluated defrost system	Easy to use but experience is needed for the evaluation

accuracy:	**references:**
As stated for the respective MTs used. Accuracy for calculated savings depends greatly on assumed utilization of the heating/cooling equipment.	Merrill, 1981.

recommended applications: To evaluate the performance of air source heat pumps or air conditioning units when the defrosting system is malfunctioning or is suspected to operate inefficiently.

alternative procedures:

additional information:

audit procedure:	**application area:**	**referenced from:**
D.1	DUCTWORK	ECO D.4, H/C.4

title:	**references to:**
EVALUATION OF AIR LEAKAGE IN DISTRIBUTION SYSTEMS	

description:

There are several simple methods to use when air leakages are suspected:

i) Evaluate the air flow in the most distant air terminals. Little or no air flow can be a signal for either leakage or unbalance.

ii) Stop all other noisy activities in the building (if necessary) and listen as you go along the duct. Some leaks give detectable noise.

iii) Inspect the duct and its surroundings. Leakage often causes dust (dirt) to settle down around openings and on surrounding walls.

Some leaks (especially in structural ducts) can be difficult to locate. If these simple methods conclude with suspicion of considerable air leakage, measurements should be done.

Survey the ventilation system of the building and choose a representative test sample(s). A test sample is a section of the system which can be sealed off from the rest of the system and from the surroundings. The area of the chosen sample shall be sufficiently large for measurement with the available test equipment, at least 10 m^2 of duct surface area. As a means of tightening, various sizes of rubber balloons can be used. The area of the sample and the total length of the joints of the sample are measured. A fan with a flow measuring tube is used to pressurize the system in steps from 100 Pa to 1000 Pa (see Fig. 1).

The leakage factor is calculated as the quotient between air leakage rate and the surface area of the sample. The leakage factor is compared with the permitted leakage rate for the system.

cost:	**ease of use:**
Equipment incl.fan pressure control and means of flow measurement appr. $2000. Time: 1-3 hr/test dep. on the accessibility of the system.	Depends on the accessibility of the system. If it is insulated, the duct area is difficult to measure.

accuracy:	**references:**
5% can be achieved.	Eurovent 2/2

---

recommended applications:

In some situations, air leakage can reduce the performance of other ECOs:

- Heat recovery: The air takes shortcuts and can bypass the regaining installation.
- Air flow continues during "off" periods.

---

alternative procedures:

In some cases the air leakage sites can be detected with a smoke bottle or similar, but this can not give a quantitative measure.

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additional information:

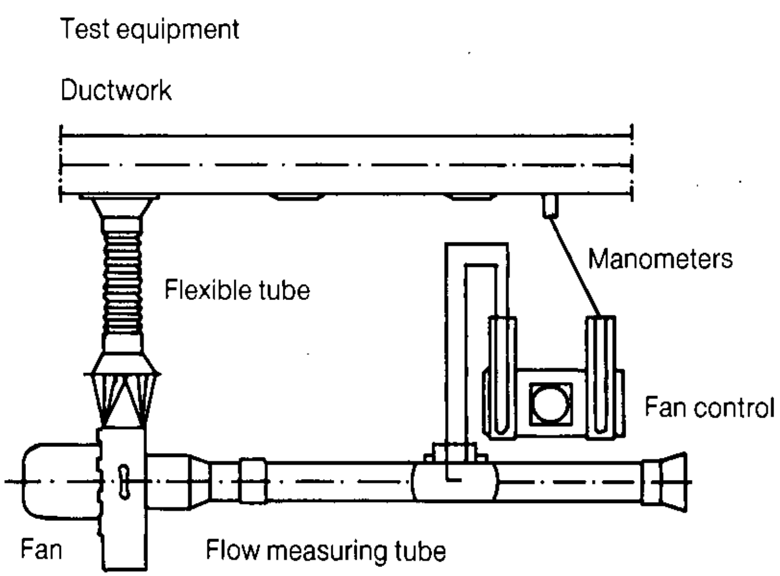

Fig. 1 Equipment for measuring air leakage in ducts.

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audit procedure:	**application area:**	**referenced from:**
D.2	DUCTWORK	ECO D.8.

title:	**references to:**
EVALUATION OF DUCT HEAT LOSS	AT D.1, MT D.2 through D.5, D.7, P.5. RV D.1

description:

In systems where the ventilation air is used to provide heating or cooling, the duct heat loss will reduce the performance of the system in extreme situations. The duct heat loss is proportional to the temperature difference between the conditioned air in the duct and the surroundings. The procedure is carried out in three steps:

i) Study the system (or the drawings of the system) in order to locate parts of the duct's surroundings where the heat loss can be considerable, e.g. uninsulated ducts passing through unconditioned areas.
ii) Measure the air temperature in both ends of the duct system (see MT D.7). Be sure to avoid the effect of possible temperature cycling.
iii) The temperature difference, ΔT, and the volumetric air flow, q_v, give the approximate heat loss, Q_{loss}, with the following formula if humidity can be neglected:

$$Q_{loss} = \text{const.} * q_v * \Delta T$$

where the constant takes the value 1.26×10^{-3}, if Q_{loss} is measured in kW and q_v in l/s. (For measurements of air flow rate, see MT D.2 through D.5). See also AT D.1

cost:	**ease of use:**
Thermometer: \$100-\$200. Time: 30-60 minutes.	Easy.

accuracy:	**references:**
Depends on temperature difference.	

recommended applications:

alternative procedures:

Measurement of duct surface temperature, and calculating heat loss (see MT P.5 and AT D.1, respectively). See also RV D.1.

additional information:

audit procedure:	**application area:**	**referenced from:**
D.3	DUCTWORK	ECO D.1.

title:	**references to:**
EVALUATION OF AIR FLOW BALANCING	MT D.8 through D.11.

description:

An unbalanced ventilation system can cause an unsatisfactory indoor climate, because it will not respond to regulation as intended. Good results of ECOs on ventilation systems depend on a well balanced system.

The procedure is carried out in three steps:

i) Ask the occupants to point out rooms/places with:
   - strong ventilation/draughts,
   - no air movements/poor air quality.

ii) Check the system drawings to point out the most distant and the terminals close to the plant.

iii) Evaluate the air flow in the different terminals. A simple relative measurement may be necessary (see MT D.8 through D.11).

The evaluation of the measurements taken should lead to a decision whether:

- the system needs balancing,
- better air flow measurements must be taken,
- the air flow balance is acceptable.

cost: Air flow measurement: See MT D.2 through D.5. Time: 1-2 hrs.	**ease of use:** Easy, although some experience is needed.

accuracy:	**references:**

recommended applications:

alternative procedures:

additional information:

WARNING! Some terminals may be (deliberately or not) blinded by the occupants. This can cause disturbances in the evaluation.

audit procedure:	application area:	referenced from:
P.1	PIPEWORK HVAC-CONTROL	ECO P.1

title:	references to:
CHECKING OF BALANCE OF PIPEWORK SYSTEMS	MT R.2

description:

If a hydronic heat distribution system is to function properly, from an energy point of view, it must be balanced, i.e. every radiator must receive exactly the water flow required to keep the wanted indoor temperature. Radiators receiving too much water will give off too much heat which will raise the room temperature. If a radiator receives too small a flow, this will result in too low a room temperature, which can be compensated for by raising the feed water temperature, resulting in even higher room temperatures where the temperature level was already too high.

i) The first check of the balancing can be made by measuring the indoor temperature in a number of rooms. The most common indication of an unbalanced system, assuming one wants to keep the same temperature everywhere, is that rooms with large heat losses, e.g. rooms on the top floor or at the gables, are colder than rooms close to the heat plant. This measurement is best performed on an overcast, cold day, the colder the better. The temperature variation should be at most 1 or 2 K for a properly balanced system.

ii) If the variation is larger, it does not necessarily mean that the heat distribution system is unbalanced. It can be due to, e.g. wrongly sized radiators, uncertainties in the calculated heat losses, neglection of infiltration losses, internal (e.g. electric loads) or external (e.g. insolation) heat sources of varying size, etc. If large variations are detected, the reason for this should be checked by a measurement of the temperature difference between feed and return water for various circulation loops.

iii) If there is a large variation also in this temperature difference, this is an indication that the water flows are not what they should be in a balanced system.

cost:	ease of use:

accuracy:	references:

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recommended applications:

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alternative procedures:

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additional information:

This procedure requires accurate and fast response temperature sensors. Be sure that temperatures are measured in the same way in all rooms, i.e., at the center of room, 1.5 m above the floor, and that the sensor is shielded from radiation sources (complaints about temperature in rooms very often are influenced by surface temperatures). (See MT R.2.)

---

audit procedure:	**application area:**	**referenced from:**
P.2	PIPEWORK SYSTEMS	ECO P.6

title:	**references to:**
PIPEWORK DISTRIBUTION EFFICIENCY	MT P.5, P.6

description:

Distribution efficiency η_d is defined as:

$$\eta_d = \frac{\text{total heat output from radiators}}{\text{total heat provided to the water by the boiler}}$$

As an estimation of the distribution efficiency using this definition would involve measurements on all radiators in the system, it is common to select one radiator to represent the radiators of the system. This radiator should be chosen so that the corresponding circulation loop has a length l given by

$$l = \Sigma\, q_i\, l_i / q$$

where the summation is over the radiators of the system, q_i and l_i are the flow rate and the length of the circulation loop for one radiator, and q is the total flow rate from the heat generator.

The distribution efficiency can then be estimated from

$$(\Delta T_s + \Delta T_r)/\Delta T$$

where ΔT_s = temperature difference between the boiler outlet and the radiator inlet (supply water.

ΔT_r = temperature difference between ratiator outlet and boiler inlet (return water).

ΔT = temperature difference between supply and return water at the boiler.

The temperature differences should be measured simultaneously (see MT P.5, P.6).

cost:	**ease of use:**
Depends on cost of thermometer.	Requires trained personnel for selecting the most suitable radiator circuit.

accuracy: Depends on both the thermometer and the choice of the radiator circuit.	**references:**

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recommended applications:

When excessive fuel consumption cannot be attributed to building envelope heat losses or poor boiler performance. Should not be applied when pipes are well insulated.

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alternative procedures:

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additional information:

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audit procedure:	**application area:**	**referenced from:**
P.3	PIPEWORK	ECO P.3, P.10, AP S.2.

title:	**references to:**
ENERGY FLOW IN HEAT DISTRIBUTION SYSTEMS	MT P.2 through P.6.

description:

The total heat supply to the pipes can be derived by measuring the water volume flow and the temperature increase across the boiler. Measuring equipment may already be included in some installations. Techniques for measuring volume flow and temperature separately are described in MT P.2 through P.4, and in MT P.5 and P.6, respectively.

For volume flow measurements, volume flow meters inserted in the water distribution imply an extra flow resistance which reduces the water flow rate. To limit this effect a type of flow meter with low resistance should chosen. It is possible, however, to compensate the pressure loss due to the volume flow meter by increasing the pump speed. One may then proceed as follows:

i) Measure the water temperature difference (ΔT) across the boiler and the supply water temperature (T_s) (e.g., by a thermometer placed in the boiler) when the boiler is on,

ii) Fit the volume flow meter in the return pipe upstream of the pump, and

iii) Keep the boiler on until the water temperature has reached the value T_s again. Measure ΔT once more and regulate the pump output by varying its speed or by bypass regulation, until the pressure reaches the same value as before.

cost:	**ease of use:**
	Requires skilled personnel.

accuracy:	**references:**

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recommended applications:

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alternative procedures:

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additional information:

By using this procedure the pressure loss over the flow meter is compensated only for one given volume flow. Different water flow rates cause different pressure losses and, consequently, require a different pump speed. By setting the radiator valves in the normal positions, the measuring error due to pressure loss across the flow meter is minimized. In order to compensate such pressure loss correctly in all circumstances, a second pump connected in series with the volume flow meter may be used (see Fig. 1). The number of revolutions of the pump should be controlled in such a way that the pressure difference across flow meter and pump remains zero.

Since the water distribution system is often very dirty, it should be possible to clean the volume flow meter during operation of the heating plant or to install a filter upstream the measuring device.

The flow rate of the heating medium can be considered as a constant if the hydraulic circuit contains a pump and if the pressure drop remains constant.

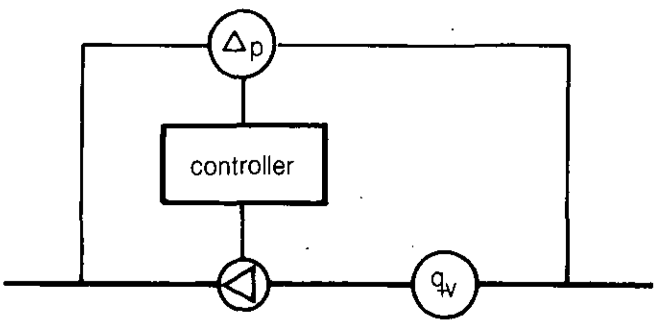

Fig. 1 Volume flow meter with pressure compensation

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audit procedure:	application area:	referenced from:
P.4	STEAM DISTRIBUTION PIPEWORK	ECO P.8, P.16

title:	references to:
STEAM TRAP INSPECTION	RV P.2

description:

An initial indication of steam trap malfunction is given by the flow of steam from system vents (e.g. condensate receiver vents).

Data collection can take a number of forms depending on the level of information one would like to know about the performance of a particular steam trap. The various types of tests (data collection activities) and the kind of information they can yield are shown in Table 1.

As a minimum for auditing and maintenance it is desirable to test for trap failure (open or closed), leakage, and backing up of condensate. Testing for steam loss at the end of the open cycle and the quantification of total steam loss (and trap efficiency) can be economically justified in some instances (see RV P.2).

A description of temperature, aural and visual testing methodologies is given below.

i) Temperature. Surface temperatures can be measured at or close to the steam trap by a variety of techniques (see MT P.5). The method has limitations since temperatures immediately before and after the trap tend to be similar, except for thermostatic type traps which should, when correctly operating, discharge steam somewhat below the steam saturation temperatures. Even in this case accuracy is limited by the accuracy of the surface temperature measurements and its ability to truly represent what is happening inside the pipe.

ii) Listening. The sound made by a steam trap is often a more reliable indication of its operation and the sound can be observed too by using a stethoscope or an ultrasonic device. The difficulty of such a method is that there are many traps without a distinctive signal. Table 2 characterises sounds of some common types of traps.

iii) Visual.
1. SIGHT GLASS METHOD - applicable where a sight glass has been fitted in the downstream side of the trap. It should be possible to see if the trap is discharging condensate and/or passing steam although it is not always clear what one is seeing.
2. SIGHT CHECK - correct operation is indicated by the regular lifting and closing of a visible ball check.
3. PET COCK METHOD - if the trap is provided with a test valve (a pet cock or small globe valve) and shut-off valve downstream (see Fig. 1):

a. Shut off downstream valve, and open test valve. The trap is faulty if there is a continuous stream of steam. Do not mistake flash steam (condensate that evaporates on exposure to normal atmospheric conditions) for a steam leak. Leaking steam will blow out continuously and have a bluish cast; flash steam appears whitish and will drift out.
b. Condensate should be observed to flow intermittantly or continuously according to the type of traps particular characteristics - see Table 2.

A recent device which is permanently installed upstream of the trap makes use of the difference in electrical conductivity between condensate and steam to detect the presence, or absence of condensate. A portable plug-in tester is required.

In all cases steam trap malfunction requires corrective action. The faulty steam trap should be stripped, cleaned and serviced, or replaced.

Where there is reason to suspect that a particular trap is not a good choice and is not operating efficiently, it may be desirable to quantify its actual performance.

See also App. C.6 and RV P.2 for estimating steam and heat losses from steam systems for those occasions where it is felt necessary to have an idea of the cost of steam leakage.

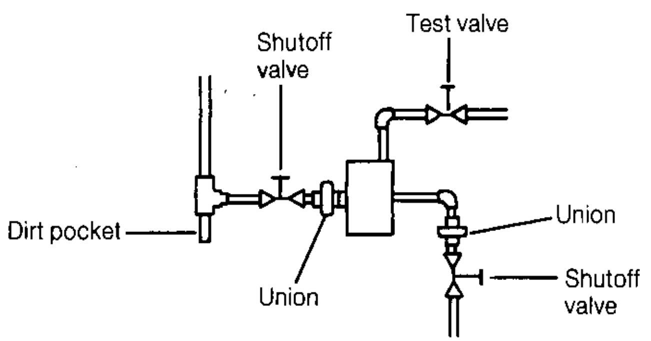

Fig. 1
Test valve method of testing steam traps.

cost:	ease of use:
Low	Ranges from easy to requiring some expertise and familiarity with different steam trap characteristics.
accuracy:	**references:**
Varies with method used and experience of auditor.	Batherman, 1982; Spirax-Sarco, 1985.

---

recommended applications:

Routine maintenance on all steam systems containing traps.

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alternative procedures:

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additional information:

TABLE 1. Trap testing methods.

Can determine if:	Temperature	Listening	Visual	Bench test	Barrel test
Trap failed open	conditional*	conditional	yes	yes	yes
Trap failed closed	yes	yes	yes	yes	yes
Leaking during closed cycle	conditional*	yes	yes	yes	yes
Loss at end of open cycle	no	no	no	no	yes
Backing up condensate	conditional*	no	yes	conditional*	yes
Total steam loss	no	no	no	no	yes
Trap efficiency	no	no	no	no	yes
Convenient	yes	yes	yes	no	no

* Conditional depending on type of trap and size of load.

TABLE 2. Characteristic discharge pattern of a number of generic trap types.

TRAP	USUAL DISCHARGE PATTERN
Thermodynamic Disc.	Blast action. Tight closure between discharges.
Thermodynamic Piston	Blast action. Continuous leakage through "bleed" orifice when main valve is closed.
Balanced Pressure Thermostatic	Blast action. Tight closure between discharges.
Liquid Expansion	Continuous dribble discharge on steady, normal or heavy loads.
Bimetal	Continuous dribble discharge varying with the amount of condensate.
Float Traps	Continuous discharge varying with the amount of condensate.
Inverted Bucket	Blast action with tight closure between discharges, except on light loads when there is a tendency to dribble.

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audit procedure:	application area:	referenced from:
P.5	HEAT DISTRIBUTION	ECO P.1

title:	references to:
HEAT EMISSION FROM HEAT TERMINALS	MT P.2 through P.6, R.2.

description:

When measuring the heat emission from heat terminals, the following general relation holds:

$$Q = Q_0 * \theta^{\beta} = q_m * \Delta T * c_p \qquad (1)$$

where

θ = difference between the mean terminal temperature and the room temperature (see MT P.5, P.6 and R.2).

q_m = mass flow through terminal (see MT P.2 through P.6)

ΔT = temperature difference between supply and return water (see MT P.5 and P.6).

c_p = specific heat capacity of water

Q = heat emission

Q_o = nominal heat emission for terminal (W/K^{β})

β = exponent, usually taking a value around 1.3, for radiators, 1.5 for thermal convectors and 1.1 for floor heating and ceiling heating.

For θ we may use

$$\theta = (T_s + T_r)/2 - T_a \qquad \text{if } (T_r - T_a)/(T_s - T_a) > 0.7$$

and

$$\theta = (T_s - T_r)/\ln((T_s - T_r)/(T_r - T_a)) \qquad \text{if } (T_r - T_a)/(T_s - T_a) < 0.7$$

where

T_s = temperature of supply water

T_r = temperature of return water

T_a = temperature of room air.

From eq. (1) it follows that the mass flow and the heat emission of the terminal can be derived from the room temperature and the temperature of the supply and return water if Q_o is known.

cost:	ease of use:
accuracy:	references:

recommended applications:

Hydronic heat distribution systems.

alternative procedures:

For the determination of the heat distribution in a dwelling over a long period, heat emission meters are also used. The amount of evaporated liquid in a capsule placed on the radiator is a measure of the total amount of heat emitted in a given period. The accuracy is 10 to 15%. Depending on the measuring period desired, a more rapidly evaporating fluid may be used, which at the same time increases the accuracy. Even if no heat is emitted by the radiator there will be evaporation, the extent of which is determined by the room temperature. This "background" evaporation must be deduced from the figure given by the evaporation meter.

additional information:

This measurement only gives an approximate result, because, due to different terminal heat emission, the value of Q_o may in practice be different from the given value, if this one has been determined in the laboratory. If the total heat emission is determined separately, however, the heat distribution over the different terminals can also be found from the total heat supplied by the boiler, (see AP P.3) which is equal to the total heat emission of all terminals, Q_{tot}, determined from the relation:

$$Q_i = (Q_{oi} * \theta_i^{\beta}) / (Q_o * \theta^{\beta}) * Q_{tot}$$

where index i refers to a single terminal.

As in this approximation it is assumed that all radiators have the same heat out-put, it is implicitly assumed that the heat emission of the pipes is also evenly distributed. In some special cases, the heat putput will change, for lower water temperatures, to
$Q = Q_o' * \theta^{\gamma}$, where Q_o' is a new value of Q_o and γ may take a value up to 1.5.

audit procedure:	**application area:**	**referenced from:**
S.1	SHW SYSTEMS	ECO S.18, S.19, S.20

title:	**references to:** AP S.3, MT P.2 through P6, AT P.1, RV S.1
SWH REQUIREMENTS	

description:

The hot water demand varies much between buildings belonging to the same building category. This demand is dependent on country or region, size of building, number of occupants, type of SHW production, storage capacity, storage losses and distribution losses.

The SHW consumption can be expressed either in terms of the volume of hot water required or in terms of the required energy for hot water generation. The net energy for hot water demand is obtained by multiplying the required volume in cubic meters by 4.2 ΔT, where 4.2 [$kJ/m^3,K$] is the volumetric heat capacity of water and ΔT is the temperature difference between the cold feed water and the SHW supply water. If to the net energy is added storage and distribution losses, one obtains the total energy demand for hot water generation.

Examples of volumetric consumptions are found in RV S.1, typical distribution, storage and generation efficiencies in RV S.2, storage losses and pipe losses are treated in AP S.3, AT P.1 and MT P.2 through P.6.

cost:	**ease of use:**

accuracy:	**references:**
	Fracastoro-Lyberg, 1983

recommended applications:

alternative procedures:
In many cases data on domestic SHW demand have been compiled at a national, regional or municipal level. The SHW demand is often expressed as dependent on a variable x as
$a + bx$
where a and b are constants and the variable x can be, for example, the number of occupants on a dwelling, the heated floor area or the number of rooms.

additional information:

audit procedure:	application area: SHW SYSTEMS IN MULTI-FAMILY AND COMMUNAL DWELLINGS	referenced from:
S.2		ECO S.16

title:	references to:
SHW STORAGE CAPACITY	AP P.3, MT P.2 through P.6, AT P.1

description:

A simple graphical technique can be used to determine the optimum SHW storage capacity when system boiler output is fixed (i.e. boiler replacement is not being considered). The procedure is carried out in six steps:

i) Monitor SHW consumption to obtain daily demand patterns. (See AP P.3 and MT P.2 through P6.)

ii) Draw up cumulative consumption graphs (as Fig. 1) from the data obtained.

iii) Draw on the graph a line AB representing the cumulative volume flow (convert boiler rating from energy to volume flow at storage temperature).

iv) The consumption below line AB will be met by the boiler.

v) The volume between AB and the demand curve must be met from storage.

vi) The value S (the maximum distance between the demand curve and AB), represents the maximum storage volume required at any one time in the day.

vii) Compare the values with actual storage capacity.

As SHW demand can vary markedly from day to day, a more accurate value of S would be obtained from a cumulative consumption graph generated from daily data averaged over a week or month. Extra storage (20-25%) is necessary to account for mixing of cold feed water with hot stored water.

cost:	ease of use:
$100-$200 dependent on the cost of monitoring SHW usage.	The method is relatively straightforward but accurate consumption data are necessary.

accuracy:	references:
10%	British Gas, 1983.

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recommended applications:

SHW generated by boiler in commercial premises, schools, apartment blocks, etc.

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alternative procedures:

AT P.1

Compare actual storage capacities with those from standard design (e.g CIBS Guide B4-7, Table B4.9).

---

additional information:

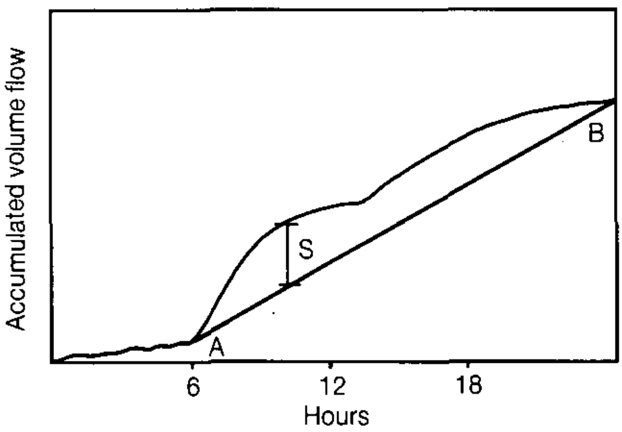

Fig. 1 Cumulative consumption graph.
For notation, see text.

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audit procedure:	**application area:**	**referenced from:**
S.3	ELECTRIC RESISTIVE STORAGE SHW SYSTEMS	ECO S.7, S.10, S.22 AP P.1

title:	**references to:**
EVALUATION OF STORAGE LOSSES FROM SHW TANK	MT R.2, P.5, AT P.1

description:

Storage losses are largely the result of conduction of heat through the walls of the storage tank.

The rate of heat loss will be dependent on tank shape, size and material, storage temperature, ambient temperature, and level of insulation.

This procedure uses the measured power input to the tank necessary to maintain a particular air/water temperature difference to calculate the standing loss.

i) Measure the ambient air temperature (see MT R.2).

ii) Measure the surface temperature of the tank (underneath the insulation) at a position corresponding to halfway down the heating element/coil (see MT P.5).

iii) Connect the sensor to a controller capable of maintaining a constant difference (e.g. 50 +- 1 ^{o}C) between the storage temperature and the ambient air.

iv) Provision should be made to measure the power input to the storage tank; a kWh meter should be sufficient.

v) Allow the tank to come up to the design storage temperature (e.g. 60 ^{o}C).

vi) Monitor the energy consumed in maintaining a fixed air/water temperature difference.

vii) After a 24 hour stabilisation period, note the energy consumed, Q, for a certain time, t. Standing loss = Q/t.

cost:	**ease of use:**
$100	Qualified technical staff required.

accuracy:	**references:**
5% using kWh meters.	

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recommended applications:

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alternative procedures:

AT P.1. See also CIBS Guide B4-7, 1986.

---

additional information:

At least 2 days should be allowed to carry out this procedure.

---

audit procedure:	**application area:**	**referenced from:**
S.4	SOLAR SHW-SYSTEMS FOR APARTMENT BUILDINGS	ECO S.22

title:	**references to:**
PERFORMANCE CHECK OF A SOLAR SHW SYSTEM	

description:

<u>Collect the following data</u>:
i) Total solar irradiation in the plane of the solar collectors,
ii) Total auxiliary energy used,
iii) Average SHW consumption.

The minimum duration should be one fortnight collecting values daily. The measurement period could be shorter or longer depending on whether or not different climatic conditions occur.

Having determined the SHW load, this must be compared with the existing SHW storage capacity: if the storage volume is larger than the SHW daily consumption, the procedure described below should make use of data averaged over periods longer than one day.

Make a plot of the daily auxiliary energy, Q_{aux}, as a function of the daily solar radiation in the plane of the collectors, Q_{sol}.

It is assumed that the SHW load (Q_{load}) is constant over the measurement period.

$$(Q_{aux})_{max} = Q_{load} + L_s$$

$$Q_s = Q_{load} \bullet L_s - Q_{aux}$$

L_s = the losses from SHW system-distribution
Q_{sol} = solar contribution to the SHW system

Two types of efficiency are commonly defined:

System efficiency $\eta_s = Q_{load}/(Q_{aux})_{max}$

Solar efficiency $\eta_{sol} = Q_s/Q_{sol}$

Both these efficiencies can be compared to reference local values or to theoretical values, RV.S.5

cost: Instrumentation: $5000. Time: 8 hrs technician for installation and recovery of instruments, 2 hrs engineer for data evaluation	ease of use: Rather easy.
accuracy: Increases with time.	**references:** Roulet, 1987.

recommended applications:

Test should be done only on those systems which do not show any visible defects i.e. as check of correct functioning after installation or during guarantee period.

alternative procedures:

additional information:

No ECOs can be recommended solely on the results of this performance check. If performance unsatisfactory, further audit steps will be needed, e.g. check insulation of collector, check insulation of HW pipes, etc.

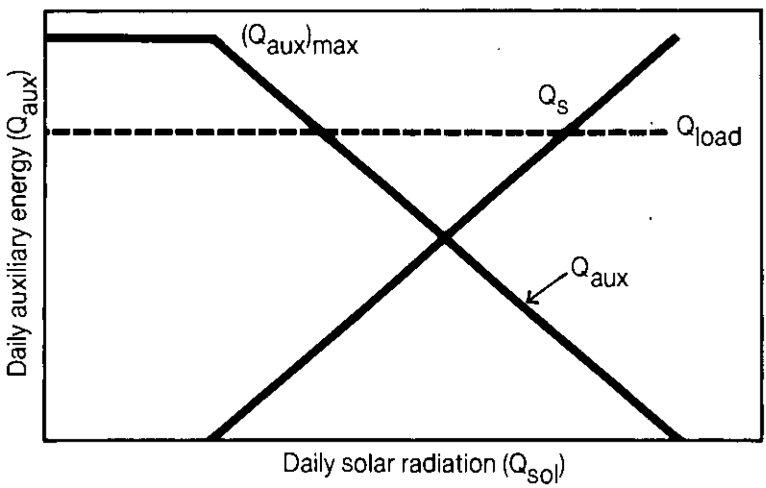

Fig. 1 Daily auxiliary energy (Q_{aux}) and solar contribution to SHW system (Q_s) versus daily solar radiation (Q_{sol}).

audit procedure:	application area:	referenced from:
S.5	SHW SYSTEMS	ECO S.4, S.8.

title:	references to:
USE OF HEAT PUMPS	AP H.6, H/C.1, MT P.2 through P.6.

description:

The viability of investing in a heat pump (HP) for SHW production is dependent on a number of factors:

i) Pattern and volume of SHW usage. Heat pumps perform best under continuous operation, therefore, buildings with flat demand profiles are most suitable.

ii) Price of competing fuels. The economics of heat pumps are strongly influenced by the price of the fuel against which the heat pump is competing, e.g. on/off peak electricity vs. gas/oil.

iii) Simultaneous requirement for space heating/cooling/chilling and SHW. The case for a heat pump is improved if the evaporator can be utilised for space cooling. This possibility will be dependent on climatic pattern and building type. If combined with heating, a hot gas cooler will keep condensing temperatures low and provide high temperature hot water at low cost.

iv) Coefficient of performance COP = (energy delivered)/(total energy input). Typical COP values are 1.5-3.0. Performance is dependent on source temperature and return water temperature (AP H.6).

v) The need for an auxiliary heater to meet peaks.

vi) Storage capacity. The use of a heat pump may require additional storage to optimise heat pump operation i.e. size storage such that heat pump can operate all night on off-peak electricity heating a volume of water sufficient to meet daytime demand. Oversized large tanks increase heat losses.

vii) Heat losses. A large part of the energy supplied to domestic hot water tanks is needed to cover heat losses. Reducing losses will directly improve the COP of heat pump systems. Problems frequently occur in double wall tanks used for combined heating and SHW production because of insufficient heat transfer between outer tank and the hot water storage. This leads to excessive condensing temperatures.

The procedure can be carried out in five steps:

1. Monitor SHW usage to determine load and demand profile.

2. Assess heating or cooling load if suitable (building fabric, heat loss coefficient, air infiltration, internal heat gains etc.).

3. Size heat pump and auxiliary heater, if necessary. Take account of annual average air temperatures, required SHW storage temperatures.

4. Check existing storage capacity. Optimise for maximum heat pump operation. Check insulation of hot water storage tanks. If hot water is heated indirectly in a double wall vessel, carefully consider the volume of the outer space. Consider positioning of temperature sensors for starting and stopping the heat pump and any supplementary heat source.

5. Determine costs of heat pump and additional storage if required, calculate prospective benefits; these will be a function of COP, current SHW production costs, costs of energy. Assess viability using simple payback period or other investment criterion.

Proper system operating conditions are determined by measuring water temperatures (MT P.5, P.6) and flowrates (MT P.2, P.3, P.4), number of starts and running time (MT EL.7). Heat pump performance is determined by means of AP H/C.1 and system performance can be evaluated by comparing annual energy requirement (AP S.1) with storage losses (AT P.1 and AP S.3).

cost:	**ease of use:**
accuracy:	**references:** Grigg, 1984, Ure, 1982, Bergström, 1985

recommended applications:

alternative procedures:

additional information:

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audit procedure:	application area:	referenced from:
L.1	LIGHTING	ECO L.9, L.14

title:	references to: RV L.2
OVERALL LIGHTING EFFICIENCY	

---

description:
Assessment of energy efficiency of the lighting system and to evaluate the influence of individual factors (e.g.: lamp luminous efficacy, luminaire efficacy, room shape and size, wall reflectance, etc.) on the effectiveness of light emission and distribution to the working plane the following procedure is used.

Basic Relationships:

i) $\Phi_{useful} = \eta * P$,

where: Φ_{useful} = useful light flux [lm],
P = electric power input [W],
η = installation efficacy [lumen/watt].

ii) $\Phi_{useful} = A_w * E_w$,

where: A_w = workplane area [m^2],
E_w = average workplane illuminance [lux].

iii) $\eta = \eta_{lamp} * \eta_{lum} * LLF * RCU = \eta_{lamp} * LLF * CU$

where: η_{lamp} = lamp efficacy [lumen/watt],
η_{lum} = luminaire efficiency (ratio of emitted flux to flux produced by lamp), also referred to as Light Output Ratio
LLF = light loss factor (reduction factor to take into account aging),
RCU = Room Coefficient of Utilization (ratio of useful flux to luminaire emitted flux).
CU = Coefficient of utilisation (ratio of useful flux to lamp emitted flux)

The data collection is as follows:

1. Determine E_w by measuring the illuminance at selected points on the workplane. For eq. (ii) to be correct area weighted average illuminance must be calculated.
2. Measure the electric power input P or estimate by adding the wattage of individual luminaires.

The data evaluation consists of:

1. Calculate η from (i) and (ii).
2. Knowing η, eq. (iii) can be used to obtain value of RCU for installation. Estimate η_{lamp} and η_{lum} from manufacturers data (see also RV L.1 and L.2), estimate LLF from RV L.2.

---

cost:	**ease of use:**
One illuminance meter Possibly, one Watt-meter needed.	Some extra calculation required for needed. disaggregation of single efficiency components.
Accuracy: If result based on correct and relevant measurements only, high. otherwise, depends on accuracy of estimation.	**references:**

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recommended applications:

When renovation of lighting system necessary, in order to establish intervention priorities.

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alternative procedures:

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additional information:

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audit procedure: L.2	application area: LIGHTING	referenced from: ECO L.17

title: LIGHTING ENERGY MONITORING	references to:

description:

To measure lighting energy consumption in any given space the following procedure is used:

i) Determine how many Lighting Energy Monitors and associated brackets are required. One is required for each switching circuit.
ii) Mount brackets on a vertical surface close to a selected luminaire in each switching circuit.
iii) Try to avoid mounting in direct sunshine or near security lamps or any light source not in that circuit.
iv) Mount accumulator on bracket and rotate the sensor so that it points towards the wall and back plate of bracket.
v) Switch on luminaires and check that accumulator is counting by observing the peridic flashing of the test monitor.
vi) To read out accumulated hours, unscrew accumulator from bracket plug in reader.

Extra care with the alignment of the sensor is required when:
(a) discrimination between adjacent luminaires on different switch circuits is necessary,
(b) lamps in different fixtures or within a single fixture are on different phases of the A-C supply.

In order to monitor a single luminaire or lamp in the presence of others close by, it is necessary in some instances to rotate the accumulator on its mount until it responds only to the luminaire or lamp of interest. If this procedure fails, then a black or low reflectance material can be adhered to the reflecting surface of the monitoring bracket to reduce the signal to the photosensor. This usually is sufficient to achieve the discrimination desired.

For each lighting switched circuit the power consumption can be calculated by multiplying the reading on the lighting accumulator by the installed load which can be obtained by counting the number and wattage of each fixture. Depending on the frequency at which accumulator readings are taken, coarse lighting profiles can be developed: e.g., work days, evening use, weekend and holiday use from which predictions of annual electrical energy consumption can be made.

cost:	**ease of use:** Simple.
accuracy:	**references:**

recommended applications:
- use to justify or confirm lighting switching options.
- use to confirm verbal descriptions of lighting switching patterns.

alternative procedures:
- kWh meters - generally more expensive, usually required to be installed on all sub-circuits because of mixed use (lighting and power) panel boards,
- time lapse photography - expensive, slow information retrieval),
- estimates - inexpensive but most often inaccurate.

additional information:
Principle of Operation:
Lighting Energy Monitor. A photo transistor whose current varies directly with the amount of light falling on it is used as an optical sensor. The detected signal is amplified, shaped and fed to a pre-scaler circuit which divides the high frequency signal to pulses. A low frequency signal is also derived from the pre-scaler circuit and is used to flash a light emitting diode on and off providing a clear indication of correct operation. The pulses are accumulated in a counter circuit. The stored information can be read out by a hand-held reader without upsetting the contents of the monitor.

audit procedure: L.3	**application area:** LIGHTING	**referenced from:** ECO L.10, L.5, L.16

title: ESTIMATION OF DAYLIGHT POTENTIAL USING AN ILLUMINANCE METER	**references to:** AP L.2, MTL.1

description:

The data collection consists of:

i) Choose a day with a relatively unchanging sky illuminance on which to carry out measurements. Choose type of sky "overcast" or "clear" depending on the preponderance of this type of sky in your area.

ii) Measure the outdoor and indoor illuminance simultaneously, as daylight levels vary very quickly. If this is not possible, measure the outside illuminance immediately prior to starting indoor measurements and at frequent intervals throughout the internal measuring procedure described in 3. below. If the measurement of outside illuminance shows significant variations, increase the frequency of outdoor measurement, repeat before and after each room measurement if significant variation noted. Outdoor measurements should be made for an unobstructed sky and no direct sunlight.

iii) For those areas thought to have some daylight potential, measure illuminance with the electric lights OFF at all those areas where critical visual tasks are performed, e.g., in an office, this would be a desk top, filing cabinet. Measurement locations should also be made cognizant of any potential lighting switching possibilities.

iv) If the room is provided with shades or drapes, repeat the indoor illuminance measurements with these devices closed and adjusted as they might be to minimise glare from the sky or to minimise unwanted solar gains.

v) Guidelines and precautions for carrying out illuminance measurements are given in MT L.1.

The data evaluation consists of

1. The daylight factor can be calculated using the formula:

$$\text{Daylight Factor} = \frac{(\text{Inside Horizontal Illuminance})}{(\text{Outside Horizontal Illuminance})}$$

Strictly speaking the measurement should be made at the same instant;hence the need to choose days with above mentioned sky conditions (no direct sunlight).

2. Construct average daily curves of inside daylight illuminance levels for a representative six months of the year (assuming approximately symmetrical throughout the year about June) from national or locally recorded outside illuminance levels (without direct sunlight) and site measured daylight factors - see Figure under "Additional Information".

3. Superimpose required illuminance level and lighting requirement profile on diagram (based on estimated or observed use of building or from lighting use survey, see AP L.2.

4. Make allowances for increases in heating energy and reductions in cooling energy brought about by a reduced lighting load. As a first approximation, assume that all the lighting reductions during the heating season must be made up from the heating plant - remember to add a boiler efficiency if fuel-fired plant and that savings during the cooling season divided by a refrigeration plant C.O.P. can be subtracted from the A/C load.

5. Where blinds or drapes are provided, some allowance for use of blinds should be made based on measured daylight factors and estimates of use.

cost: Equipment - $100+ for illuminance meter Data Collection - 10 to 15 minutes per workplace	**ease of use:** Data Collection simple, calculations more involved.
accuracy: Measurement accuracy 15%.	**references:**

recommended applications:
- where daylight potential has been positively identified.

alternative procedures:
i) More accurate and expensive but time-saving -use daylight factor meter.
ii) Calculate daylight factor.
iii) Other calculation techniques are given in the references, alternatives, for more accuracy detailed hourly analysis methods such as DOE 2 could be used.

additional information:

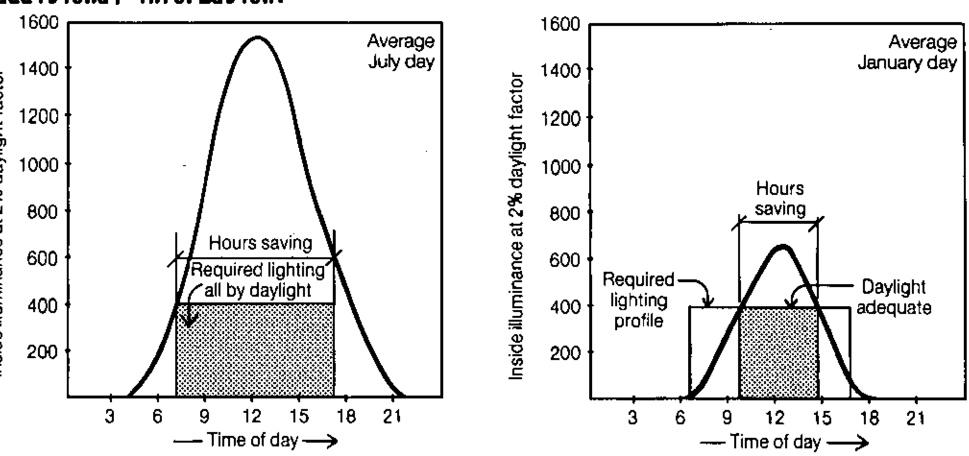

FIG. 1 Examples of daylight potential.

audit procedure:	application area:	referenced from:
EL.1	ELECTRICAL	ECO EL.5, AP EL.2

title:	references to:
EVALUATION OF POWER FACTOR CORRECTION FOR CHARGES BASED ON MEASURED POWER FACTOR	AP EL.2 and EL.3, MT EL.5, AT EL.5, RV EL.6.

description:

Determine the present overall system power factor (PF) using one of the methods described on MT EL.5. The data evaluation is as follows:

i) If the (PF) is lower than that at which correction charges apply, proceed to step 2; otherwise discount the ECO as inappropriate.

ii) Calculate the total reactive power required using AT EL.2 to bring the installation up to the point at which PF charges would no longer apply.

iii) Make a list of all the equipment for which PF correction might be appropriate noting its power, voltage and period of operation. For this and subsequent stages the format shown in Table 1 might be adopted.

iv) For each equipment identify the maximum permissible capacitor reactive power that could be connected to the equipment (column 5), consult local wiring codes and motor manufacturer - sample data are given on RV EL.6.

v) In column 6 note the approximate cost of providing individual power factor correction capacitors for each piece of equipment down to the frame power size below which central group power factor correction generally becomes more economical (typically 10 kW, or 10 hp, consult local power factor correction equipment manufacturers for better guidance).

vi) Organise the individual PF capacitors in ascending order per unit (kvar) cost - use column 7. Normally reactive power per unit cost <u>decrease</u> with increasing unit size and voltage.

vii) In the order defined by Step 7, calculate the <u>cumulative</u> effect on the <u>system power</u> factor of progressively adding individual PF correction capacitors - use column 8. Stop at the point when the power factor is no longer below that one for which power factor penalties are incurred - to continue past this point would <u>not</u> result in further savings. It will be necessary to refer to the tariff agreement to determine the point beyond which PF correction is not required.
If this point has not been reached by the time all individual power factor equipment has been considered, it will be necessarry to consider group power factor correction equipment to make up the deficit.

viii) The method described above will not necessarily provide an acceptable payback and the usual form of cost benefit analysis must then be carried out based on projected power factor cost savings and the capital cost of the equipment. Actual power factor savings will need to be worked out on the basis of the tariff agreement in place.

ix) For simplicity, the steps described above do not address in detail the necessity to consider individual equipment operation and their effect on the variation of system power factor with time. Additional consideration is needed where motor operation is intermittent in nature.

cost: Low cost of labour, see MT EL.5 for equipment cost. Calculation can be time consuming.	**ease of use:** Overall PF measurement fairly simple with digital power factor rate and clamp on current probes. Analysis can become complex if motor usage is intermittent.
accuracy: See MT EL.5 for instrument accuracy.	**references:** Freeborn, 1980, Bell and Hester, 1980.

recommended applications:

1. Installations where power factor penalty charges are being incurred because of low power factor and power factor improvement are being pursued through the use of capacitors.
2. Power factor improvements are possible through the correct matching of motor size and driven load or using high efficiency motors. See AP EL.3. For an optimal solution both procedures should be considered together. The lowest cost of individual equipment power factor correction be it through a replacement motor or the installation of a capacitor, should be used in the procedure described here.

alternative procedures:
See AP EL.2 where charges based on kVA demand.

additional information:

TABLE 1. Power factor correction evaluation form.

1 EQUIP REF	2 FRAME POWER	3 VOLTS	4 EQUIPMENT OPERATION	5 MAX ALLOWABLE CAPACITOR REACTIVE POWER	6 APPROX COST OF PF CAPACITOR	7 ORDER OF ASCENDING PER UNIT COST	8 CUMULATIVE EFFECT ON SYSTEM PF

See also Section C. 10.

audit procedure:	application area:	referenced from:
EL.2	ELECTRICAL	ECO EL.5, AP EL.1

title: EVALUTATION OF POWER FACTOR CORRECTION WHEN REACTIVE POWER IS CHARGED THROUGH kVA DEMAND	references to: AP EL.1, EL.3, MT EL.4, EL.5, AT EL.4, RV EL.6.

description:

Check coincidence between possible poor power factor and peak demand to ensure that power factor correction could in fact lower the recorded demand. This can be done by:

i) monitoring demand and power factor simultaneously (see MT EL.4 and EL.5), or
ii) measuring the power factor of individual motors known to be operating at the time at which the peak load is known or assumed to occur. (See MT EL.5.)

The data evaluation is as follows:

1. Make a list of all the equipment that runs at the time of peak demand and for which power factor correction might be appropriate noting its power and voltage. For this and subsequent stages the format shown in Table 1 might be adopted.
2. For each equipment identify the maximum permissible capacitor kvar that could be connected to the equipment (column 4) consult local wiring codes and/or motor manufacturer - sample data are given on RV EL.6.
3. In column 5 note the cost of providing individual power factor correction capacitors for each piece of equipment down to the frame power size below which central group power factor correction generally becomes more economical (typically around 10kW (10 hp), consult local power factor correction equipment manufacturers for better guidance).
4. Calculate for each motor in turn in the order of descending motor size:
   a) the kVA savings for each piece of equipment using AT EL.2 (column 6),
   b) the annual cost saving based on the kVA saving times the kVA demand charge (column 7), and
   c) the payback (column 7) or other economic criteria.

   Where there are motors of differing voltages it will be necessary to check at which point capacitors for smaller motors at higher voltages become cheaper per unit of kvar than larger motors at lower voltages.

   Stop the calculations at the point at which the payback does not meet the desired economic benefit.
5. If power factor correction for all the larger size motors calculated above meet the desired economic benefit, continue the analysis for incremental amounts of group power factor correction equipment until the point at which adding additional equipment is judged to be no longer cost effective.

cost: Analysis of demand and power factor variation can be costly due to equipment cost and data analysis	**ease of use:** Overall power factor and demand recording is fairly simple with digital recorders and clamp on current probes. Analysis can become complex if motor usage is intermittant or unpredictable.
accuracy: See MT EL.5 for instrument accuracy.	**references:** Freeborn, 1980, Bell and Hester, 1980.

recommended applications:

1. Installations where charges are made for kVA demand and reduction in reactive power component is being considered through the use of capacitors.
2. Power factor improvements are possible through the correct matching of motor size and driven load or using high efficiency motors. See AP EL.3. For an optimal solution both procedures should be considered together. The lowest cost of individual equipment power factor correction be it through a replacement motor or the installation of a capacitor, be used in the procedure described here.

alternative procedures:

See AP EL.1 where charges are made on the basis of measured power factor.

additional information:

TABLE 1. Kvar correction evaluation form.

1	2	3	4	5	6	7	8
EQUIP REF	FRAME POWER	VOLTS	MAX ALLOWABLE CAPACITOR REACTIVE POWER	COST OF POWER FACTOR CAPACITOR	kVA SAVING	$ SAVING	PAYBACK (OR OTHER ECONOMIC CRITERIA)

audit procedure:	application area:	referenced from:
EL.3	ELECTRICAL	ECO EL.7, EL.9, EL.10, AP EL.1, EL.2, AT EL.3.

title:	references to: ECO EL.7, EL.9
EVALUATION OF MOTOR EFFICIENCY IMPROVEMENT	MT EL.5, AT EL.1, EL.3, D.1, RV EL.2, EL.3, EL.4

description:

Data Collection:
Determine the existing motor operating point (percent of full load) by:
i) Measuring the power factor PF (MT EL.5) and using the relationship between power factor and percent full load. Use manufacturer's data for the motor in question or use the generic data provided on RV EL.3, or
ii) for fan and pump motors, determine the operating point of the fan and pump (see App. C.5) and hence from the fan/pump manufacturer's data determining the load on the motor.

Data Evaluation:
1. Determine the real and reactive power (or power factor) draw at this operating point again using manufacturer's data (preferred) or data provided on RV EL.4.
2. Determine the real and reactive power improvements possible for:
   a) ECO EL.7 Power Factor Controller: Use manufacturer's data for motor characteristic changes for PF controller selected.
   b) ECO EL.9 High Efficiency Motor: Use manufacturer's data for high efficiency motor or use data on RV EL.2.
   c) ECO EL.10 Correct Matching of Driven Load and Motor: Use manufacturer's data for new motor size or use data on RV EL.3.
3. Calculate "direct effect" savings; i.e. savings directly related to the question of the motor being retrofitted. See AT EL.1.
4. Calculate indirect effect of the ECO on heating and cooling loads:
   a) If the motor is not directly in a conditioned space or conditioned air stream; e.g. exhaust fan motors, pump motors in plant rooms, there will be no "indirect effect".
   b) If the motor is in a heated space and might usefully contribute to the heating of that space; e.g. a supply air fan in which the motor is in the airstream or equipment actually in the space, then there will be a proportionate increase in the energy required for heating.
   c) If the motor is in a cooled space or airstream, there will be proportionate reduction in the energy required for cooling.

Some guidance on how these indirect effects might be accounted for using hand calculations are given in AT EL.1. Alternatively, hourly computer analysis models might be considered which can normally handle interactions, especially where HVAC systems are concerned, more effectively.

cost: Refer to measurement techniques for Data Collection costs.	**ease of use:** Measurements fairly easy. Calculations can be detailed if indirect effects need to be considered.
accuracy: Refer to measurement techniques for Data Collection accuracy. Power factor methods are probably more reliable. Direct energy effect can be reliably calculated; indirect will be approximate.	**references:**

recommended applications:

alternative procedures:

additional information:

audit procedure:	application area:	referenced from:
EL.4	ELECTRICAL	ECO EL.4

title:	references to: MT EL.4 and M.1
EVALUATION OF THE POTENTIAL FOR LOAD SHEDDING CONTROLS	

description:

Some preliminary activities are:

i) Obtain copies of utility bills showing historical record of demand. Check for demand figures that are estimates, not actual meter readings. Determine annual cost of demand charges.
ii) Based on amount of annual demand charges and possible projected savings through demand control (say a minimum of 5 to 10%) make a decision on the need for further evaluation.

The data collection is carried out as follows:

1. Determine the pattern of load demand through a combination of the following activities and available data.
   a) Utility demand billing records.
   b) Existing demand records taken by building operations staff.
   c) Monitoring building demand over a number of days (see MT EL.4 and M.1). Some thought should be given to the selection of the demand monitoring periods to obtain the most useful results. The following guidance is given:
      - Where there is little or no seasonal variations in demand or where the same equipment runs throughout the year - time of demand monitoring is not critical.
      - Where there is little or no seasonal variation in demand but different equipment runs in different times of the year (e.g. electric heating replacing electrically driven cooling equipment) - ideally, demand monitoring should be made over different periods of the year
      - Where there are large seasonal variations - monitoring is desirable as in b. above except where demand charges are based on the maximum demand in the year (as opposed to individual monthly charges). In this case it is obviously desirable to do the demand monitoring during the period of peak demand.
   d) Reviewing operating schedules of equipment obtained by site inspection, review of specifications, control setpoints, discussions with building operators, etc.

2. Make a list of the major electrical equipment in the facility that could be shut off for short periods if necessary (only motors greater than approximately 1 kW or 1 hp, or less if they create secondary electrical energy demands, e.g. exhaust fans in electrically heated buildings.

electric heating equipment greater than 1 kW, decorative lighting that could be turned off, etc.).
For each piece of equipment note:
a) load (kW or kVA, whichever is used for demand billing purposes),
b) how long it could be turned off without unacceptable adverse effects,
c) possible adverse effects on a) environment and b) equipment itself,
d) maximum recommended number of STOP/STARTS per hour (Berutti, 1984),
e) whether load when switched off results in kWh savings in addition to possible demand saving (e.g. ventilation fans), or whether load is merely deferred until switched back on again (e.g. electric water heaters).

3. Based on the information collected in 2. above, make preliminary listing of equipment which could be acceptably shut off. Taking the largest piece of equipment first, and progressively taking smaller equipment, calculate the effect of shut off on the annual demand cost (either kW or kVA according to the billing method), and where appropriate kWh saving.

4. Taking the equipment with the largest annual demand cost saving, and progressively taking smaller equipment, estimate the cost of providing a demand control system. Note:
   a) For a small number of individual controlled loads a simple system might be most cost effective, such as a simple time clock or instantaneous load recording system. For a larger number of loads more sophisticated load forecasting type systems would be appropriate. In an installation with a large number of loads two or more scenarios, with different levels of sophistication, might be tried.
   b) The largest savings might not necessarily be in the order of largest equipment, since some equipment may not operate all year - some equipment might have kWh reductions in addition to demand reductions.
   c) Where an energy management system (EMS) is being considered one should either take the incremental capital cost of providing the demand control function or somehow apportion the total cost between demand limiting and other EMS cost saving opportunities.

5. For each of the above steps (incremental reductions in demand) calculate the payback (or other economic criteria) until the economic benefit does not meet with that desired. It is useful to plot the results on a graph (as per Fig. 1) to determine the optimum investment; i.e. best return on capital. (The demand controller cost per piece of equipment controlled will decrease with increasing number of pieces of equipment, however, the incremental energy/demand saving will also decrease.)

cost: Can be relatively high cost depending on extent of demand monitoring and complexity of installation.	**ease of use:** Demand monitoring fairly easy but calculations require experienced personnel for best results
accuracy: Accurate enough for investment decision - actual operation of demand control system may need to be fine tuned to actual building operation.	**references:** Neca, 1975, Spethmann, 1981 and Berutti, 1984.

recommended applications:
Wherever there is potential for demand related savings.

alternative procedures:

additional information:

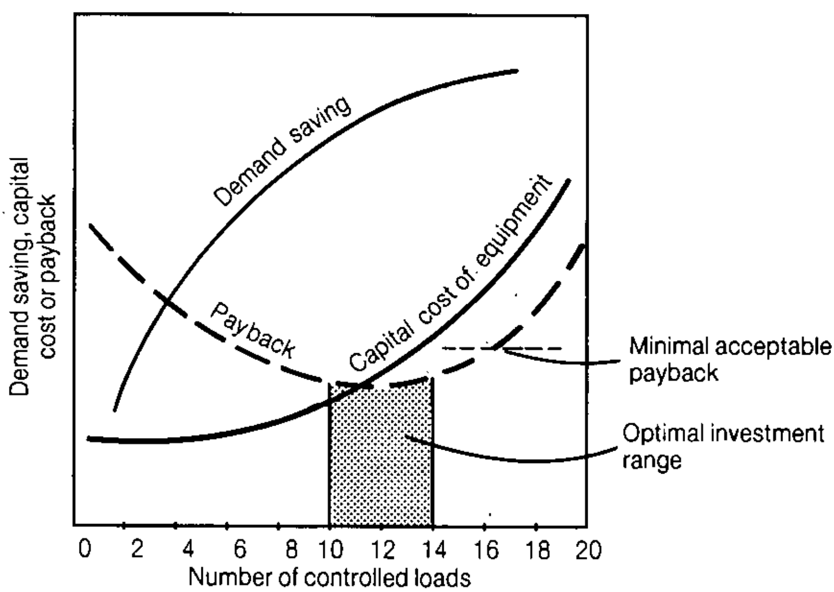

Fig. 1 Determination of the optimal investment point.

APPENDIX G MEASUREMENT TECHNIQUES

INTRODUCTION TO APP. G

This appendix gives an overview of Measurement Techniques (MT) applicable for the evaluation of Energy Conservation Opportunities.

The measurement techniques are arranged according to the building component category system (see Introduction, p. 10) used in this Source book.
The description of the format used for presenting measurement techniques is identical to the one described for Audit Procedures (App. F).

The purpose of carrying out a measurement is to know if building functions are according to design and to identify and quantify abnormalities in building functions.

Measurements may serve more than one purpose and may be classified according to the objective of the measurement or the objects measured, for example:
Objectives:

- Building rating
- Preliminary audit
- Disaggregation audit
- ECO identification
- Post Implementation Performance Analysis

Objects:

- Environment
- Envelope
- HVAC installations or energy systems
- Comfort level of the users.

The first question to be answered is what information is to be provided by the measurement, with what accuracy, details or circumstances.

One should clearly define or identify:

i) the method to measure; ii) the kind of instruments; iii) the choice of the place to measure; iv) the duration of measurement; v) the way to carry out the measurement and vi) the cost of measurements.

Without this one risks getting useless measurements and worthless results.

It is important that measurements are made by a qualified person. The best instrument may provide irrelevant results when badly used or even out of order. A competent technician knows how to manage the instrument and how to make an interpretation of the results avoiding common mistakes.

It is important that when both partners of a contract are carrying out measurements, they do it with the same instruments and at the same place.

A list of all Measurement Techniques is given below.

LIST OF MEASUREMENT TECHNIQUES (MT)

TITLE

ENVELOPE (E)

E.1 Measurement of outdoor air temperature.
E.2 Surface temperature measurements on buildings.
E.3 Measurement of wind speed and direction.
E.4 Measurement of the integrated solar radiation.
E.5 Measurement of humidity.

REGULATION (R)

R.1 Measurement of building time constants.
R.2 Measurement of indoor air temperature.
R.3 Measurement of thermal comfort.
R.4 Measurement of indoor air velocity.
R.5 Measurement of humidity.

HEATING (H)

H.1 Measurement of the running time of the boiler.
H.2 Measurement of flue gas temperature.

DUCTWORK (D)

D.1 Choice of cross-sectional measurement point in an air duct.
D.2 Using Prandtl-tube (Pitot-tube) for measurement of air velocity in ducts.
D.3 Air flow measurement in ducts using hot-wire anemometer.
D.4 Air flow measurement in ducts using rotating vane anemometer.
D.5 Air flow measurement using trace gas techniques.
D.6 Measurement of pressure drops in air ducts.
D.7 Measurement of temperature and humidity in air ducts.
D.8 Air flow measurement on exhaust terminal with anemometer-hood.
D.9 Air flow measurement on supply terminal with bag.
D.10 Air flow measurement on supply terminal with anemometer-hood.
D.11 Air flow measurement on supply terminal by a zero pressure method (flow finder).

PIPEWORK (P)

P.1 Measurement of static pressure in pipes.
P.2 Flow rate in pipes (orifice plate).
P.3 Flow rate in pipes (flow meters).
P.4 Flow rate in pipes (portable ultrasonic flow meter).
P.5 Measurement of pipe surface temperature.
P.6 Fluid temperature in pipes.

LIGHTING (L)

L.1 Measurement of illuminance with lux-meter.

ELECTRICAL SYSTEMS (EL)

EL.1 Electrical measuring instruments.
EL.2 Measurement of current.
EL.3 Measurement of electrical potential.
EL.4 Measurement of electric power (demand).
EL.5 Measurement of power factor.
EL.6 Measurement of electrical energy consumption.
EL.7 Monitoring electric equipment usage.

MISCELLANEOUS (M)

M.1 Photographic data logger.

measurement technique: E.1	**application area:** ENVELOPE AND REGULATION	**referenced from:** AT E.1.
title: MEASUREMENT OF OUTDOOR AIR TEMPERATURE		**references to:**

description:

In measurements of outdoor air temperature a correct siting of temperature instruments is very important due to large temperature gradients occurring close to surfaces exposed to radiation. These gradients are influenced by the amount of solar radiation, by re-emitted infrared radiation in the night-time, by the radiative properties of the surrounding surfaces, and by local air movements. WMO (1971) recommends that the instrument is placed 1.25 m above a surface covered by grass with free exposure to the wind.

This is seldom possible in densely built areas, and there is also the danger of interference by people. It is, therefore, common to place the sensor on a building facade or on the roof. The sensor should then be shielded from direct solar radiation and from the influence of the building surface temperature. This can be achieved by placing the sensor on a building facade facing north, at a distance of about 0.5 m from the wall. The disadvantage of placing the sensor at the building site is that comparisons with meteorological station data becomes difficult. The local temperature is in general not the same.

The use of a ventilated sensor is recommended if great accuracy is desired. A sensor of this type requires frequent maintenance if used for a long period, due to the collection of dust and dirt and interference by birds.

Calibration of thermometers should always be performed before the instrument is used for the first time and then at regular intervals. The instruments should be calibrated against some more accurate (secondary standard) calibrated temperature sensor.

For almost all purposes hourly sampling of outdoor air temperature should be sufficient, since air temperature does not normally vary more rapidly than this. For more accurate measurements the sampling could be done every 5 minutes and an average value be recorded hourly. In other cases even daily or weekly averages could be used, but sampling should always be performed at least every third hour. The properties of some temperature sensors are summarised in Table 1.

cost: Cost for sensor.	**ease of use:**
accuracy:	**references:** Fracastoro-Lyberg, 1983.

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recommended applications:

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alternative techniques:

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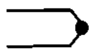
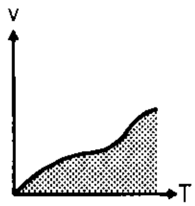
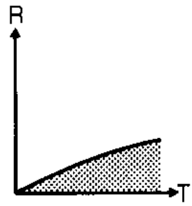
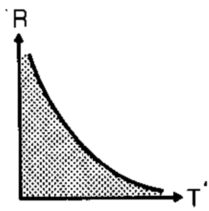
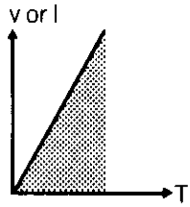
additional information:

TABLE 1 Properties of temperature sensors.

				
	THERMOCOUPLE	RTD	THERMISTOR	I.C. SENSOR
				
ADVANTAGES	• Self-powered • Simple • Rugged • Inexpensive • Wide variety of physical forms • Wide temperature range • Fast	• Most stable • Most accurate • More linear than thermocouple	• High output • Fast • Two-wire dims measurement • Large resistance change at low temperatures • Inexpensive • Accurate	• Most linear • Highest output • Inexpensive
DISADVANTAGES	• Non linear • Low output • Reference junction required • Least stable • Amplification required	• Expensive • Slow • Current source required • Small resistance change • Low absolute resistance • Self-heating	• Non linear • Limited temperature range • Fragile • Current source required • Self-heating	• T < 200°C • Power supply required • Slow • Self-heating • Limited configurations • Poor stability

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measurement technique:	application area:	referenced from:
E.2	ENVELOPE AND REGULATION	ECO E.10, E.13, E.14, E.17, E.23.

title:	references to:
SURFACE TEMPERATURE MEASUREMENTS ON BUILDINGS	

description:

When measuring surface temperatures there should be good contact between the sensor and the surface.

Instruments having a direct read-out (analog or digital) may be used for more qualitative measurements (surveys). Then, a measuring time of some minutes is required.

For a quantitative analysis of surface temperatures a recording instrument is needed. Then, measuring times of several days are required.

If only one, or a few, sensors are used and one wants to get a representative temperature of an indoor surface, the sensor must be positioned carefully to avoid positions with temperatures deviating strongly from the average one (for example, see Fig. 1).

The sensor should not be placed close to

i) Radiators or other heat sources in indoor measurements,
ii) Windows, exterior walls or thermal bridges,
iii) Close to interior partitions, floor or ceiling in indoor measurements,
iv) Close to air inlets or outlets or places with draught.

The sensor should be shielded from contact with the air by placing a cover of insulating material over it. The sensor should not be facing radiation sources like the sun, radiators or windows. Preferably the sensor cover should be painted in the same color as the surface.

cost:	ease of use:
Cost for instrument.	Difficult.

accuracy:	references:
At position of sensor 0.5 K. As average value of surface 1 K.	Fracastoro-Lyberg, 1983.

recommended applications:

Evaluation of condensation risk.
Quantitative evaluation of thermal bridges.
Evaluation of comfort problems.
Evaluation of thermal performance of walls.

alternative techniques:

Infrared sensor and cameras.

additional information:

In general surface temperature measurements are part of a more detailed measuring program in which other quantities have to be measured too.
For example, the evaluation of thermal bridges requires at least an interior surface temperature, an outdoor air temperature and an indoor air temperature.

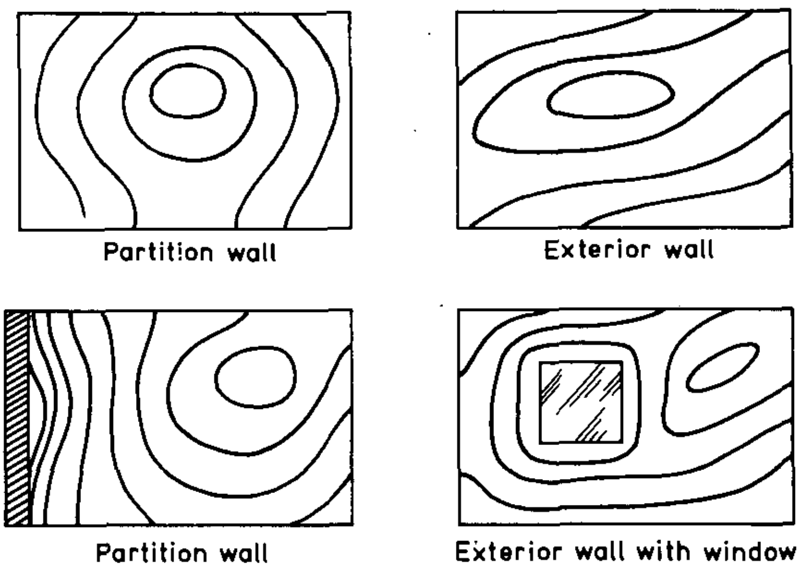

Fig. 1 Examples of isotherms (1 K) on partition walls and exterior walls in a room.

measurement technique:	**application area:**	**referenced from:**
E.3	ENVELOPE AND REGULATION	

title:	**references to:**
MEASUREMENT OF WIND SPEED AND DIRECTION	

description:

Most instruments for wind measurements normally only measure the horizontal component by measurement of the wind speed and its direction. In meteorology, wind speed is measured at a height of 10 meters above open terrain, and is reported in m/s. For wind measurements weather-proof and rigid built instruments are necessary.

The requirements for the measurement of the "meteorological" wind speed can in general not be fulfilled in built areas. It is common to measure the wind speed above the roof. An anemometer is placed on a mast on the roof. The anemometer should be positioned at an altitude at least a few meters above the highest point of the roof. Otherwise there is a risk that the anemometer may be in the leeward wake of the building at least for some wind directions and record completely false values of the wind speed.

The cup anemometer is the most common instrument for measuring wind speed. It consists of three or four hemispherical cups mounted on a vertical shaft. This transmitter can be used in the range from 0 to 60 m/s and within a temperature range from -35 to +80^{o}C, but the effective range depends on the mechanical features of the sensor.

Wind direction is defined as the direction from which the wind is blowing. The wind direction sensor is usually a wind vane or a "wind flag". The conversion of wind direction into a loggable value presents some difficulties. Sometimes an endless coiled and 3 times tapped ring potentiometer is supplied for the transmission according to the principle of the electrical axle. The indication of direction is often non-continuous.

cost:	**ease of use:**

accuracy:	**references:**
5-20% (see text).	Fracastoro-Lyberg, 1983.

---

recommended applications:

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alternative techniques:

Alternative instruments for the measurement of wind speed are:

1. The deflecting vane anemometer consists of a pivoted vane enclosed in a case. Air exerts a pressure on the vane passing through the instrument upstream to downstream. The instrument gives instantaneous readings on an indicating scale. Three vanes can be combined to measure all components of the wind velocity. Its range is from 1 to 120 m/s and its accuracy is 5%. Needs periodic check of calibration.

2. The revolving wheel anemometer consists of a light revolving wheel connected to a set of recording dials which read linear meters of air passing in a measured time. This instrument has a very low sensitivity, and is usually employed in the range 1-120 m/s. Its accuracy varies between 5 and 20%.

3. The propeller anemometer consists of a light plastic propeller mounted on an axle. The number of revolutions per unit of time is proportional to the wind velocity component parallel to the axle. Three propellers can be mounted on axles perpendicular to one another to measure all three components of the wind velocity. The advantages of this instrument are: the short response time making it possible to measure velocity and large-scale turbulence in three dimensions, e.g., close to external walls, and the relatively small error. This instrument has therefore become popular in monitoring of buildings. The disadvantages are the need for calibration and frequent maintenance. This instrument should not be used in strong winds (above 20 m/s).

---

additional information:

It is generally preferable that all meteorological data are collected on the same time basis. Nonetheless, a shorter sampling interval (ranging from a few seconds to a few minutes) should be used for rapidly varying quantities such as wind velocity and direction. For most models describing the energy balance of the building, the average values over a period ranging from a quarter of an hour to four hours should be sufficient.

---

measurement technique:	**application area:**	**referenced from:**
E.4	ENVELOPE SOLAR	ECO E.3, E.22.

title:	**references to:**
MEASUREMENT OF SOLAR INTENSITY	

description:

Measurements of solar radiation are, in general, more complicated than the measurement of other climatic variables affecting the energy balance of a building. This is due to the wave length and angle dependence of solar intensity.

It is common to restrict the measurement of solar radiation on buildings to the measurement of the radiation impinging upon building facades with a southernly orientation and to the radiation impinging upon the horizontal plane. Procedures are available by which the radiation on facades can be predicted from measurements of the radiation on a horizontal plane (Duffie-Beckman, 1980).

The instrument most commonly used for the measurement of solar radiation is the pyranometer. The accuracy of pyranometers is determined by their degree of independance on wave length and orientation relative to the sun. Devices used for measuring solar intensity are also affected by the environmental air temperature and, therefore, measured data have to be corrected for this effect.

The absorbing surface of a pyranometer is covered by a semispherical glass dome, which should be kept clean. In humid areas it may be advisable to use a fan to prevent condensation of moisture on the glass dome.

For measurements of the diffuse component of atmospheric radiation the pyranometer is shielded from the direct solar radiation by movable ring tracking the solar path. For more information on the use of pyranometers, see e.g. Coulsson, 1975.

cost: $500.	**ease of use:** Easy.

accuracy:	**references:**
2%.	Duffie, 1980; Coulsson, 1975.

recommended applications:
Use with degree day monitor to calculate equivalent net collector area of a passive solar house.

alternative techniques:
Use a solarimeter and an integrator.

additional information:

measurement technique:	**application area:**	**referenced from:**
R.1	REGULATION	AP R.2.

title:	**references to:**
MEASUREMENT OF BUILDING TIME CONSTANTS	MT R.1, MT R.2.

description:

The time constant of the heating system is neglected in this procedure. The heating system is shut off in the evening and the indoor and outdoor temperatures are recorded at least every hour until morning. Assuming a nominally constant outdoor temperature, the time constant τ is determined from:

$$T_i - T_e = const.* \exp(-t/\tau)$$

where

T_i is the indoor temperature (see MT R.2),

T_e is the outdoor temperature (see MT E.1) and

t is the time from shutting-off the heating system.

The value of τ is determined by plotting $\ln(T_i - T_e)$ versus the time t and fitting data by a straight line. The slope of the straight line gives the value of $1/\tau$.

To increase the accuracy of the procedure, data from the first few hours should not be used in the fit. Preferably the measurements should be performed after an overcast day to avoid influence from heat storage of solar radiation. If possible, one can also increase the indoor temperature by a few degrees above the normal one for a few days before the measurement. This will raise the lowest indoor temperature and reduce complaints from occupants.

cost:	**ease of use:**
accuracy:	**references:**

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recommended applications:

For evaluation of savings with setbacks and estimation of building preconditioning period.

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alternative techniques:

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additional information:

When plotting data one can expect a curve like in Fig. 1.

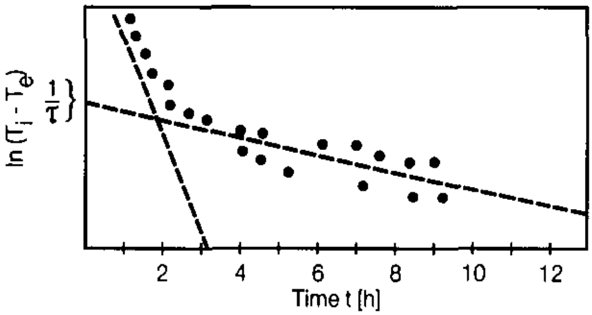

Fig. 1 Example of result from building time constant measurements.

The reason for excluding data from the first few hours is that these data will describe the time constants of the heating system and the indoor air.

Warning: This procedure should not be used for the determination of time constants used for purposes other than calculation of temperature setback effects or other effects with a duration of 6 to 12 hours.

It is assumed that the outdoor temperature is constant. One must therefore check that the change in outdoor temperature during the measurements is small compared to the change in indoor temperature.

---

measurement technique:	**application area:**	**referenced from:**
R.2	REGULATION	AP R.2, R.5, MT R.1.

title:	**references to:**
MEASUREMENT OF INDOOR AIR TEMPERATURE	MT E.1

description:
The most important factor to consider in indoor air temperature measurements is the positioning of the sensor. The error resulting from a wrong positioning will in general be much larger than any errors stemming from the accuracy of the sensor or errors from the data collection system.

To avoid influence of vertical temperature gradients the sensor should be placed at least 0.2 m from the ceiling and the floor. The sensor should not be placed in the vicinity of radiators or other heat sources or close to windows or other cold spots. The sensor should not be placed close to air inlets or outlets, below or above windows or at other positions where there is a draught. The sensor should not be facing radiators, windows, or other sources of radiation. If the sensor is placed on a wall, it should be protected from contact by placing insulating material between the sensor and the wall. If the measurement is an instantaneous one, one should note that the time variation of the indoor temperature during a day may amount to several degrees.

The use of a ventilated sensor is recommended if a high degree of accuracy is required. For a discussion on the advantages and disadvantages of various sensors that can be used in indoor air temperature measurements, see MT E.1.

When monitoring the indoor air temperature, the sampling should be frequent, e.g. every minute, but in general it will be sufficient to store hourly or daily averages.

cost:	**ease of use:**
Low cost	Simple.

accuracy:	**references:**
At measurement position 0.1-0.5 K. As an estimate of average room temperature 0.5-1.0 K.	Fracastoro-Lyberg, 1983.

recommended applications:
In investigations of thermal discomfort, in PIPA analysis to check indoor temperature before and after implementation of ECOs and in evaluations of building energy balance for conductive, radiative and ventilative heat losses.

alternative techniques:

additional information:

measurement technique:	**application area:**	**referenced from:**
R.3	REGULATION	AT R.8, RV R.1

title:	**references to:**
MEASUREMENT OF THERMAL COMFORT	

description:

Thermal comfort is a measure of how the human body experiences the thermal environment. This will vary from one individual to another. The thermal comfort will depend on clothing, activity, air temperature, temperature of surrounding surfaces, air humidity, air speed, etc. (see section C.2). No single measurement can be constructed where all these factors are combined. The simplest measure used is the operative temperature. This is a weighted average of the air temperature and the temperature of surrounding surfaces. Depending on level of description, different weights can be applied to the radiative temperature from different directions which are not the same, referred to as the radiative temperature asymmetry.

When the weight is the same for all directions, the operative temperature is usually measured by using a globe thermometer. This is a thin-walled globe with a diameter of 0.15 m, painted black. The sensor is placed inside the globe. One has to wait for thermal equilibrium. The main disadvantage is the approximation of the human body by a sphere, and the difficulty of calibration.

The globe thermometer is suspended at the test point and one has to wait for thermal equilibrium. The reading of the thermometer is interpreted as the mean operative temperature. In case of air velocities past the globe exceeding 0.5 m/s, calculation procedures can be used which correct for the air speed. In this case also the air temperature has to be measured (ISO/DIS 7726).

cost:	**ease of use:**
Low cost.	Simple, but calibration difficult.

accuracy:	**references:**
Instrument errors small compared to systematic errors.	ISO/DIS 7726, 1985; Bruel and Kjaer; Exett Sales.

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recommended applications:

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alternative techniques:

1. Instead of a globe thermometer, more elongated bodies can be used. One instrument uses as a sensor body a long ellipsoid (Bruel and Kjaer). The instrument includes a thermal comfort meter with a display showing operative temperature or predicted mean vote (PMV). The instrument can be connected to a recorder. It can be set for specific values of clothing, activity and vapor pressure when used to predict comfort temperature or PMV. In this case the sensor body is heated, which reduces the time for achieving thermal equilibrium.

2. The third instrument consists of a small white plastic cube with plane black sensors fitted into facets of the cube (Exett Sales). The sensors record the hemispherical operative temperature for each of the six sides of the cube. By calculating a weighted average of these six operative temperatures, it is possible to simulate the thermal comfort of a person standing up or seated. The operative temperature and the hemi-spherical radiative temperature asymmetry, as specified above, can be read off directly from a visual display. The instrument can be connected to a recorder.

For the two instruments described above, no correction for air flow past the sensors is available. These instruments are not recommended for use in environments with strong air flows.

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additional information:

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measurement technique: R.4	application area: REGULATION	referenced from:
title: MEASUREMENT OF INDOOR AIR VELOCITY		**references to:** AP E.10.

description:

The measurement of indoor air flow is in general difficult because the flow pattern is seldom stable and the air velocity is relatively small. The velocity fluctuations are often of the same magnitude as the speed of the air. This makes it very difficult to perform measurements with visual reading of the instrument.

Before measurements of the air velocity in a space are performed, it is important to get a picture of where the space air velocities are strongest. This can be done rather quickly using a smokepuffer or a smoke-stick. The simplest way of measuring the average air speed is by using a smoke-stick, or a smokepuffer, and a stop watch. This method can in general only be used for concentrated air streams with small diffusion (see AP E.10).

If sensors have to be used it may seem advantageous to use a non-directional anemometer (an anemometer that can measure only the speed of air stream, not the direction), since the air flow in a room is usually neither visible nor constant. The instruments that can be used in practice are, however, either completely directional (the response of the sensor depends on the direction of the air flow) or difficult to make non-directional.

Some anemometers use the rate of cooling of a heated body as the sensing head. If the heated body is spherical in shape such an anemometer would in principle be non-directional. However, in practice most instruments of this type are more or less directional. Often the heated body is of a shape other than spherical. The response to a change of air speed is often slow.

When instruments are calibrated, one must take into account the temperature, humidity, and atmospheric pressure. They require accurate calibrations at regular intervals. These calibrations should always be carried out in a miniature wind tunnel, or some other suitable device, at the relevant temperature.

cost:	ease of use:
accuracy:	**references:**

---

recommended applications:

---

alternative techniques:

The thermal comfort of an occupant exposed to "draught" will depend not only on the average speed of the air, but also on the magnitude and frequency of the fluctuations in air velocity. It is therefore in general not sufficient to measure only the average air speed. To obtain a stable average value of the air speed, it is in general necessary to extend the measurement over a time of at least several minutes and then perform the averaging over this time interval.

Some sensors that can be used are the heated thermocouple anemometer and the thermistor anemometer. The heated thermocouple anemometer has a rather slow response to rapid velocity fluctuations, and is rather insensitive for small air velocities. Therefore, this type of instrument should only be used for steady-state measurements and for air velocities greater than 5 cm/s. The heated thermocouple anemometer is a comparatively cheap instrument.

A simultaneous determination of air speed and direction can be performed if directional sensors, e.g. hot wire anemometers are used. But this will require the use of six sensors and the data must be numerically processed. Determination of the air flow in this way is therefore seldom performed in practice.

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additional information:

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measurement technique:	**application area:**	**referenced from:**
R.5	REGULATION AND ENVELOPE	MT D.7

title:	**references to:**
MEASUREMENT OF HUMIDITY	

description:

The Psychrometer, or Wet and Dry bulb thermometer, consists of two temperature sensors, one with a cotton sock wetted with distilled water. The sensor with the sock will register a temperature close to the thermodynamic wet bulb temperature. Knowing the dry bulb and wet bulb temperatures and the barometric pressure, the relative humidity can be determined.

Psychrometers cannot be used when the air temperature is below 0 ^oC. They need frequent cleaning and replacement of the cotton sock. If properly maintained, the accuracy is about 0.5 K if the relative humidity is above 20%.

Some requirements for outdoor use of the psychrometer are:

i) The wet and dry bulbs should be ventilated and protected from radiation by a minimum of two poolished metal shields,
ii) At sea-level air should be drawn across the bulbs at a rate between 2.5 and 10 m/s, and
iii) Measurements should be performed at a height between 1.25 and 2 meters above ground level.

The Lithium-Chloride cell hygrometers exploit the property of the salt lithium-chloride (LiCl) to become electrically conductive when absorbing moisture from the air. The sensor, a cell containing a lithium-chloride solution, is heated by passing an AC between the electrodes. This reduces the moisture content and increases the resistance of the solution. An equilibrium temperature which is measured by a separate sensor, is reached. This temperature can be converted into a dew-point temperature. The LiCl hygrometer is a simple and comparatively cheap instrument. The operating range can be from -29 to 70 ^oC with an accuracy of 2 K. Air velocities above 10 m/s may shift the calibration. Exposure to high humidities and a simultaneous loss of power, e.g. due to a power failure, may dissolve the salt and necessitate a refurbishment of the instrument.

cost:	**ease of use:**
	See text.

accuracy:	**references:**
See text.	ASHRAE, 1979, 1981.

---

recommended applications:

Measurement of humidity or relative humidity outdoor, indoor, or in air ducts.

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alternative techniques:

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additional information:

Many sensors measuring relative humidity (RH) have the draw-back that exposure to high relative humidities may result in a loss of calibration. Also, they are not very reliable at low temperatures.

The ion exchange resin (or Pope-type) sensor is relatively inexpensive. This type of sensor is often found in hygrometers monitoring the RH of relatively constant temperature air streams because of its fast response and durability. However, the electrical resistance between the electrodes is nonlinear and temperature dependent. The Pope-type sensor is limited to temperatures lower than 75% and is highly sensitive to organic solvents (e.g. oil vapor) and chemical components that attach polystyrene.

Many versions of RH sensors utilizing a thin film polymer or ceramic are now commercially available. Sensors with high sensitivity (2% RH accuracy) and fast response are available in the medium to low price range. The operating temperature range is approximately 5 to 55 ^{o}C. Some sensors are equipped with a sintered metal filter to shield the sensor from the majority of particulate matter found in the air. Exposure to high humidities for several minutes may result in loss of calibration or even loss of the sensor itself.

The high humidity restrictions of various sensors can be avoided by raising the temperature of the high relative humidity air before it is measured. This can be accomplished by passing a sample of the air to be monitored through a simple heat exchanger, for example, by using the air adjacent to the air-handler.

---

measurement technique:	**application area:**	**referenced from:**
H.1	BOILERS	ECO H.13, H.15, MT H.4.

title:	**references to:**
MEASUREMENT OF THE RUNNING TIME OF A BOILER	MT EL.7, H.4, H.5

description:
The measure of the running time of a boiler can be achieved with different types of instruments and different degrees of accuracy:
i) With a counter: measure the running time for a day or a week.
ii) With a data logger: measure the running time every hour.
For these measurements, the instrument has to be connected to the valve commanding the injection of the oil or of the gas or to the motor (see MT EL.7).

cost:	**ease of use:**
Counter: $10-$15. Data logger: $200-$500.	Simple.

accuracy:	**references:**
5 minutes for counter, 1 second for data logger	

recommended applications:
Determination of the energy signature.
Monitoring of heating plant and control.
Check of boiler oversizing.
Determination of boiler stand-by losses.

alternative techniques:

additional information:
The running time reflects not only the true heat load. The regulation setting of the heating system may induce overheating. Measurement of running time must include room temperature control. It is useful to measure the running time associated to different states of the system:

i) Standby by different boiler temperature,
ii) Running time during normal heating (day from 9 a.m. to 9 p.m.) and reduced heating (night from 10 p.m. to 6 a.m.),
iii) Startup peak power after temperature setback.

The interpretation of the data includes
- extrapolation of the running time at the lowest design outdoor temperature,
- operation when steady-state conditions are reached.

If the burner runs with several running speeds (high/low fire), the measurement of the running time has to be carried out separately for each speed. Counters or data loggers must then be connected to the commands of each speed. By modulating burners, measurement of the running time must be replaced by measurement of oil or gas consumption (see MT H.4 and H.5).

measurement technique:	**application area:**	**referenced from:**
H.2	HEATING	ECO H.15, H.19, AP H.1.

title:	**references to:**
MEASUREMENT OF FLUE GAS TEMPERATURE	AP H.4, MT H.3.

description:

The flue gas temperature is measured in the middle of the smoke stack, at an approximate distance of one diameter from the boiler's exit.

It is measured with the burner at the normal running rate, some minutes after the burner has been engaged and steady-state temperature conditions have been reached.

The temperature must be measured at the same place as that of the CO_2-content (MT H.3).

Types of thermometers to be recommended:

i) Bimetal thermometers,
ii) Thermocouples,
iii) Electronic thermometers with:
- resitive sensors,
- thermocouples.

cost:	**ease of use:**
Cost of sensor.	Simple.

accuracy:	**references:**
3-5 K.	

recommended applications:

A component part of the determination of the combustion efficiency and heat transfer efficiency.

alternative techniques:

additional information:

This is one of the measurements carried out by automated integrated instruments for the measurement of combustion efficiency (see AP H.4). For burners with several running rates, the measure has to be repeated for each speed.

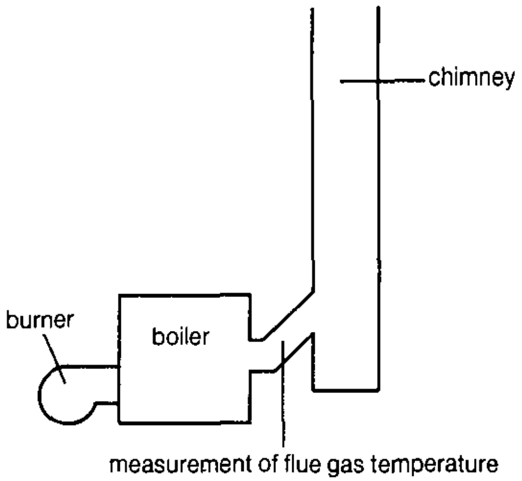


Fig. 1 Measurement of flue-gas temperature.

measurement technique:	**application area:**	**referenced from:**
H.3	HEATING PLANT	AP H.1

title:	**references to:**
CARBON DIOXIDE OR OXYGEN CONTENT OF FLUE GAS	

description:

The carbon dioxide (CO_2) or oxygen (O_2)content of the flue gas is measured in the middle of the smoke stack at the boiler's exit, at a distance of one diameter from the boiler's exit. The CO_2 (or O_2) content must be measured at the same place as for the flue gas temperature (MT H.2).

It is measured with the burner at the normal running speed, some minutes after the burner has started up and temperature steady-state conditions have been reached.

The Bacharach device is one of the simplest to perform the measurement of the CO_2 (or O_2) content : a given volume of flue gas is contained within an enclosure. The CO_2 is then absorbed by a special liquid. The diminution of the gas volume is related to the CO_2 (or O_2) content of the gas and can be read on a graduation scale.

The CO_2 (or O_2) measurement can also be carried out by automatic instruments measuring the combustion efficiency (see AP H.1). Usually an oxygen cell is used which must be replaced yearly. The reading is almost instantaneous allowing immediate adjustments of the boiler/furnace efficiency.

cost:	**ease of use:**
Cost for simplest Bacharach device is appr. $100 ranging to $1500 for automated systems.	Simple

accuracy:	**references:**
1 %	

recommended applications:

Any fuel-fired system in the determination of the combustion efficiency.

alternative techniques:

additional information:

For burners with several operational levels, the measure has to be repeated for each level.

measurement technique:	**application area:**	**referenced from:**
H.4	HEATING PLANT	MT H.4

title:	**references to:**
MEASUREMENT OF FUEL CONSUMPTION IN A GIVEN PERIOD	MT H.5

description:

If a fuel meter is installed:

i) Take the difference of the meter readings at the end and at the beginning of the period.

If the burner is non-modulating, that is the fuel flow-rate is constant, then:

ii) Multiply the fuel flow-rate (MT H.5) by the on-time of the burner (MT H.1) within the measurement period.

If the oil tank shape, capacity and layout is known, then:

iii) Measure the fuel level at the beginning and at the end of the period. Technical tables exist which provide the correspondance between the liquid level in the tank and the liquid volume. Hence the fuel consumption can be obtained as the difference between the final and the initial fuel volumes.

If a rough estimate is acceptable,

iv) Analyse the fuel supplies from the fuel bills.

cost:	**ease of use:**
It depends on the labour time.	Simple

accuracy:	**references:**
2 - 5 %	

recommended applications:

alternative techniques:

additional information:

measurement technique:	**application area:**	**referenced from:**
H.5	HEATING PLANT	MT H.4, H.1

title:	**references to:**
MEASUREMENT OF FUEL CONSUMPTION FLOW-RATE	

description:

i) If a fuel meter is installed, for each heating mode (high/low fire) divide the difference of the two meter readings taken at the end and at the beginning of a preset time interval by the length of this interval;

If a fuel meter is not installed, then:

ii) Look at the fuel spray nozzle type and read the working pressure of the fuel feed pump and derive, from the nozzle technical table to corresponding fuel flow-rate; or

iii) Disconnect the fuel supply pipe and connect it to a small bottle containing a known amount of fuel. Record the time the burner needs to consume this amount. The ratio of the fuel quantity by the consumption time will give the fuel flow-rate, or

iv) Install a fuel flow-meter and see point i) above.

cost:	**ease of use:**
Fuel meter 50-100$ Labour 10- 30 minutes	

accuracy:	**references:**
	Roulet, 1987.

recommended applications:

alternative techniques:

additional information:

measurement technique:	**application area:**	**referenced from:**
D.1	DUCTWORK	ECO D.4, MT D.2 through D.5.

title:	**references to:**
CHOICE OF CROSS-SECTIONAL MEASUREMENT POINTS IN AIR DUCTS FOR MEASUREMENT OF VELOCITY	

description:

As guidance to the location of a suitable place for measurements use Fig. 1.

With certain disturbances, e.g. throttling dampers, a considerably longer distance may be required. In circular ducts the plane of measurement should be positioned at least 150 mm upstream of any duct-joint. Avoid measurement after propeller fans or two bends directly connected to each other in different planes. The swirl from such disturbances can give considerable errors so far downstream as 30 diameters (d).

In rectangular ducts the plane of measurement should be positioned at least 50 mm upstream of any duct-joint. Rectangular ducts having dimension >600 mm are usually split. One should if possible perform the measurement from the duct-side having no cracks. Test first the velocity at the measurement cross-section.

i) Measure the dynamic pressure at the centre of the cross section.

ii) Find the position of the maximum dynamic pressure and note its value.
   a) If this maximum is situated farther from the duct wall than 0.1 d, and the maximal dynamic pressure is less than 2 times the dynamic pressure at the centre, the measurement plane is acceptable and the measurement points are then selected according to Fig. 2 and 3.
   b) If both conditions are not fulfilled an alternative measurement plane should be sought.

iii) If no measurement plane that fulfills the condition in ii)a and b is found, there are two possibilities:
   a) Measure according to Fig. 2 and 3, but with total accuracy reduced to 12-15%.
   b) Use the alternative procedure: Increase number of measuring points and total accuracy of 8%.

iv) Conditions for using method in iii): The maximum dynamic pressure is located further from the duct wall than 0.1 d and is less than 4 times dynamic pressure in the duct center.

v) If no measurement plane fulfills the conditions in iv), then flow measurement using Pitot-tube should <u>not</u> be performed.

vi) After measurement the duct-holes should be plugged.

cost: ! **ease of use:**

accuracy: ! **references:**

recommended applications:

alternative techniques:

additional information:
Circular cross section: a> 5d.
Rectangular cross section: a>6 D (D= hydraulic diameter = A/O where A= cross area and O circumference of duct).

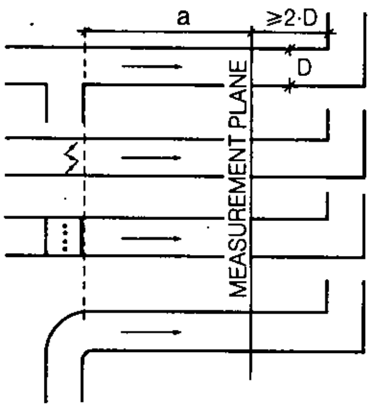


Fig. 1
Guide for positioning of measurement plane.

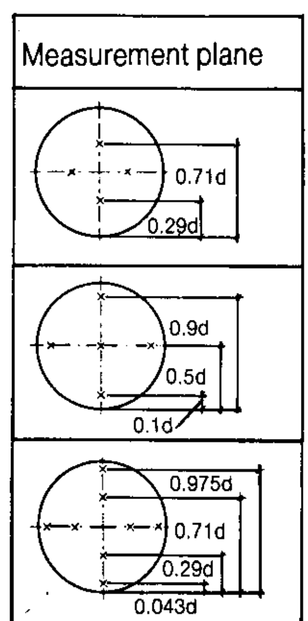
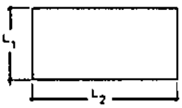


Fig. 2
Positions of measurement in the measurement plane. Circular cross section.



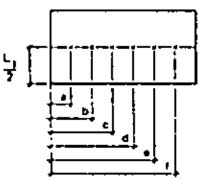
In accordance with new duct standard ISO 1807

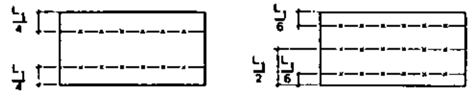
Two alternatives for L_2: I $200 < L_2 \leq 300$
II $400 < L_2 \leq 2\,000$

For alt. I note that: $a = 0.08 \cdot L_2$, $b = 0.43 \cdot L_2$, $c = 0.57 \cdot L_2$, $d = 0.92 \cdot L_2$
For alt. II note that: $a = 0.060 \cdot L_2$, $b = 0.235 \cdot L_2$, $c = 0.430 \cdot L_2$, $d = 0.570 \cdot L_2$
$e = 0.765 \cdot L_2$, $f = 0.940 \cdot L_2$

Three alternatives for L_1:

① $200 < L_1 \leq 400$ ② $400 < L_1 \leq 800$ ③ $800 < L_1 \leq 2\,000$





For these alternatives the following positions of measuring points are then obtained:

L_2	200	250	300	400	500	600	800	1 000	1 200	1 400	1 600	1 800	2 000
a	16	20	25	25	30	35	50	60	70	85	95	110	120
b	85	110	130	95	120	140	190	235	280	330	375	420	470
c	115	140	170	170	215	260	345	430	515	600	690	775	860
d	184	230	275	230	285	340	455	570	685	800	910	1 025	1 140
e	–	–	–	305	380	460	610	765	920	1 070	1 225	1 380	1 530
f	–	–	–	380	470	565	750	940	1 130	1 315	1 505	1 690	1 880

Fig. 3 Positions of measurement in the measurement plane. Rectangular cross section. All measures are in mm.

TABLE 3. Correction factor for temperature and barometric pressure.

Temperature in duct [°C]	Static pressure in duct [mbar] 970-1000	1000-1030	1030-1060
0	0.98	0.96	0.95
20	1.02	1.00	0.98
40	1.05	1.04	1.02

TABLE 4. Correction factor for cross section.

Circular cross section	$d < 160$ mm	0.96
	$200 < d < 400$ mm	0.97
	$500 < d < 12250$ mm	0.98
Rectangular cross section	$L_1 > L_2$	0.94
	$L_1 = L_2$	0.96
	$L_1 < L_2$	1.02

measurement technique:	**application area:**	**referenced from:**
D.2	DUCTWORK	ECO D.4, H.25, H/C.7, H/C.8, AP D.3

title:	**references to:**
FOR MEASUREMENT OF VELOCITY IN DUCTS USING PRANDTL-TUBE (PILOT-TUBE)	MT D.1, D.3, D.4, D.5.

description:

The airflow rate is calculated from a series of velocity measurements in the cross section of a duct. Determination of velocity (dynamic pressure) is done with a Pitot tube.

The method is fundamental and in wide use. For shorter straight duct length than about 5 diameters (5 d) before and 2 d after measurement plane the method error inreases. For better accuracy: Measure in more points, see Alternative Techniques 1.

Equipment:

i) Pitot tube,
ii) Rubber or plastic tubes,
iii) Micromanometer, U-tube,
iv) Thermometer,
v) Aneroid barometer,
vi) Plastic plugs,
vii) Steel measuring tape,

Preparation (on site):

1. The measurements are taken in a plane of measurement (as in MT D.1). Observe that minimum distance to downstream disturbances should be 2 d to 3 d.
2. Remove external insulation. Avoid measuring in internally insulated ducts. If the ducts are internally insulated, the measuring points in Tables 1 and 2 must be recalculated.

Preparation (instruments):

1. Set up the manometer horizontally on a stable base.
2. Couple the tubes between the Pitot tube and the manometer.
3. Check that the column of liquid is free from air.
4. Adjust the manometer to the correct angle. To obtain the best reading accuracy it is important to use the angle that gives the greatest deflection.
5. If necessary check and adjust the manometer's zero setting.

The air velocity v at each measurement point is then calculated from the dynamic pressure, p, by using the relation

$$v = const. * \sqrt{p}$$

If $_{0}$p is measured in [Pa] and v in [m/s], the constant is equal to 1.29 (at $20^{o}C$ and 1013 mb).

The volumetric air flow rate, q_v, is then obtained from the average velocity of the measurement points, v, and the cross section area, A, as

$$q_v = v * A.$$

If a high accuracy is desired, the velocity should be corrected for barometer pressure (see Table 3, MT D.1) and for duct cross section (see Table 4, MT D.1).

cost: Equipment: $120. Data collection and calculation: About 1 h per duct.	**ease of use:** Simple for a trained person. Often difficult to find sufficient straight duct length.
accuracy: 7% for straight duct length >7 d. 15% for str. duct length 4-7 d.	**references:** NVG, 1983.

recommended applications:

alternative techniques:

1. When no recommended measurement plane is found, i.e. when straight duct length is shorter than 7-8 d or special disturbances are located upstream the measurement plane. The number of measuring points is increased and a special method of calculation is applied. See Reference. The method error is then 7%.

2. For ducts with velocities lower than 3 m/s: Use MT D.3 (Hot wire anemometer).

3. For large, rectangular ducts (side over approximately 2 m) and brickwork ducts: Use MT D.4: (Rotating vane anemometer).

4. For permanent monitoring or single measurement with less accuracy: Use MT D.5: (Tracer gas).

additional information:

measurement technique:	**application area:**	**referenced from:**
D.3	AIR DUCTS	ECO D.2, D.4, H/C.7, H/C.8, H.25, AP D.3, R.4

title:	**references to:**
AIR FLOW MEASUREMENT IN OUCTS USING HEATED WIRE ANEMOMETER	MT D.1, 0.2, D.4, D.5.

description:

In order to determine the air flow rate in a duct one may use a heated wire anemometer for velocity measurement. A number of measurement points are determined as in MT D.1.

This method is advantageous for duct velocity lower than 3 m/s, where the accuracy is better than that of a Pitot tube, due to the instrument error at low velocities.

Instead of maximal dynamic pressure in MT D.1 the maximal velocity should be applied:
- In point ii)a: Max. velocity less than 1.4 times center velocity.
- In point iv): Max. velocity less than 2 times center velocity.
- The hot-wire anemometer should have been accurately calibrated at the temperature existing in the duct. (If the calibration is performed at $20^{\circ}C$ only and the measurement is done at $30^{\circ}C$ an error of 10% in the velocity measurement may occur.)

The volumetric air flow is determined from the average velocity as in MT D.2. Use a Pitot tube or a smoke pencil to control that counterflow does not occur in the measurement plane.

cost: Equipment from $500. Data collection and calculation 1/2-1 h per duct.	**ease of use:** Simple for a trained person.
accuracy: With calibrated anemometer the total error is about 5% higher than for MT D.2, i.e. 10-20%.	**references:** NVG, 1983.

recommended applications:

alternative techniques: MT 0.2, 0.4, D.5.

additional information:
Conditions for using this method: The heated wire anemometer has a sensor-shaft of equal or smaller thickness than a similar Pitot-tube. The velocity can be corrected for the duct cross section as in MT D.2.

measurement technique:	**application area:**	**referenced from:**
D.4	DUCTWORK	ECO D.2, D.4, H/C.7, H/C.8, H.25

title:	***references to:***
AIR FLOW MEASUREMENT IN DUCTS USING ROTATING VANE ANEMOMETER	MT D.1, D.2, D.3, D.5.

description:

Use a rotating vane anemometer for velocity measurement in a number of points across the duct selected as described in MT D.1.

This method is advantageous for large, rectangular ducts (side over approximately 2 m) and brickwork ducts where a Pitot tube is difficult to use.

Instead of maximum dynamic pressure in MT D.1 the maximum velocity should be applied:

- In point ii)a: Max. velocity less than 1.4 times center velocity.
- In point iv): Max. velocity less than 2 times center velocity.

When a rotating vane anemometer with separate stopwatch is used, the anemometer is held for 10-15 seconds in each measurement point. At the end of each measurement period the instrument is transferred to the next point *without stopping the rotation. At the end of the final period the anemometer* is stopped and the stopwatch is read. The anemometer value is divided by the time registered and this average velocity is corrected with the anemometer's calibration curve.

When a direct-reading rotating vane anemometer is used, the average velocity of each point must be determined. Every measured value is then corrected with the anemometer's calibration curve. Then the total average velocity is calculated.

The volumetric air flow is determined from the average velocity as in MT D.2.

cost: Equipment: From \$300. Data collection and calculation: 1-1 1/2 h per duct.	**ease of use:** Simple for trained persons. It may be difficult to enter the duct and find sufficient straight duct length.
accuracy: 5% higher *total error than for* MT D.2, i.e. 10-20%	**references:** NVG, 1983.

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recommended applications:

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alternative techniques:

MT D.2, D.3, D.5.

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additional information:

The method should not be used if the hydraulic diameter of the duct is smaller than 5-6 times the anemometer diameter.

Due to mechanical friction in the anemometer the lowest velocity to be measured is 1 m/s for mechanical vane anemometers and about 0.3 m/s for electronic vane anemometers.

The rotating vane anemometer must be calibrated once a year in a wind tunnel. The anemometer should be mounted on a shaft about 1.5 m long when the anemometer is handheld towards the air stream.

For correction factors, see MT D.1.

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measurement technique:	**application area:**	**referenced from:**
D.5	DUCTWORK (AIR CONDITIONING CENTRALS)	ECO D.2, D.4, H/C.7, H/C.8, H.25, AP D.3

title:	**references to:**
AIR FLOW MEASUREMENT USING TRACER GAS TECHNIQUES	MT D.2, D.3, D.4.

description:

One of the difficulties involved in measuring the air flow rate in ventilation ducts is that there are often insufficient straight sections preceding or following the measurement plane. However, when tracer gas is used for the measurement of air flow rate, it is an advantage to have much turbulence induced by dampers, bends, etc. because the tracer gas method may only be used when a homogeneous mixture of the tracer gas in the air can be maintained.

The method is based on injecting a known low rate of a tracer gas into the ventilation duct. When the tracer gas further downstream is well-mixed with the ventilation air, the air flow rate is calculated from the concentration of the tracer gas.

The method requires a continuous, known flow rate of tracer gas, q_s, [m^3/s] and a thorough mixing of the tracer gas with the air transported in the duct, q_v [m^3/s]. If the concentration in the cross section used for sampling is called C_s (fractional units) with steady-state condition, the following relation is obtained:

$$q_v = q_s/C_s$$

Equipment:

i) Tracer gas analyzer.
ii) Tracer gas + reduction valve (manometer).
iii) Flowmeter for tracer gas (rotameter).
iv) Thermometer for tracer gas and duct air.
v) Probe for distribution of tracer gas in the duct.
vi) Probe for sampling.
vii) Plastic plugs to plug holes.

cost:	**ease of use:**
Equipment: From \$7000. Data collection and calculation: 1-3 h per duct.	Trained staff necessary.

accuracy:	**references:**
Total probable error = 10-15% depending on mixing length and quality of gas analyzer.	NVG, 1983.

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recommended applications:

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alternative techniques:

MT D.2, D.3, D.4.

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additional information:

If a rotameter is used as a flowmeter for tracer gas, it must be calibrated for the actual tracer gas. It is quite impossible to use a single factor for conversion of the rotameter's calibration curve from air to tracer gas.

The flow rate of the tracer gas is corrected to apply at the prevailing temperature in the ventilation duct. Therefore the temperature of the tracer gas must be measured when passing through the rotameter. The corrected flow rate is obtained from (see Fig.1):

$$q_s\ (corr) = q_s\ (1.96-0.67\ t_f)/(1.96-0.67\ t_d)$$

where
q_s = tracer gas flow rate at tracer gas temperature at flowmeter,
t_f = temperature of tracer gas at flowmeter [^oC],
t_d = temperature of tracer gas in duct [^oC].

To obtain the highest accuracy in measurement of the air flow rate, it is necessary to ensure the least possible variation in gas concentration over the measuring plane. Some variations have to be accepted because sufficiently long duct sections are not available. A considerable decrease in the mixing length can be obtained if the tracer gas is injected simultaneously through a number of openings in the cross section (at least four) and if the sampling is carried out in more than one point. See Table 1.

A considerable decrease in the mixing length is also obtained if the tracer gas is injected upstream of a fan. See Table 1.

TABLE 1. Recommended ratio (mixing length)/(hydraulic diameter)(1/D) for method errors of 5 and 10%.

Arrangement of injection, duct and sampling		1/D for method error 5%	10%
Injection at centre	Straight duct without disturbance Sampling at centre	80	60
Injection through a ring whose diameter is 63% of the duct diameter (4 holes in a ring).	Straight duct without disturbance		
	a) sampling at centre	25	20
	b) sampling at 4 points in duct (situated as in injection)	15	10
	Duct with two 90° bends		
	a) sampling at centre	20	15
	b) sampling at 4 points in duct (situated as in injection)	10	5
	Injection preceding a fan and sampling following fan.	10	5

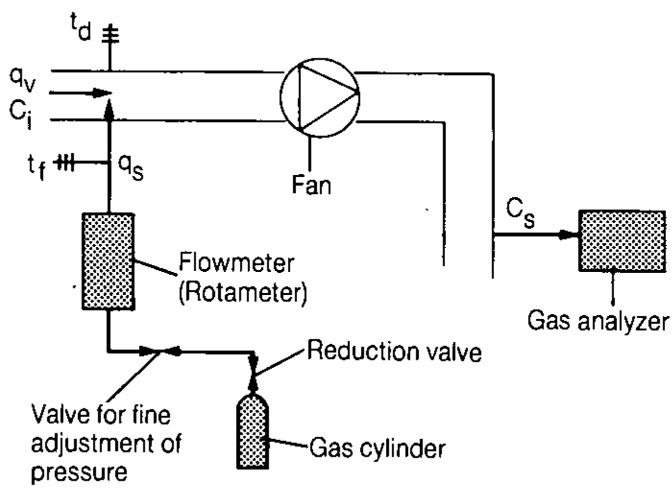

Fig. 1 Flow measurement with tracer gas in ducts.

measurement technique:	**application area:**	**referenced from:**
D.6	DUCTWORK	ECO D.3, AP R.4

title:	**references to:**
MEASUREMENT OF PRESSURE DROPS IN AIR DUCTS	

description:

A survey of the ductwork should also address i) the possibility of rebuilding those parts with a high pressure drop and ii) the necessity of cleaning the inside of the ductwork system.

Excessive pressure drops may occur in:

i) Fan inlets and outlets,
ii) Sharp, large bends without turning vanes,
iii) Two bends in different planes,
iv) On-site built transitions,
v) Intake and outlet terminals,
vi) Heat exchangers in the system.

The instrumentation needed is:

- Manometer with differential ranges 0-2000 Pa,
- Inclined liquid manometer,
- Mechanical or electronic manometer;
- Rubber tubes and
- Pitot static tube (Prandtl-tube) for use in ducts with high velocities.

Drill small holes (diameter 2-3 mm) in the duct wall before and after the part to be tested. Connect the rubber tubes to the manometer and fasten the tubes against the duct wall over the holes. Read the pressure difference on the manometer.

If the pressure difference is less than 5-10 times the calculated dynamic pressure in the duct, means should be taken to reduce errors due to turbulence and dynamic pressure losses in the measuring holes by:

1. Removing inside burrs in the measuring holes with a special tool, or
2. Drilling bigger holes.

Take measurements with a Pitot static tube, connected to the total pressure outlet (the nose),and adjust the tube nose against the air flow. The procedure is most correct when duct velocity exceeds 5-6 m/s or when the duct cross area differs with more than 10-20% between the measuring points (the pressure drop is taken as the difference in total pressure between the measuring points, with the pressure in the room outside the duct as reference.)

The required pressure drop is the difference in total pressure before and after the examined part of the ductwork. If the duct velocity is the same before and after (i.e. when the duct cross area is the same), the difference in total pressure equals the difference in static pressure, and measuring static pressure in duct holes is sufficient. The total pressure is obtained from:

$$p_t = p_s + p_d$$

p_t = total pressure [Pa]
p_s = static pressure [Pa]
p_d = dynamic pressure [Pa] = $\varrho/2 * v^2 = 0.6\ v^2$
v = velocity [m/s].

Results should be compared with manufacturers or standard component pressure loss data. It may be necessary to also measure actual flow rate (see MT D.1 through D.5).

cost:	**ease of use:**
Data collection: 10-15 minutes per component.	Simple. Evaluation of results need some knowledge of ventilation components.
accuracy:	**references:**
10-15%	

recommended applications:

alternative techniques:

additional information:

Limitations.

Measurement shortly after a fan or damper should be avoided because of high local velocities which increase the measuring error to more than 20%.

measurement technique:	**application area:**	**referenced from:**
D.7	DUCTWORK	ECO D.1, H/C.1, H.25 AP 0.2

title:	**references to:**
MEASUREMENT OF TEMPERATURE ANO HUMIDITY IN AIR DUCTS	MT R.5.

description:

In supply air ducts temperature and humidity may vary across the section of the duct. A heat recovery device, heating/cooling coils and air mixing units often produce an uneven temperature (and humidity) profile across the section. Measurements made near these components should be made with great care.

If by traversing with the measurement probe, the temperature and relative humidity maximal differences are smaller than 0.5 K and 5%, respectively, then the profile in the cross section can be regarded as homogeneous.

If the limits are exceeded, then the measurements should be taken according to the descriptions given in MT D.1.

In exhaust air ducts the temperature and humidity profile in exhaust air ducts are usually homogeneous. Therefore it is enough with one measuring point, preferably in the middle of the cross section.

Equipment for temperature measurement: Thermometer according to users demand for accuracy, for humidity measurement: Lithium-Cloride cell hygrometer. This instrument demands frequent calibration. Use an aspiration psycrometer as a calibrator or for more accurate measurement (see MT R.5).

cost:	**ease of use:**
Equipment: From $50.	Simple.

accuracy:	**references:**
Depends on instrument accuracy.	

recommended applications:

alternative techniques:

additional information:

measurement technique:	**application area:**	**referenced from:**
D.8	DUCTWORK	ECO D.2, D.4.

title:	**references to:**
AIR FLOW MEASUREMENT ON EXHAUST TERMINAL WITH ANEMOMETER-HOOD	MT D.2 through D.5.

description:

This method is easy to use on smaller air exhaust terminals. Different types of hot-wire instruments and mechanical air velocity instruments can be fitted with a hood for air flow measurement on exhaust air devices. Some of these instruments are listed in Table 1.

The calibration curves of the instruments are influenced to a certain degree by the type of exhaust air device on which it is used. The instruments may give an additional error of 5% depending on the type of valve. Calibration in combination with the actual installation of the instrument should therefore be carried out if the greatest possible precision is to be obtained.

All measuring instruments fitted with a hood affect the air flow through the device because a pressure drop occurs in the measuring hood. When the pressure drop across the hood and the exhaust air device is known, the correct flow can be calculated: Correct flow = measured flow times correction factor from Table 2.

All hot-wire instruments are delicate and need calibration and adjustment one or two times a year.

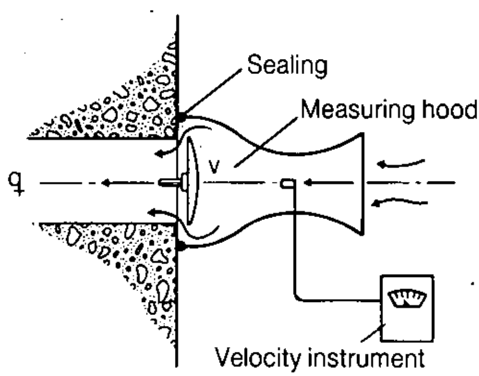

Fig. 1
Measurement of flow with anemometer hood.

cost: Equipment: From \$600. Data collection: 5-15 minutes per exhaust terminal.	**ease of use:** Simple.
accuracy: Total random error: For newly calibrated instrument: 12%. With calibration curve for the actual terminal: 7%.	**references:** NVG, 1983.

recommended applications:

alternative techniques:
MT D.2 through D.5.

additional information:

TABLE 1. Flowmeters.

Type of instrument	Air flow range [m^3/h]	[l/s]
Swema AFM-66B (Sweden)	5-30, 30-230	1.4-64
Alnor + AM-300 (Finland)	20-300	5.5-83
Alnor + AM-600 (Finland)	50-750	14-208
Alnor + AM-1200 (Finland)	100-1500	28-417
Veab LM-200 (Sweden)	20-200	5.5-55
Bal-cone + CF matic, AMC (USA)	0-1700 (5 sizes)	0-472
Alnor Balometer (USA)	0-3400 (4 sizes)	0-945

TABLE 2. Correction factor for pressure drop across flowmeter.

Pressure drop across the flowmeter in percent of the pressure drop across the exhaust air device*	Correction factor
5	1.01
10	1.05
20	1.11

* Including pressure drop to nearest branch duct.

measurement technique:	**application area:**	**referenced from:**
D.9	DUCTWORK	ECO D.2, D.4.

title:	**references to:**
AIR FLOW MEASUREMENT ON SUPPLY TERMINAL WITH BAG	MT D.2 through D.5, D.10

description:
This method is a precision method for air supply terminals and easy to use when there is sufficient space and flat surface around the terminal.

The method, illustrated by Fig. 1, implies that a rolled-up measuring bag, of a certain volume and mounted on a frame, is placed over the device so that this is completely covered. The time that elapses until the bag is filled with air to a certain overpressure, is noted. The volumetric air flow rate, q_v, is then obtained from the equation:

$$q_v = V/t,$$

where V = volume of measuring bag, and t = filling time.

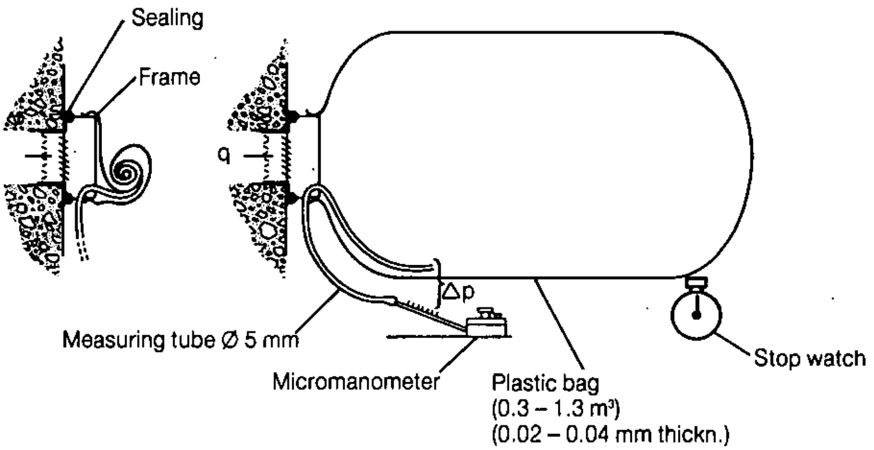

Fig. 1 Measurement of air flow with plastic bag.

cost:	**ease of use:**
Equipment included one factor calibrated bag: From $650. Data collection: 10-20 min. per supply terminal (two persons).	Simple, but some training necessary. Most effective with two persons.

accuracy:	**references:**
Total random error 4%.	NVG, 1983.

---

recommended applications:

---

alternative techniques:

MT D.2 through D.5, D.10.

---

additional information:

The lower limit of the pressure drop for a terminal (including pressure drop to nearest branch duct), when measuring a device mounted in a ceiling, is approximately 10 Pa. When the device is installed in a wall it is approximately 50 Pa. For measurements on wall-mounted devices, it is necessary to lift the measuring bag in order to decrease the pressure in the bag.

The maximum flow rate is about 500 m^3/h (0.13 m^3/s) with a bag of 13 m^3.

Place the frame with the rolled-up (airless) bag over the device and start the stopwatch.

Filling time to an overpressure of 3 Pa is noted. If the filling time is below 10 seconds the measurement is repeated with a bag of greater volume.

If such a greater bag is not available the measurement should be repeated 2-3 times.

Measuring bags including frames and other accessories can be obtained from, for example, Matforum Hans Blixt AB, Solna, Sweden.

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measurement technique:	application area:	referenced from:
D.10	DUCTWORK	ECO D.2, D.4.

title:	references to:
AIR FLOW MEASUREMENT ON SUPPLY TERMINAL WITH ANEMOMETER-HOOD	MT D.2 through D.5, D.9.

description:

This method is easy to use for balancing air supply systems, but needs calibration for each type of terminal if accurate measurements are desired.

To obtain a good degree of measuring accuracy with the instruments mentioned in MT D.8, regardless of whether the airstream is symmetric or not, an extension hood is required. This hood should have a length 3 times the greatest hydraulic diameter of the hood (limited availability).

The anemometer used is a rotating vane anemometer positioned in the circular outlet of the hood. To obtain the best measuring result the outlet diameter of the hood should be 1.5 times the diameter of the rotating vane anemometer.

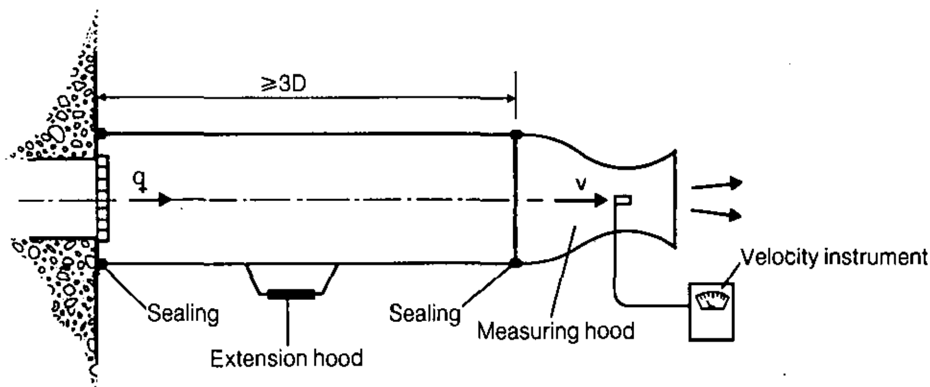

Fig. 1 Measurement of flow with anemometer hood.

cost:	ease of use:
Equipment: From $700. Data collection 5-15 minutes per supply terminal.	Simple, but the hoods may be heavy to handle for one person. Calibration necessary.

accuracy:	references:
Total random error: 7% on condition that instrument is newly calibrated, hood is calibrated on actual terminal type, correction is made for hood pressure drop.	NVG, 1983.

---

recommended applications:

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alternative techniques:

MT D.2 through D.5, D.9.

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additional information:

Limitations:

If absolute values for air flow rate is wanted, the methods require calibration in combination with the supply air device concerned. All measuring instruments fitted with a hood influence the airflow through the instrument as a certain degree of pressure drop is set in the measuring hood.

Correction for pressure drop: Correct flow = measured flow times a correction factor from Table 1.

TABLE 1. Correction factor for pressure drop across flowmeter.

Pressure drop across the flowmeter in percent of the pressure drop across the exhaust air device*.	Correction factor
5	1.01
10	1.05
20	1.11

* Including pressure drop to nearest branch duct.

---

measurement technique:	**application area:**	**referenced from:**
D.11	DUCTWORK	ECO D.2, D.4.

title:	**references to:**
AIR FLOW MEASUREMENT ON TERMINALS BY A ZERO PRESSURE METHOD (FLOW FINDER)	

description:

With the zero pressure method the resistance of the measuring instrument is compensated by means of a fan, so that the characteristic of the air distribution system is not influenced by the measurement.

Because of the zero pressure method the air flow is virtually not influenced by the placing of the instrument before an outlet or grille. The instrument is set manually. The zero pressure indicator will indicate if the air flow on the scale of the instrument is higher or lower than the measured air flow.

The instrument itself and the zero pressure indicator react instantly so that the air flow that is to be measured can be determined very rapidly.

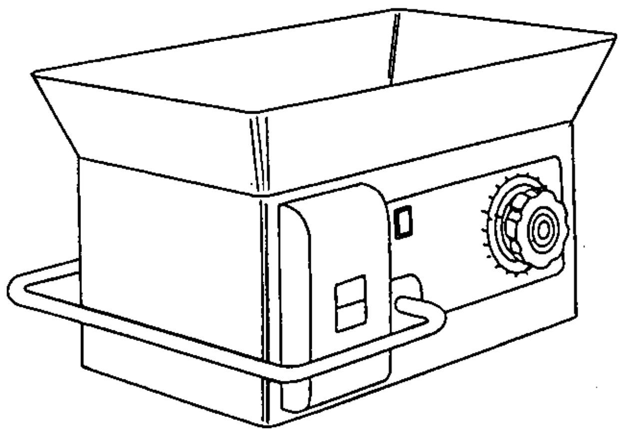

Fig. 1 An example of the instrument described, the Flow Finder.

cost:	**ease of use:**
Approximately $1000.	Simple.

accuracy:	**references:**
5% of the reading +/- 0.0003 m^3/s (1 m^3/h)	ACIN

recommended applications:

- grills, registers, diffusers,
- low air volumes or velocities,
- natural ventilation rates.

alternative techniques:

MT 0.2 through 0.5, 0.9, 0.10.

additional information:

measurement technique: P.1	**application area:** PIPEWORK (HEATING, SHW, REFRIGERANT SYSTEMS)	**referenced from:** ECO P.9, P.11, MT P.6, P.2

title: MEASUREMENT OF STATIC PRESSURE AND PRESSURE DROPS IN PIPES	**references to:**

description:

If there are no built in manometers or manometer connections, one can proceed as follows:
After draining pipework, drill a tapping in the pipe so that the hole emerges perpendicular to the pipe inner wall with a clean sharp edge. Fit a pressure gauge in the pipework.

If manometers have to be connected to a refrigerant system always check for possible leakage at the connections using a refrigerant leakage detector. Also make sure that the manometer is suitable for the intended working pressure (e.g. do not confuse high and low pressure connections).

To measure pressure drop across any pipework component, measure static pressures as close as practical and on both sides of the component.

cost: Standard type service manometers \$40-\$100 Precision electronic transducers \$200-\$300.	**ease of use:** Should be fitted by experienced personnel.
accuracy: Dependent on gauge 2-5%	**references:**

---

recommended applications:

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alternative techniques:

1) For low pressure pipes a simpler technique can by applied.
Fit a twin lock test plug and insert a hollow needle through the rubber seal. Connect the needle via flexible armoured hose to a pressure gauge or manometer.

2) To measure the pressure at a draw-off point in a SHW system one can proceed as follows.
Connect a pressure gauge (Bourdon type) of appropriate sensitivity to the draw-off point using armoured flexible hose secured with suitable clips (e.g. Jubilee clips).

This can be carried out by unskilled personnel.

---

additional information:

If manometers are being fitted for longer periods always use metallic connecting tubes (copper, steal etc.). Rubber hoses normally used for service applications are not diffusion proof and will slowly leak.

Leak detection using a gas flame in refrigerant systems is efficient but not to be recommended since refrigerants may decompose and form toxic gases in the presence of an open flame. Use electronic type detectors.

When disconnecting pressure tubes from refrigerant systems remember that refrigerant may have condensed (especially on the high pressure side) in the tube and this will evaporate violently on disconnection of the tube. Be sure to protect eyes or skin since evaporating temperature at ambient pressure can be in the range of -30 to -45 ^{o}C. If connecting pipes have large volumes it should be arranged with switching valves so that refrigerant can be sucked back into the system before disconnecting the manometers. WARNING: Not to be carried out in ammonium systems except by licensed technicians.

---

measurement technique: P.2	**application area:** PIPEWORK	**referenced from:** ECO P.3 S.7, S.11, S.12, S.15, AP P.3, P.5, S.1, S.2, S.5, MT P.3, P.4, S.1

title: FLOW RATE IN PIPES (ORIFICE PLATE)	**references to:** MT P.1, P.3, P.4

description:

An orifice plate is a metal plate with a circular concentric orifice. When placed in a pipe, the plate partially obstructs the flow, causing a loss of pressure. The volumetric flow rate is related to the pressure differential across the plate by the equation:

$$q_v = C_d A_o \sqrt{(2\Delta p/\rho)} / \sqrt{[1-(A_o/A_p)^2]}$$

where q_v = volumetric flow rate [m^3/s]
A_p = cross-sectional area of pipe [m^2]
A_o = cross-sectional area of orifice in plate [m^2]
C_d = discharge coefficient of orifice plate
Δp = pressure differential [Pa]
ρ = density of the fluid in the pipe [kg/m^3].

The pressure on either side of the plate is measured via pressure tappings, one drilled a distance of one pipe diameter d upstream of the plate and on a distance d/2 downstream of the plate.

The value of C_d depends on the Reynolds number but for the flows considered here can be taken equal to 0.60.

cost: For complete plate and flange assembly (50 mm diameter) $600. Differrential pressure transmitter, diaphragm type $1200.	**ease of use:** Fitting and calibration of the device should be performed by qualified staff.
accuracy: 2-3% uncalibrated. 1% calibrated (provided the discharge coefficient is known).	**references:**

recommended applications:

Available for pipe diameters 25 mm - 600 mm.

alternative techniques:

MT P.3, P.4.
Measure pressure across system pump (MT P.1). Flow rate can be established from pump characteristics.

additional information:

The installation of an orifice plate will normally require removing a length of pipe unless it can be fitted between two existing flanges in the pipework.

Flanged couplings should be attached to the pipe ends at the cut-out and the plate fitted between them, and pressure tappings should be made on either side of the flanges (see MT P.1).

Pipes above 100mm diameter should use four equi-spaced tapping holes at each measurement point joined with tubing to form a piezometer ring. This ensures that variations in the flow profile around the pipe are averaged.

For the measurement of the pressure differential one may use a differential pressure Bourdon gauge (convenient but not as accurate as other devices, a mercury manometer, a pressure transducer, etc.).

Concentric orifice plates cannot be used with dirty fluids; eccentric or chord orifice plates should be used - these allow a free path along the bottom of the pipe which prevents the build up of solids behind the plate (see reference).

Equipment is readily available.

Introduction of orifice into pipework systems reduces the flow rate.

measurement technique:	**application area:**	**referenced from:** ECO P.3
P.3	HYDRONIC HEAT DISTRIBUTION OR SHW SYSTEMS	S.7, S.11, S.12, S.15, AP P.3, P.5, S.1, S.2, S.5, MT P.2, P.4, S.1

title:	**references to:**
FLOW RATE IN PIPES (FLOW METERS)	MT P.2, P.4

description:

The installation of a meter to measure hot water flow or assess SHW demand patterns will normally require breaking into existing pipework. It will therefore be necessary to valve off the supply and drain down the system.

Suitable meters are:
plastic turbine - for use in cold water,
steel turbine - for use in hot water,
positive displacement (e.g. rotary piston),
electro-magnetic flowmeters.

Consideration should be given to using meters which can be fitted with electrical pulse generators in order that the flow data can be remotely displayed or logged.

If the configuration of the pipework ahead of the meter is likely to generate swirl or disturbed velocity profiles, a flow conditioner should be fitted upstream. The upstream pipe should also be straight for a length > 10 pipe diameters before the meter and > 5 pipe diameters after the meter. Positive displacement meters are generally insensitive to flow disturbances.

cost:	**ease of use:**
\$50-\$150.	Fitting and calibration of meters should be performed by qualified staff.

accuracy:	**references:**
2% (dependent on flow rate).	ISO 4064, Part 2, ISO Standards Handbook 15.

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recommended applications:

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alternative techniques: MT P.2, P.4

SHW flow can be measured directly by fitting a hot water meter in the draw-off pipe from the storage cylinder/tank or the flow side of instantaneous hot water heaters.

---

additional information:

In applications to SHW systems, the following should be considered:
Measurement of the hot water draw-off from storage cylinder/tank may be made by metering the flow of cold feed water into the cylinder/tank. Metering the cold feed permits the use of less expensive meters having plastic rather than stainless steel moving parts.

In dwellings where the storage cylinder is fed from a cold water cistern (e.g. dwellings with electric resistive SHW heating) it may be possible to plug a cold water meter into the outlet at the bottom of the cistern. (This outlet should feed the storage cylinder/tank only). This avoids disruption of the pipework and reduces meter installation costs. (fit a reverse flow release valve downstream of the meter to avoid reverse flow caused by expansion of water in the storage tank - registering on the meter.)

Flow strainers should be fitted upstream of meters fitted on the hot water side of a storage tank to prevent detritus from the tank clogging the meter.

---

measurement technique:	**application area:**	**referenced from:** ECO P.3
P.4	PIPEWORK	S.7, S.11, S.12, S.15, AP P.3, P.5, S.1, S.2, S.5, MT P.2, P.3, S.1,

title:	**references to:**
FLOW RATE IN PIPES (PORTABLE ULTRASONIC FLOWMETER)	MT P.2, P.3

description:

In situations where the installation of an invasive type meter is not justified because of expense or inconvenience, an alternative is to use a portable clamp-on ultrasonic flow meter.

A version is available which uses the "time of flight" technique. Two transducers are clamped either side of the pipe at a pre-determined angular displacement and act as alternating transmitters/receivers of ultrasonic pulses. Flow velocity is calculated within the instrument by comparing the time taken for the ultrasonic pulse to travel "against" the flow with the time taken "with" the flow.

Accuracy depends on knowing the internal diameter of the pipe and calculating the Reynolds Number, for which a preprogrammed calculator is provided.

This Measurement Technique should only be applied to flows far from a pipe bend (more than 30 diameters).

cost:	**ease of use:**
$3000 or hire $300/week.	First use requires supplier supervision.

accuracy:	**references:**
Manufacturer claims 5% over full range. Poor at low flows.	

recommended applications:
Pipe size: 25mm - 2000 mm.
Pipe material: metal or plastic.
Maximum temperature: 200 ^{o}C.
Can be used to measure hot or cold water flows in any application.

alternative techniques: MT P.2, P.3 .

additional information:
One set of transducers covers all pipe sizes. Outputs show velocity and cumulative flow. Analogue output 4-20 mA proportional to velocity.
An example of equipment of this type is the "Portaflow" manufactured by Micronics, Southport, U.K.

measurement technique:	**application area:**	**referenced from:** ECO P.3
P.5	HEAT DISTRIBUTION AND SHW SYSTEMS	P.10, AP P.2, P.3, P.4, P.5, S.1, S.2, S.3, S.5

title:	**references to:**
MEASUREMENT OF PIPE SURFACE TEMPERATURE	MT P.6.

description:

In pipeworks with thin-walled pipes or pipes made out of a material which is a good heat conductor, the surface temperature will be close to the fluid temperature. This fact forms the basis for a non-invasive technique for measuring fluid temperature.

The sensor should have a low thermal mass, for example, thermocouples or platinum resistance thermometers can be used. The pipe surface where the sensor is to be placed should be cleaned and polished. The sensor should be attached firmly so that there is good contact between pipe and temperature sensor. A glue with good heat conductive properties can be used.

After application, the sensor and the pipe should be enclosed in several centimeters of insulating material for a distance of 5 to 10 pipe diameters, or at least 10 to 20 cm, upstream and downstream of the sensor.

To reduce the influence of the flow temperature profile and obtain a better measure of the average flow temperature, the sensor should be positioned downstream and close to a bend or an obstruction to the flow.

The response time to variations in flow temperature varies with the thickness of the pipe wall and the thermal mass of the sensor. This may create problems in pipes with intermittent flow such as draw-off in SHW systems.

cost: Thermocouples $7. Platinum resistance thermometers $5. Thermistors $4 to $40.	**ease of use:** Semi-skilled personnel.
accuracy: 1 K. Up to 10K if not correctly applied.	**references:** Fracastoro-Lyberg, 1983.

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recommended applications:

Measurement of surface temperature for pipes and tanks.

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alternative techniques:

MT P.6.

---

additional information:

Thermocouples may be subject to interference from stray electrical currents in metal pipes. The leads to the sensor should be drawn back and forth a few times (see Fig. 1) and taped to the pipe to minimize heat conduction between the sensor and the surroundings through the leads. Special care should be taken when measuring high temperatures (80-120 ^{o}C). Ordinary adhesive or polymeric insulation can not be used. Also, thermocouples should be welded or contact pressed and not soldered.

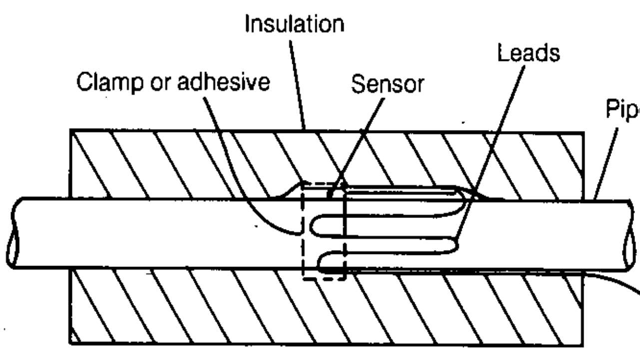

Fig. 1 Insulated sensor on pipe.

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measurement technique:	**application area:**	**referenced from:** ECO P.3
P.6	HEAT DISTRIBUTION AND SHW SYSTEMS	P.10, S.7, S.11, S.12, S.15, AP S.1, P.2, P.3, P.5, S.2, S.5.

title:	**references to:**
FLUID TEMPERATURE IN PIPES	MT P.1, P.5.

description:

Temperature measuring devices can be positioned in the flow. This will require breaking into existing pipework to fit thermometer pockets or test plugs (and associated fittings) into which the measurement devices can be inserted.

A thermometer pocket - a metal tube protruding into the pipe, with its inner end sealed and its outer end open. The pocket is filled with a heat transfer medium and a mercury thermometer - or other measuring device - inserted into it.

Twin lock test plug - a metal tube protruding into the flow. The inner end is open and the outer end fitted with a rubber seal. Temperature measuring devices can be pushed through the seal into the flow.

By producing a strong turbulent flow at the sensor, the temperature gradient becomes smaller and a more accurate measurement is obtained.

The thermometer pocket or test plug is, in small diameter pipes, usually placed in a bend (see Fig. 1). The sensor must be placed as far as possible into the socket. If thermocouple wire is used, galvanic contact should be avoided. It is recommended to kink the thermocouple wire a couple of times before bringing it into the socket, to prevent heat conduction through the supply wires to the thermocouple (see Fig. 1).

cost:	**ease of use:**
Test plug $3 each. Thermometer $3-$7 each.	Plumber required to fit pockets etc.

accuracy:	**references:**
Better than 1 K.	

recommended applications:

Large diameter or thick walled hot water pipes.

alternative techniques:
MT P.5. The delivery temperature at draw-off points in SHW systems can be measured using a hand-hold digital thermometer. Refrigerant temperature is easily determined from a pressure measurement (see MT P.1) by reading a table of saturated vapor pressure versus temperature for the refrigerant in question.

additional information:

The response time of the thermometer pocket itself may be significant. With test plugs the response time is that of the measuring device i.e. effectively instantaneous for thermocouples and PRTs.

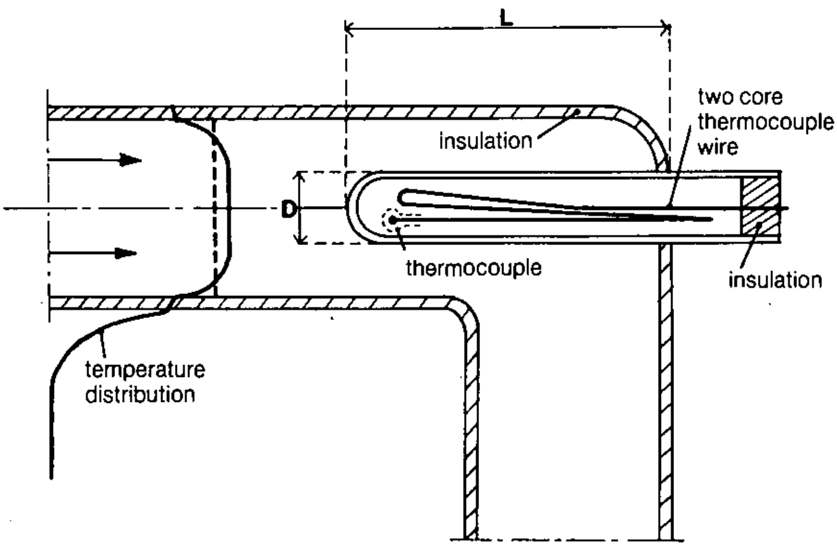


Fig. 1 Sensor in thermometer pocket.

measurement technique:	**application area:**	**referenced from:**
L.1	LIGHTING	ECO L.6, L.14, AP L.3

title:	**references to:**
MEASUREMENT OF ILLUMINANCE WITH LUX-METER	

description:

The measurement should be made under steady state conditions and during ongoing work if done at a work place. This means allowance for warm-up time for the lamps and care that varying daylight does not influence the measurement of the electric light.

Instrument: Cosine and V_λ-corrected sensor preferably connected by a flexible cable to analog or digital display.

cost:	**ease of use:**
Instrument: US$500-1000 Time: 10-15 min. per workplace	Easy to handle

accuracy:	**references:**
10% of measured value	

recommended applications:

- In connection with alterations in the lighting system.
- After complaints.

alternative techniques:

additional information:

As age of lamps and maintenance of fittings and room influence the illuminance, care must be taken when comparing the performance of an old installation with a new one.

Calibration must be controlled at regular intervals.

measurement technique:	! application area:	! referenced from:
EL.1	! ELECTRICAL	! MT EL.2, EL.3, EL.4
title: ELECTRICAL MEASURING INSTRUMENTS		! **references to:** MT EL.2, EL.3, EL.4

description:

The information contained on this sheet should be of general interest to those persons considering purchasing or using electrical measuring instruments. In MT EL.2 through 4 instructions on how to use the instruments are given.

1. Ways of Defining Accuracy. There are a number of ways of defining accuracy and the would-be purchaser should be careful when comparing the published accuracy of different equipment. Common methods include:

   i) percentage of full scale,
   ii) percentage of actual reading value,
   iii) a "resolution"; this is common for instruments with digital readout and is often stated as the number of digits.

   In most cases, particularly for quality instruments, the stated accuracy will be for some particular set of circumstances; e.g. type of waveform or frequency; often some indication of loss of accuracy when used outside of these circumstances is given. See below for details.

2. Factors that may affect Instrument Accuracy: Before purchasing or using instruments it should be checked that the instrument accuracy will not be compromised by its use in the intended application. In most cases, the effect on accuracy of the parameters given below are given by the instrument manufacturer.

   i) frequency - often a single frequency or frequency range is given,
   ii) waveform - accuracy is often quoted for a pure sine wave or with reference to a maximum "crest factor" (see App. C),
   iii) range - accuracy may vary from one range to another and may be specified for a mid range application,
   iv) power factor - applies to power factor and power measurements only: accuracy of instruments may be limited at very low power factors.

3. Conventional or Digital Type Meters. For auditing and many other purposes, digital type meters (DM) are replacing conventional analogue instruments of the moving iron and electrodynamometer type because of lower cost and ease of use. Their accuracy is normally more than adequate for auditing purposes. Some advice in this regard is given below.

   i) Cheaper instruments tend to be very frequency and waveform dependent. Avoid purchasing instruments that give accuracy for DC ampere or volt only, since DC range will seldom be used and is inherently the most accurate of all the "waveforms" that might be encountered. Instruments providing true rms measuring will normally have better accuracy over a wide range of frequencies and waveforms (see App. C).

ii) Most quality DM instruments are suitable for use with crest factors up to 3:1 (some up to 6:1) and should be suitable for most power measuring needs (a pure sine wave has a crest factor of 1.4:1).

Other factors to look for when selecting digital meters are:

i) Range of measurements - single meters often have the capability to measure two or more of the following: - ampére, volt, ohm, power factor, rpm and temperature.
ii) Analogue or digital displays. Digital displays avoid readout errors especially where the instrument must be used in difficult locations.
iii) Reading freeze - facilitates reading where meter dial cannot be read as measurement is taken.
iv) Display invert - may ease reading of meter in difficult locations.
v) Analogue output - which can be used with a strip chart or data logger to provide a permanent and continuous record.

cost:	**ease of use:**
accuracy:	**references:** ECM, 1984 and Risse, 1985.

recommended applications:

alternative techniques:

additional information:

measurement technique:	**application area:**	**referenced from:**
EL.2	ELECTRICAL	

title:	**references to:**
MEASUREMENT OF CURRENT	MT EL.1 and EL.4

description:

Methods of measurement depends on instrument choice and loads being measured. Options for AC systems are:

i) Moving iron analogue instrument installed in series with load (Fig. 1). Method limited to range of instrument, typically up to 100 A. Inherently measures rms value but has non-linear scale (cramped at low end, open at high end).

ii) Moving iron analogue instrument used with a current transformer (Fig. 2). Current transformer extends range of instrument.

iii) Clamp on ammeter/current probes (Fig. 3) is the preferred method for auditing purposes since it is not necessary to interrupt the power circuit to take a measurement. Typical ranges available 0.1 to 1000 A wide scale, less expensive instruments 3-500 A.

Instruments are often multi use; i.e. volt, ampére, ohm.

cost:	**ease of use:**
Moving iron: $200-$600 and up according to current range. Clamp on: $100 and up.	Easy, particularly using clamp ons.

accuracy:	**references:**
Moving iron: 0.5% of full scale Clamp on: 1 to 2% full scale	

recommended applications:

1. Establishing patterns of electrical energy use.
2. Simplified and approximate method of measuring electrical demand (see MT EL.4).

alternative techniques:

additional information:

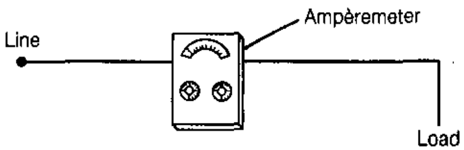


Fig. 1 Ampéremeter in series with loads.

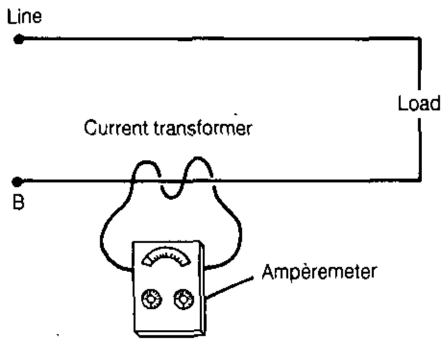


Fig. 2 Ampéremeter and current transformers.

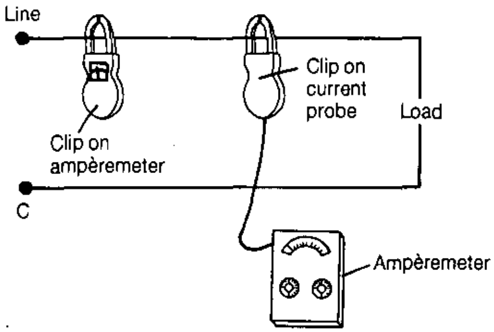


Fig. 3 Using clamp on ampére meter or current probe and remote device.

Note Recording ampéremeters are available giving a permanent record of current variation with time.

measurement technique:	**application area:**	**referenced from:**
EL.3	ELECTRICAL	ECO EL.2

title:	**references to:**
MEASUREMENT OF VOLTAGE	MT EL.1

description:

For all low voltage applications (less than 1000 V). Voltmeter is connected across the terminals of the circuit to be measured. See Fig.1.

Instrument choice for AC power systems measurement are:
i) Moving Iron (analogue) type, typical range 0-950 V. Inherently Measures rms value,
ii) Digital type most suitable and least expensive for audit work. Typical range 0.1 to 1000 V wide scale, less expensive 100 to 600 V.

Instruments are often multi use; e.g. volt, ampére, ohm.

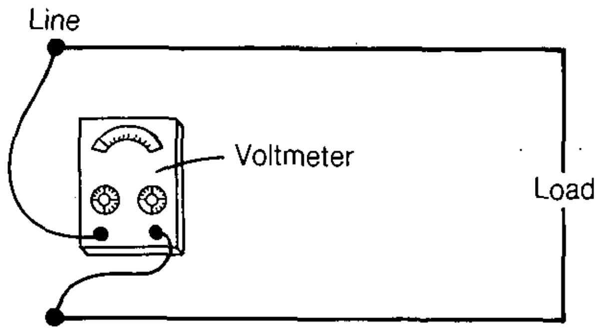


Fig. 1
Measurement of voltage.

cost:	**ease of use:**
Moving Iron: $200-$400 depending on range. Digital: $100 and up.	Every easy to use. Exercise caution to avoid electric shock.

accuracy:	**references:**
Moving Iron: 0.5% of full scale. Digital: 0.8 to 2% full scale	See also MT EL.1.

recommended applications:

1. Checking adequate supply voltages and volt age drops along feeders (low voltage can effect equipment performance, e.g. motors).
2. In power and power factor measurements.

alternative techniques:

additional information:

measurement technique: EL.4	**application area:** ELECTRICAL	**referenced from:** AP EL.2, EL.4, MT EL.2, EL.5, EL.6
title: MEASUREMENT OF ELECTRIC POWER (DEMAND)		**references to:** MT EL.1

description:

Power measurements are normally made using a portable wattmeter; the exact details of the method of measurement depend upon the size of the load, type of distribution (single or three phase) and instruments used.

Instrument choices:

i) Electrodynanometer (analogue) wattmeter. Typical range 120/240 V and 0.1 to 25 A (i.e. 12 W to 6 kW). Range can be extended indefinitely with use of current and potential transformers. Ability to measure power of waves with high crest factor, typically up to 8 or more.

ii) Digital - uses voltage probe(s) and clip on amp probe. Typical range 2 to 200 kW although higher wattage instruments (up to 2 MW) available. PREFERRED METHOD FOR AUDIT PURPOSES. Fig. 1 illustrates method of connection for power measurements. Typical maximum crest factor range of 3 but up to 6 or more available.

Capability of output for recorder with some instruments.

Often instruments provided with facility for measuring current, voltage and power factor.

cost: Electrodynanometer: \$700-\$800 single phase, \$1000+ for 3 phase. Digital: \$650 and up.	**ease of use:** Digital method relatively easy. Electrodynanometer fragile and easily damaged by overloads, especially when measuring very low power factor.
accuracy: Electrodynanometer: 0.5% of full scale. Digital: 1 to 2%.	**references:** See also MT EL1. For definition of crest factor see Section C.10.

recommended applications:

Instantaneous measurement of electrical demand for building or sub systems or for individual pieces of equipment.

alternative techniques:

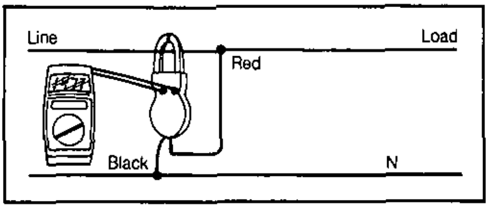
1. Power readings can be approximated by measuring current (a voltage being assumed) or current and voltage if the power factor is known or can be approximated.
2. Where <u>Watt</u> demand meters are installed demand can be read directly. Note that some demand meters record VA <u>not</u> W.
3. Where <u>kWh</u> meters are installed, the demand can be obtained by measuring the time for the consumption of X kWh; where X is read from the meter dial and the demand is given by

$$\frac{X * 60}{\text{time for consumption X (minutes)}}$$

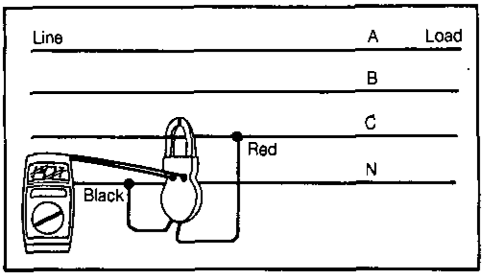
If 'X' is not given in units of kWh, 'X' has to be multiplied by the meter multiplier, which is normally indicated on the face of the meter.

additional information:

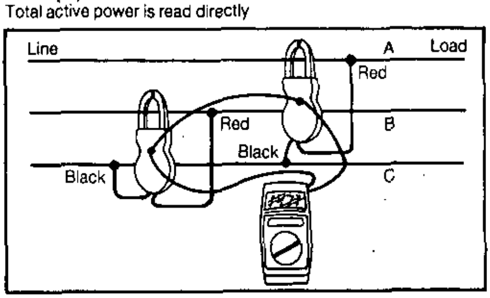
Single Phase – Active Power [W]
Total active power is read directly: P



Three Phase 4 Wire Balanced – Active Power [W]
Total active power is three times the meter reading: 3P



Three Phase 3 Wire Balanced and Unbalanced – Active Power [W]
Total active power is read directly



Three Phase 4 Wire Unbalanced – Active Power [W]
Total active power P is read directly

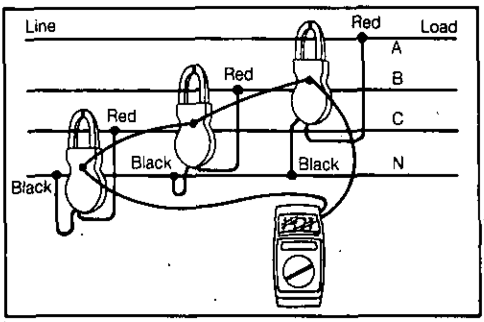


Fig. 1 Measurement of power using a digital Wattmeter.

measurement technique:	**application area:**	**referenced from:**
EL.5	ELECTRICAL	AP EL.1, EL.2, EL.3

title:	**references to:**
MEASUREMENT OF POWER FACTOR	MT EL.4

description:
Measurement of power factor can be made directly using a power factor meter. (Often such a function is combined with power measurement in a single instrument.)

Instrument choices (power factor meters):
i) Analogue. Often limited volt and ampére range requiring use of current transformers. Special instruments required for measuring very low power factors; i.e. power factors less than 0.5.
ii) Digital. Typical range 0 to Unit power factor 0-600 V, 3-500 A although accuracy falls off at lower power factors. PREFERRED METHOD FOR AUDITS since no need to interrupt power supply. See Fig. 1 for hook-up details.

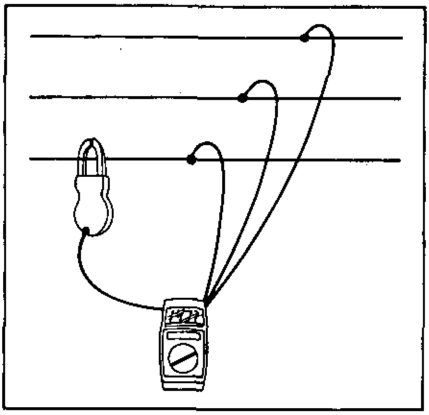


Fig. 1
Measurement of power factor using a power factor meter.

cost:	**ease of use:**
Analogue: $700 and up.	
Digital: $200 and up.	

accuracy:	**references:**
Analogue: 3% of full scale	
Digital: 3% of full scale	

recommended applications:
To determine power factor of building distribution or sub distribution systems or power factor of individual pieces of equipment.

---

alternative techniques:

1. By measuring power, voltage and current separately and calculating power factor using the relationship:

   $$\text{Power factor} = \frac{\text{Power (as indicated by wattmeter)}}{\text{Volt * Ampére}}$$

   To determine the power factor for the complete building the utility watt hour meter could be used to give a power reading (see MT EL.4).
2. By measuring power and reactive power separately using a wattmeter, see Fig. 2 and calculating power factor using the relationship:

   Power factor = (Real Power)/√((Real Power)^2 + (Reactive Power)^2).

Note that this method is strictly only correct for pure AC (sinusoidal) wave forms. The power factor so calculated will however give a reliable indication of the potential for power factor correction.

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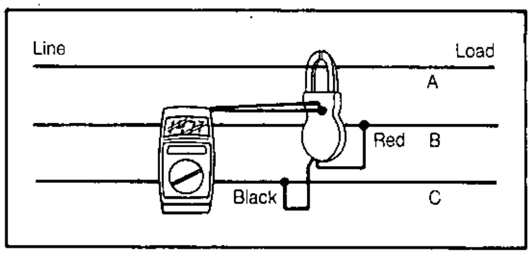
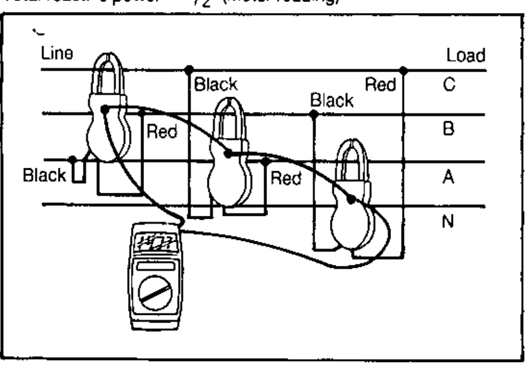
additional information:

Fig. 2
Measurement of reactive power.

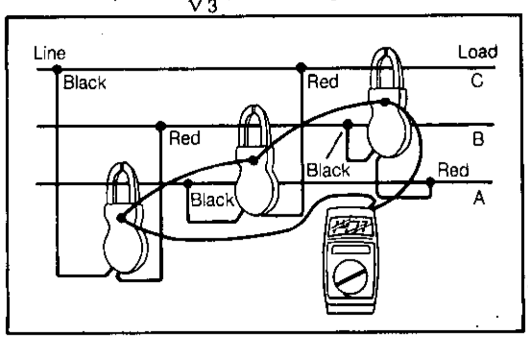
Three Phase 3 Wire Balanced – Reactive Power [VA]
Total reactive power = $\sqrt{3}$ · (meter reading)



Three Phase 4 Wire Balanced and Unbalanced – Reactive Power [VA]
Total reactive power = $^1/_2$ · (meter reading)



Three Phase 3 Wire Unbalanced – Reactive Power [VA]
Total reactive power = $\frac{1}{\sqrt{3}}$ (meter reading)



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measurement technique: EL.6	application area: ELECTRICAL	referenced from: ECO H/C.2, H/C.7, H/C.8, H/C.13, H/C.14
title: MEASUREMENT OF ELECTRICAL ENERGY CONSUMPTION		**references to:** MT EL.4, EL.7

description:

Electrical energy consumption can be directly measured using either integrating watt-hour meters or recording wattmeters.

i) Integrating watt hour type. This is the simplest type of device which provides a single record of accumulated energy use (kWh). Digital type portable instruments are available or permanent, electromagnetic rotating disc type (as used by utility companies for billing purposes) can be used. Unless the meter is read frequently, it gives no indication as to the profile of electrical energy use. A photographic technique can however be used to record the accumulated consumption on a regular basis (MT M.1). See also "Alternative Methods".

ii) Recording wattmeter type. These instruments provide a record of the variation of power demand (kW) with time. The record may be given on a chart or the demand might be printed out at selected intervals. Electrodynanometer and digital type instruments are available. Manual integration is required to find the actual energy consumption. DIGITAL TYPE WITH CLIP ON CURRENT PROBES ARE MOST APPROPRIATE FOR AUDITING PURPOSES.

Epuipment connections are similar to those described for power measurements (MT EL.4). Some instruments (digital type) offer both functions. Some types developed especially for monitoring energy use of appliances and small equipment straight from the equipment line cord.

cost:	ease of use:
Very large variations depending on range, accuracy, type and features.	Range of difficulty. Digital type generally relatively easy to use.
accuracy:	**references:**
As given on MT EL.4.	

---

recommended applications:

Complete building, sub system or individual equipment energy use determination.

---

alternative techniques:

1. For measuring/recording total building consumption the utility watt-hour meter can be utilised. To provide an automatic logging facility the utility can sometimes provide a pulse generating meter which generates a pulse for each meter disc rotation which can then be recorded and used to generate a demand profile. Alternatively an external pulse initiating device can be installed along with the counter and logging equipment.

2. For approximations of power consumed a recording ammeter instrument could be used. The accuracy of such a method will depend on the extent to which voltage and power factor can be assumed to be constant and is known.

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additional information:

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measurement technique:	**application area:**	**referenced from:** ECO H/C.
EL.7	ELECTRICAL	1, H/C.3, H/C.7, H/C.13, H/C.14, H.23, MT EL.6

title:	**references to:**
MONITORING ELECTRIC EQUIPMENT USAGE	MT H.1

description:

This description relates to the use of a running time meter.

An electromagnetic sensor is placed with the help of a velcro fastener on the cover of the piece of equipment to be measured. A built-in signal strength meter is used to test that a sufficiently strong electromagnetic field exists.

Devices of this kind are often battery operated and requires no connection to the electrical system, is left to record the operation of the equipment from which the following can be determined.

i) Running time (hours).
ii) Total (elapsed) time (hours).
iii) Total number of starts.
iv) Maximum and minimum running times.

cost:	**ease of use:**
US$ 150	Simple to use.

accuracy:	**references:**
0.1% better than.	MITEC, 1981

recommended applications:

Monitoring the use of electrical equipment which emit an electromagnetic field - primarily motors, (e.g. pumps and fans) but can be used on other equipment such as electromagnetically operated control valves.

alternative techniques:

Record current or power consumed by the equipment using clip on amp probe or wattmeter and data logger or strip chart recorder. For some applications simple counters can be used (see MT H.1).

additional information:

An example of a running time meter, the MITEC running time meter, is shown in Fig. 1 (MITEC, 1981).

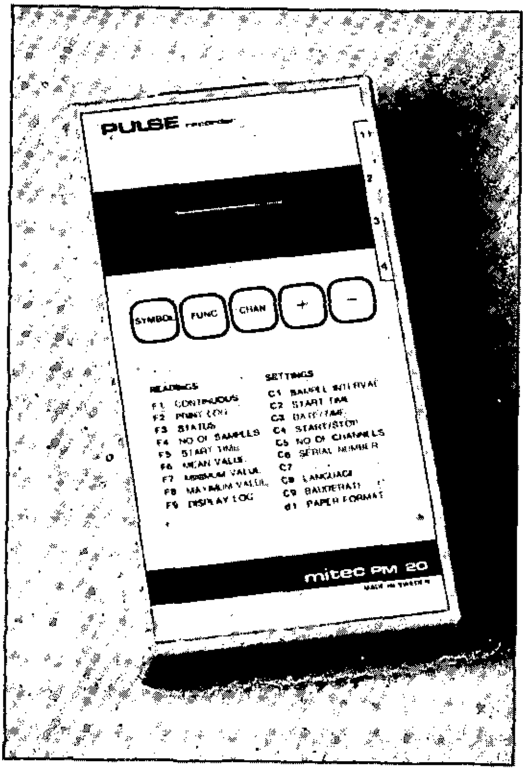

Fig. 1 Example of a running time meter.

measurement technique:	**application area:**	**referenced from:**
M.1	MISCELLANEOUS	AP EL.4.

title:	**references to:**
PHOTOGRAPHIC DATA LOGGER	

description:
A cine-camera with remote-control single frame exposure capability can be used to serve as a data logger to record any visual readout such as an electric watt-hour meter.

The procedure can be used for recording existing metering or can be used with site-installed metering such as thermo-electric digital thermocouple indicators. A digital display clock can be incorporated into the field of view to provide an independent time base.

A commercially available program timer can be used to trigger the camera at intervals as short as 5 minutes. The normal battery camera supply typically enclosed in the camera handle, can be replaced by larger "lantern" style for longer operation.

Lowlight cameras using 160 ASA super 8 standard 50' cartridges provide 3600 frames and are recommended.

In order to maintain film readability, processing by high quality photographic laboratories is recommended. Specks in the processed film because of poor processing can cause loss of data in a frame; splices can cause the loss of a number of hours of data.

Processed film can be viewed through a standard cine-viewer-editor. It is useful to transfer the information directly into a data processing system for which data handling programs can be pre-prepared. Typically this process takes less than 2 minutes per frame of information containing nine 6-digit numbers.

cost: $400 for camera, tripod and program timer	**ease of use:** Simple.
accuracy: As accurate as transducers.	**references:** Jones and Johnson, 1980.

recommended applications: Where small number of data channels are required, where it is required to record existing visual output meter, with wide angle lens camera can also be used to record such things as occupancy, use of blinds, shadows, number of lights on (in large open spaces).

alternative techniques: Electronic data loggers.

additional information:

APPENDIX H ANALYSIS TECHNIQUES

INTRODUCTION TO APP. H

This appendix contains a number of Analysis Techniques (AT) including algorithms presented in a common format. All Analysis Techniques here are either required for the evaluation of an Energy Conservation Opportunity (Appendix O), for performing an Audit Procedure (Appendix F), or can be applied for other reasons during an audit.

The Analysis Techniques are arranged in groups and individually numbered following the standard category system used throughout this Source Book (see Introduction, p. 10) to aid filing and referencing. An index listing each AT is provided below.

The format used for presenting Analysis Techniques is identical to the one described for Audit Procedures (App. F).

This appendix contains only simple algorithms and none of the more sophisticated models necessary for a more detailed evaluation of many ECOs, or for the evaluation of a combination of ECOs. For a description of more complex models, see Ch. 6.

LIST OF ANALYSIS TECHNIQUES (AT)

ELECTRICAL SYSTEMS (EL)

EL.1 Savings from electrical equipment changes.
EL.2 Calculating the required reactive power for power factors correction.
EL.3 Evaluation of motor speed control devices.

MISCELLANEOUS (M)

M.1 Energy signature.
M.2 Bin analysis methods.
M.3 Effect of changes in space gains.
M.4 A method for assessing comfort and energy consumption.
M.5 Simple pay-back time of an investment.
M.6 Discounted Payback time of an investment.
M.7 Present Value or Net Life Cycle Savings of an investment.
M.8 Internal Rate of Return of an investment.
M.9 Cost for Savings of an investment.

analysis technique:	**application area:**	**referenced from:**
E.1	ENVELOPE, HEATING AND COOLING	

title:	**references to:** MT E.1.
HEATING AND COOLING DEGREE DAYS	RV E.1

description:
The following notation is used:

HDD Number of heating degree days [K*days],
CDD Number of cooling degree days [K*days].
T_e Daily average external temperature [^oC],
T_b Base temperature [^oC],
T_i Average internal temperature [^oC]
$\bar{T}_e$ Seasonal average external temperature [^oC]
T_{ref} Reference temperature [^oC]
n_h Number of heating days
n_c Number of cooling days

The number of heating degree days is calculated from

$$HDD = \Sigma_1^{n_h} \quad (T_b - T_e) \qquad \text{for } T_b > T_e.$$

Similarly, the number of cooling degree days is calculated form

$$CDD = \Sigma_1^{n_c} \quad (T_e - T_b) \qquad \text{for } T_e > T_b.$$

For the measurement of T_e, see MT E.1. Values of the base temperature, see RV E.1.

The number of heating or cooling degree hours can be calculated in the same manner as above, but the summation is performed over hours instead of days.

Degree days can be used:

i) As a climatic index,
ii) To predict the energy demand,
iii) To compare the energy demand between different years.

In the first case the numbers n_h and n_c may be defined "a priori". They may also, assuming that there is a constant amount of free heat gains in the case of heating and an external temperature below which no conditioning is required in the case of cooling, be defined by the intersection of the external temperature and reference temperatures (see Fig. 1). In the third case the numbers n_h and n_c are given by the actual length of the heating and cooling seasons, which can be determined by the building owner, manager, or occupant or given by local or state regulations.

accuracy:	**references:**

recommended applications:

---

alternative techniques:

---

additional information:

The Degree Day concept has been used to determine the annual heating energy demand since a long time. The reason for this is as follows. The net energy supplied by the heating plant to the building, E_h, may be considered to depend upon the sum of the energy losses due to transmission and ventilation, E_{loss}, and solar and internal heat gains, E_g, as $E_h = E_{loss} - E_g$.
Assuming that E_{loss} is proportional to the average indoor-outdoor temperature difference $T_i - \bar{T}_e$ and to the length of the heating season, one gets

$$E_h = const * (T_i - \bar{T}_e) * n_h - E_g.$$

The base temperature, T_b, can then be defined from

$$E_g/E_{loss} = (T_i - T_b)/(T_i - \bar{T}_e) \text{ which gives } E_h = const * HDD.$$

From this also follows that the base temperature also depends on the average internal temperature considered "normal" in a particular country, so that the definition of degree days varies from one country to another (see RV E.1).

The use of a standard DD value for all building types, irrespective of shape factor, glazing and insulation levels, is a crude approximation, no longer valid for solar houses or low energy houses.

The use of degree days to determine the cooling energy demand is less common because transmission and ventilation heat flows are often only a small fraction of the cooling load. However, a good correlation may sometimes be found between CDD and cooling energy demands, due to a strong correlation between air temperature <u>and</u> air humidity or solar radiation which are two factors strongly influencing the cooling load.

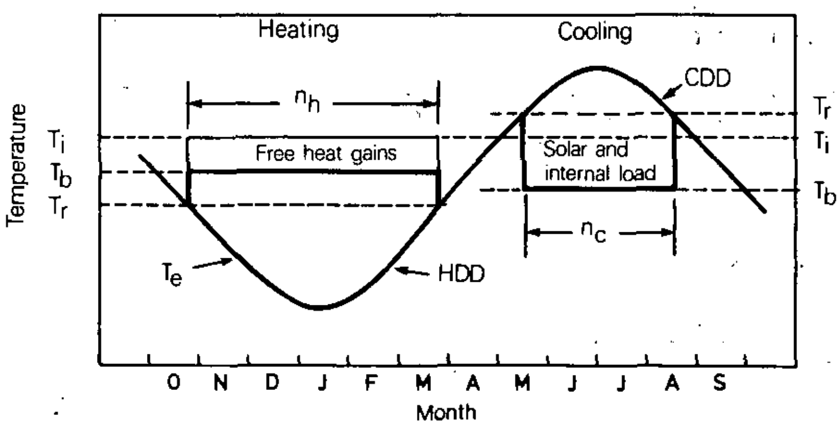

Fig. 1 Shematic figure illustrating the degree day concept.

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analysis technique:	application area:	referenced from:
E.2		AP E.3, E.4.

title:	references to:
DETERMINATION OF AIR CHANGE RATES FROM TRACER GAS MEASUREMENTS	

description:

The following notation is used (for definition of methods, see AP E.3):

n rate of air exchange [h^{-1}],

t time [h],

V building volume [m^3],

q flow of tracer gas [m^3/h],

C_s tracer gas concentration,

i) Decay method. Plot the tracer gas concentration versus time. Let C_{s1} and C_{s2} be the concentration at times t_1 and t_2 and A be the area below the curve between C_{s1} and C_{s2}. The air exchange rate is then given by

$$n = (C_{s1} - C_{s2})/A.$$

A simpler but less accurate method to evaluate data using tracer gas decay is to plot the log of the concentration versus time (hours). Periodic measurements will fall on a straight line with a small scatter if the volume is well mixed (see Fig. 1). The slope of the line is the rate of air exchange per hour. Any improvement to retrofit action will alter the slope and normally will be evident in less than one hour.

ii) The constant flow method. This method requires a determination of the rate of air exchange, the measurements starting at time t=0, from the equation

$$n = (q - \exp(-nt)/(C_s(t)*V).$$

iii) The constant concentration method. Here the rate of air exchange can be determined from

$$n = q/(C_s*V).$$

accuracy:	references:

---

recommended applications:

---

alternative techniques:

---

additional information:

When the decay method is used, the seed gas is introduced to the building volume under study and the decay of the tracer gas concentration is recorded.

The constant flow implies that a constant amount of seed gas is introduced into the building volume and the tracer gas concentration is recorded.

The constant concentration method relies on a feed-back mechanism to continuously introduce an amount of seed gas into the building volume in such a way that the tracer gas concentration is kept constant.

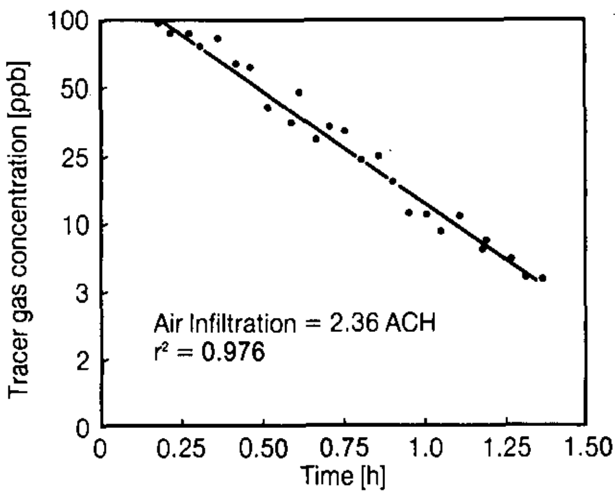

Fig. 1 Example of plot of tracer gas concentration versus time.

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analysis technique:	application area:	referenced from: AT E.4
E.3	ENVELOPE	

title:	references to: AT H.1
HEAT LOSS MODEL FOR EVALUATING ENVELOPE ECO SAVINGS	

description:
This is a simple steady-state model which calculates building energy requirements over the heating season. The computation required can be done readily on a pocket calculator.

The model uses seasonal mean values of internal and external temperature to calculate the seasonal energy consumption of a simple building (single 20 m). Separate allowance is made for incidental gains.

The following notation is used.

T_i mean internal temperature over heating season [^oC],
T_e mean external temperature over heating season [^oC],
A_i area of building envelope component [m^2],
U_i U-value of building component [$W/m^2.K$],
V building heated volume [m^3],
n ventilation and infiltration rate [h^{-1}],
t_h length of heating season [days],
L_h average daily heat loss [kWh/day],
Q_h average daily heating requirement [kWh/day],
Q_g internal free daily heat gains [kWh/day],
Q_{sol} average daily solar gains [kWh/day],
Q_a annual heating requirement [kWh/yr] (see AT H.1).
$\eta_{p,s}$ seasonal efficiency of heat plant.

The model encompasses predictions of L_h, Q_h, Q_a and the annual heating cost:

$L_h = 24*(\Sigma A_i U_i + n*V/3)* (T_i - T_e)/1000$,
$Q_h = L_h - Q_g - Q_{sol}$,
$Q_a = Q_h * t_h / \eta_{p,s}$.

Total energy cost = Q_a* (unit cost of energy) [\$/kWh].

accuracy:	references:

---

recommended applications:

The method used is not sufficiently refined to make accurate predictions of energy consumption over short periods. However, it does allow for the effect of improving insulation levels, double glazing, etc. and different heating standards to be assessed over a heating season by recommending suitable mean internal temperatures corresponding to different insulation levels, heating standards and occupancy patterns.

---

alternative techniques:

---

additional information:

Internal free heat gains consist of metabolic heat from occupants, heat losses from SHW production, appliances, lighting, etc.

Useful solar gains depend on area and orientation of glazing; latitude of building site, thermal building mass, etc.

Data on internal free heat gains and useful solar gains in general show large regional variations and dependence on building type, but are available for many locations. When applied to predicting savings from upgrading insulation level or glazing, this model has in many cases been shown to have a tendency to overestimate the savings.

House occupants may choose to take their benefit from ECO implementation in the form of improved comfort levels. For example, they may choose to enjoy higher internal temperature after cavity-wall filling than before it. This will reduce the magnitude of the cost savings.

---

analysis technique: E.4	**application area:** ENVELOPE	**referenced from:** ECO E.8, E.9, E.10, E.11, E.12, E.13, E.14, E.15, E.16, E.17, E.20, E.22, E.24, E.28.
title: U-VALUES AND INFILTRATION RATES FOR BUILDING COMPONENTS		**references to:** AP E.5, E.7, E.12, AT E.3, RV E.2, E.4, E.6

description:
The U-value of a building component can be calculated by adding the thermal resistances of the elements comprising the wall or roof, etc. and taking the reciprocal i.e.

$$U = 1/(R_{si} + R_1 + \ldots + R_n + R_{se}).$$

The thermal resistance R is given by $R = d/\lambda$.

Here,

U = thermal transmittance [$W/m^2,K$],

R_{si} = inside surface resistance [$m^2,K/W$],

R_1, R_2, R_n = thermal resistance of wall or roof element [$m^2,K/W$],

R_{se} = external surface resistance [$m^2,K/W$],

d = thickness of element [m],

λ = thermal conductivity of element [$W/m,K$].

Conductivities for a number of building materials can be found in RV E.2

The effective leakage area is determined from

$$A = q/\sqrt{(2\,\Delta p/\rho)}$$

where q = air flow rate [m^3/s],

ρ = density of air [kg/m^3],

Δp = pressure difference [Pa],

A = effective leakage area [m^2].

The effective leakage area is determined by pressurization test (AP E.5, E.7, E.12) of a building or a building component. The effective leakage area is often defined for a fixed value of the pressure difference, e.g. 4 Pa.
The measurements may be performed for higher pressure differences, and an extrapolation is made to the fixed value defining the effective leakage area, e.g. by plotting q versus $\sqrt{\Delta p}$.

---

accuracy: ! **references:**

---

recommended applications:

This AT does not take into account the influence from thermal bridges.

---

alternative techniques:

---

additional information:

Typical ventilation rates for varying building tightnesses are given in RV E.4. Leakage areas [cm^2/m^2] for different window and door types with and without weatherstripping are given in RV E.6. Note that the ventilation rate (air changes per hour) calculated by an analysis of the leakage areas around windows and doors will be an underestimate of the true ventilation rate as it will take no account of infiltration through other parts of the building envelope.

The effect on the energy requirements of the building resulting from changes in component U-values, building ventilation rate (as discussed above) and incidental gains (e.g. reduction in solar gain due to the filling in of windows), can be individually or collectively analysed using a simple heat loss model such as that for dwellings discussed in AT E.3.

---

analysis technique:	**application area:**	**referenced from:**
R.1	REGULATION	ECO R.3, R.4, R.5, R.20, R.21, R.26, R.34, R.36, D.2, D.4.

title:	**references to:**
CALCULATION OF SAVINGS OF ECOS INVOLVING REDUCTIONS IN VENTILATION AIR	AT E.1, M.2.

description:

Energy savings are possible in two principal areas:

i) requirements for conditioning outside air,
ii) fan power savings.

At design conditions for a change in ventilation rate:

$$\Delta q = 4.3 * \Delta Q * \Delta h$$

where
ΔQ = change in design load [W];
Δq = change in design flow rate [m^3/s];
Δh = enthalpy difference between inside and outside conditions [kJ/kg air].

Where latent loads have no impact upon the energy savings, i.e. where humidification or mechanical cooling is not provided or when the humidity in outside air can be neglected, e.g. in cold climates, Δq is given by:

$$\Delta q = 1.2 * \Delta Q * \Delta T$$

where
ΔT = temperature difference between inside and outside conditioning [K].

Equations concerning fan energy savings are given in App. C.5.

Energy savings can be calculated using either degree day (see AT E.1), bin (see AT M.2) or hourly methods (see Ch. 7) depending upon the particular circumstances as outlined below.

For calculating ventilation energy changes, degree-day calculations are normally only applicable for heating only applications and to those instances where system operation and space temperatures are maintained constant. Where ventilation is scheduled on and off or where cooling or humidification is involved, it is normally necessary to move to bin or hourly methods.

In considering ventilation equipment operation, the impact of its operation on the movement of air from other zones or its influence on the infiltration rate should not be ignored.

Where cooling is involved, particularly in those instances where cooling cycles are employed, the use of hourly calculation methods provide the most satisfactory results but often cannot be justified because of the expense. In such cases it may be useful to try and justify the implication of an ECO based on calculations carried out just for the colder months.

Fan energy consumption changes can be calculated by multiplying the change in fan motor power consumption by the hours of fan operation. The only exception to this rule is where a fan is cycled to maintain a lower ventilation rate than would be obtained were the fan to be operated continuously.

These general rules can be applied to estimating the energy implication of ECOs.

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accuracy:	**references:**

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recommended applications:

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alternative techniques:

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additional information:

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analysis technique:	**application area:**	**referenced from:**
R.2	REGULATION, NIGHTTIME COOLING	ECO R.6, R.36.

title:	**references to:**
ESTIMATION OF SAVINGS ASSOCIATED WITH NIGHTTIME VENTILATION COOLING	MT M.2.

description:
Savings associated with nighttime cooling are only possible where cool outside air is used for cooling in place of mechanically cooled air. Actual savings possible will depend on a number of variables which will also affect the way in which calculations need to be made. These variables include:

i) Building occupancy during nighttime cooling.
If the building is unoccupied, nighttime cooling should be limited to removing the residual cooling load remaining from the occupied period.

ii) Natural or mechanical ventilation.
Ventilation fans use energy and one must consider the relative energy required to run the fans as opposed to mechanical cooling. For marginally cool outside air the fans will have to run longer to achieve the same cooling as would otherwise be possible using air conditioning. A similar tradeoff is required for VAV systems where one might trade low fan volumes with mechanical cooling against high volumes of possibly warmer outside air.

iii) Ventilation fan control.
Fan energy can be minimised by controlling fan use as opposed to running ventilation fans continuously through the cooling season evenings while the space is calling for cooling. When the building is unoccupied, control could be by:
  a) turning fans on at some pre-determined outside air temperature which is considered to give economical cooling for the fan power involved.
  b) delaying and limiting the operation of the fans to the coldest period of the night.

A bin method type of analysis (MT M.2) can be applied to estimate savings as long as bin data are available, broken down, as a minimum, into daytime and nighttime hours.

To account for variable loads (e.g. in the case of unoccupied building the residual daytime cooling load) and the type of control systems described in iii) above hourly analysis methods (see Ch. 7) are considered necessary.

accuracy:	**references:**

recommended applications:

alternative techniques:

additional information:

analysis technique:	**application area:**	**referenced from:**
R.3	WARM AIR, HYDRONICALLY HEATED SYSTEMS	ECO R.8.

title:	**references to:**
ESTIMATION OF ENERGY SAVINGS ASSOCIATED WITH COIL CIRCULATOR SHUT-OFF	AT P.1, O.1.

description:
Energy savings are derived from two areas:

1) Circulator (pump) electricity savings, and
2) Convection losses from heating coil.

Circulator Savings can be simply calculated by multiplying the projected number of hours that the pump can be turned off by the pump electrical load. *For heating coil circulators, the circulator can normally be turned off by* scheduling it off for all those hours that the outdoor temperature is above the building "balance temperature" (the outdoor air temperature at which heating is no longer required). An exception would be where full year operation of the heating coil is required, e.g. in re-heat type systems. For cooling, the cooling coil circulator can be turned off for all those hours that the outside air is lower than the lowest air temperature below which cooling is not required, or for those HVAC systems with full air economisers, below the scheduled deck temperature.
Temperature-frequency data tables normally obtainable from local meteorological stations can be used to find the number of hours above or below certain temperatures.

Try to justify capital cost of ECO on this basis alone before carrying out more involved calculations for coil heat losses.

Heating Coil Savings are only realisable where the heating coil would otherwise be kept hot and would normally not be applicable to those H&V systems where night/unoccupied mode of operation relies on maintaining full heat to the coil and cycling fan for temperature control. (Normal daytime operation would see continuous fan operation and the temperature of the coil supply water modulated by a thermostat.)

Heat Loss from Coils occurs if the coil circulator is not shut off. Note that some heat may contribute usefully to the space heating needs.

i) Through insulated pipe to and from coil,
ii) Through uninsulated coil headers and frame and through the circulator case, and
iii) From fins and tubes in the coil, natural heat transfer tends to heat up surrounding air in ductwork causing an increase in heat loss through ductwork. This heated air can also leak out of outside air dampers.

The difficulty in estimating the heat loss from these areas comes as a result of trying to estimate surface heat transfer coefficients. This is not too much of a problem for insulated surfaces item i) (the coefficient is small compared to the insulation), but it is important for uninsulated metal. Surface heat transfer coefficients are dependent on surface temperatures, air temperatures, and the resistance to free convection.

Approximation may be made for items in ii) using the following relationships:

$$q_c = h_c * A * (T_s - T_a)$$

where
q_c = free convection heat loss [W]
h_c = convective heat transfer coefficient, see below, [W/m^2,K],
A = surface area, [m^2],
T_s = surface temperature [^oC],
T_a = air temperature [^oC].

Free convection from various surfaces to air at atmospheric pressure

Vertical plane or cylinder	$h_c = 1.42*(\Delta T/h)^{1/4}$,
Horizontal cylinder	$h_c = 1.32*(\Delta T/d)^{1/4}$,
Heated plate facing upward or cooled plate facing downward	$h_c = 1.32*(\Delta T/l)^{1/4}$,
Heated plate facing downward or cooled plate facing upward	$h_c = 0.61*(\Delta T/l)^{1/5}$,

where ΔT = temperature difference $T_s - T_a$, [K],
h = height [m],
d = diameter, [m] and
l = mean of two dimensions for rectangle [m].

Note that in the above formulas radiative losses are not taken into account. See also AT P.1 and AT D.1.

Estimates for iii) are more difficult and unless there is an obvious convection or leakage to outside it is probably not worthwhile to try and compute this component. There will be a heat build up in the duct during the fan off period as the coil looses heat to the surrounding duct air. The result will be some increase in duct heat losses, a major portion of the heat should however be carried off into the space once the fan restarts unless time between fan starts are long and the heated air travels along the ductwork system aided by natural buoyancy.

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accuracy: ! **references:**

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recommended applications:

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alternative techniques:

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additional information:

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analysis technique:	application area:	referenced from:
R.4	PARKING GARAGES AND VEHICLE FACILITIES	ECO R.16, R.39.

title:	references to:
ESTIMATION OF VENTILATION LOAD AND FAN ENERGY SAVINGS AND CALCULATION OF TIME WEIGHTED CONCENTRATION LEVELS	AT E.1, M.2, RV R.7.

description:

Exposure standards are often expressed in terms of time weighted averages (TWA). An understanding of the calculation of TWA values is required in all those instances where TWA exposure standards apply and intermittent ventilation techniques are being considered. TWA is calculated using the following equation:

$$TWA = \Sigma_{i=1}^{n} C_i t_i / t$$

TWA has the same units as C
$C_1, \ldots, C_n$ = concentration during different time periods (e.g., ppm or mg/m^3),
$t_1, \ldots, t_n$ = time duration of the exposure at the concentration C [h],

t = defined time period, often taken as 8 hours but normally defined in exposure standards.

Note that "peak" or "excursion" values are often specified which define the absolute level of concentration permissible irrespective of the time involved - such values also need to be considered when carrying out intermittent ventilation calculations.

For parking garages, it is first necessary to have some idea of the frequency and period of operation of the vehicles from which profiles of use and carbon monoxide production can be established. It is useful to develop two profiles; the first that represents peak or design conditions, the second representing the average or typical case (monitored data could be used if available).

The peak case can be used to establish the minimum acceptable continuous ventilation rate necessary to meet the required exposure standard using the formula:

$$q = N*c*V*10^6/(60*C)$$

where
q = ventilation rate [l/s],
N = number of vehicles in operation,
c = rate of production of carbon monoxide [g/min] (see RV R.7),
C = permissible concentration level [ppm],
V = specific volume of ventilating air [m^3/kg].

For the "typical day", the use of a steady state calculation will suffice in most applications using either a daily average (time weighted) number of vehicles in operation or dividing the profile into a number of time periods and calculating average values over each time period. This last approach has some merit where operation is not uniform over the day and some weight can be given to differing temperatures throughout the day when calculating energy savings.

Where the garage ventilating air is required to be heated (which is the only appreciable reason for considering a CO controlled ventilation system), the heating energy savings can be calculated as the difference between the fixed and variable ventilation rate using a degree method or, for greater accuracy, a bin method (see AT E.1 and AT M.2).

In addition, there will be fan energy savings which can be calculated from the product of fan motor load and difference in number of operating hours of the vent fan(s). (This assumes fans will turn on and off to meet the required rate of ventilation.)

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accuracy:	**references:**

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recommended applications:

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alternative techniques:

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additional information:

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analysis technique:	**application area:**	**referenced from:**
R.5	REGULATION	ECO R.19.

title:	**references to:**
BASIC RELATIONSHIPS - EVAPORATIVE COOLING	AT M.2, RV R.8.

description:

The effectiveness of evaporative cooling, ε, is defined from

$$\epsilon = (T_1-T_2)/(T_1-T_3),$$

where:

T_1 = dry bulb temperature air entering evaporative cooler,

T_2 = dry bulb temperature leaving evaporative cooler,

T_3 = wet bulb temperature entering evaporative cooler.

Some examples are given in RV R.8.

The psychrometric process (direct, indirect or indirect-direct combination) is schematically shown in Fig. 1.

An indirect system entails the use of a heat exchanger. Evaporative cooling is utilised to cool one air stream which in turn transfers heat (cooling) to a second air stream via the heat exchanger.

For the analysis of savings, a bin method (see AT M.2) with coincident wet bulb data, or wet bulb/dry bulb coincident temperature frequency data are required. Hand calculations can be quite tedious and computer versions using the same methods or, preferably, hourly methods are more appropriate.

accuracy:	**references:** ASHRAE Equipment, Ch. 4, 1983; ASHRAE Systems, Ch. 39, 1984; Pearson, 1982; Dombroski, 1984; Meyer, 1983; Eskra, 1980 and Supple, 1982.

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recommended applications:

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alternative techniques:

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additional information:

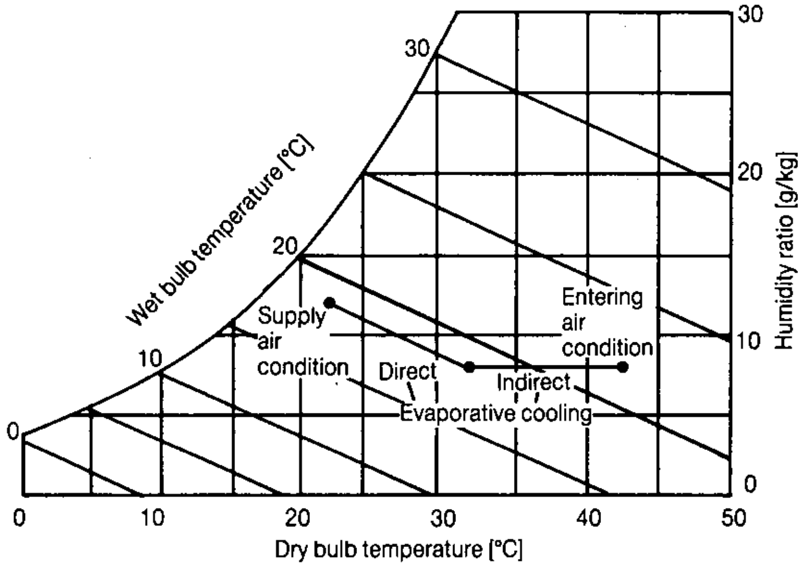

Fig. 1 Psychrometric process, direct, indirect and indirect-direct combination.

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analysis technique:	application area:	referenced from:
R.6	SVIMMING POOL HALLS	ECO R.15, R.35, M.?

title:	references to:
SWIMMING POOL HALL HUMIDITY CONTROL - BASIC RELATIONSHIP	RV R.12.

description:

The pool water evaporation rate, w_p, is given by

$$w_p = f*A*(C_1+C_2*v)*(p_w-p_a)/Y \qquad [1]$$

where:

w_p = water evaporation rate [kg/s],
A = surface area of pool [m^2],
f = "occupancy factor" allows for increased evaporation resulting from the wetting of the pool surrounding or use of pool covers.
C_1 = 0.0887 W/m^2,
C_2 = 0.07815 J/m^3,
v = air speed over water surface [m/s],
Y = latent heat of vaporisation at surface water temperature [kJ/kg],
p_a = saturation pressure at room air dewpoint [Pa],
p_w = saturation vapor pressure taken at the surface water temperature [Pa].

For reference values see RV R.12.

For values of Y about 2,330 kJ/kg and values of v ranging from 0.05 to 0.15 m/s, one can use a simplified expression:

$$w_p = 4.0*10^{-8}*A*f*(p_w-p_a) \qquad [2]$$

The pool water makeup heat loss is given by

$$q_h = 2300\ w_p + 4.19(T_p-T_m) \qquad [3]$$

where:
q_h = latent component and sensible component [W],
T_p = pool water temperature [^oC],
T_m = makeup water temperature, [^oC].

The minimal air flow required to remove the evaporated water, q_a, is given by:

$$q_a = 830\ q_h/(w_i - w_e),$$

where:

q_a = flow of air [l/s],

w_e = humidity ratio of outdoor air at design criteria [kg/kg],

w_i = humidity ratio of swimming pool air at design criteria [kg/kg].

The values of w_o and w_i can be obtained from psychrometric charts.

The minimal air flow rate should not be less than that required for air quality purposes.

For most practical cases, where it can be assumed that the swimming pool hall is <u>not</u> air conditioned, the ventilation loss q_v is given by

$$q_v = 1.21 * q_a * (T_i - T_e)$$

where

q_v = ventilation loss [W],

T_i = inside air temperature [^oC],

T_e = external air temperature [^oC].

The total design heat loss is given by the sum of the Ventilation loss and the Pool water loss.

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accuracy:	**references:**

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recommended applications:

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alternative techniques:

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additional information:

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analysis technique:	**application area:**	**referenced from:**
R.7	SWIMMING POOL HALLS	ECO R.15, R.35, M.11

title:	**references to:**
SWIMMING POOL HALL HUMIDITY CONTROL - SPECIFIC ECO EVALUATION METHODS	AT E.1, E.2, RV R.12.

description:

There are two basic options:

i) Reducing pool evaporation rate.
ii) Reducing ventilation loss.

Reduction of <u>Pool Evaporation Rate</u>:

Possible options include permitting higher room humidities or lowering pool water temperature; in practice only real option is to use a pool cover which typically would reduce evaporation rate by 85% to 90%.

Reduction in evaporation rate (see RV R.12) will permit lower ventilation rates or in the case of mechanical humidifier installation, reduced system operation.

Reduction of <u>Ventilation Loss</u>:

Possible options include ventilation rate controlled by a space humidistat, air to air heat recovery or mechanical dehumidification systems.

The following recommendations are based on the assumption that the pool hall is <u>not</u> air conditioned.

Energy savings can be estimated by calculating the before and after retrofit situation using a degree-day method (see AT E.1).

In all instances, except the constant ventilation case, it is important to consider:

a) the variations in pool evaporation rate with occupancy, and
b) the variations in the moisture content of the outside air and its subsequent effect on the moisture balance of the pool air.

i) Constant Ventilation Rate.

The degree day method could be applied to estimate the ventilation loss. As a first approximation pool water heating requirement can be estimated using average monthly differences between supply and pool water temperatures and a constant pool water evaporation rate. Inaccuracies are introduced in such an approach, however, since the pool hall humidity will vary with outside air conditioning. Bin (see AT E.2) or hourly techniques could be used to improve the accuracy of the estimation.

ii) Humidistat Control.

A bin method is the least complex method with an acceptable degree of accuracy for calculating ventilation losses. Bins should be arranged on the basis of outside conditions and use of pool, e.g. occupied and unoccupied periods. Average occupancy factors, not design values, should be used during the occupied periods to calculate, in conjunction with outside conditions, the desired ventilation rate.

If the humidistat is used to cycle ventilation fans on and off, as opposed to constant room air recirculation and outside air-return air mixing dampers, there will be additional fan energy savings. Such savings are difficult to estimate without using an hourly calculation method but in most cases, especially in colder climates, the savings will be small compared with the ventilation air savings.

The use of average monthly values as described above should be satisfactory for estimating pool water heating requirements.

iii) Mechanical Dehumidification.

A mechanical dehumidifier (heat pump) is typically used to condense the moisture out of the swimming pool hall air and return it to the pool, the mechanical energy, provided by the compressor motor, expended to condense the water vapor being dumped into the pool hall where it contributes to the heating of the space.

In such an installation ventilation is normally only provided to satisfy occupancy requirements and should be shut off when the pool is unoccupied or varied proportionately with occupancy density.

Pool water heating is eliminated.

The electrical energy expended to condense the water vapor in the pool air is usually provided by equipment suppliers. As a minimum a bin method can be used to calculate the useful contribution of this compressor energy to the pool hall heating. In a retrofit situation it is possible to provide the humidifier as a separate system to the pool heating and ventilation system while in a new installation it is normal for optimum energy saving and lowest installed cost to integrate it into a common heating, ventilating and humidity control system. When two separate systems are installed there is inevitably some waste energy when excess compressor heat creates a "cooling load" in the space requiring the introduction of cooler, but in fall through spring, tempered outside air. This interaction is difficult to estimate.

iv) Heat Recovery.

A heat recovery system can be installed with constant or humidistat controlled ventilation but the expense of installing heat energy justifies the installation of humidistat control.

Method of accounting for ventilation savings are described in AT R.1. The use of average monthly values can be used to estimate pool water heating requirements.

v) Pool Covers.

Unless degree days are available broken down into periods that approximate breakdown of hours when pool is used and not used, use bin or hourly analysis methods to estimate ventilation loss are recommended. An "occupancy factor" of 0.1 to 0.15 can be used to calculate the evaporation rate for those hours when the pool cover is in place.

Whenever the pool water evaporation rate is reduced or condensed water vapor is returned to the pool (e.g. mechanical dehumidification or condensate from heat recovery devices), there will be an additional saving resulting from a reduction of water charges.

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accuracy:	**references:**

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recommended applications:

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alternative techniques:

As referenced above.

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additional information:

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analysis technique:	application area:	referenced from:
R.8	REGULATION	ECO R.38.

title:	references to:
EFFECT OF RADIANT HEATING ON HEATING LOADS	MT R.3, AT E.4.

description:
Radiant heating systems provide "equal comfort" at lower air temperatures than would convective systems.

The amount by which the air temperature may be "depressed" depends upon the net radiant effects from the envelope and heating system.

The result of a possible lower inside air temperature has a direct impact on the reduction in ventilation and infiltration losses which in most cases can be considered the most significant factor.

Secondary factors which can often be ignored for the purposes of estimation of energy savings include:

i) A change in the fabric loss by conduction - the warming of the room surfaces by radiation tending to increase conduction losses whilst the reduced air temperature tends to lower it,
ii) Back loss through radiant sources increasing local heat loss by conduction.

The operative temperature (see MT R.3) takes account of the differing effects of air temperature and radiant temperature on thermal comfort.

The operative indoor temperature, $T_{o,i}$, is defined as a weighted average of the indoor air temperature, $T_{a,i}$, and the mean radiant temperature $T_{r,m}$

$$T_{o,i} = a^* T_{a,i} + b^* T_{r,m}$$

where a+b=1. It is common to take, for example, a=b=0.5 or a=1/3, b=2/3.

The mean radiant temperature, $T_{r,m}$, is defined from

$$T_{r,m} = \Sigma_k T_{s,k} A_k w_k / (4\pi\ l_k^2)$$

where:

$T_{s,k}$ is the surface temperature of wall element #k,

A_k is the area of wall element #k,

l_k is the mean distance from the point where the operative temperature is considered (usually in the middle of a room) to wall element #k.

w_k are weigthing factors such that

$$\Sigma A_k w_k / l_k^2 = 4\pi$$

which is fulfilled, for example, if all w_k=1 corresponding to a measurement of the mean radiant temperature by a globe thermometer.

For radiative heating then

$$T_{o,i} = a*T_{a,i}(rad)+b*\Sigma_k T_{s,k} A_k w_k/(4\pi l_k)+b*T_r A_r w_r/(4\pi l_r^2)$$

and for convective heating

$$T_{o,i} = a*T_{a,i}(conv)+b*\Sigma_k T_{s,k} A_k w_k/(4\pi l_k)+b*T_{s,r} A_r w_r/(4\pi l_r^2)$$

where the summation is over all wall elements where there is no radiator (or where the radiator would be in the case of convection) and

T_r = surface temperature of the radiator,

A_r = area of radiator,

l_r = distance to radiator,

w_r = weighting factor for radiator,

$T_{s,r}$ = surface temperature of wall element at the position of the radiator in the case of convective heating.

The difference in indoor air temperature between radiative and convective heating is then ΔT_i.

$$\Delta T_i = T_{a,i}(conv)-T_{a,i}(rad) = b/a*(T_r-T_{s,r})w_r A_r/(4\pi l_r^2)$$

and the reduced load, ΔL, can be derived from

$\Delta L = \Delta T_i*(\Sigma U_i A_i+V*n/3)$ where

A_i is the surface of building envelope element #i [m^2],

U_i is the effective U-value (insulation + film coefficient, see AT E.4) of building envelope element #i [W/m^2,K],

V is the heated volume [m^3],

n is the number of air changes per hour,

ΔL is the reduced load [W].

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accuracy: ! **references:**

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recommended applications:

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alternative techniques:

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additional information:

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analysis technique:	application area:	referenced from:
H.1	HEATING	ECO H.17, AT E.3

title:	references to:
SEASONAL EFFICIENCY OF OIL/GAS FIRED BOILER/PLANTS	AP H.1, H.2

description:

The seasonal efficiency of a boiler (or of a heating plant) can be obtained from the corresponding full load thermal efficiency. The following notation is used:

η_c = burner combustion efficiency (AP H.1),
η_b = boiler full load thermal efficiency (AP H.2),
η_p = heating plant thermal efficiency (AP H.2),
w_o = fractional on-time of the burner when the boiler output valve is closed, that is no heat distributed to the system (AP H.2),
w_1 = fractional on-time of the burner with boiler output valve open but with distribution valves closed (no heat load to the building),
w_m = average burner fractional on-time during the heating season which can be obtained by dividing the running time of the burner over the heating season by the corresponding operation time of the heating plant. It can also be obtained using the energy signature, AT M.1, $w(T_e) = a-b^* T_e$ to estimate w_m:

$$w_m = a - b^*T_m \quad \text{where } T_m = \text{average outdoor temperature.}$$

The boiler seasonal efficiency, η_{bs}, is then given by:

$$\eta_{b,s} = \eta_b^* (w_m - w_1)/w_m^*(1-w_1)$$

A very similar relationship is used to get the seasonal thermal efficiency of the heating plant, $\eta_{p,s}$, (boiler and storage, see AP H.2)

$$\eta_{p,s} = \eta_p^* (w_m-w_1)/ w_m^*(1-w_1)$$

accuracy:	references:

recommended applications: On-off or High-low burners. Applicable to single boiler installations with modification of equations for multiple boiler plants.

alternative techniques:

additional information:

analysis technique:	**application area:**	**referenced from:**
H/C.1	HEATING AND COOLING PLANTS	ECO H.25.

title:	**references to:**
SEASONAL PERFORMANCE FACTORS OF HEAT PUMPS ANO CHILLERS	

description:

An example (in this case an outdoor air heat pump) of the kind of information necessary to determine the seasonal performance factor for heat pumps and chillers is given in Fig. 1. In practice, the neutral point for the load lines (assumed to be linear) do not always coincide due to internal loads, type of building etc.

The simplest method for determining the heating seasonal performance factor (SPF_h) or the cooling seasonal performance factor (SPF_c) is to use a bin method (see AT M.2) to lump the number of hours of a season into for example 5^oC dry-bulb temperature bins (n_j hours in bin # j for outdoor temperature $T_{e,j}$) and noting the corresponding heat $P(T_{e,j})$. By utilizing the steady state (SS) performance curves for heating (P_h), heating COP (COP_h), cooling (P_c) and cooling COP (COP_c) for the respective bin dry-bulb outdoor temperatures ($T_{e,j}$) of the heating and/or cooling season, SPF_h and/or SPF_c, can be estimated from

SPF_h = seasonal output/seasonal input =

$$= \Sigma\, n_j * P(T_{e,j}) / \Sigma\, n_j * (P(T_{e,j})/COP_h(T_{e,j}) + P(T_{e,j}) - P_h(T_{e,j})\ )$$

where the summation index j runs over the bins, and similarly

$$SPF_c = \Sigma\, n_j * P(T_{e,j}) / \Sigma\, n_j * (P(T_{e,j})/COP_c(T_{e,j}) + P(T_{e,j}) - P_c(T_{e,j})\ )$$

The difference $P-P_h$ or $P-P_c$ is the supplementary heat/cool required below/above the balance point.

For more sophisticated calculations, the number of bins can be increased or computer programs can be used. The SS performance curves may have to be modified to account for decreased efficiency at part load operation or due to defrosting requirements.

accuracy:	**references:**

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recommended applications:

Calculation of estimated performance and possible savings for heat pumps and chillers over long periods, normally 1 year.

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alternative techniques:

1) Integration of heatpump input and output power along a duration curve for the outdoor temperature over a year.
2) More sophisticated computer simulation programs.
3) Simply note heat pump COP at the average outdoor temperature during the heating season (correct for required supplementary heating).

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additional information:

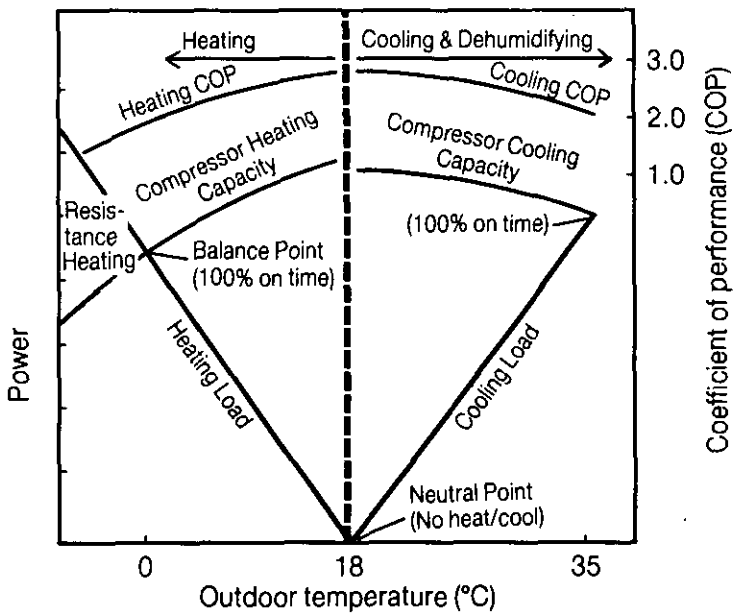

Fig. 1 Schematics of information necessary for determination of seasonal performance factor of heat pumps and chillers. The diagram describes how the heating or cooling load and the compressor capacity vary with outdoor temperature for an outdoor air heat pump. As the outdoor temperature falls, the cool and heating capacity fall until at the balance point in the heat pump just matches the increasing heating load.

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analysis technique:	**application area:**	**referenced from:**
D.1	DUCTWORK	ECO D.9.

title:	**references to:**
HEAT TRANSMISSION FROM DUCTWORK	

description:
The following notation is used:

a,b	[m]	side lengths of duct,
l	[m]	length of duct,
u	[m/s]	average air velocity in duct,
D	[m]	hydraulic diameter = 4ab/(2a+2b) = 2ab/(a+b),
T_f	[K]	average fluid temperature,
T_a	[K]	temperature at inner surface of duct,
T_b	[K]	temperature at outer surface of duct + insulation
T_e	[K]	external temperature,
d_i	[m]	thickness of insulation,
λ_i	[W/m,s]	conductivity of insulation material
Q	[W]	heat losses,
A	[m^2]	area of duct = 2*l*(a+b),
σ	[$W/m^2,K^4$]	= 5.7 10^{-8}, Stefan-Boltzmann constant,
ε		emissivity of outer surface.

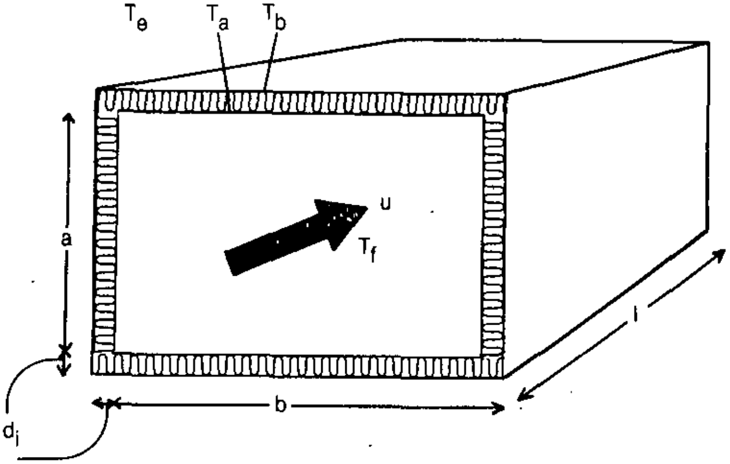

Fig. 2 Schematics of an air duct and notation.

i) For <u>well insulated ducts</u>, such that $|T_b-T_e| << |T_f-T_e|$, an upper limit of the heat flow, q, is obtained from

$$q < \lambda_i * A*(T_f-T_e)/d_i$$

or, if T_b has been measured, from

$$q < \lambda_i*A*(T_f-T_b)/d_i.$$

ii) <u>Otherwise</u>, determine the coefficients h_i, h_r, and h_c from

	h_i	h_r	h_c
Uninsulated ducts vertical	$h_i = 104*u^{0.8}/(T_f^{0.58}*D^{0.2})$	$4*\sigma\varepsilon*T_e^3$	$75*(T_f-T_e)^{1/3}/T_e^{2/3}$
Uninsulated ducts horizontal			$5.8*(T_f-T_e)^{1/4}/(T_eD)^{1/4}$
Insulated ducts vertical	$1/h_i = 1/(T_f^{0.58}D^{0.2}/104u^{0.8}+d_i/\lambda_i)$		$75*(T_f-T_e)^{1/3}/T_e^{2/3}$
Insulated ducts horizontal			$5.8*(T_f-T_e)^{1/3}/(T_eD)^{1/4}$

From these values calculate x_o from

Uninsulated ducts vertical: $x_o= h_i/ [h_i+h_r+h_c+ (T_f-T_e)/ T_e*(3h_r/2-h_c/3)]$

horizontal: $x_o= h_i/ [h_i+h_r+h_c+ (T_f-T_e)/ T_e*(3h_r/2-h_c/8)]$

Insulated ducts vertical: $x_o= h_i/ (h_i+h_r+h_c)$

horizontal: $x_o= h_i/ (h_i+h_r+h_c)$

and calculate x_1 from

vertical $x_1 = h_i/ [h_i+h_r+h_c*x_o^{1/3}+ x_o* (T_f-T_e)/ T_e* (3h_r/2- h_c*x_o^{1/3}/3)]$

horizontal $x_1 = h_i/ [h_i+h_r+h_c*x_o^{1/4}+ x_o* (T_f-T_e)/ T_e* (3h_r/2- h_c*x_o^{1/4}/8)]$

The heat losses, Q [W], are then calculated from

$$Q = h_i * (1- x_1)* (T_f- T_e)* A$$

---

accuracy: 15 % ! **references:**

---

recommended applications:
Ducts where $!T_f-T_e! < 40$ K and a,b < 0.5 m.

---

alternative techniques:

---

additional information:

The emissivity ε can be taken to 0.75 for metals that are not clean and polished and to 0.9 for other materials.

---

analysis technique:	**application area:**	**referenced from:** ECO P.3
P.1	PIPEWORK	P.6, S.7, S.10, S.11, S.15, S.16, S.23, AP S.1, S.2, S.3.

title:	**references to:**
HEAT TRANSMISSION FROM PIPEWORK AND TANKS	

description:

The following notation is used:

a [m] inner radius of pipe,
b [m] outer radius of pipe and insulation,
l [m] length of pipe,
d [m] diameter = 2b,
T_f [K] average fluid temperature,
T_a [K] temperature at inner surface of pipe, assumed equal to T_f,
T_b [K] temperature at outer surface of pipe + insulation,
λ_i [W/m,K] conductivity of insulation material,
A [m^2] area of pipe + insulation = $2\pi b l$,
Q [W] heat losses,
σ [$W/m^2,K^4$] = $5.7\ 10^{-8}$, Stefan Boltzmann constant,
ϵ emissivity of outer surface.

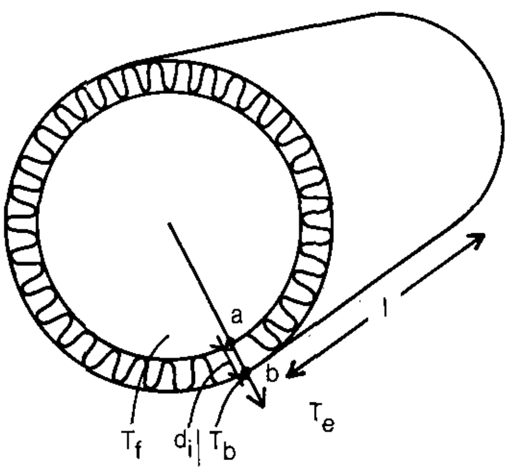

Fig. 1 Schematics of insulated pipe.

i) For <u>well insulated pipes</u>, such that $|T_b-T_e| \ll |T_f-T_e|$, an upper limit of the heat flow, q, is obtained from

$$q < \lambda_i A(T_f-T_e)/(b \ln b/a)$$

or, if T_b has been measured, from

$$q < \lambda_i A(T_f-T_b)/(b \ln b/a)$$

ii) <u>Otherwise</u>, determine the coefficients h_i, h_r, h_c, from

	h_i	h_r	h_c
Uninsulated pipes			
vertical	-		$75 * (T_f-T_e)^{1/3} / T_e^{2/3}$
horizontal	-		$5.8 * (T_f-T_e)^{1/4}/(T_e d)^{1/4}$
		$4\sigma\epsilon T_e^3$	
Insulated pipes	$\lambda_i/(b \ln b/a)$		
vertical			$75 * (T_f- T_e)^{1/3} / T_e^{2/3}$
horizontal			$5.8 * (T_f- T_e)^{1/4}/(T_e d)^{1/4}$

For <u>uninsulated</u> pipes, the heat losses are then given by

vertical pipes: $q = (T_f-T_e)*A*(h_r+ h_r 3(T_f-T_e)/(2T_e) + h_c - h_c(T_f-T_e)/(3T_e))$

horizontal pipes: $q = (T_f-T_e)*A*(h_r+ h_r 3(T_f-T_e)/(2T_e) + h_c - h_c(T_f-T_e)/(8T_e))$

For <u>insulated pipes</u>, calculate x_o from

$$x_o = h_i/(h_i+ h_r+ h_c/2)$$

and then calculate x_1 from

vertical pipes: $x_1= h_i/(h_i+ h_r+ h_c x_o^{1/3} +x_o(T_f-T_e)(3h_r/2 - h_c x_o^{1/3}/3)/T_e)$

horizontal pipes $x_1= h_i/(h_i+ h_r+ h_c x_o^{1/4} +x_o(T_f-T_e)(3h_r/2 - h_c x_o^{1/4}/8)/T_e)$

which gives the heat losses

$$Q = h_i * (1-x_1)*(T_f- T_e)* A$$

---

accuracy: 15 % ! **references:**

---

recommended applications:

Pipes with water where $!T_f - T_e! < 150$ K and diameter < 0.3 m and cylindrical tanks.

---

alternative techniques:

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additional information:

The emissivity can be taken to 0.75 for metals except when clean and polished and to 0.9 for other materials.

---

analysis technique:	**application area:**	**referenced from:**
P.2	STEAM PIPEWORK	ECO P.3, P.8, P.13, P.16

title:	**references to:**
HEAT TRANSFER IN STEAM SYSTEMS	

description:

Steam that has been completely evaporated and contains no droplets of water is defined as dry saturated steam. Properties of dry saturated steam are normally given in steam tables. In practice steam is rarely ever in this precise state for long and is usually either in a "wet" or "superheated" state.

Wet steam contains tiny droplets of water. The quantity of water contained in *the steam is described by its dryness fraction* x_{df} *where:*

$$x_{df} = \frac{\text{Volume of Wet steam}}{\text{Volume of dry saturated steam}}$$

Superheated steam is obtained when the steam is subjected to additional heating out of the presence of water (so that no further steam is produced). Properties of superheated steam are also tabulated in steam tables.

Total heat content of steam or enthalpy is composed of three components.

1. Sensible heat of water.
2. Latent heat of evaporation.
3. *Sensible heat of superheated steam.*

For most HVAC applications the use of superheated steam is not normal (the rate of energy release from superheated steam at heat exchangers whould be less than that of dry saturated steam since the latter readily condenses giving up its latent heat component which is proportionately far greater than the other components).

For steam in its non-superheated state, total heat content, h_g, is given by:

$$h_g = h_f + x_{df} * r$$

where, if h_g is measured in [kJ/kg]

h_f = specific enthalpy of water at its saturation temperature [kJ/kg]

$r = h_g - h_f$ = specific enthalpy of evaporation [kJ/kg steam]

Heat release (transfer) at heat exchangers is given by the difference in enthalpy between the inlet and outlet of the heat exchanger; i.e.

$$\Delta h_g = h_{g,i} - h_{g,o}$$

where

Δh_g = heat transfer [kJ/kg]

$h_{g,i}$ = enthalpy of steam at inlet [kJ/kg]

$h_{g,o}$ = enthalpy of condensate at outlet [kJ/kg]
Values of h_g can be found in steam tables (a limited range of values are given in Table 1).

The heat required to raise steam, Δh, is given by

$\Delta h = h_{g,o} - h_{f,i}$

where

$h_{g,o}$ = enthalpy of steam at outlet, and
$h_{f,i}$ = enthalpy of boiler feed water at inlet.

Condensate formed within a heat exchanger will be initially at the same temperature and pressure as the steam. If condensate at this condition is discharged to a lower pressure than in the condensate return system, it will contain more heat than necessary to maintain a liquid state and this excess heat will cause some of the condensate to evaporate or "flash" to steam.

The amount of flash steam can be calculated by:
Flash steam [%] = $100(h_{f,1} - h_{f,2})/r_2$

where

$h_{f,1}$ = enthalpy of liquid at the pressure of steam
$h_{f,2}$ = enthalpy of liquid at the condensate return system pressure
r_2 = enthalpy of vaporisation at the condensate return system pressure.

For non-superheated steam, the temperature and pressure of steam bear a direct relationship with one another, if one variable is known the other can be deduced; e.g. if steam pressure is known the temperature can be found by looking up the corresponding temperature in the steam tables.

This, however, is only true where the steam is pure steam and contains no other gases such as air. To understand the implications of trapped air in a steam system one needs to refer back to Dalton's law of partial pressures which states: "the total pressure of a mixture of gases is equal to the sum of the pressures of the individual constituents". If steam contains some proportion of entrapped air, the pressure indicated by a pressure gauge, p, will be given by:

$p = p_g + p_a$

where

p_g = the pressure exerted by the steam, and
p_a = the pressure exerted by entrapped air.

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accuracy: ! **references:**

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recommended applications:

alternative techniques:

additional information:
TABLE 1. Properties of water and steam.

Temp [°C]	Pressure [Pa]	Volumity [m^3/kg] water (*10^3)	vapor	Enthalpy [kJ/kg] water(h_f)	vapor(h_g)	Phase change enthalpy [kJ/kg] $r=h_g-h_f$
50	012.3	1.012	12.05	209	2591	2382
55	015.7	1.014	9.58	230	2600	2370
60	019.9	1.017	7.68	251	2609	2358
65	025.0	1.019	6.20	271	2617	2346
70	031.1	1.022	5.04	292	2626	2333
75	038.5	1.025	4.13	313	2635	2321
80	047.3	1.029	3.41	334	2643	2308
85	057.8	1.032	2.83	355	2651	2295
90	070.1	1.035	2.36	376	2659	2282
95	084.5	1.039	1.98	397	2667	2269
100	101.3	1.043	1.67	418	2675	2256
110	143.2	1.051	1.21	461	2690	2229
120	198.5	1.060	0.891	503	2705	2201
130	270.1	1.069	0.668	546	2718	2172
140	361.4	1.079	0.508	588	2732	2143
150	476	1.090	0.392	631	2744	2112
160	618	1.102	0.306	675	2756	2081
170	792	1.114	0.242	719	2767	2048
180	1002	1.127	0.193	762	2777	2014
190	1255	1.141	0.156	807	2785	1978
200	1555	1.156	0.127	852	2793	1941
210	1908	1.172	0.104	897	2798	1901
220	2320	1.190	0.0861	943	2802	1859
230	2797	1.208	0.0715	989	2804	1814
240	3348	1.229	0.0597	1037	2804	1767
250	3978	1.251	0.0500	1085	2801	1716
260	4694	1.275	0.0421	1134	2796	1662
270	5505	1.302	0.0355	1185	2788	1603
280	6419	1.332	0.0301	1237	2778	1542
290	7445	1.365	0.0255	1290	2764	1475

analysis technique:	**application area:**	**referenced from:**
S.1	SOLAR SHW SYSTEMS	ECO S.20

title:	**references to:**
PERFORMANCE PREOICTION FOR SOLAR SHW SYSTEMS	

description:

There are several methods by which the performance of closed-loop solar hot water systems can be assessed. This method is a simple, workable and in most cases sufficiently accurate method (Lunde, 1980).

The performance of a solar SHW system is expressed in terms of the factor f defined as the proportion of the SHW demand actually met by solar energy or $f = q_n A/L$

where q_n is the heat flux actually collected,
A is the solar collector area, and
Q_{load} is the SHW load.

The above definition of f is not of much use for practical estimates of f, it is more fruitful to express f as dependent on two functions, f_b, the potential solar participation with maximum storage and a constant storage base temperature, and the storage function f_s. The function f_b is defined from

$$f_b = F_i * F_x * \overline{\tau\alpha} * \; I_T - U_L * (T_b - T_a) * t_T * \; A/Q_{load}$$

where: F_i is the collector overall factor as specified by the manufacturer (in practice it takes a value between 0.8 and 1),
F_x is the heat exchanger factor as specified by the manufacturer,

$\overline{\tau\alpha}$ is the average of the product of the transmittance and absorbance of the collector,
U_L is the collector overall losses factor as specified by the manufacturer [$W/m^2,K$]
T_b is the base temperature of the storage [^oC]
T_a is the air temperature [^oC]
I_T is the sum of the daily radiations at the desired tilt and azimuth accumulated during the times while the instantaneous radiation is above the appropriate threshold at which the collector has a positive thermal efficiency (I_T is a meteorological variable),
t_T is the total time period for collector operation [Ms].

The function f_s is defined from
$f_s = F_i F_x \; U_L / m_c$

where m_c is the storage capacity of the tank per degree Kelvin divided by the collector area [$MJ/K,m^2$]

The factor f can then be estimated from

$$f=f_b(1.1138-0.271\ f_b + 0.006\ f_b^3 - 0.01214\ f_s + 0.000152\ f_s^2)$$

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accuracy:
5% for monthly values.
1% for yearly values.

references:
Lunde, 1980.

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recommended applications:

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alternative techniques:

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additional information:

In practice, f is usually calculated on a monthly or yearly basis. The parameters x, T_a, I_T and t_T then have to be estimated for the relevant period. The parameter x is dependent on the collector physical factors and climatical parameters, its characteristics are often provided by the manufacturer. The equation for the factor f is based on a fit to monthly values.

analysis technique:	application area:	referenced from:
S.2	SHW SYSTEMS	ECO S.1, S.2, S.3, S.5, S.8, S.9, S.11, S.16, S.18, S.19, S.21, P.6

title:	references to:
ENERGY SAVINGS IN SHW SYSTEMS	RV S.2

description:

The energy consumption of a SHW system can be calculated from:

$$E = V * \Delta T * 4.2/\eta_t$$

where E = energy consumption [MJ]
ΔT = temperature difference between SHW and cold feed water [K]
V = water consumption [m^3]
η_t = overall SHW production efficiency (see RV S.2).

Energy savings can be achieved by:

i) Reducing the water consumption V,
ii) Reducing ΔT, and
iii) Increasing the overall efficiency η_t.

(i) The ECOs that reduce water consumption are the following:
- avoid leaks (S.10)
- use cold water for laundry (S.3)
- install flow restrictors (S.9)
- install metering devices (S.19)
- install-improve water temperature regulation (S.5).

In this case, having estimated the water consumption reduction ΔV, the energy saved, ES, is

$$ES = \Delta V \; \Delta T \; 4.2/\eta_t.$$

(ii) A reduction of ΔT, from ΔT_1 to ΔT_2 may be due to:
- installation of water heater exchanger (S.8)
- reduction of temperature (S.1)

$$ES = V(\Delta T_1 - \Delta T_2)4.2/\eta_t.$$

(iii) The improvement of SHW production efficiency from η_{t1} to η_{t2} can be achieved by:

- reduction in use of pumps (S.2)
- reduction of temperature (S.1)
- installation of control-timers to reduce use of pumps (S.11)

- insulation upgrade (P.6)
- optimizing storage tank (S.16)
- adding a booster to storage (S.18)

The energy savings are given by:

$$ES = V*\Delta T*4.2(1/\eta_{t2} - 1/\eta_{t1})$$

Energy costs can also be reduced by switching to a cheaper energy source.

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accuracy:	**references:**

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recommended applications:

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alternative techniques:

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additional information:

See respective ECOs.

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analysis technique:	**application area:**	**referenced from:** ECO L.1
AT L.1	*LIGHTING*	*L.2, L.3, L.4, L.5, L.6,* L.10, L.12, L.16, L.18

title:	**references to:**
ESTIMATION OF ENERGY SAVINGS FOR LIGHTING SYSTEMS	

description:

For all Lighting ECOs energy saving is only achieved:

- if the operating time t of the lights is reduced;
- if the electrical installed power P for lighting is reduced.

Hence, the annual energy savings ES of a set of ECOs can be calculated by:

$ES = P_b\ t_b - P_a\ t_a$ [kWh/yr]

where:

P_b (P_a) = installed power before (after) retrofitting [kW],

t_b (t_a) = operating time per year before (after) retrofitting [h/yr].

For daylight, delamping and improved lighting efficiency (power reduction for constant illuminance), $t_a = t_b$.

The power reduction for a constant illuminance level E_v *can be estimated* from:

$P_b - P_a = E_v\ (1/\eta_b - 1/\eta_a)$

where η_b and η_a are the installed efficacies before and after retrofit, respectively.

For daylight switching and reduced operating times, $P_a = P_b$.

accuracy: ! **references:**

recommended applications:

alternative techniques:

additional information:

analysis technique: AT L.2	**application area:** LIGHTING	**referenced from:** ECO or AP: ECO L.5, L.16

title: ESTIMATION OF ENERGY SAVING DUE TO PHOTO-ELECTRIC CONTROL	**references to:** AT L.1, RV L.5

description:

Purpose:
Estimation of energy saving due to the application of photo-electric controls:
i) Photo-electric on/off switching control,
ii) Continuous photo-electric dimming.

Procedure:
1. Calculate or determine the daylight factor. (For daylight factor calculation methods, see reference BSI, 1982).
2. Estimate what the set point illuminance will be when the photo-electric controls will be installed.
3. Estimate from the daylight factor and the set point illuminance the number of working hours per year during which luminaires will be switched off (for an example see RV L.5).
4. Calculate energy saving using AT L.1.

accuracy:	**references:**

recommended applications:

alternative techniques:

additional information:

analysis technique:	**application area:**	**referenced from:**
AT EL.1	ELECTRICITY	ECO EL.4, AP EL.3, AT EL.3

title:	**references to:**
SAVINGS FROM ELECTRICAL EQUIPMENT CHANGES	

description:

In calculating the impact of changes involving electrical equipment, it is important to take into account both the Direct Effect, and where present, the Indirect Effect.

The "DIRECT EFFECT" is concerned with the actual effect observed in the piece of equipment being changed. E.g. the change in electrical energy consumption of a lighting fixture after delamping.

The "INDIRECT EFFECT" is concerned with the effect of the change on other equipment; i.e. not the equipment directly involved in the retrofit. To continue the above example, the "indirect effect" of delamping might be increased use of heating and a reduction of cooling energy. This indirect effect might be observed in the same fuel source or in a different fuel source.

This AT describes the calculation of the indirect and direct effects of retrofitting on electrical energy costs. Electrical Energy Costs may be comprised of costs associated with one or more of the following:

i) Energy consumption. Charges for per unit (kWh) consumption, which may vary with amount used or time of day.
ii) Energy demand. Either kW or kVA maximum demand might be used as a basis for billing.
iii) Power factor (PF). Charges for poor power factor might be separately made on the basis of measured power factor (usually below some minimum accepted value, typically 0.85 to 0.9) or covered by the kVA demand charge.

Retrofits might create savings (or increases) in one or more of these areas.

Changes to electrical equipment will inevitably result in a drop in consumption and there is a strong chance that they will affect the demand. Changes involving motors may, in addition to providing consumption and possibly demand variations, affect the overall system power factor. Just how the changes affect cost will depend upon the actual tariff arrangement which must be read and fully understood before undertaking estimates of utility savings.

As a first step the direct effect of the retrofit on consumption, demand and power factor can be calculated; in simple terms:

i) Consumption = Δ * (hours of operation) * (unit charge), where Δ = change in electrical demand in kW.

Where unit costs vary with amount consumed take care to use the correct unit rate which will require that the overall unit consumption pattern be considered.

ii) Demand = Δ' * (unit demand charge),
where Δ' = effect of the Δ on the total building demand which is not necessarily equal to Δ. The coincidence of the equipment operation with the time of peak load occurrence must be checked in order to determine Δ'. Δ and Δ' may be in kW or kVA depending upon the particular utility practices and tariff agreement.

iii) Power factor = whichever is the lowest of
$(PF_1 - PF_2)$ * power factor unit cost, or
$(PF_1 - PF_3)$ * power factor unit cost,
where PF_1 is the power factor before and PF_2 the power factor after retrofit and PF_3 the power factor below which PF charges are incurred.

Obviously varying loads caused by occupant use (e.g. in lighting systems or modulation of output (e.g. motor speed control) require more detailed and careful analysis.
Calculations will need to be carried out on a monthly, quarterly or annual basis as demanded by the particular tariff agreement.

The calculation of indirect effects is inevitably more difficult and approximate in nature unless detailed hourly computer models are used which can account for interactions in a more precise manner. These indirect costs can be calculated following the calculation of direct cost, or the overall net Δ and ΔPF's can be calculated prior to working out the actual dollar cost, Δ and ΔPF being the net effects of the "direct" and "indirect" electrical equipment changes. The difficult part of the process is determining on what other systems and to what extent the effect of a particular retrofit will be felt. The answer to the first part of the problem can, for the large part, be found on the ECO descriptions (Appendix D) and/or on the worksheets (Appendix E). For the second part specific advise is generally given on Analysis Techniques addressing the evaluation of a specific ECO or range of similar ECO types.

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accuracy: ! **references:**

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recommended applications:

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alternative techniques:

Detailed Computer Models.

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additional information:

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analysis technique:	**application area:**	**referenced from:**
AT EL.2	ELECTRIC MOTORS	ECO M.I.2, AP EL.1, EL.2

title:	**references to:**
CALCULATING THE REQUIRED REACTIVE POWER FOR POWER FACTORS CORRECTION	

description:

With reference to Fig. 1:

Required kVA (BC) to bring power factor from cos φ_1 to cos φ_2,
where cos φ_1 = existing power factor
and cos φ_2 = desired power factor, is given by: (AC-AB),
where

AC = 0A tan φ_1,
AB = 0A tan φ_2,
i.e.;
BC = 0A (tan φ_1 - tan φ_2),
where:
tan φ_1 = $\surd$ $(1-(PF_1)^2)$,
and
tan φ_2 = $\surd$ $(1-PF_2)^2)$,
0A = Real Power (kWh),
PF_1 = Initial Power Factor,
PF_2 = Required Power Factor.

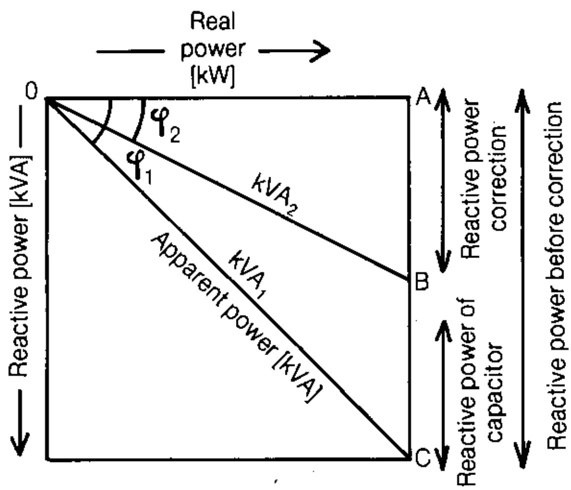

Fig.1 Vector diagram.

accuracy:	**references:**

recommended applications:

alternative techniques:

Alternatively, use Table 1 (see below) as follows:
Reactive Power (kVa) = Real Power (kW) * Multiplier (Table 1)

additional information:

TABLE 1. Multipliers for power factor correction.

Original power factor	Desired power factor 0.85	0.90	0.95	0.98	1.0
0.60	0.713	0.849	1.004	1.130	1.333
0.62	0.646	0.782	0.937	1.063	1.266
0.64	0.581	0.717	0.872	1.063	1.201
0.66	0.518	0.654	0.809	0.935	1.138
0.68	0.458	0.594	0.749	0.875	1.078
0.70	0.400	0.536	0.691	0.817	1.020
0.72	0.344	0.480	0.635	0.761	0.964
0.74	0.289	0.425	0.580	0.706	0.909
0.76	0.235	0.371	0.526	0.652	0.855
0.78	0.182	0.318	0.473	0.599	0.802
0.80	0.130	0.266	0.421	0.547	0.750
0.82	0.078	0.214	0.369	0.495	0.698
0.84	0.026	0.162	0.317	0.443	0.646

analysis technique:	**application area:**	**referenced from:**
AT EL.3	ELECTRIC MOTORS	ECO EL.6, P.15 R.32 R.22, R.5

title:	**references to:**
EVALUATION OF MOTOR SPEED CONTROL DEVICES	RV EL.1, AP EL.3,AT EL.1

description:

1. It is first necessary to develop an annual operating profile for the piece of driven equipment. The most suitable form of this profile is the number of hours of operation over various load ranges ("bins") (see Fig. 1). This load profile will depend upon the annual variation of load for which the driven equipment is meeting and methods of calculating this are described in those analysis techniques associated with the various ECO options (P.15, R.22, R.5 and EL.6). Where the motor operation effects maximum demand and the maximum demand charge is made monthly or bimonthly, it is desirable to list the maximum values of load on the equipment in each month.

2. For each of the load ranges used in the above, determine the motor/speed controller combined efficiency and power factor. Use manufacturers' data for the equipment under consideration or use data provided on RV EL.1.

3. Calculate the "<u>Direct Effects</u>". These may involve savings in electrical consumption, demand and power factor (see AT EL.3) resulting from the difference in the constant speed device operating at whatever load is imposed upon it (usually <u>not</u> the frame power) and the variable speed device operating over a range of conditions.
   For an example (see Fig. 1).

   $$\text{Energy savings} = (kW_c\, t_c) - \Sigma_{i=1}^{n} (kW_i\, t_i),$$

   where kW_c = constant speed device electrical demand,
   t_c = constant speed device total operating time [h],
   kW_i = variable speed device electrical demand in bin "i",
   t_i = variable speed device operating time in bin "i" [h].

   Demand calculations are based on the % full load in each month (or demand billing period) and the actual motor load (kW or kVA) at the particular operating point.

4. Calculate the "<u>Indirect Effect</u>". There will be indirect savings in cooling and increases in heating if the motor is in a heated or cooled space or in a conditioned airstream (excluding exhaust fans). See item 4 on AP EL.3 and AT EL.1 for guidance on how these indirect effects might be calculated.

accuracy:

references:
Electrical Construction and Maintenance, 1983.

recommended applications:

alternative techniques:

Detailed hourly method.

additional information:

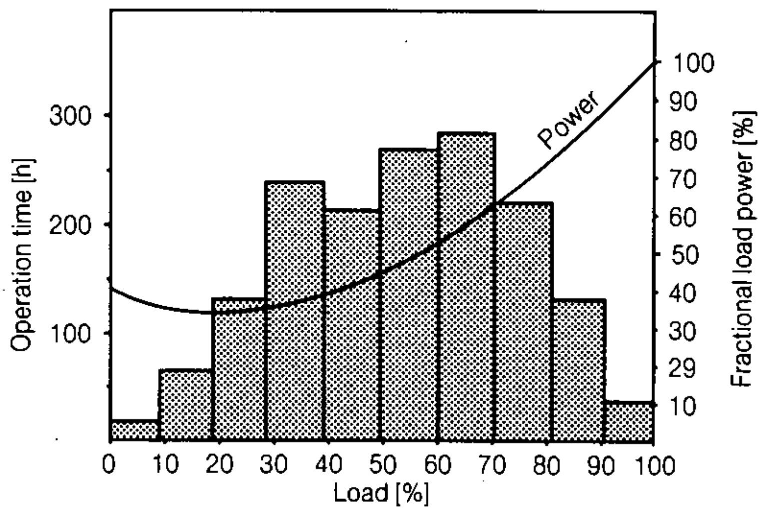

Fig. 1 Hourly bin load data and efficiency of speed control device at various loads relative to full load.

analysis technique: M.1	**application area:** HEATING, REGULATION AND SURVEILLANCE OF ENERGY CONSUMPTION	**referenced from:** Several places.

title: ENERGY SIGNATURE	**references to:**

description:

The energy signature technique is a single measure model (see Ch. 7) expressing the dependence of energy consumption on the outdoor air temperature or the indoor-outdoor temperature difference. Energy is mostly to be interpreted as energy for heaing or, if no disaggregation of end use of energy has been performed, as the combined energy consumption for heating and some other end-use (e.g SHW production).

It is generally assumed that for a range of outdoor temperatures or indoor-outdoor temperature differences there is a linear relation between energy and temperature. Outside of this range it is generally assumed that one can define either

i) an outdoor temperature above which no heating is required (balance point temperature) for the case when energy is identified as energy for heating, or
ii) an outdoor temperature (or temperature difference) above (or below) which energy consumption is constant (base load).

These assumptions are shown graphically in Fig. 1.

When applying the energy signature technique it is common to use daily, weekly or monthly averages of energy consumption and temperature. Hourly values have been used for assessing situations with temperature setback or intermittent heating (see Fig. 2).

The dependence of energy on temperature is in general determined by linear regression to measured data.

The energy signature technique is in general too simple to be applied to cooling situations (see Ch. 7) except where heating and cooling periods are well defined and separated.

accuracy: Oepending on temperature range. In general about 10%.	**references:** Fels, 1986; OFAC, 1983.

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recommended applications:
- Control of energy consumption.
- Instrumented energy auditing for short term analysis.
- Analysis of heating plant and regulation efficiency.

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alternative techniques:

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additional information:
Using the energy signature technique, it is possible to analyse the energy consumption of a building using daily data from a period of two or three weeks, using weekly data from three or four months, or using monthly data from a year. The energy signature technique is a tool for improved operation and surveilience of heating plants. See also chapter 6.

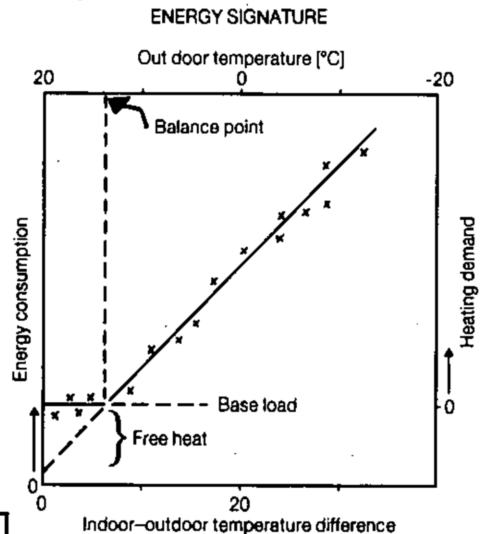


Fig. 1
The energy signature model.

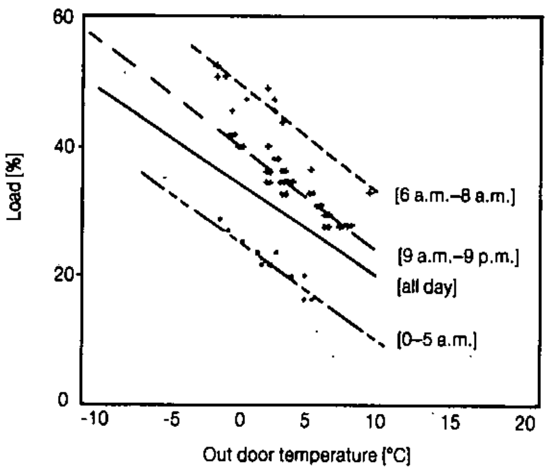
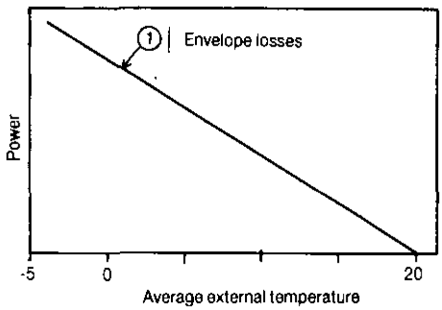
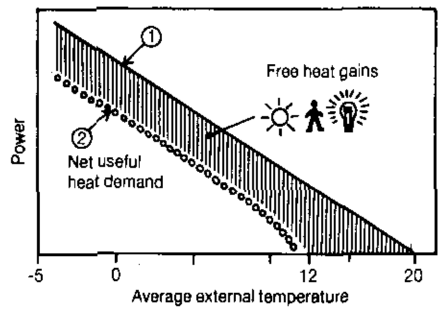


Fig. 2
Example of use of energy signature for temperature set-back.

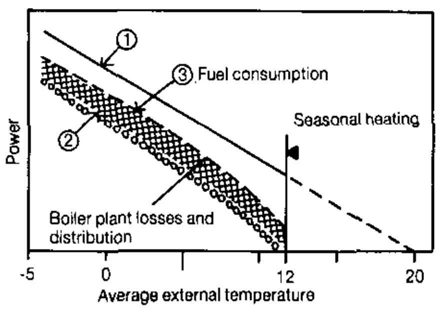
The way in which different energy components add up to produce the energy signature is illustrated in Fig. 3. It is also shown how, for mild weather conditions, the curve may bend due to, e.g. poor low load boiler performance, simultaneous heating and cooling or window opening.



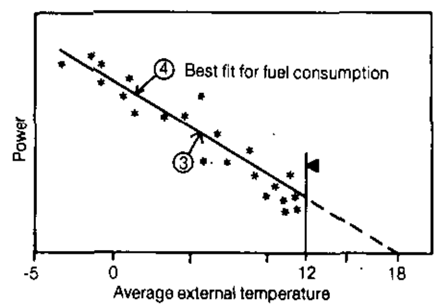
a) Envelope losses can be considered linear.



b) Solar free heat gains from electricity and the presence of occupants cover a part of the envelope losses. The remainder is the net space heat requirement which has to be supplied by the heat plant.



c) In the range of 10 to 15 ^{o}C outside temperature, the net heat requirement will fall to zero and the boiler plant can be shut off. This is the seasonal heating limit. The boiler plant and the distribution system also have losses and these must be added to the net space heat requirement. The result is the curve of fuel consumption.



d) Experience has shown that the curve of fuel consumption in a normal case can be expressed by a linear relationship. Points lying outside of a certain range show abnormal situations which have to be considered separately.

Fig. 3
Illustration of energy signature models for a building with a boiler

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analysis technique: M.2	**application area:** GENERAL	**referenced from:**

title: BIN ANALYSIS METHODS	**references to:**

description:

The principle of all bin type analysis methods is the analysis of the building, systems or equipment as a series of separate individual calculations or models, each calculation or model representing a different set of conditions. The models are based on the average condition over each of the separately identified operating conditions.

The definition of these models must be detailed enough to distinguish between significantly different operating conditions, yet be of a manageable number to make hand calculations practicable. (As the extreme illustration an hour by hour analysis could be thought of as a bin method with 8,760 separate bins or models.)

The separate models can be setup on the basis of a number of different bin types as detailed below:

1. OUTDOOR DRY BULB TEMPERATURE - This is perhaps the most familiar use where heat gains and losses are calculated for a number of outdoor air temperature ranges. Equipment that operates within a certain range of outdoor temperatures, e.g. heating or chilled water pumps, can also be accommodated by arranging bins to coincide with equipment operating ranges. Typically bin temperature data are available from meteorological organisations. Methods of deriving bin data from monthly average temperatures are available (Erbs, 1983).

2. OUTDOOR WET BULB TEMPERATURE - Normally coincident wet bulb; i.e. coincident with the dry bulb data, are used to account for humidification and latent cooling effects.

3. OCCUPANCY - often it is important to distinguish between occupancy states of the building to accommodate different internal gain profiles, ventilation requirements and temperature setpoints.

4. PART LOAD EFFICIENCY - Part load performance of equipment can be calculated on the basis of its performance over a number of ranges of part load.

5. SOLAR GAINS - Can be approximately handled by using different values on the basis of the coincidence between solar gains and outdoor temperature, time of day or time of year.

For the simple cases the actual energy consumption is calculated by summing the products of the average load and the number of operating hours in each of the various bins.

Further, the results of one series of calculations, say calculating space heating loads on the basis of outdoor dry bulb temperature bins and occupancy could be organised into bins of hours for various load ranges which could then be used for the purposes of estimating boiler fuel consumption.

6. MISCELLANEOUS - Many other ways of identifying significantly different operating conditions might exist, especially in complex HVAC systems and the calculation method can become quite involved; e.g. "The Modified Bin Method" (ASHRAE Fundamentals, Ch. 2, 1985), and a modified bin method for heat pump application (Cane, 1979).

An example of bin type techniques is given below as an illustration.

Example: Estimate the annual fuel consumption for a building with an overall envelope loss (conduction and infiltration) of 1 kW/K; constant ventilation load of 0.5 kW/K; constant internal gain of 7.5 kW, a constant maintained temperature of 20^{0}C; and a 70 kW gas furnace with data as shown in Table 1.

For the -33^{0}C bin:

Frequency =	3 h
Envelope loss + Ventilation load = (53.0+26.5) kW=	79.5 kW.
Head load = Heat loss - heat gains =	72.0 kW.
Percentage Full load =	80%.
Efficiency (η) at this load =	.72.
Calorific value of gas =	38 MJ/m^3
Gas consumption =	
(Heat Load*Number of Hours)/(η*Calorific Value*3.6 kWh/MJ)=	
(72 kW)*(3 h)/0.72/(38 MJ/m^3)/(36 kWh/MJ) =	2 m^3 of gas

The calculation is repeated for the other temperature bins and the results summed for the annual consumption. The results are given in Table 1.

TABLE 1. Summary of data.

Bin [°C]	Frequency [h]	Envelope loss [kW]	Vent load [kW]	Internal gains [kW]	Heat load [kW]	Part load fraction	η	Gas Consumption [m^3]
17	1269	3.0	1.5	7.5	0	0	-	-
12	1182	8.0	4.0	7.5	4.5	.05	.51	76
7	984	13.0	5.5	7.5	12.0	.13	.61	142
2	1259	18.0	9.0	7.5	19.5	.22	.64	280
-3	993	23.0	11.5	7.5	27.0	.30	.66	297
-8	728	28.0	14.0	7.5	34.5	.38	.67	274
-13	549	33.0	16.5	7.5	42.0	.47	.69	244
-18	336	38.0	19.0	7.5	49.5	.55	.69	176
-23	130	43.0	21.5	7.5	57.0	.63	.70	77
-28	30	48.0	24.0	7.5	64.5	.72	.71	20
-33	3	53.0	26.5	7.5	72.0	.80	.72	2
								1588

accuracy:

references:

recommended applications:

alternative techniques:

1. Simpler: Oegree Oay.
2. More complex: Hourly.

additional information:

analysis technique:	**application area:**	**referenced from:**
M.3	GENERAL	

title:	**references to:**
EFFECT OF CHANGES IN SPACE GAINS	

description:

Many ECOs, if implemented, would result in a change to the rate at which heat is inadvertantly or indirectly added to the space.

Examples include:

i) Insulation of pipework,
ii) Installation of smaller electric motors,
iii) Equipment scheduling,
iv) Changing window to walls, and
v) Lighting changes.

The changes in heat release will indirectly affect the heating and/or cooling required for the space and these indirect effects need to be evaluated when estimating direct energy savings.

For determining the net effect of space heat gains, one can proceed as follows:

1. As a first approximation the indirect effects of a change in heat gain (Q) can be taken as:

$$Q = \Delta q_c * t_c/COP + \Delta q_h * t_h/\eta$$

where:
COP = seasonal efficiency of the cooling plant,
η = seasonal efficiency of the heating plant.
Δq_c = change in hourly heat gain rate to space during cooling season,
Δq_h = change in hourly heat gain rate to space during heating season,
t_c = number of hours cooling required,
t_h = number of hours heating required,

The number of hours that the heating and cooling must operate can be taken from norms for the location, or for more accuracy can be taken as the number of hours below the heating balance point and number of hours above the cooling balance point for heating and cooling respectively.

The heating and cooling balance setpoints can be calculated from fuel bills or monitored data using regression techniques (see AT M.1). Local meteorological records often provide temperature frequency data from which the number of hours above or below a specific temperature can be found.

Where the change in rate of internal gains is large, e.g. in a major delamping exercise, it would be worthwhile to estimate the effect on the heating and cooling balance points and hence any changes to the number of heating and cooling hours.

2. CAUTION should be exercised where zoning and HVAC system characteristics may be such that the effect is not felt on the system energy consumption. For example, the reduction in space heat gain in a zone of a terminal re-heat system may result in extra re-heat being required during cooling, thereby cancelling the heat gain savings (rebalancing could of course eliminate or minimise this effect.)

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accuracy:	**references:**
Detailed Hourly Methods or Bin Methods.	

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recommended applications:

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alternative techniques:

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additional information:

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analysis technique: M.4	**application area:**	**referenced from:**

title: DELIVERABLES/OIAGRAMS. A METHOO FOR ASSESSING COMFORT AND ENERGY CONSUMPTION	**references to:**

description:

This method provides a measure of the comfort level compared to the energy consumption (=performance level).

Data are collected by inquiries. The diagrams have to be used (and data collected) with the "instructions for use" as described below. Simple diagrams are used. (See Fig. 1.) The method can be used for assessing the performance level of i) mobility, ii) equipment and iii) conditioning. Here we describe how the method is applied for assessing the performance level of conditioning. For full details, see ref. The example given refers to Swiss conditions.

Direction for use of the diagrams:

THE DIAGRAM links the energy consumed, the equipment and the way it is used. These links can be represented for the three groups: EQUIPMENT (fittings), MOBILITY and CONOITIONING.

The purpose of the diagram is the allow you:
i) to know the specific consumption for each of the three groups,
ii) to know the position relative to the average consumption (the relations presented here refers to Swiss conditions).

Description of the digrams

Each diagram consists of 2 vertical half-axes (1 and 2) and of 2 horizontal half-axes (3 and 4). Vertical axes stand for availability and horizontal axes stand for use. Each variable corresponds to a coefficient which varies between 0.5 to 1.5, the norm being 1. Each diagram indicates a global consumption for housing equipment (fittings). The global consumption has to be written down under this indication.

Example: CONDITIONING

Note:

Each of the 4 main variables for conditioning performance is made out of many components. Work out the mean to obtain only one final coefficient for each half axis (see Fig. 2).

1. Availability - (building)

1a. Insulation and 1b. Architecture

Process:

a) Write down the coefficient corresponding to the type of insulation and architecture of your building (according to types indicated on the diagrams).
b) Work out the mean of these coefficients and write it down on half-axis 1.

2. Availability - (local climate).

2a. Number of heating days and 2b. Mean winter temperature.

Process:

a) Write down on the scale the number of days per winter during which the heating is on (if the number of sunny days without wind during this period is known they can be deducted for the total).
b) Same for mean outside winter temperature.
c) Write down the mean of a) and b) on half-axis 2.

3. Uses: comfort level

3a. Living rooms and 3b. Sleeping rooms.

3a.
i) Determine the temperature inside the living rooms in winter.
ii) Determine the kind of insulation inside the living rooms: concrete, metal, plaster.
iii) Write down the point corresponding to the answers to a) and b) on the scale 3a) e.g.: if the temperature is 20^{o}C and plaster insulation, mark a cross under 20^{o}C:

concrete - metal
<u>plaster</u> 20^{o}C
x
wood o

If you have 20^{o}C and wood insulation, write a cross below, on the left of 20^{o}C

20^{o}C
<u>wood</u> x

3b)
iv) Determine the number of sleeping romms per living room (1, 2 and 3).
v) Determine the temperature inside the sleeping room(s).
vi) Write down these results on scale 3b.
vii) Work out the mean of result 3a) and 3b) and write it down on half-axis 3.

4. Uses - Others

4a) Renewed servicable volume and 4b) Number of presence hours.

a) Work out the number of servicable m^{3}, <u>per person</u> in the house or flat.
b) Work out the air-renewal level (0.5, 1 or 2 ACH).

c) Multiply results a) and b) and write down on scale 4a.

Conclusion:

A coefficient of more than 1 means that ratio between performance and energy consumption is rather good. Less than 1 means that the ratio is rather bad, that is: your energy consumption is too large, compared to the way it is useful for you. If a coefficient shows bad values, it will be important to know why by inquiring further about it.

Measure interpretation:

The last conclusion already gives the first elements for the interpretation of the diagrams. The performance ruler shows the possibilities for the following energy economies.

- Lower performance level through lower comfort level.
- Lower performance level of fittings by improving the envelope quality.
- Performances improved by lower consumption due to a better quality of equipment.

Still, the energy availability can be regulated according to the performance level or adapted thanks to adequation of the equipment. The performance diagram gives means to describe the kind of uses and it makes it easier to choose the right equipment.

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accuracy: ! **references:** Saugy, 1985

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recommended applications:
The diagrams allow comparisons between performances and comfort levels in different buildings. They show the places where the energy consumption is too high compared to the comfort level.

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alternative techniques:

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additional information:

Performances are analysed in 3 groups:

1. MOBILITY (people, objects, information): This group takes into account the inside architecture of the building and its situation towards working places, schools, etc.
2. EQUIPMENT: Fittings for food supply (cooking, refrigerating, etc.), leisure, etc.
3. CONDITIONING: deals with the climate realised inside the building (heating, air conditioned, etc).

Performance is the ratio between availability of equipment, temperature, etc. and used made of these.

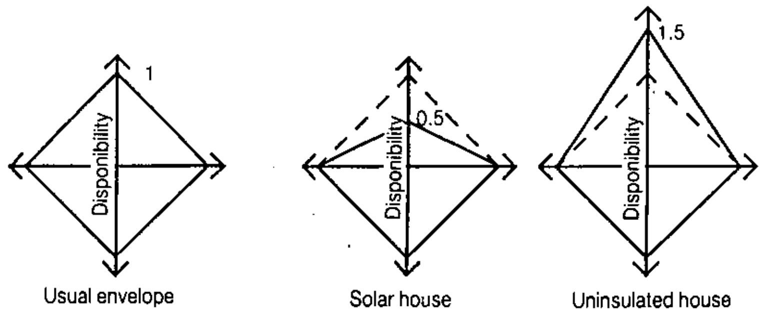

Fig. 1 Examples of envelope performance.

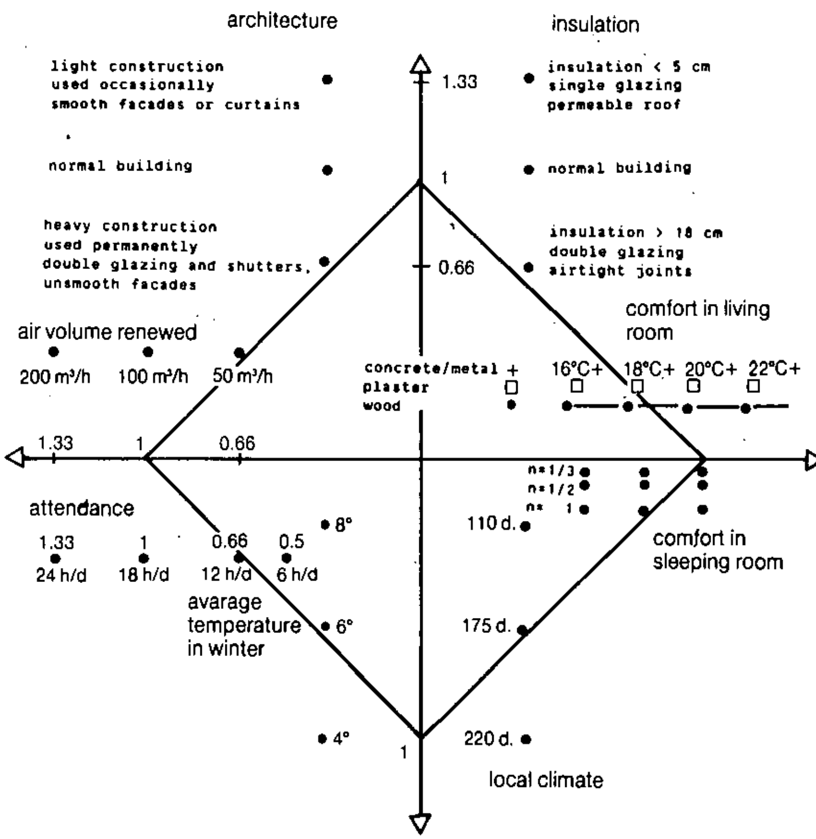

Fig. 2 Diagram for assessing space conditioning performance.

analysis technique:	**application area:**	**referenced from:**
M.5	ECONOMIC EVALUATION	

title:	**references to:**
SIMPLE PAYBACK TIME OF AN INVESTMENT	

description:

Simple payback time [years], PBT, can be calculated from PBT = $\Delta I/\Delta E$
where
ΔI = cost of the investment, expressed in current value (of the year 0) [cost],
ΔE = annual cost saving corresponding to the investment, expressed in current value (of the year 0) [cost/year].

The PBT is to be compared with the estimated lifetime of the investment. This indicator tends to favor short term investment ECOs.

The simple PBT is easy to evaluate, but has some disadvantages:

i) The simple PBT does not take into account the effect of the current discount rate. This means for the PBT to be accurate that the sponsor must not borrow money to pay the investment.
ii) The simple PBT does not take into account the effect of the escalation rate of prices, especially as far as energy prices are concerned.
iii) The simple PBT does not take into account the life-time of the investment. For example two retrofits with the same payback but with different life expectances are clearly <u>not</u> equal investments.

accuracy:	**references:**

recommended applications:

alternative techniques: AT M.6 through 9

additional information:

analysis technique: M.6	**application area:** ECONOMIC EVALUATION	**referenced from:**

title: DISCOUNTED PAYBACK TIME OF AN INVESTMENT	**references to:**

description:

Discounted payback time [years] can be calculated from

Discounted PBT = $\ln[\,\Delta I*(R-1)/(\Delta E*R)+1]/\ln[R]$
where

R = (1+j)/1+i)
ΔI = cost of the investment expressed in current value (year 0) [cost]
ΔE = total annual cost saving corresponding to the investment, expressed in current value (year 0) [cost/year].
i = current discount rate [fraction].
j = real escalation rate of energy prices [fraction].

Unlike simple payback time, the discounted PBT takes into account the effects of the current discount rate and of the escalation rate of energy prices.

This indicator, however, gives no weight to the cost savings occuring after the payback period. Thus, it gives a short term vision of the profit-earning capacity of an investment.

accuracy:	**references:**

recommended applications:

alternative techniques: AT M.5, M.7, M.8, M.9

additional information:

analysis technique:	**application area:**	**referenced from:**
M.7	ECONOMIC EVALUATION	

title:	**references to:**
"PRESENT VALUE" OR "NET-LIFE CYCLE SAVINGS" OF AN INVESTMENT	

description:

Present value or net life cycle savings of the investment [cost], PV, can be calculated from

$$PV = -\Delta I + \Delta E * R * (R^n - 1)/(R-1) - \Delta M * P * (P^n - 1)/(P-1)$$

where

$R = (1+j)/(1+i)$ and $P = (1+m)/(1+i)$.
ΔI = cost of the investment, in current value (year 0) [cost].
ΔE = annual cost saving corresponding to the investment, in current value (year 0) [cost/year].
ΔM = annual maintenance cost, in current value (year 0) [cost/year].
i = current discount rate [fraction].
j = real escalation rate of energy prices [fraction].
m = real escalation rate of maintenance costs [fraction].
n = lifetime of the investment [years].

The higher the Present Value of an investment, the higher its profit earning capacity for a given discount rate.

This is the most complete indicator to measure the profit-earning capacity of an investment over its whole lifetime, taking into account the investment cost, but it has some disadvantages:

i) The lifetime of the investment must be estimated.
ii) An hypothesis is necessary on the evolution of energy prices.
iii) A value of the current discount rate must be chosen in order to perform the evaluation. This value must take into account the financial risk associated to the investment, which is generally difficult to quantify.
iv) The use of the Present Value as an economic indicator is based on the assumption that the Present Value decreases exponentially as function of the current discount rate. This assumption is true for most Energy Conservation investments. It may not be true when different projects involving different energy sources are to be compared.

accuracy: ! **references:**

recommended applications:

alternative techniques: AT M.5, M.6, M.8, M.9

additional information:

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analysis technique:	**application area:**	**referenced from:**
M.8	ECONOMIC EVALUATION	

title:	**references to:**
"INTERNAL RATE OF RETURN" OF AN INVESTMENT	

description:

The internal rate of return [fraction], IRR, may be calculated as follows: First calculate the value of R which satisfies the following equation:

Present Value = 0 or $\Delta I = \Delta E * R * (R^n - 1)/(R-1)$, or

$$R^{n+1} - R*(\Delta I/\Delta E + 1) + \Delta I/\Delta E = 0 \qquad [1]$$

Second calculate the corresponding value of i = IRR from the relation:

R =(1+j)/(1+IRR), or

$$IRR = [(1+j)/R] - 1 \qquad [2]$$

where

ΔI = cost of the investment, in current value (year 0) [cost].

ΔE = annual cost saving corresponding to the investment, in current value (year 0) [cost/year].

j = real escalation rate of energy prices [fraction].

n = lifetime of the investment [years]

The IRR may be compared with the borrowing rate; if the IRR < borrowing rate, the investment is not profit earning.

The evaluation of the IRR of an investment does not require the choice of a discount rate when comparing two investments and it gives a range of discount rates in which the investment keeps its profit earning capacity.

The use of this indicator has some draw-backs:

i) The IRR is influenced by the distribution law of the savings as function of the time and tends to only be applicable to short term earning investments.

ii) The use of the IRR to compare different investments with each other (the greater the IRR, the more profit earning the investment), is based on the assumption that the Present Value decreases exponentially as function of the current discount rate so that equation [1] has only one root. This assumption may not be true in certain cases as explaned in AT M.7 4).

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accuracy: ! **references:**

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recommended applications:

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alternative techniques: AT M.5, M.6, M.7, M.9

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additional information:

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analysis technique:	**application area:**	**referenced from:**
M.9	ECONOMIC EVALUATION	

title:	**references to:**
"COST FOR SAVINGS" OF AN INVESTMENT	

description:

The cost for savings, CS, can be calculated from

$$CS = \frac{\Delta I + \Delta M*P*(P^n-1)/(P-1)}{\Delta E*R*(R^n-1)/(R-1)}$$

with $R = (1+j)/(1+i)$ and $P = (1+m)/(1+i)$

where

ΔI = cost of the investment, in current value (year 0) [cost].
ΔE = annual cost saving corresponding to the investment, in current value (year 0) [cost/year].
ΔM = annual maintenance cost, in current value (year 0) [cost/year].
i = current discount rate [fraction].
j = real escalation rate of energy prices [fraction].
m = real escalation rate of maintenance costs [fraction].
n = lifetime of the investment [years].

The profit earning capacity of the investment is directly estimated by comparing the cost for savings with 1:

$CS>1$ = the investment is not profit earning,
$CS=1$ = the total savings over the whole lifetime are just equal to the total cost,
$0<CS<1$ = the lower the CS, the higher the profit earning capacity of the investment.

accuracy:	**references:**

recommended applications:

alternative techniques: AT M.5 through 8

additional information:

APPENDIX I REFERENCE VALUES

INTRODUCTION TO APP. I

A fundamental part of any audit step is the comparison of measured values of indicators with required or desired values of the same indicators. This appendix is intended to be a collection of the most frequently used reference, legal and target values against which values obtained from building audits may be compared.

Such values may refer to the whole building (e.g. energy indicators) or to component performance. It must be remembered, however, that often the Reference Values (RV) are country dependent. In fact, the average performances and the desired targets vary with technological level, climate, occupants' habits and behavior, etc. Even values, which should be invariant, such as fuel heat content or material conductivities, are found to vary from country to country.

The text has, therefore, been written with the intention of providing the reader with a list of values that should be adapted to the appropriate national (and regional) situation. The values supplied should only be regarded as examples of indicators or parameters.

The Reference Values are presented in standard forms. The application area, the audit step, the audit procedures and the specific ECOs, where the Reference Values are used, are highlighted.

The conceptual guideline for the compilation of this Appendix was not only to provide example values but also brief information on how to obtain and use them. It is not always possible to distinguish the legal from target values. In some cases they coincide. This is particularly true when new, advanced legal standards have been introduced by national governments in the framework of an energy conservation policy. The advance performance of a new component (e.g. condensation gas boiler, heat pump) can be considered as "design" and "target" value at the same time.

For a discussion of Reference Values, see Ch. 2. A list of Reference Values is given below.

LIST OF REFERENCE VALUES (RV)

TITLE

ENVELOPE (E)

E.1 Heating degree-days.
E.2 Volumetric heat loss coefficient.
E.3 Building component U-values.
E.4 Ventilation rates and ventilation openings.
E.5 Building air tightness.
E.6 Building component air tightness.

REGULATION (R)

R.1 Thermal comfort.
R.2 Tolerable contaminant concentrations.
R.3 Plant preheating (and precooling) relationships.
R.4 Exhaust hood performance data.
R.5 Typical damper leakage data.
R.6 Typical VAV fan controller characteristics.
R.7 CO emission and garage ventilation requirements.
R.8 Typical evaporative cooling equipment performance.
R.9 Effect of poor maintenance on the efficiency of a reciprocating compressor.
R.10 Occupancy and ventilation rates.
R.11 HVAC equipment service lifetime expectations.
R.12 Swimming pools reference data.

HEATING (H)

H.1 Heating plant combustion efficiency.
H.2 Boiler thermal efficiency and stand-by losses.
H.3 Heating plant life factors.
H.4 Performance of fire-places.

HEATING/COOLING (H/C)

H/C.1 Performance indices of heating and cooling devices.
H/C.2 Air to air heat recovery, typical efficiencies.

COOLING (C)

C.1 Effect of chilled water temperature on chiller COP.
C.2 Effect of condenser temperature on chiller COP.
C.3 Part load chiller performance.
C.4 Effect of condenser fouling on chiller performance.

DUCTWORK (D)

D.1 Target values for duct insulation and leakage.
D.2 Air filter performances.

PIPEWORK (P)

P.1 Recommended insulation thicknesses for hot pipes.
P.2 Steam trap application guide and losses evaluation.

SERVICE HOT WATER (S)

S.1 Water and SHW consumption.
S.2 Efficiencies for SHW systems.
S.3 SHW flow rates and temperatures.
S.4 Makeup water supply temperatures.
S.5 Solar SHW heater.
S.6 Water Quality

LIGHTING (L)

L.1 Illuminance levels, installed power.
L.2 Installed efficacy of lighting equipment.
L.3 Luminous efficacy for different lamp types.
L.4 Light loss factors.

ELECTRICAL SYSTEMS (EL)

EL.1 Typical characteristics of various motor speed control options.
EL.2 Typical high efficiency motor improvements.
EL.3 Variation of efficiency and power factor with part load.
EL.4 Variation of motor efficiency with motor size.
EL.5 Electrical system equipment life.
EL.6 Electric motors - maximum kvar for PF correction and moment of inertia capabilities.
EL.7 Typical electrical appliance loads and usage.

reference values:	**application area:**	**referenced from:**
E.1	ENVELOPE	AP E.1, AT E.1

title:	**references to:**
HEATING DEGREE-DAYS	

audit stage:
Disaggregation/ECO Detailed Evaluation.

description:

In Table 1 are given some base and reference temperatures for heating degree-day calculations (see AT E.1).

TABLE 1. Degree-day base and reference temperatures.

Country	Base temperature [^oC]	Reference temperature [^oC]
Canada:	18.0	
France: poorly insulated buildings	18.8	
highly insulated buildings	16.0	
FR Germany and Italy:	19.0	12.0
The Netherlands:	18.0	
Sweden:	17.0	11.5
U.K.: (Gas Council Standard)	15.5	15.5
Other institutes - working days	18.3	
Other institutes - night, week-ends	12.8	
USA:	18.3	18.3

The annual heating requirements are usually calculated from the degree-days for a continuously heated building.

For an intermittently heated building the heating requirement will be reduced. The magnitude of this reduction will depend on three factors:

1. the length of the occupation period (both number of days per week and number of hours per working day),

2. the thermal mass of the building (stored heat is dissipated and must be replaced during the heating-up period),

3. response characteristics of the heating system.

The IHVE Guide (1970) suggests the use of three correction factors:

1) - for length of working week

7 days	1.00
5 days (week-end shut-down)	
massive buildings	0.85
lightweight buildings	0.75

2) - for length of working (heating) day

		if bldg. mass light	if bldg. mass heavy
occupied period	4 h	0.68	0.96
	8 h	1.00	1.00
	12 h	1.25	1.02
	16 h	1.40	1.03

3) - for building and plant response

		if plant response quick	if plant response slow
continuous 24 h heating		1	
night shut-down building mass	light	0.55	0.70
	medium	0.70	0.85
	heavy	0.85	0.95

reference values:	application area:	referenced from:
E.2	ENVELOPE TRANSMISSION	

title:	references to:
VOLUMETRIC HEAT LOSS COEFFICIENT	

audit stage:
Building Rating/Disaggregation/Preliminary Audit.

description:

The volumetric heat loss coefficient is defined as (Building transmission losses)/(Building heated volume).

Fig. 1 shows the volumetric heat loss coefficient required by Italian law, as a function of the number of degree-days and of the shape factor Envelope Area/Volume (A_e/V).

Typical values of shape factors are $[m^2/m^3]$
- for apartment buildings 0.30 - 0.55
- for mid-terrace houses 0.50 - 0.60
- for semi-detached houses 0.60 - 0.75
- for detached houses 0.79 - 0.90

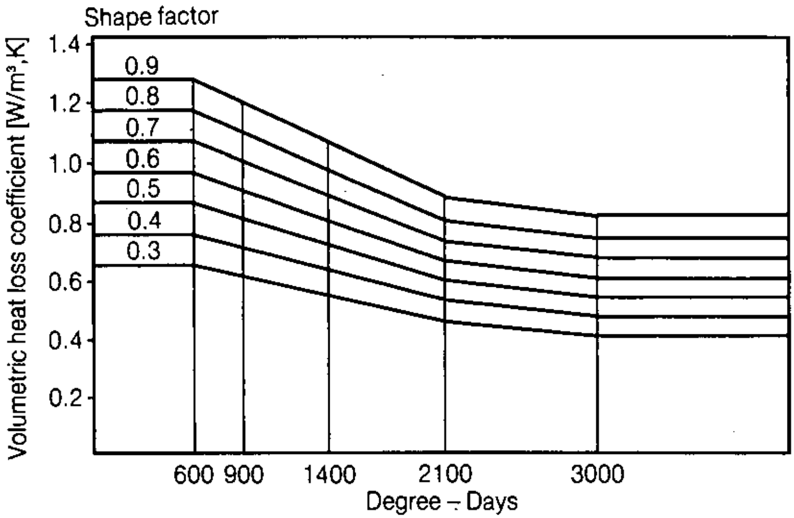


Fig. 1 Example of legal values for volumetric heat loss coefficient.

reference values:	application area:	referenced from:
E.3	ENVELOPE - TRANSMISSION LOSSES	ECO E.8, E.9, E.10, E.11, E.12, E.13, E.14, E.15, E.16, E.17, E.20, E.28.

title:	references to:
BUILDING COMPONENT U-VALUES	

audit stage:
ECO Identification/ECO Detailed Evaluation.

description:

Several countries have norms imposing maximum limits on the U-values for the structural components of new buildings.

Reference and target values for building structural components are usually issued by technical institutes, such as ASHRAE for USA or SIA for Switzerland. Such standards are often adopted by governments.

The maximum permitted heat transfer coefficients of building elements in various countries are quoted in Table 1.

TABLE 1. Maximum permitted heat transfer coefficients, U-values [W/m^2,K].

	Roof	Exp. outside	Exp. floor structures	Floor structure above crawl-space	Floor structure on earth	Floor structure above cellar	Windows	Doors	Max. window area	Bldg aver. wall
Canada 1978	0.14[1]-0.40	0.27-0.40	0.21-0.40	0.21-0.40	0.21[2] 0.40	0.21-0.40	2.2-3.3	0.7	15 %	-
Denmark 1979	0.20	0.30-0.40[3]	0.20	0.30	0.30	0.40	2.90	2.00	15 %	
Netherlands 1978	0.78	0.78	0.78	1.92	1.92	1.92	2.80[4]			
Norway 1980	0.23	0.25	0.23	0.30	0.30	0.30	2.10	2.00	15 %	
Sweden 1980	0.17[1]-0.20	0.25-0.30	0.17-0.20	0.30	0.30	0.50	2.00	1.00	15 %[5]	
Switzerland 1980	0.50	0.60	0.60	0.60	0.80	0.80	3.30			0.60-0.75[6]
United Kingdom 1982	0.35	0.60	0.60						12 %[7]	
United States 1980 ASHRAE	0.14[1]-0.28	0.60-1.60[8]		0.25-2.00	0.34-3.33	0.25-2.00				

1 Figures vary depending on climate zones (Sweden) or number of heating degree days (United States, Canada).
2 Perimeter insulation required if floor <600 mm below ground level.
3 Depends on wall density, the higher demand on lightweight walls.
4 Only in living room and kitchen.
5 Of "external" floor area (+3 % of internal floor area).
6 Values for mean conditions, the lower value for single-family house.
7 Figure shown is percentage of perimeter wall area (including party walls). Greater percentage is possible by using double or triple glazing.
8 Includes windows and doors.

In Table 2 are given thermal conductivities for some common building materials.

TABLE 2. Thermal conductivity of building materials [W/m,K].

Material	Thermal conductivity
Asbestos-cement	0.58
Brickwork, common	0.84
Cellular glass	0.05
Compressed straw slabs	0.09
Concrete:	
ballast	1.0-2.0
cellular	0.10-0.28
clinker	0.33-0.40
foamed slag	0.14-0.25
vermiculite	0.07-0.28
Cork board	0.05-0.06
Fibreboard	0.05
Glass	1.02
Glass fibre	0.036
Glass wool	0.035
Hardboard	0.10
Perlite, expanded	0.052
Plasterboard	0.16
Plaster, dense	0.50
Plywood	0.14
Polyisocyanurate, cellular	0.020
Polystyrene, expanded	0.036
Polyurethane, cellular	0.023
Polyurethane, foam	0.023-0.026
Stone	1.30-2.80
Tiles, roof	0.83-0.94
Timber, softwood	0.14
Ureaformaldehyde foam	0.032-0.040
Cellulosic insulation	0.035-0.045
Cement plaster	0.072
Vermiculite	0.03-0.04
Wood wool slabs	0.08-0.14

reference values: E.4	**application area:** ENVELOPE - VENTILATION	**referenced from:** AT E.4.
title: VENTILATION RATES AND VENTILATION OPENINGS		**references to:**

audit stage: Disaggregation.

description:

A summary of minimal ventilation (outdoor air supply) rates specified in various countries is presented in Table 1. Comparison is difficult because the rates are variously expressed, either in terms of air changes per hour (ACH), minimal flow rate [l/s] or flow rate per square meter of floor area [l/m^2.s] or per person [l/s,p]. In those countries where mechanical ventilation is not mandatory in dwellings, ventilation requirements are also specified in terms of the minimum area of ventilation openings (see Table 2).

TABLE 1. Minimal ventilation rates.

	Residential Buildings					Offices	
Country	Whole dwelling	Living room	Bed room	Kitchen	Bath room	No smoking	Smoking
Canada	0.5 [ACH]						
Denmark	0.5 [ACH]			15-20 [l/s]	15 [l/s]		
Finland	0.35 [$l/s,m^2$]			8.8 [l/s]	6.4 [l/s]	0.8 [$l/s,m^2$]	1.6 [$l/s,m^2$]
Italy		4.5 [l/s,p]	4.2 [l/s,p]	1 [ACH]	2 [ACH]		
Netherlands		21-42 [l/s]		21-28 [l/s]	14 [l/s]		
Norway				22 [l/s]	17 [l/s]		1.4 [$l/s,m^2$]
Sweden	0.35 [$l/s,m^2$]			10 [l/s]	10 [l/s]		
Switzerland				23-33 [l/s]	17 [l/s]		
Scotland		3-8 [l/s,p]	3-8 [l/s,p]	6 [ACH]	3 [ACH]		
USA	0.35 [ACH]	1.5 [l/s,p]	1.5 [l/s,p]	50 [l/s]	25 [l/s]		10 [l/s,p]
European Community						5.5 [l/s,p]	8.3 [l/s,p]

TABLE 2. Minimum ventilation openings for residential buildings.

	Denmark	Netherlands	England	Norway	Sweden
Living room		0.02-0.04 m^2	0.5*		
Bedroom		0.02-0.04 m^2	0.5*		
Kitchen	0.015-0.02 m^2	0.02-0.03 m^2	0.5*	0.02 m^2	0.02 m^2
Bathroom	0.015 m^2	0.01 m^2	0.5*	0.015 m^2	0.015 m^2

* per cent of floor area.

reference values:	**application area:**	**referenced from:**
E.5		ECO E.18, AP E.6, E.7.

title:	**references to:**
BUILDING AIR TIGHTNESS	AP E.5

audit stage:
Detailed ECO Evaluation.

description:

Measurements of building air tightness are usually carried out by pressurisation (see AP E.5). Currently, Sweden and Norway are the only countries that have air-tightness norms for whole buildings. Table 1 shows such legal values, in terms of the permitted air changes per hour [ACH] at a pressure difference of 50 Pa.

TABLE 1. Acceptable maximum leakage factors for houses.

Type of building	Leakage [ACH] at 50 Pa Sweden	Norway
Detached and linked houses	3.0	4.0
Other houses, max. 2 storeys	2.0	3.0
Houses with 3 or more storeys	1.0	1.5

reference values: E.6	**application area:** ENVELOPE - INFILTRATION	**referenced from:** ECO E.7, E.18, E.28, E.29, AP E.12, AT E.4.

title: BUILDING COMPONENT AIR TIGHTNESS	**references to:** AT E.4.

audit stage:
Detailed ECO Evaluation.

description:

In some countries target values for the air tightness of building components are provided by building norms. Table 1 shows legal values of Swedish Norms (SBN 1975).

TABLE 1. Maximum accepted air leakage at a difference in air pressure of 50 Pa.

Building element	Acceptable air leakage [m^3/m^2,h] 2 storeys or less	3 storeys or more
External wall	0.4	0.2
External window and door *	1.7	1.7
External roof, floor between a dwelling and the external air or a ventilated space.	0.2	0.1

* Refers to the air tightness of the joint between the frame and window sash or door leaf respectively.

Many countries have issued standards and norms for window test methods and maximal leakage rates. Standard values are usually given in terms of leakage rate per metre of opening joint or per m^2 of total window area. Windows are often divided into various classes.

Figures 1 and 2 show the window air leakage rates per m joint length and per m^2 window area, respectively, as a function of pressure difference for different classes of windows, as defined in various countries.

In Table 2 are shown leakage areas (see AT E.4) for different building components. The values are average values from measurements in houses.

Typical infiltration rates through doors is presented in Fig. 3.

Infiltration rates for windows are given in Fig. 4.

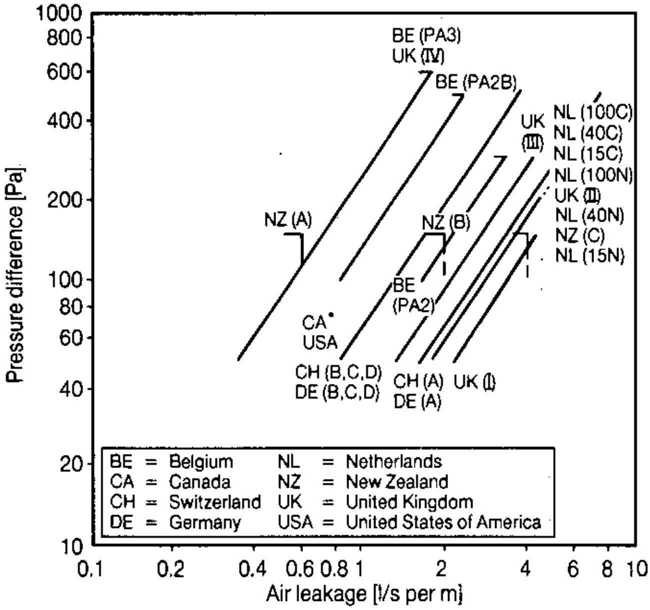


Fig. 1
Legal values for window leakage per meter of joint length.

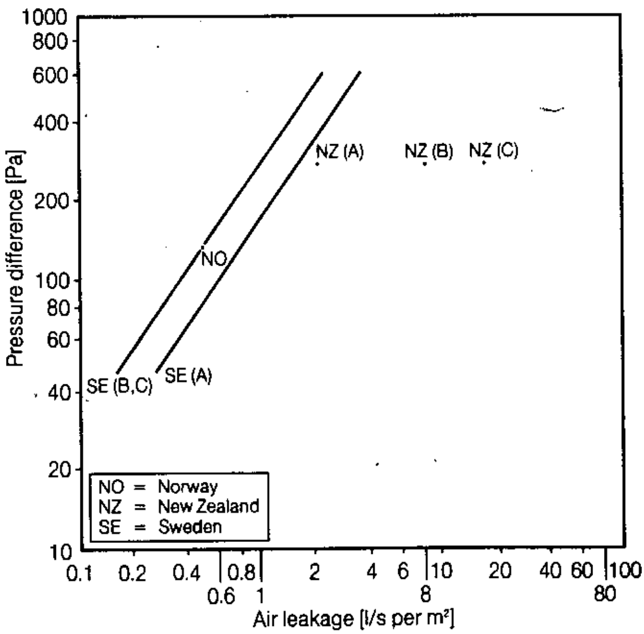


Fig. 2
Legal values for window leakage per square meter of window surface area.

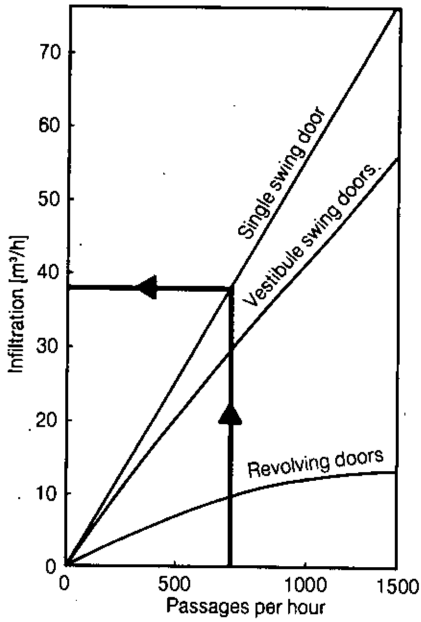
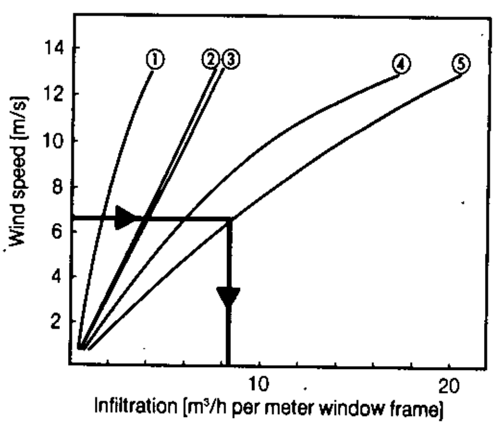


Fig. 3 Infiltration through doors.



KEY TO WINDOW INFILTRATION CHART (LEAKAGE BETWEEN SASH & FRAME)

TYPE	MATERIAL	WEATHERSTRIPPED?	FIT
①ALL HINGED	WOOD METAL	YES YES	AVG. AVG.
②ALL HINGED DBL. HUNG	WOOD METAL STEEL	NO NO NO	AVG. AVG. AVG.
③ALL DBL. HUNG	WOOD STEEL	YES YES	LOOSE AVG.
④CASEMENT	STEEL	NO	AVG.
⑤ALL HINGED	WOOD	NO	LOOSE

Fig. 4 Infiltration through window frames.

TABLE 2. Component leakage areas.

Component	Estimate
SILL caulked	0.8 [cm^2/m of perimeter]
not caulked	4 ["]
JOINTS (not taped, no vapor barrier)	1.5 [cm^2/m^2 wall joint]
CASEMENT weather stripped	0.8 [cm^2/m^2 window area]
or AWNING not weather stripped	1.6 ["]
SINGLE HUNG WINDOW weather stripped	2.2 ["]
not weather stripped	4.4 ["]
DOUBLE HUNG WINDOW weather stripped	3.0 ["]
not weather stripped	6.0 ["]
SINGLE SLIDER weather stripped	1.8 ["]
not weather stripped	3.6 ["]
DOUBLE SLIDER weather stripped	2.6 ["]
not weather stripped	5.2 ["]
SINGLE DOOR weather stripped	8 [cm/m^2 of door area]
not weather stripped	11 ["]
DOUBLE DOOR weather stripped	8 ["]
not weather stripped	11 ["]
ACCESS TO ATTIC OR CRAWL SPACE	
not weather stripped	30 ["]
WOOD FRAME WALL-WINDOW caulking	0.3 [cm^2/m^2 window area]
no caulking	1.7 ["]
MASONRY WALL-WINDOW caulking	1.3 ["]
no caulking	6.5 ["]
WOOD WALL-DOOR FRAME caulking	1.0 [cm^2/m^2 door area]
no caulking	5 ["]
GAS WATER HEATER (in conditioned space)	20 [cm^2]
ELECTRIC OUTLETS AND SWITCHES not gasketed	0.5 ["]
RECESSED LIGHT FIXTURES	10 ["]
PIPE PENETRATIONS caulked or sealed	1 ["]
not caulked	6 ["]
DUCT PENETRATION sealed or vapor barrier	1.6 ["]
unsealed or no vapor barrier	24 ["]
FIREPLACE W/O INSERRT damper closed	69 ["]
damper open	350 ["]
FIREPLACE WITH INSERT damper closed	36 ["]
damper open	65 ["]
KITCHEN FAN damper closed	5 ["]
damper open	39 ["]
BATHROOM FAN damper closed	11 ["]
damper open	20 ["]
DRYER VENT damper closed	3 ["]
AIR CONDITIONER (wall or window unit)	24 ["]

reference values:	application area:	referenced from:
R.1	REGULATION	ECO R.1.

title:	references to:
THERMAL COMFORT	MT R.3.

audit stage:
ECO Identification/Evaluation.

description:

Recommended Comfort Requirements.

1. Light mainly sedentary activity during winter conditions (heating period).
   a) The operative temperature (see MT R.3) should be between 20 and 24°C.

   b) The vertical air temperature difference between 1.1 m and 0.1 m above floor (head and ankle level) should be less than 3 K.

   c) The surface temperature of the floor should normally be between 19 and 26 °C, but floor heating systems may be designed for 29 °C.

   d) The mean air velocity should be less than 0.15 m/s.

   e) The radiant temperature asymmetry from windows or other cold vertical surfaces should be less than 10 K (in relation to a small vertical plane 0.6 m above the floor).

   f) The radiant temperature asymmetry from a warm (heated) ceiling should be less than 5 K (in relation to a small horizontal plane 0.6 m above the floor).

2. Light, mainly sedentary activity during summer conditions (cooling period).

   a) The operative temperature should be between 23 and 26°C.

   b) The mean air velocity should be less than 0.25 m/s.

Mean metabolic rates per square meter of body area for different activities are given in Table 1 (ISO 7730-1984). The mean body surface area for males is 1.7 to 1.8 square meters, and for females from 1.5 to 1.6 square meters (in Europe and Northern America, see Fracastoro-Lyberg 1983).

App. I Reference Values (R)

TABLE 1. Metabolic rates of different activity levels.

Activity	Metabolic rate [W/m^2 body surface area]
Reclining	46
Seated, Relaxed	58
Standing, Relaxed	70
Sedentary activity (office, dwelling, school, laboratory)	70
Standing activity (shopping, laboratory, light industry)	93
Standing activity (shop assistent, domestic work, machine work)	116
Medium activity (heavy machine work, garage work)	165

reference values:	**application area:**	**referenced from:**
R.2	REGULATION	

title:	**references to:**
TOLERABLE CONTAMINANT CONCENTRATIONS	

audit stage:
ECO Identification/Evaluation.

description:

Accepted level of contamination for different examples of contaminants are given in Table 1. (AFS, 1984 and SBN, 1980)

TABLE 1 Tolerable contaminant concentrations

Contaminant	Source	Accepted 24 h average	15 min average
Acetone	O, R	250 ppm	500 ppm
Benspyrene	C, ES, TS	0.005 mg/m^3	0.03 mg/m^3
Benzene	C, ES	5 ppm	10 ppm
Carbon dioxide	O	5000 ppm	10000 ppm
Carbon monoxide	ES, C, TS	35 ppm	100 ppm
Ethanol	O	1000 ppm	-
Formaldehyde	BM, TS	0.8 ppm	-
Nitrogendioxide	C, ES	2 ppm	-
Nitrogenmonoxide	C, ES	25 ppm	50 ppm
Radon (old buildings)	BM, ES	400 Bq/m^3	-
(rebuild)		200 Bq/m^3	-
(new buildings)		70 Bq/m^3	-
Gamma radiation	BM, ES	50 µR/h	-
Toluene	BM, C, ES	80 ppm	100 ppm
Xylene	BM	80 ppm	100 ppm

BM = building materials, C = combustion, ES = external source,
O = occupants, R = repair work, TS = tobacco smoke.

reference values:	**application area:**	**referenced from:**
R.3	REGULATION	ECO R.2.

title:	**references to:**
PLANT PREHEATING (ANO PRECOOLING) RELATIONSHIPS	

audit stage: ECO Identification/Evaluation.

description:

TABLE 1. Allowances for intermittent heating (U.K. design conditions), after IHVE Guide Book A, 1970).

Plant characteristics		$-1^{o}C$ outside		$5^{o}C$ outside	
Response	Plant size ratio	Preheating time [h]	Fuel consumption [%]	Preheating time [h]	Fuel consumption [%]
Heavyweight building:					
	1.2	v.long	96	5.0	89
	1.5	6.5	91	2.8	84
Short	2.0	3.3	85	1.4	81
	2.5	1.8	82	0.7	78
	3.0	1.1	80	0.3	76
	1.2	v.long	96	5.9	90
	1.5	6.5	91	4.2	88
Long	2.0	4.4	89	3.0	87
	2.5	3.4	87	2.3	86
	3.0	2.8	86	1.9	85
Lightweight building:					
	1.2	7.0	75	1.5	56
	1.5	3.0	60	0.8	53
Short	2.0	0.9	54	0.5	52
	2.5	0.6	53	0.4	51
	3.0	0.4	52	0.3	50
	1.2	long	80	3.5	66
	1.5	4.0	69	2.3	62
Long	2.0	2.4	62	1.8	58
	2.5	1.9	59	1.6	57
	3.0	1.7	58	1.5	56

Notes:
1. The Table is based on an indoor-outdoor temperature difference of 20 K and an occupied period of 8 h, for a 7 day week.
2. Plant size ratio =(Normal max plant output)/(Design load for 20 K rise)
3. Examples of short response plant - direct warm air heating, forced convection; gas or electric radiant panels. Examples of long-response plant - hot water systems with radiators, convectors or radiant panels. Embedded panels have time constants of several hours, and intermittent operation leads to very little economy in fuel.
4. Heavy structure: curtain walling, masonry or concrete (especially multi-storey), subdivided with heavy partitions or floors.
5. Light structure: single-storey, factory type construction; little or no solid partition; structures lined with insulating materials.
6. Fuel consumption is expressed as a percentage of fuel needed for continuous operation.

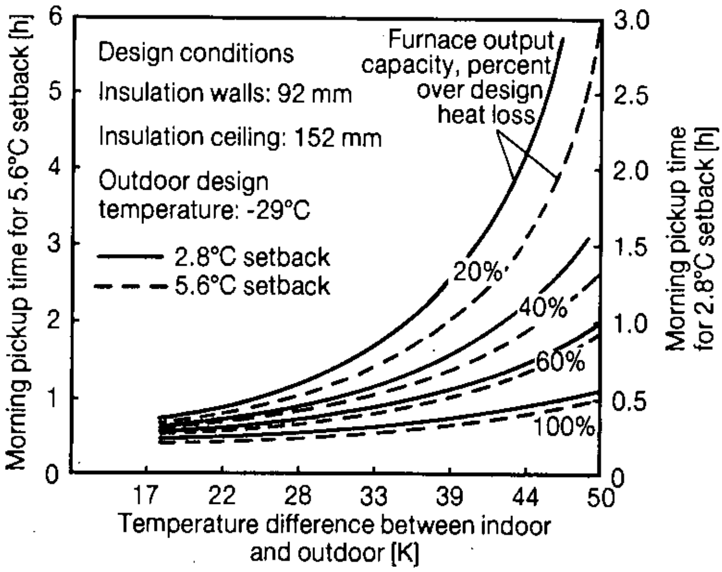


Fig. 1 Time required for furnace to pick up space temperature after night set-back.

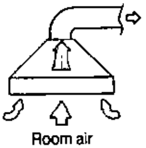
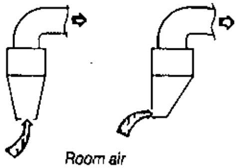
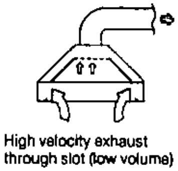
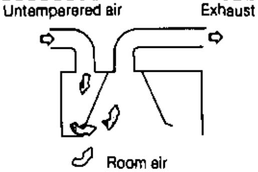
reference values: R.4 ! **application area:** REGULATION ! **referenced from:** ECO R.20, R.21.

title:
TYPICAL EXHAUST HOOD PERFORMANCE DATA

references to:

audit stage:
ECO Identification/Evaluation.

description:
Some exhaust hood performance data for kitchen ventilation are displayed below (Dubin, 1975). For industrial ventilation see ACGIH, 1986.

TYPE	SKETCH	CRITERIA	COMMENTS
Canopy		0.38 to 0.51 m/s recommended face velocity. Absolute minimum 0.3 m/s.	
Slot		230 to 310 l/s per linear metre recommended velocity.	Can substantially reduce volume of exhaust air required (as compared to Canopy).
High Velocity		Maintain face velocity <u>along the hood perimeter</u> as for canopy.	
Push Pull			Can reduce amount of conditioned air exhausted by 70 to 85%.

Comments:

1. Use of low end of range if large hoods and constant air movement, use high end of disturbing room air current, e.g. island canopies.
2. Maintain suitably high duct air velocities (9 to 12 m/s) to limit the settling of grease particles.

reference values:	! application area:	! referenced from:
R.5	! REGULATION AND AIR ! OISTRIBUTION	! ECO R.11. !

title:	! references to:
TYPICAL DAMPER LEAKAGE DATA	! !

audit stage:
ECO Identification/Evaluation.

description:

Damper leakage for different damper styles and pressures are shown in Fig. 1 (after Honeywell, undated).

Leakage rate variations with size for a low leakage damper without edge seals is presented in Fig. 2 (CAM, 1982).

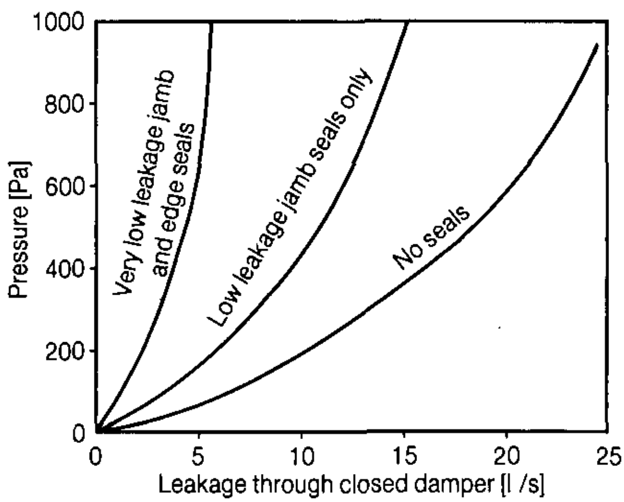


Fig. 1 Damper leakage for different damper styles and pressures.

Note: Variations can vary greatly between different manufacturers and sizes (see next figure). Leakage data for standard dampers is not normally available and depending on the quality of the product and maintenance, leakage can be several times greater than that shown.

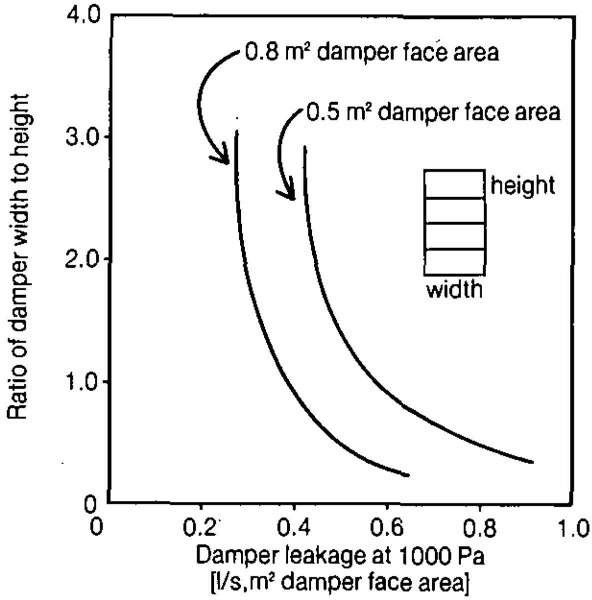


Fig. 2 Leakage rate variations with size for a low leakage damper without edge seals.

Note: If dampers without edge seals are contemplated there is some advantage to using off square configurations to minimise edge leakage.

For dual duct and variable volume boxes the design leakage is 2 % at 0.75 Pa static pressure.

reference values:	application area:	referenced from:
R.6	REGULATION	ECO R.32.

title:	references to:
TYPICAL VAV FAN CONTROLLER CHARACTERISTICS	

audit stage:
ECO Identification/Evaluation.

description:

VAV fan controller characteristics are displayed in Fig. 1 (Honeywell, 1976).

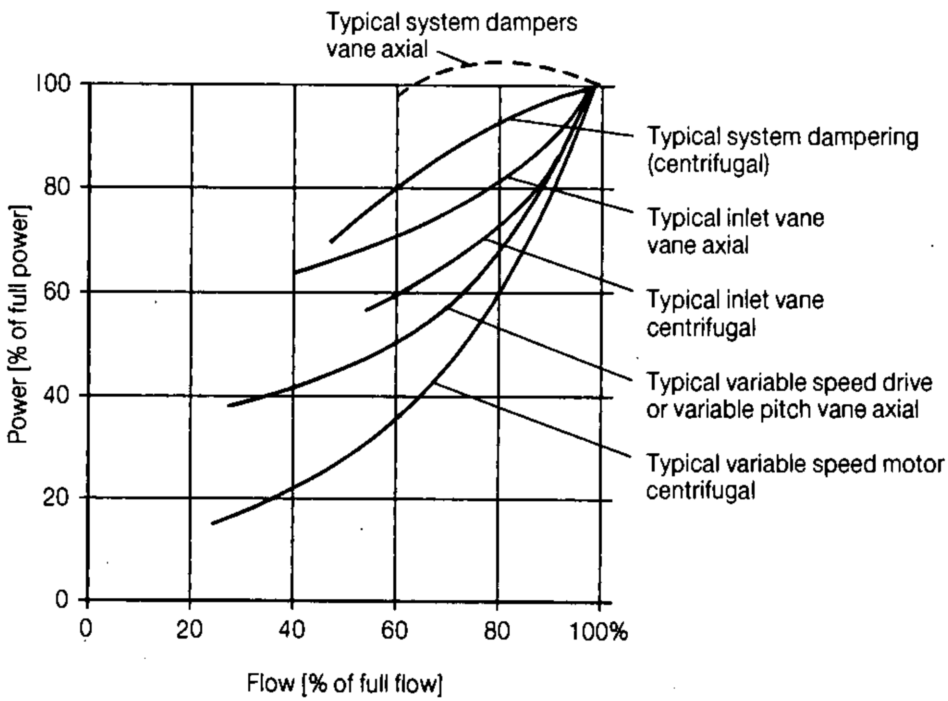


Fig. 1 VAV fan controller characteristics.

reference values:	application area:	referenced from:
R.7	HVAC	ECO E.16, AT R.4.

title:	references to:
CO EMISSION AND GARAGE VENTILATION REQUIREMENTS	

audit stage:
ECO Identification/Evaluation.

description:

In Table 1 are shown some typical CO emissions within parking garages (ASHRAE Fundamentals, Ch. 13, 1985). The assumed vehicle speed is 8 km/h.

TABLE 1. Predicted CO emission within parking garages.

Location	Hot Emissions (Stabilized) [g/min] 1980	Hot Emissions (Stabilized) [g/min] 1985	Cold Emissions [g/min] 1980	Cold Emissions [g/min] 1985
Sea Level				
Summer	12.3	3.6	25.0	9.4
Winter	12.3	3.6	59.4	20.1
High Altitude				
Summer	13.3	3.9	34.3	11.5
Winter	13.3	3.9	83.1	24.7
California				
Summer	9.3	2.6	22.9	9.7
Winter	9.3	2.6	42.1	16.1

Parking Garage Maximal Concentration 100 ppm for one hour or longer (measured between 900 and 200 mm from floor) 400 ppm at any time. This is deemed to be satisfied by supplying 14 m^3/h of outside for each m^2 of floor area (DBC, 1984).

REPAIR GARAGES Time weighted average for 8 hour day or 40 hour week not to exceed 35 ppm. Tail pipe exhaust of 340 m^3/h per vehicles under 6.5 litre engine, 68 m^3/h if larger. Plus general ventilation of 2.550 m^3/h per repair bay (OML, 1982).

reference values:	application area:	referenced from:
R.8	REGULATION	ECO R.19, AT R.5.

title:	references to:
TYPICAL EVAPORATIVE COOLING EQUIPMENT PERFORMANCE	

audit stage:
ECO Identification/Evaluation.

description:
Some data on evaporative cooling equipment performance are shown in Tables 1 and 2 and in Fig. 1. Table 1 displays energy consumption for indirect/direct combinations., Table 2 effectiveness of direct equipment (Supple, 1982) and Fig. 1 effectiveness of indirect equipment.

TABLE 1. Energy use indirect/direct combinations.

1% Mean-Coincident Wet Bulb Design Temperature	Energy Use of Equipment*
10^{o}C and lower	0.06 kW (electrical)/kW cooling
23^{o}C and higher	0.23 kW (electrical)/kW cooling

* By comparison, refrigeration system with air cooled condenser has consumption normally greater than 0.28 kW/kW.

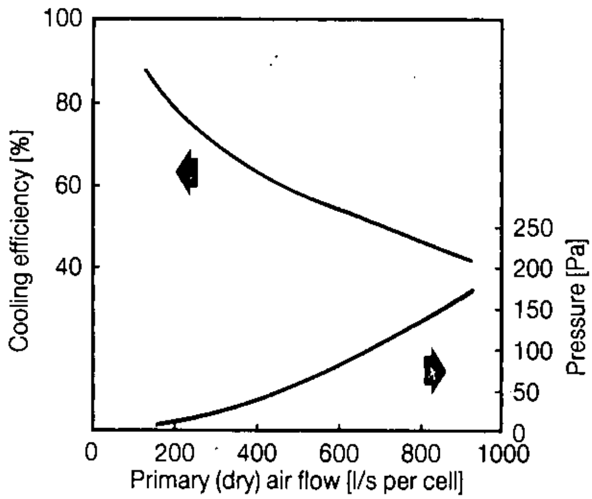


Fig. 1 Effectiveness of indirect evaporative cooling equipment.

TABLE 2. Effectiveness of direct equipment.

	Washer Type Single Spray Bank	Opposed Spray Banks	Capillary Cell	Cellulose Fill
Fan Power [kW] 4720 l/s at 2.5 m/s	.41	.29	.71	.21
Recommended Spray Water Flow l/s water 5 m^3/s air	2.4	5.1	5.7	.4
Pump Power [kW] per 4720 l/s [Head, kPa]	.90 (224)	1.9 (224)	1.79 (224)	.052 (69)
Saturation Efficiency Percent	55	86	98	89
Washer Length in Direction of Air Flow [m]	1.2	2.8	1.5	.8
Relative First Cost	Low	High	High	Low

Saturation efficiency can be pictured as the ability of the washer to change the leaving air quality to approach the saturation curve on the wet bulb line of a psychometric chart.

$$\text{Saturation Efficiency [\%]} = \frac{DB\ (in) - DB\ (out)}{DB\ (in) - WB\ (in)} \times 100$$

reference values:	**application area:**	**referenced from:**
R.9	REGULATION AND COOLING PLANT	ECO R.12.

title: EFFECT OF POOR MAINTENANCE ON THE EFFICIENCY OF A RECIPROCATING COMPRESSOR

References to:

audit stage:
Preliminary ECO Evaluation.

description: In Table 1 is shown the effect of poor maintenance on a 5 ton capacity reciprocating compressor (Korte, 1976).

TABLE 1. Effect of poor maintenance on compressor efficiency.

	Condition			
	Normal	Dirty Evaporator	Dirty Condenser	Dirty Evaporator Condenser
Suction				
Temperature [°C]	4.4	2.8	5.6-6.7	1.7
Gauge Pressure [kPa](1)	476	446	496-517	461
Discharge				
Temperature [°C]	48.9	48.9	54.4-60.0	54.4
Gauge Pressure [kPa]	1810	1807	2063-2352	2063
Compression Ratio(2)	3.31	3.49	3.62-3.96	3.84
Compression Capacity [kW]	18.2	17.1	17.3-15.1	14.7
Power Input [kW](3)	6.5	6.3	7.1-7.6	6.5
EER(4) (kW/kW)	9.54	9.28	8.31-7.24	7.69
Capacity Reduction [%]	-	5.6	4.8-11.3	19.4

(1) Refrigerant 22
(2) Ratio of absolute discharge and suction pressures
(3) Three phase power
(4) Energy efficiency ratio

reference values:	**application area:**	**referenced from:**
R.10	REGULATION	ECO R.5.

title:	**references to:**
OCCUPANCY AND VENTILATION RATES	RV E.4.

audit stage:
ECO Identification/Evaluation.

description:
Occupancy and required ventilation rates for commercial facilities are shown in Table 1 (for residential building ventilation requirements, see RV E.4). In Fig. 1 are shown some typical occupancy densities for different times of the day.

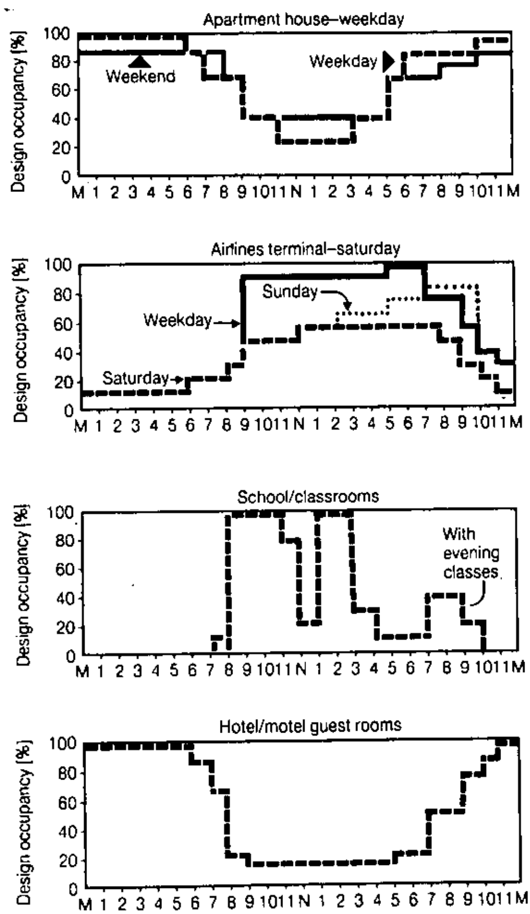


Fig. 1 Examples of occupancy for some building categories.

TABLE 1. Occupancy and required ventilation rates for commercial facilities.

		Occupancy [person/m^2 floor area]	Outdoor air requirements [l/s,person] Smoking	Non-smoking
Food and Beverage Services:	Dining rooms	0.7	17.5	3.5
	Cafeterial, fast food facilities	1	17.5	3.5
	Bars and cocktail lounges	1	25	5
Hotels, Motels, Resorts, Dormitories and Correctional Facilities:	Bedrooms (single, double)	0.05	15	7.5
	Living rooms (suites)	0.2	25	12.5
	Baths, toilets (attached to bedrooms)		25	25
	Lobbies	0.3	7.5	2.5
	Conference rooms (small)	0.5	17.5	3.5
	Assembly rooms	1.2	17.5	3.5
Offices:	Office space	0.07	10	2.5
	Meeting and waiting spaces	0.6	17.5	3.5
	Corridors and utility rooms		0.10	0.10
	Locker and dressing rooms	0.5	17.5	7.5
Retailed stores:	Basement and street floors	0.3	12.5	2.5
	Upper floors	0.2	12.5	2.5
	Storage areas (serving sales and storerooms)	0.15	12.5	2.5
	Malls and arcades	0.2	5	2.5
	Shipping and receiving areas	0.1	5	2.5
	Warehouses	0.05	5	2.5
Educational facilities:	Classrooms	0.5	12.5	2.5
	Laboratories	0.3	-	5
	Training shops	0.3	17.5	3.5
	Music rooms	0.5	17.5	3.5
	Libraries	0.2	-	2.5
Hospitals:	Patient rooms	0.2		
	Public areas	0.15		

reference values:	application area:	referenced from:
R.11	REGULATION	ECO R.43.

title:	references to:
EQUIPMENT SERVICE LIFETIME EXPECTATIONS	

audit stage:
ECO Identification/Evaluation.

description:

TABLE 1. Regulation equipment service lifetime expectations.

Equipment		Expected lifetime [years]	
Roof top conditioning units:	Compressors	15-20	
	Motors	15-20	
	Fan bearings	10	
	Heat and cool coils	15-20	DX,water or steam
		15	electric
	Condenser - Cleanable	20	
	Non-cleanable	10	
Heat pumps (small):	Air to Air Residential		
	Air to Air Commercial	15	
	Air to Water Commercial	19	
Window and thru the wall units:	Overall	10	Residential Grade
		15	Commercial Grade
Condensing equipment:	Computer and small condensers (split system)	15	
Valves and controls:	Valves Actuators		
	- Hydraulic	15	
	- Pneumatic	20	
	- Self-contained	10	
	Dampers	20	
	Controls		
	- Pneumatic	20	
	- Electric	16	
	- Electronic	15	
Terminal units:	(a) Fan coils, induction unit		
	Overall	20	
	Motors	10	
	Coil	7 to 10	
	(b) Unit heaters		
	Gas and electric	13	
	Hot water and steam	20	

reference values:	**application area:**	**referenced from:**
R.12	regulation	ECO R.15, AT R.6.

title: SWIMMING POOL HALL REFERENCE DATA

references to:

audit stage:
ECO Identification/Evaluation.

description:

Pool water temperature		Swimming pool hall air temperature
Pleasure	24 to 27°C	24 to 29°C
Therapeutic	29 to 35°C	27 to 29°C
Competition	22 to 24°C	

Swimming pool Hall humidity: 50 to 60%.

TABLE 1 Swimming pool evaporation rates [kg/s per m^2 of pool area]
(occupancy factor = 1, pool water temperature 25°C, air velocity 0.5 to 1.5 m/s.)

Temperature [°C]	Relative humidity 50%	60%
24	6.66	5.40
26	6.28	4.92
28	5.40	3.88
30	4.41	2.72

Occupancy factors (f)
(To account for variations in pool water evaporation rate with pool usage).

Private pools	Design 1.0	Average 1.0
Public and Institutional	Design 2.0	Average 1.0 to 2.0 depending on use
With pool covers	0.1 to 0.15	

reference values:	**application area:**	**referenced from:**
H.1	CONTROL HEATING PLANT	ECO H.4, H.8, H.11, AP H.2.

title:	**references to:**
HEATING PLANT COMBUSTION EFFICIENCY	

audit stage:
Detailed ECO Evaluation.

description:

The inclusion of latent heat in the calculation of the combustion efficiency (see App. C.4 and AP H.1) gives the gross combustion efficiency whereas neglecting it gives the net combustion efficiency. The difference between the two efficiencies is 6% for gas oil, 3% for heavy oil, 11% for natural gas and 3% for coal.

The calorific values used for the heat contents of the various fuels may also be gross or net (in many countries these are refered to as the upper and lower heating powers). The gross heat content of various fuels is given in Table 1 (ASHRAE, 1985). The ratio of Gross to Net Calorific Values is 1.11 for natural gas, 1.09 for liquid petrol gas and 1.07 for oil. Unburnt particles can be neglected in a properly working boiler.

TABLE 1. Gross heating values for some fuels.

Fuel		Density [kg/m^3]	Heating Value [kJ/kg]
Natural gases	High inert type	0.80 to 0.85	44.8 to 46.0
	High methane type	0.71 to 0.74	52.9 to 54.0
	High kJ type	0.75 to 0.87	53.5 to 48.4
Liquified gases	Commercial propane	2.65	50.1
	Commercial butane	1.99	49.0
Fuel oils Grade	1	0.83 to 0.80	45.8 to 46.3
	2	0.87 to 0.83	45.2 to 45.8
	4	0.93 to 0.89	44.2 to 45.0
	5L	0.95 to 0.92	44.0 to 44.4
	5H	0.97 to 0.95	43.8 to 44.1
	6	1.01 to 0.97	42.9 to 43.7
Coal		-	25 to 33

Usually, the definition of combustion efficiency takes into account only the dry stack losses (see App. C.4). Fig. 1 shows ranges of dry stack losses for light oil and natural gas boilers as a function of the temperature difference (between exhaust gas and boiler room temperatures) and the CO_2 content.

Continuously reading, fully automatic combustion testers measure the oxygen content of flue gases rather than the CO_2 content. However, there is a close relationship between the two concentrations. Table 2 provides the correspondance between oxygen and CO_2 concentration and optimal ranges are indicated.

TABLE 2. Relation between O_2 and CO_2 content in flue gases.

Oxygen [%]	Excess Air [%]	Equivalent CO_2 content [%] Gas	Oil	Coal
1	5	11.3	14.7	17.1
2	10	10.8	14.0	16.3
3	17	10.2	13.3	15.4
4	23	9.6	12.5	14.6
5	31	9.0	11.8	13.7
6	40	8.5	11.1	12.8
7	50	7.9	10.3	12.0
8	61	7.4	9.6	11.1
9	75	6.8	8.8	10.3
10	91	6.2	8.1	9.4
11	110	5.7	7.4	8.6
12	133	5.1	6.6	7.7
13	162	4.5	5.9	6.8
14	200	3.9	5.2	6.0
15	250	3.4	4.4	5.1
16	320	2.8	3.7	4.2

Oxygen related to excess air and CO_2 (Dry basis assuming no air inleakage).

In many European countries <u>legal and target</u> values for the combustion parameters and boiler minimum efficiency are defined or recommended in norms and regulations.

Typical target values of combustion efficiency for modern equipment are given in Table 3.

TABLE 3. Combustion efficiency for modern boilers.

Heating equipment		Combustion efficiency*
Burner with one running speed:		0.92-0.93
Burner with two running speed:	low fire	0.95-0.96
	high fire	0.92-0.93
Gas condensation boilers:		1.00-1.05

(*) Values refer to fuel Net Calorific Value.

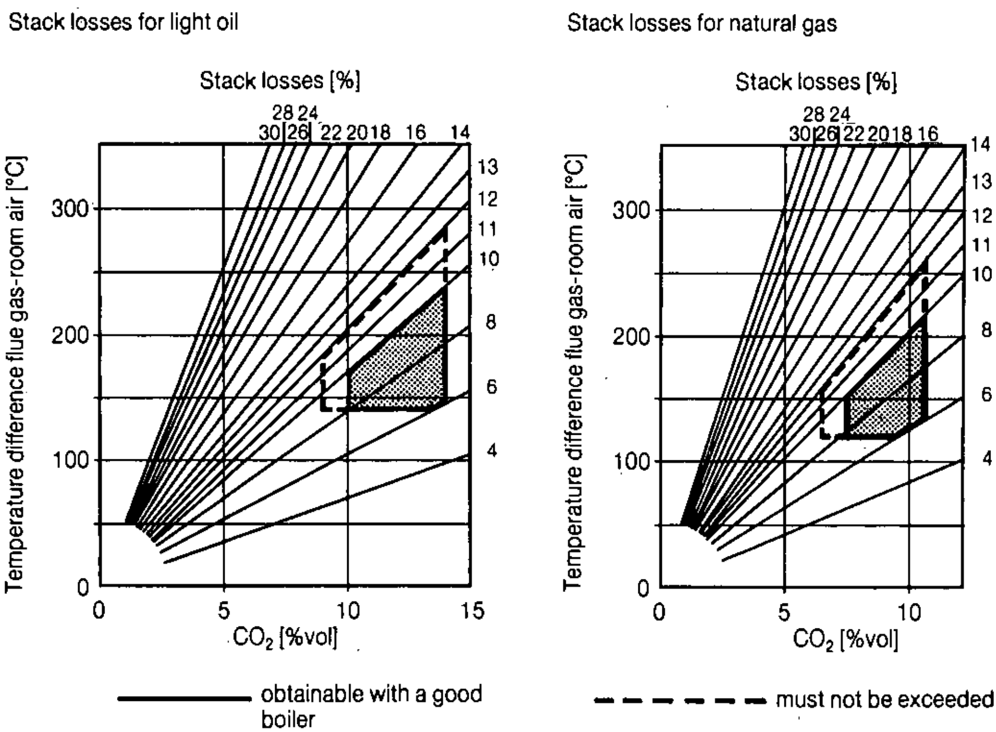


Fig. 1 Stack losses for various flue-gas temperatures and content of CO_2.

reference values:	application area:	referenced from:
H.2	HEATING PLANTS	ECO H.1, H.3, H.20.

title:	references to:
BOILER THERMAL EFFICIENCY AND STAND-BY LOSSES	AP H.2

audit stage:
ECO Identification and Detailed Evaluation.

description:

The boiler thermal efficiency (see App. C.4 and AP H.2) can be estimated in various ways. It is sometimes assumed that environmental losses constitute a certain fraction of the stand-by losses (e.g. in Switzerland where 2/3 is assumed), or that the boiler efficiency is equal to the combustion efficiency reduced by a certain percentage (in France and Belgium a percentage between 2 and 6 is assumed depending on boiler insulation). In some cases norms require a minimal boiler efficiency. An example is shown in Fig. 1 (from the Netherlands).

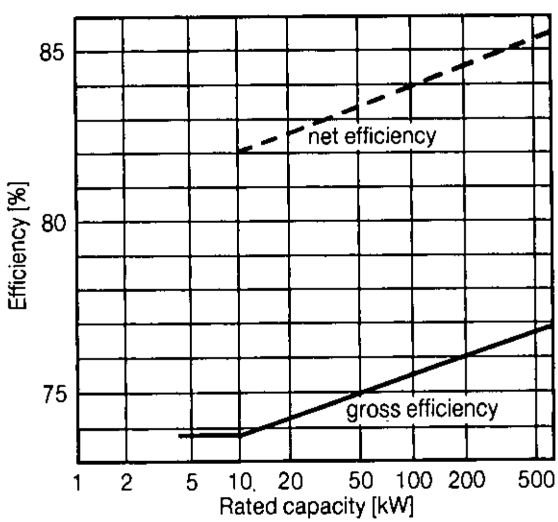


Fig. 1 Example of boiler efficiencies required by norms.

Boiler stand-by losses include all the heat losses of a boiler during the OFF period of the burner (see App. C.4 and AP H.2). Some reference values are given in Table 1.

TABLE 1. Reference values for boiler stand-by losses.

Boiler capacity	<100 kW	>100 kW
Old cast iron boiler with poor or no insulation	0.04-0.06	0.03
Pressurised steel or cast iron boilers'	0.02	0.02
Modern boilers with good isulation	0.01	0.01

Target values for stand-by losses can also be related to the unit heated floor area of the building, for example the following target values have been proposed (Switzerland) for

- jacket losses 0.3 W/m^2,
- draught losses 0.2 W/m^2,
- other heating plant losses 0.7 W/m^2.

Stand-by losses can be reduced by careful insulation of the boiler walls. Target values for boiler insulation thickness are:

- for high temperature hot water and steam systems 120 mm,
- for medium temperature hot water systems 100 mm,
- for low temperature hot water systems 80 mm.

reference values:	**application area:**	**referenced from:**
H.3	HEATING PLANTS	ECO H.24.

title:	**references to:**
HEATING PLANT LIFE FACTORS	

audit stage:
ECO Identification and ECO Detailed Evaluation.

description:
Reference value for the expected life time of heating equipment are given in Table 1. It must be stressed that these values can vary considerably according to the construction quality levels (depending on the manufacturer), the type of fuel used and the plant capacity and operation mode.

TABLE 1. Life factors for heating equipment.

Type	Item	Typical economic life [years]
Steam and HTHW boiler plant	Shell and tube boilers	15 to 25
	Water tube boilers	25 to 30
Medium and low pressure boiler plant	Steel boilers	15 to 20
	Sectional cast-iron boilers	15 to 25
	Electrode boilers	30 to 40
Boiler plant auxiliaries	Combustion controls	15 to 20
	Boiler electrodes	5 to 10
	Feed pumps	15 to 20
	Feed treatment plant	15 to 20
	Firing equipment	15 to 20
	Fuel handling plant (solid)	10 to 15
	Fans	15 to 20
	Instrumentation	10 to 20
Steel chimneys		8 to 15
Heating installations	Calorifiers and heat exchangers	20 to 25
	Control equipment	15 to 20
	Pipework installations	25 to 30
	Pumps	20 to 25
	Radiators, cast iron	20 to 25
	Radiators, steel	15 to 20
	Suspended ceiling heaating	15 to 20
	Tanks (depends on material and location)	15 to 30
	Valves	20 to 25
	Incinerators	15 to 20

reference values:	application area:	referenced from:
H.4	REGULATION	ECO H.26

title:	references to:
TYPICAL FIREPLACE EFFECTIVENESS	

audit stage:
ECO Identification/Evaluation.

description:

Typical values for fireplace effectiveness are given in Table 1 (Ashrae, Ch.26, 1983).

TABLE 1 Typical values for fireplace effectiveness.

Type	Approximate Efficiency	Notes
Simple Fireplaces, Masonry or Pre-fabricated	-10% to +10%	Radiates heat in one direction only. Heats only small area.
High Efficiency Fireplaces	25% to 45%	Heats larger areas. Long service life. Max. safety.
Box Stoves	20% to 40 %	Radiates heat in all directions. Low initial cost. Heats large areas. Fire hard to control. Short life. Wastes fuel.
Airtight Stoves	40% to 55%	Radiates heat in all directions. Long burn times, high heat output. Longer service life. Can create creosote problems.
High Efficiency Airtight Stoves	50% to 65%	Radiates heat in all directions. Long burn times, high heat output. Long life. Creosote problems. High purchase prices.

reference values:	**application area:**	**referenced from:**
H/C.1	HEATING AND COOLING	ECO H/C.16.

title:	**references to:**
PERFORMANCE INDICES OF HEATING AND COOLING DEVICES	

audit stage:
Disaggregation and ECD Detailed Evaluation.

description:

Seasonal performance indices and typical values for heating and cooling equipment and major appliances are shown in Table 1.

The performance indices used are:

i) The AFUE (Annual Fuel Utilization Efficiency) index which is used for gas and oil furnaces and boilers. It is the seasonal average fraction of chemical energy in the fuel available as heat at the furnace plenum or boiler outlet.

ii) The SPF_h (Heating season performance factor). This is equal to the seasonal average ratio of heat energy output to electrical energy input, and

iii) The SPF_c (Cooling season performance factor) equal to the ratio of cooling energy delivered to electrical energy used which is a dimensionless quantity.

Test procedures for these indices have been defined in the U.S., for example by the Department of Energy.

TABLE 1. Seasonal energy performance characteristics for energy-intensive devices.

System	Expected life (years)	Performance index	Average 1980 stock	Best 1982 new
Gas furnace	23	AFUE	0.60	0.95
Oil furnace	23	AFUE	0.66	0.88
Electric heat pump	12			
Heating		SPF_h	1.7	2.6
Cooling		SPF_c	1.9	3.3
Central A/C	12	SPF_c	1.9	4.1
Room A/C	15	SPF_c	1.9	3.2
Gas water heater	13			
Stand alone		Overall efficiency	0.44	0.62
Furnace add-on		Overall efficiency	-	0.83
Electric water heater	13	Overall efficiency of COP	0.73	0.95

In Table 2 are given requirements for minimal coefficient of performance (COP) for heating and cooling equipment (ASHRAE 90A-1980).

TABLE. 2 Minimal required COP, for heating and cooling equipment.

Equipment		Minimal COP
Heat pumps:		
Outdoor Ambient 8.3DB/6.1WB	Air	2.7
Outdoor Ambient -8.3DB/-9.4WB	Air	1.8
Entering Water 15.6	Water	3.0
Cooling Equipment		
Electrically Driven < 19KW	Air	2.28
	Water	2.58
Electrically Driven >19KW	Air	2.40
	Water	2.69
Gas/Oil Fired		0.48
Steam/Hot Water Operated		0.68
Cooling Component Electric Water Chiller		
Self-Contained Centrifugal	Air	2.34
	Water	4.04
Self-Contained Reciprocating	Air	2.46
	Water	3.51
Condenserless Reciprocating	Air	2.90
	Water	3.51
Compressor and Condensing Units Reciprocating	Air Cooled	2.78
	Evap. Cooled	3.66
	Water Cooled	3.66

DB = Outdoor dry bulb temperature
WB = Outdoor wet bulb temperature

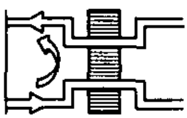
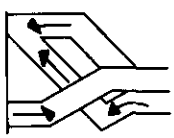
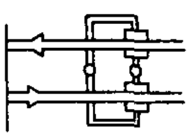
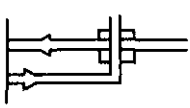
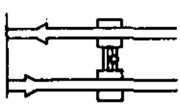
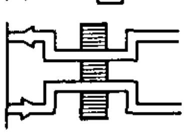
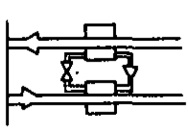
reference values:	**application area:**	**referenced from:**
H/C.2	REGULATION	ECO H/C.17

title: AIR TO AIR HEAT RECOVERY
- TYPICAL EFFICIENCIES

References to:

audit stage:
ECO Identification/Evaluation

description:
TABLE 1 Typical Velocity/Pressure Drops

SCHEMATIC	Type	Efficiency	Installation Criteria	Face Velocity [m/s]
	Rotating heat *exchanger*	65-90% most 70-80%	Supply & exhaust ducts need to be *near to one another*	2.5 to 4
	Steady-state exchange beds with valve adjustment	50-80%	Supply & exhaust ducts need to be near one another	
	Two element systems, open type	about 60%	Supply & exhaust ducts need not to be near one another	
	Air-to Air Fixed Plate	60-80% most 65-70%	Supply & exhaust ducts need to be near one another	
	Runaround Coils	40-65%	Supply & exhaust ducts need not be near one another	
	Heat-pipe heat *exchanger*	40-80%	Supply & exhaust ducts need to be near *one another*	2 to 4
	Heat-pump		Supply & exhaust ducts need not be near one another	

Pressure Drop Range	Temperature Range [^{0}C]	Cross Contamination	Control and Special Properties and Comments
100 to 175 at 2.5 m/s	-60 to 800	Yes	Control of number of revolutions; heat & water vapor recovery possible. Typical maximum unit size 32,000 l/s; 4.25 m diameter.
		Yes	Control of switch frequency; heat & water vapor recovery possible; some leakage inevitable.
		Yes	Control by flow rate of circulating fluid; bactericidal action; capture of dust; only heat & water vapor recovery.
125 to 400	up to 80	Little	Control by air bypass; simplicity; reliability of operation. Typical size 0.5 to 1.0 m per 1000 l/s.
		None	Shunt control of circulating fluid
100 to 175 at 2 m/s		None	Control by air bypass or varying inclination
		None	Control by compressor performance; integration with remaining parts of the air conditioning system

reference values:	**application area:**	**referenced from:**
C.1	CENTRAL COOLING PLANT	ECO C.1

title:	**references to:**
EFFECT OF CHILLED WATER TEMPERATURE ON CHILLER COP	

audit stage:

description:

The increase in chiller COP when raising the chilled water temperature is displayed in Fig. 1 (Dubin, 1975).

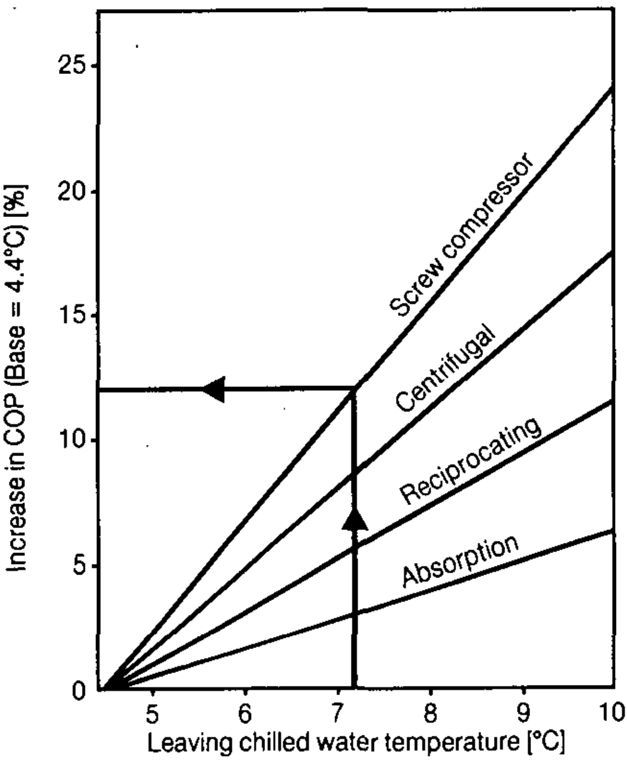


Fig. 1 Increase in chiller COP versus temperature of leaving chilled water.

reference values:	application area:	referenced from:
C.2	CENTRAL COOLING PLANT	ECO C.2

title:	references to:
EFFECT OF CONDENSER TEMPERATURE ON CHILLER COP	

audit stage:

description:

The decrease in chiller COP when lowering the condensing temperature is displayed in Fig. 1 (Dubin, 1975).

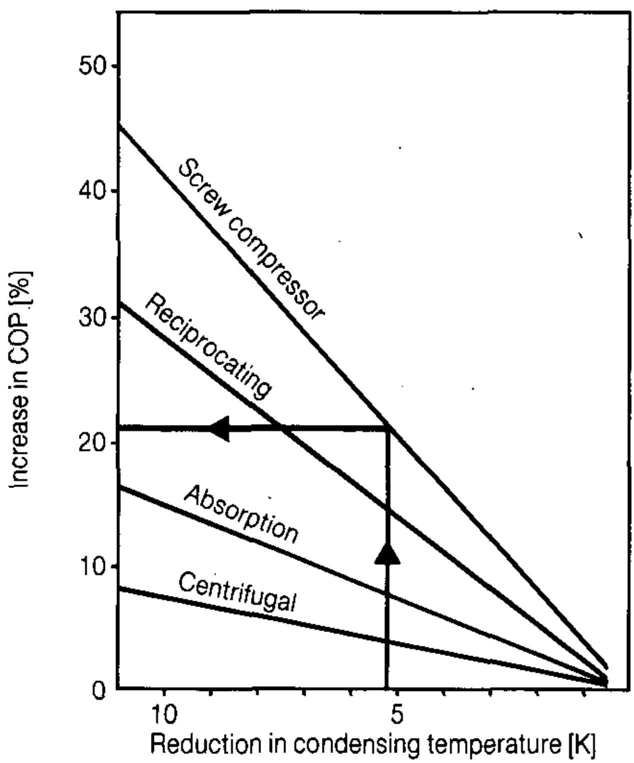


Fig. 1 Increase in chiller COP versus reduction in condensing temperature.

reference values:	**application area:**	**referenced from:**
C.3	CENTRAL COOLING PLANT	ECO H/C.13

title:	**references to:**
PART LOAD CHILLER PERFORMANCE	

audit stage:

description:

The part load chiller performance with various capacity control methods is displayed in Fig. 1, absorption chillers, in Fig. 2, reciprocating processors and in Fig. 3, centrifugal compressors.

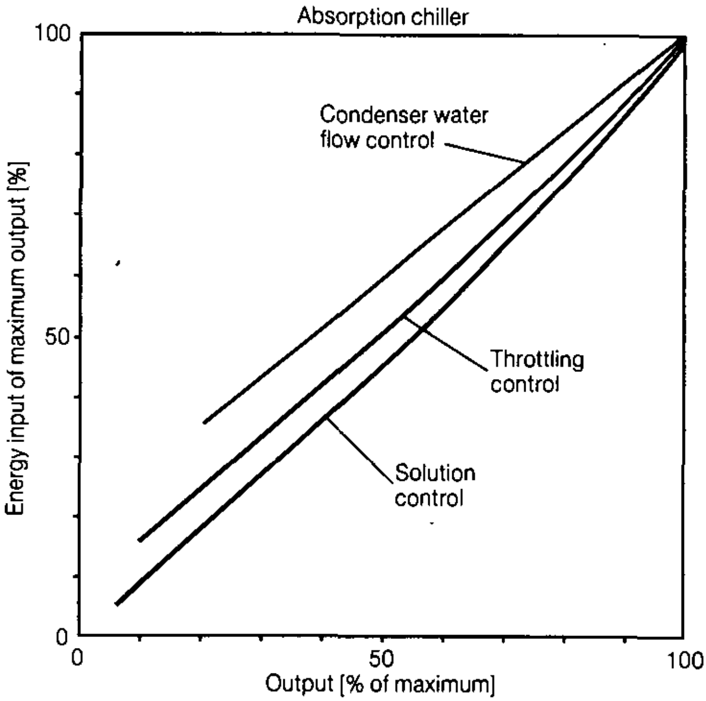


Fig. 1 Fractional energy input versus fractional. output for absorption chillers.

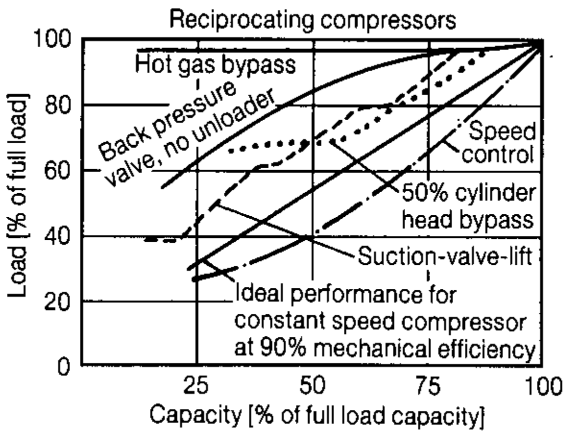


Fig. 2 Fractional load versus fractional capacity for reciprocating compressors.

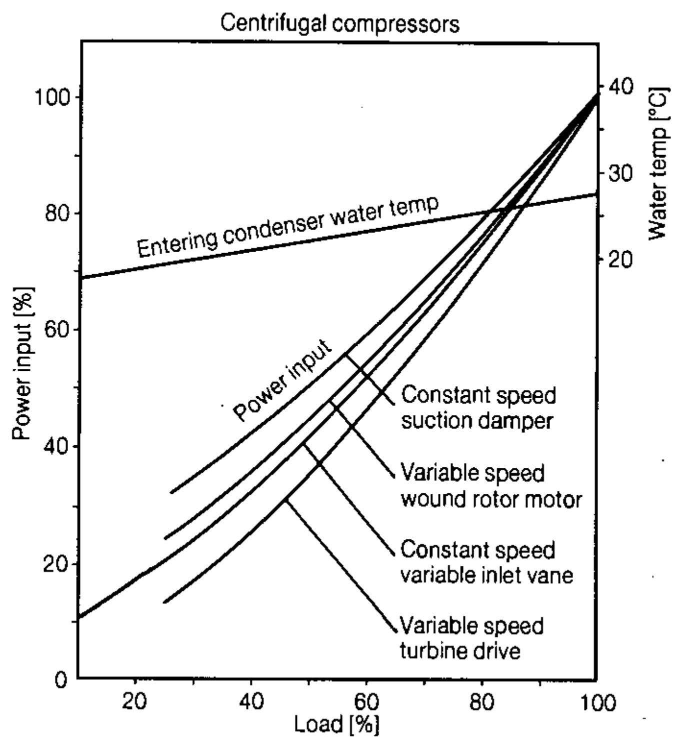


Fig. 3 Fractional power input versus load fraction for centrifugal compressors.

reference values:	application area:	referenced from:
C.4	CENTRAL COOLING PLANT	ECO C.4

title:	references to:
EFFECT OF CONDENSER FOULING ON CHILLER PERFORMANCE	

audit stage:

description:

The performance of the heat transfer coefficient and the fouling factor with time is displayed in Fig. 1 (Kragh, 1976). The relation between the relative power and the condenser fouling factor, FF, is

Relative power [%] = 100* (1 + 1080 FF).

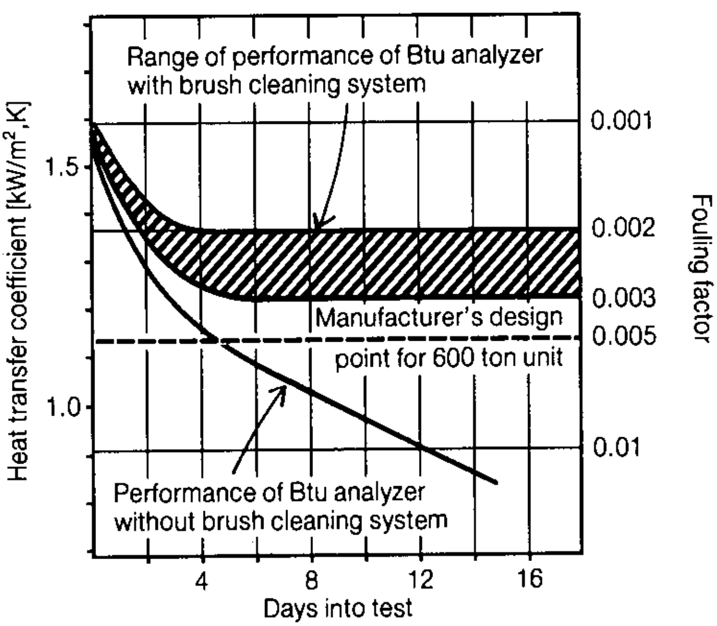


Fig. 1 Heat transfer coefficient and fouling factor versus time for chiller condensors.

reference values:	**application area:**	**referenced from:**
D.1	DUCTWORK	ECO D.4, D.9, AP D.2

title:	**references to:**
TARGET VALUES FOR DUCT INSULATION AND LEAKAGE	

audit stage:

description:

Target Values for duct insulation and duct leakage (ASHRAE Standard 90.75, 1980) are:

Duct Insulation: U-value: $47.3/\Delta T$ [W/K,m^2],
where
ΔT = temperature difference between air in duct and environment.

Note: Target Value may be influenced by degree of heat losses contributing to space heating.

TABLE 1 Target values for duct leakage

Systems operating at static pressure	Highest permissible leakage at 1.25 * design pressure
< 500 Pa	5% of design flow
> 500 Pa	1% of design flow

reference values:	**application area:**	**referenced from:**
D.2	VENTILATION	ECO D.7.

title:	**references to:**
AIR FILTER PERFORMANCES	

audit stage:
ECO Identification/ECO Detailed Evaluation.

description:

The difference between the pressure drop across the filter when clean and during operating life can give information on the fan capacity variation.

TABLE 1. Air filter comparison.

Filter type	Cleanable 5 cm thick	Throwaway 5 cm thick	Automatic roll	Pleated 5 cm thick
Size of Filter Bank				
Height * Width [cm*cm]	120 * 180	120 * 300	170 * 150	120 * 240
Average Efficiency				
Dust Spot	8 to 10%	10 to 15%	20 to 25%	36%
Filter Life				
Hours	600	480	3,750	2,000
Pressure Drop [Pa]				
Initial	20	25	100	35
Final	100	75	100	150
Average	60	50	100	92

reference values:	application area:	referenced from:
P.1	PIPEWORK	ECO P.3, P.6.

title:	references to:
RECOMMENDED INSULATION THICKNESSES FOR HOT PIPES	

audit stage:

description:

Thermal insulation levels of pipework systems are specified norms in various countries.
The current codes usually indicate that all pipework for heating/cooling must be insulated (including pipes passing inside cavity walls). The minimum values of insulation thickness are given, as a function of pipe diameter and fluid inlet temperature. Examples of such values are given in Table 1 (ASHRAE, 10-75) and Table 2 (Energy Efficiency Office, Booklet 8, 1984).

TABLE 1. Minimal piping insulation.

System	Fluid Temperature [^{0}C]	Insulation thickness [mm]
Heating:		
High Pressure Steam	150-230	40-90
Medium Pressure Steam	120-150	40-75
Low Pressure Steam	<150	25-50
Condensate	90-105	35-50
Hot Water	<95	15-40
Hot Water	>95	25-50
Cooling:		
Chilled Water	5-15	15-25
Refrigerant and Brine	<0	25-50

Comments: Values are based on an heat conductivity of the insulating material from 0.06 to 0.07 [$W/m^2,K$] and an average environmetnal temperature of 25^{0}C. Lower levels can be used for pipe diameters <25 mm and higher levels for pipe diameters >100 mm (after ASHRAE 90-75).

TABLE 2. Thickness of thermal insulation for heating installations.

System	pipe diameter [mm]	Moisture content of insulation [% of dry weight] <2.5	2.5-4	4-5.5	5.5-7
		Minimal insulation thickness [mm]			
LTHW (Low temperature hot water system) Fluid temperature <95°C. System not part of MTHW or HTHW injection system.	15	25	25	38	38
	20	25	32	38	38
	25	25	38	38	38
	32	32	38	38	50
	40	32	38	38	50
	50	38	38	50	50
	65	38	50	50	50
	80	38	50	50	50
	100	38	50	50	63
	125	50	50	63	63
	150	50	50	63	63
	200	50	50	63	63
	250	50	63	63	63
	300	50	63	63	63
		Moisture content			
		2.5	2.5-4.1	4.1-5.5	5.5-7
		Minimal insulation thickness			
MTHW (Medium temperature hot water system) Pressurized system open or closed to the atmosphere. 95°C < fluid temperature < 120°C. Max gauge pressure 350 kPa	15	25	38	38	38
	20	32	38	38	50
	25	38	38	38	50
	32	38	50	50	50
	40	38	50	50	50
	50	38	50	50	50
	65	38	50	50	50
	80	50	50	50	63
	100	50	63	63	63
	125	50	63	63	63
	150	50	63	63	63
	200	50	63	63	63
	250	50	63	63	75
	300	63	63	63	75

System	Pipe diameter [mm]	Moisture content <2.5	2.5-4.4	4.4-5.8	5.8-7
		Minimal insulation thickness [mm]			
HTHW					
(High temperature	15	38	50	50	50
hot water system)	20	38	50	50	50
Pressurized system	25	38	50	50	50
closed to the	32	50	50	50	50
atmosphere. Fluid	40	50	50	50	63
temperature >120°C.	50	50	50	75	75
Gauge pressure	65	50	63	75	75
<1000 kPa	80	50	63	75	75
	100	63	63	75	100
	125	63	63	100	100
	150	63	63	100	100
	200	63	63	100	100
	250	63	75	100	100
	300	63	75	100	100

Values are based on an environmental temperature of 20°C and dry ambient air.

reference values:	application area:	referenced from:
P.2	PIPEWORK	ECO P.8, P.16, AP P.4.

title:	references to:
STEAM TRAP APPLICATION GUIDE AND LOSSES EVALUATION	

audit stage:
ECO Identification/Evaluation.

description:

STEAM TRAP CLASSIFICATION: Steam traps are classified by their method of operation:

i) Thermostatic traps react to the difference in temperature between steam and condensate (includes bellows thermostatic, bimetallic and thermostatic).
ii) Mechanical traps are buoyancy operated by the difference in density between steam and condensate (includes float and thermostatic, open bucket and inverted bucket).
iii) Kinetic traps rely on the difference in flow characteristics of steam and condensate (includes thermodynamic disc, impulse piston and orifice).

Steam traps suitable for different applications are listed in Table 1. Annual steam trap heat losses for various hole sizes and pressures are given in Fig. 1.

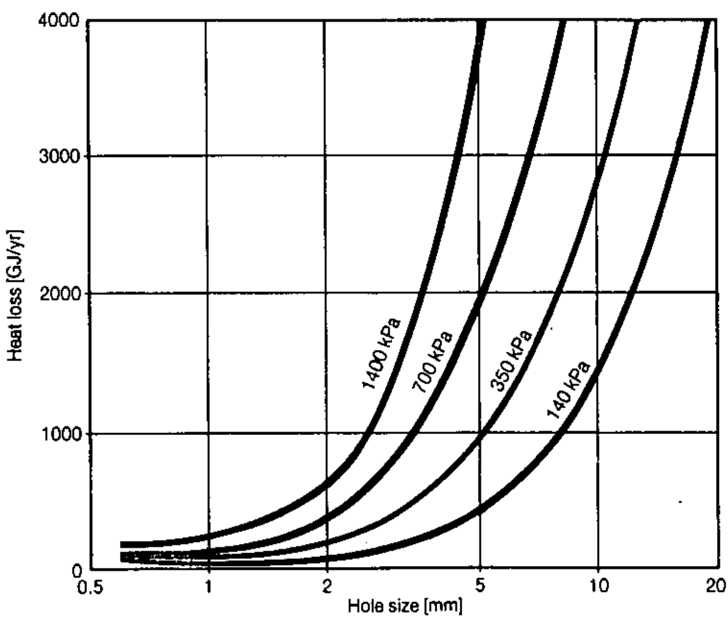


Fig. 1 Steam trap heat loss.

TABLE 1 Suitable steam traps

Application		First choice	Second choice
Air heating coils:	Low pressure	FT	-
	Medium & high pressure	FT	TD
	Make-up air	FT	-
	Pipe coils	BM	BT
Convectors & wall-lin		BT	FT
Heating & ventilation		FT	-
Radiators		BT	BM
Unit heaters:	Suspended	FT	TD
	Cabinet	FT	BT
Absorption chillers		FT	-
Evaporators		FD	IB
Fuel oil preheaters		FT	TD
Ironers		TD	IB
Jacketed vessels, kettles		FT	TD
Kilns - brick & plock		TD	BM
Laundry, shirt presses		TD	IB
Liquid heating pipe coils		FT	TD
Main drips:	Low pressure	FT	IB
	Medium pressure	FT	TD
	High pressure	TD	BM
	Outdoors	TD	BM
Plating tanks		TD	BM
Presses-platen		TD	IB
Rotating cylinders		FT	TD
Shell & tube heat exchangers		FT	TD
Separators		FT	TD
Storage tanks-outdoor		BM	TD
Tracer lines		TD	BM
Tumble dryers		FT	TD
Water heaters:	Instantaneous	FT	-
	Storage	FT	-

FT = Float & Thermostatic
IB = Inverted bucket
TD = Thermodynamic disc
BT = Bellows thermostatic
BM = Bimetal thermostatic

reference values:	**application area:**	**referenced from:**
S.1	SHW SYSTEMS	ECO S.17, AP S.1

title:	**references to:**
WATER AND SHW CONSUMPTION	

audit stage:
Disaggregation, ECO Identification, ECO Detailed Evaluation.

description:

The water use in residences varies widely (see AP S.1). In most investigations in western countries the average use of SHW has been found to lie in the range of 30-60 l/day per capita, corresponding to a net or useful energy consumption of 3 to 6 GJ/year and capita (see Fracastoro-Lyberg, 1983).

For non-residential use the values in Table 1 can be used (after EAM, 1984).

TABLE 1. Non-residential water use.

Building category		Water use/day [l] (hot or cold)	SHW use/day [l]	Supply temperature [^oC]
Office buildings:		10/capita	8	45-65
Department stores (without kitchen or cafeteria):		5/customer	4	45-65
Kitchens and cafeterias:		10/meal	8	45-80
Schools (without cafeteria or athletic facilities):		10/capita	8	45-80
Hospitals	Medical:	120/capita		44-65
	Surgical:	200/capita		(kitchen at 80)
	Maternity:	200/capita	100-150	
	Mental:	100/capita		
Hotels:		120/capita	100	45-65
Laundry:		20/kg dry laundry	13	70

reference values:	application area:	referenced from:
S.2	SHW SYSTEMS	ECO S.2, S.11, P.6, AP S.1

title:	references to:
EFFICIENCIES FOR SHW SYSTEMS	

audit stage:
Disaggregation/ECO Identification/ECO Detailed Evaluation.

description:

In Table 1 is given distribution, storage, generation and overall efficiencies for various SHW systems. In Table 2 is given a more detailed picture of distribution efficiencies in residential buildings.

TABLE 1. Efficiencies for SHW systems.

SHW System	Generation Efficiency	Storage Efficiency	Distribution Efficiency	Overall Efficiency
Individual El. with storage	1.0	0.75	0.85	0.64
Individual Gas with storage	0.65	0.75	0.85	0.41
Individual Gas instant.	0.65	1.0	0.85	0.55
Individual District Heating	1.0[a]	1.0	0.85	0.85
Central system	0.65[c]	0.90	0.30[b]	0.18
	0.65[c]	0.90	0.80[b]	0.47
District Heating	1.0[a]	1.0	0.30[b]	0.30
	1.0	1.0	0.80[b]	0.80

a) Distribution losses outside building not included.
b) 0.30 very low value, 0.80 very high value (see Table 2). Low values are typical in large widely dispersed systems or where water use is light or intermittent (Jones, 1980).
c) Average of winter (8 months) efficiency 0.80 and summer (4 months) efficiency 0.40.

TABLE 2. Distribution efficiency for SHW systems in residential buildings.

Building type	SHW consumption [l/day and capita] 20	30	40	50
Single family house (no SHW circulation)	.30-.65	.35-.70	.40-.75	.50-.85
Apartment bldg. (8-16 dwellings)	.40-.70	.45-.75	.55-.80	.65-.85
Apartment bldg. (40-100 dw., 3-4 floors)	.30-.60	.35-.65	.40-.70	.50-.75
High rise apartm. bldg. (40-100 dwellings)	.35-.70	.45-.75	.50-.80	.55-.85

The lower value refers to a building with un-insulated pipes and continuous SHW circulation, the higher value to a building with good insulation and SHW circulation time-control.

reference values:	**application area:**	**referenced from:**
S.3	SHW SYSTEMS	ECO S.1, S.14.

title:	**references to:**
SHW FLOW RATES AND TEMPERATURES	

audit stage:
ECO Identification, ECO Detailed Evaluation.

description:

The flow rate from faucets can vary considerably depending on the line pressure and faucet type. Reference and Target values are given in Table 1 (ASHRAE 90A-80). Representative hot water utilization temperatures are given in Table 2 (ASHRAE Systems, Ch. 34, 1984).

TABLE 1. Reference and Target values for flow rates.

Flow device	Reference values [l/min]	Target values [l/min]
Sink Faucet:	20	2
Shower Head:	20-30	10

Target reduction due to aerators can range between 1/3 and 2/3 of normal reference value. The corresponding energy savings can be evaluated from Fig. 1.

The desirable water line pressure lies in the range 150-250 kPa. Pressure reducers should be applied when water pressure is above this range. The flow rate reduction can be obtained from Fig. 2.

TABLE 2. Representative Hot Water Utilization Temperatures

Use		Temperature [^{o}C]
Lavatory:	Hand washing	40
	Shaving	46
Showers and tubs		43
Therapeutic baths		35
Commercial dishwashing:	Wash	60
	Sanitizing rinse	82
Commercial and institutional laundry		82
Residential dishwashing and laundry		60
Surgical scrubbing		43

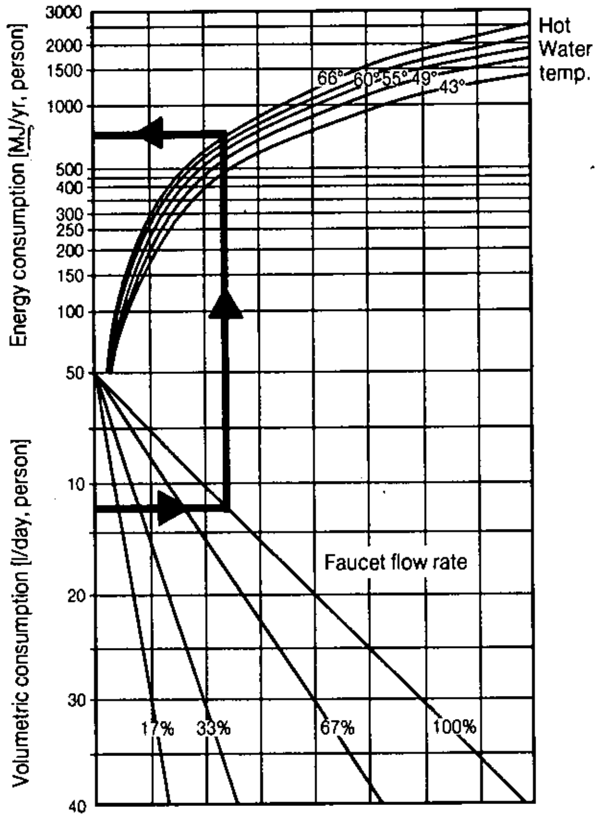


Fig. 1 Hot water savings from use of aerators.

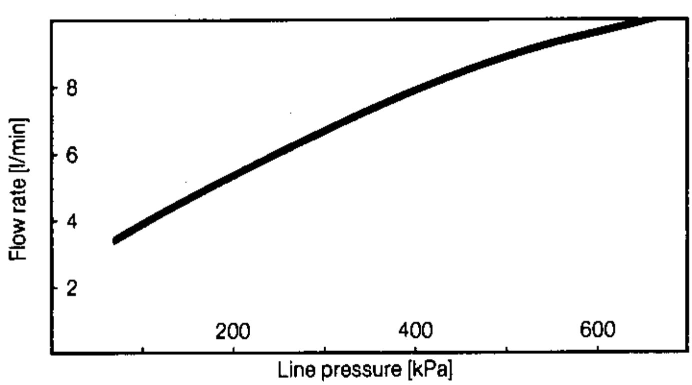


Fig. 2 Restricted flow shower head.

reference values:	application area:	referenced from:
S.4	SHW SYSTEMS	

title:	references to:
MAKE-UP WATER SUPPLY TEMPERATURES	

audit stage:
ECO Detailed Evaluation.

description:

The average temperature of cold feed water entering a building is in general close to the average air temperature of a year, except in cold areas where special precautions have been taken to avoid freezing, such as burying pipes deeply, insulating pipes or placing the pipes so that the sewage water can heat the cold water.

An example of the air temperature and the make-up water temperature outside and inside a building is shown in Fig. 1 (Jones, 1980). The low line of the temperature profile represents the water temperature in the buried pipework system. The high line is a result of the water in the piping system within the building being heated by its surroundings and is typically what happens during periods of low or no water use.

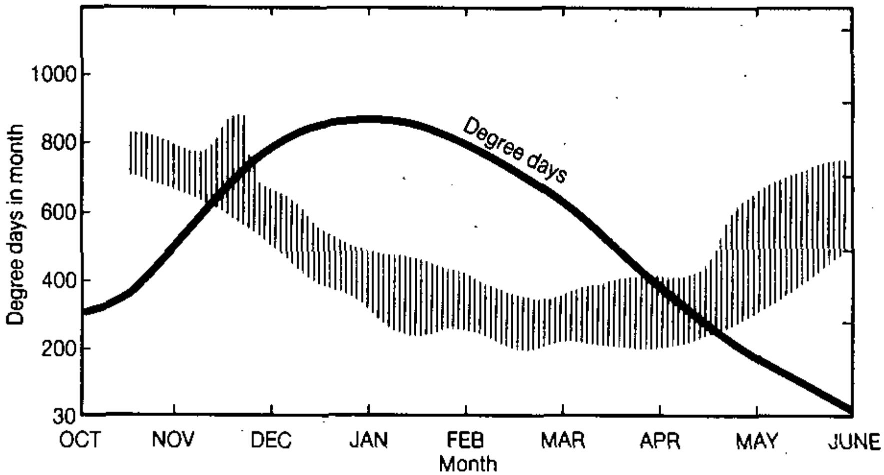


Fig. 1 Seasonal variation of cold water supply temperature.

reference values:	**application area:**	**referenced from:**
S.5	SHW SYSTEMS	ECO S.20

title:	**references to:**
SOLAR SHW HEATER	

audit stage:
Disaggregation/ECO Identification/ECO Detailed Evaluation.

description:
Quick evaluation of the possible energy savings due to the installation of a solar SHW heater can be carried-out with the help of indicators of SHW production of solar collectors, as shown in the example of Table 1 for some Italian regions.

TABLE 1. Daily production of SHW at 50^{0}C from 1 m^2 solar collector.

Location	Global annual radiation/m^2 horizontal surface [kW/m^2,yr]	SHW production (at 50^{0}C) [l/day]	Energy saved [kWh/m^2,yr]
Lombardy	1060	31	500
Tuscany	1210	33	550
Central Italy	1310	38	620
Sicily, Sardinia	1400	42	630

The proper sizing of the solar system can be checked against standards; for example, for Southern Italy the proper sizing of the tank is about 60 l per square meter of solar collector, and the proper sizing of the solar collecctor is from 0.45 to 0.60 m^2 per occupant in multi-family residential buildings.

reference values:	**application area:**	**referenced from:**
S.6	SHW AND PIPEWORK SYSTEM	ECO P.9, S.12.

title:	**references to:**
WATER QUALITY	

audit stage: Evaluation

description:

In Table 1 are given limits for some acceptable feedwater and boiler water properties (Standard UNI-CTI 8065).

TABLE 1. Acceptable limit of feedwater and boiler water properties.

Property	Feedwater	Boiler water
pH	> 7	9 - 11.5
OH ions conc.	-	< 800 ppm $CaCO_3$
Hardness	< 0.5 °Fr	< 0.5 °Fr
Copper	< 0.002 ppm Cu	-
Iron	< 0.3 ppm Fe	< 0.5 ppm Fe
Clorides	< 200 ppm NaCl	< 3000 ppm NaCl
Organic compunds	< 5 ppm $KMnO_4$	-
Oils	< 1 ppm	
Conc. of Aliphatic Polyammines	-	> 20 ppm
Total salinity		< 4000 ppm NaCl

reference values:	application area:	referenced from:
RV L.1	LIGHTING	ECO L.4, L.6, L.13, L.18

title:	references to:
ILLUMINANCE LEVELS, INSTALLED POWER	

audit stage:
All steps.

description:

Table 1 gives an example of recommended values for average illuminance levels (CIBS, 1984, Part 2), and Table 2 gives recommended values for the installed power for lighting (ASHRAE Standard 90 IP).

For more extended lists or specific national recommendations, see the appropriate national publications.

TABLE 1. Average illuminance levels.

Building type	Mean illuminance [lux]
Office	500
Shop	500
Factory (Rough work)	300
Factory (General)	500
Factory (Fine work)	750
Warehouse	300
Residential	100
Hotel	100
Hospital	100
Educational	300

Values IN Table 2 are based on the following hypotheses:

1- Lighting is by fluorescent lamps having a luminous efficacy of 55 lm/W.
2- Illuminance, power loading, and occupancy hours are standard values taken from CIBS codes.
3- It is assumed that 90% of lighting fixtures are simultaneously on for industrial and commercial buildings, 75% for other buildings.
4- Room index is taken to be 5 for industrial buildings and 2 for other buildings.

TABLE 2. Installed power for lighting [W/m^2].

Building category	$100m^2$	$400m^2$	$1000m^2$	$2000m^2$	$3500m^2$
Food services:					
Fast food/Cafeteria	15	14	13	13	13
Leisure dining/Bar	22	20	16	14	14
Offices:					
Based on 1/3 open plan	20	19	18	17	16
Retail (incl. Display)					
Department and speciality stores	35	32	26	24	22
Service establishments and supermarkets	32	28	23	21	20
Garages	3	3	2	2	2
Schools:					
Pre/Elementary	18	18	17	16	15
High School	20	20	20	19	18
Technical	25	25	22	20	18
Warehouse/Storage	8	7	5	4	4
Factory and workshop	20	20	18	17	17

reference values:	application area:	referenced from:
RV L.2	LIGHTING	ECO L.8, L.13, L.14.

title:	references to:
INSTALLED EFFICACY OF LIGHTING EQUIPMENT	

audit stage:
All steps.

description:

The installation efficacy of a lighting installation is defined in AP L.1.

Ranges of recommended installed efficacies for different application areas are given in Table 1. Values are grouped according to:

- Application area.
- Room index, RI, which is defined as:
  RI = l*w/(h*(l+w)),
  where l, w are the room length and width and h is the height of the luminaires above the working plane.
- Lamp color rendering group, as defined in Table 2.

When considering the recommended ranges of installed efficacy the following points should be borne in mind:

- A range of installed efficacies rather than a single value is recommended because the installed efficacy for each specific application will vary with the reflectance of the room surfaces and the cleanliness of the interior. A very dirty interior will have an installed efficacy towards the low end of the range because the reflectances of surfaces within the interior will inevitably be low. Conversely, a very clean interior can have an installed efficacy towards the top end of the range, provided the reflectances of surfaces in the interior are high.

- The ranges of installed efficacies apply to general lighting installations, i.e. the same illuminance is provided over the whole working plane. They should not be applied to localised or local lighting systems.

- Where special luminaires, e.g. explosion proof luminaires, are required, the range of installed efficacies should be derated by a factor 0.7.

- Where a Glare index (IES Glare Index) of less than 19 is required for commercial and retail premises or a Glare Index of less than 22 is required for industrial purposes, the range of installed efficacies should be derated by a factor 0.7.

- Where considerable obstruction to the lighting is likely to occur, the range of installed efficacies may be derated considerably.

TABLE 1. Installed efficacy range targets for uniform lighting installation (lm/W).

Application area	Room Index	Lamp 1B	Color 2	Rendering 3	Group 4
High bay industrial	1		18-29	14-23	21-45
	2		23-37	18-29	27-55
	5		27-43	20-32	32-60
Industrial (not high bay)	1	14-23	14-23	14-23	19-31
	2	18-29	18-29	18-29	23-37
	5	20-32	20-32	20-32	26-42
Commercial	1	14-19	14-19	14-19	
	2	18-27	18-27	18-27	
	5	20-32	20-30	20-30	

TABLE 2. Correlated color temperature classes and color rendering groups.

Correlated Color	Temperature (CCT)	CCT Class
	CCT < 3300K	Warm
3300K	CCT < 5300K	Intermediate*
5300K	CCT	Cold

Color rendering groups	CIE general color rendering index (R_a)	Typical application
		Wherever accurate color matching is required, e.g. color printing inspection.
1B	$80 < R_a < 90$	Wherever accurate color judgements are necessary and/or good color rendering is required for reasons of appearance, e.g. shops and other commercial premises.
2	$60 < R_a < 80$	Wherever moderate color rendering is required.
3	$40 < R_a < 60$	Wherever color rendering is of little significance but marked distortion of color is unacceptable.
4	$20 < R_a < 40$	Wherever color rendering is of noimportance at all and marked distortion of color is acceptable.

* This class covers a large range of correlated color temperatures. Experience in the U.K. suggests that light sources with correlated color temperatures approaching the 5300K end of the range will usually be considered to have a "cool" color appearance.

reference values:	**application area:**	**referenced from:**
RV L.3	LIGHTING	ECO L.12, L.18

title:	**references to:**
LUMINOUS EFFICACY FOR DIFFERENT LAMP TYPES	RV L.2

audit stage:
All steps.

description:

The purpose of these data is to permit estimates of potential energy savings associated with switching lamp type. The data below include ballast losses.

The auditor should also be aware of the color rendering properties (color rendering index, R_a: see RV L.2).

Lamp type	Ra-index
A Incandescent (inert filling)	100
B Incandescent (halogen)	100
C High-pressure Mercury Fluorescent (HPL-N)	96–47
D High-pressure Mercury + Metal Halide (HPI)	67–86
E High-pressure Sodium (SON)	25
F Low-pressure Sodium (SOX)	5

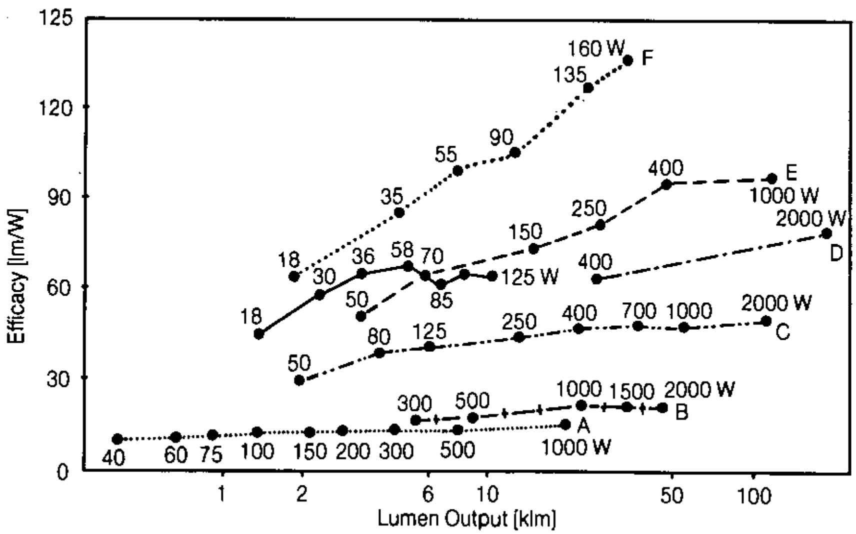


Fig. 1 Efficacy versus Lumen output for different lamp types (after Philips, Eindhoven, The Netherlands).

reference values: RV L.4	**application area:** LIGHTING	**referenced from:** ECO L.7
title: LIGHT LOSS FACTORS		**references to:**

audit stage:
Detailed ECO Evaluation.

description:

The purpose of RV L.4 is to provide information enabling an estimate of the performance reduction of lighting installations as a consequence of lamp aging and dirt deposition on the luminaire and wall surfaces, and to allow evaluation of the potential of ECOs associated with luminaire maintenance, lamp replacement and wall cleaning.

Fig. 1 shows the percentage reduction of illuminance as a function of type in a lighting installation subjected to periodical cleaning and relamping.

To evaluate the loss of light output with time in use, the Light Loss Factor (LLF) is used, which is defined as the ratio of the illuminance produced by the lighting installation at some specified time to the illuminance produced by the same installation when new.

Since the reduction in lighting depends on three distinct factors, LLF can be calculated as the product of three coefficients:

LLF = LLMF * LMF * RSMF

where

LLMF = Lamp Lumen Maintenance Factor,
LMF = Luminaire Maintenance Factor,
RSMF = Room Surface Maintenance Factor.

LLMF depends on the lamp type, and should be determined from manufacturer's data.

LMF values are shown in Fig. 2 for a number of luminaire/activity/location categories, which are specified in Table 1.

RSMF values are shown in Fig. 3, for three categories of room: very clean, average cleanliness, and very dirty.

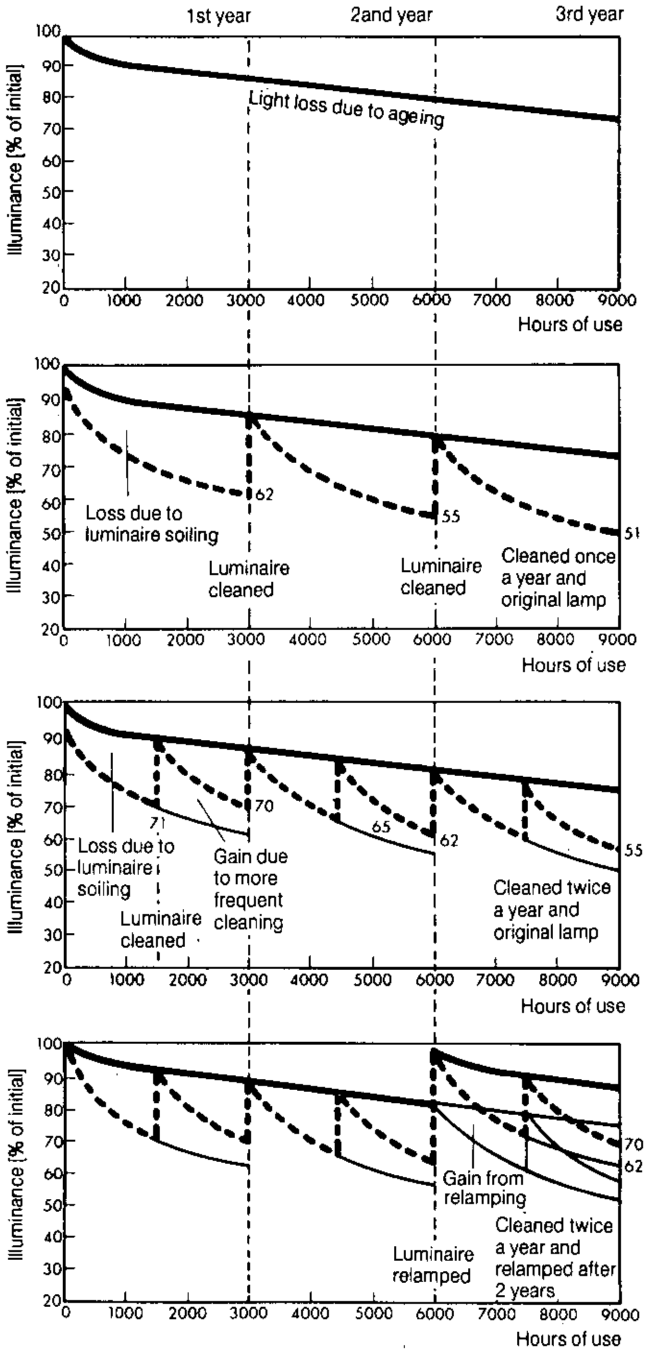


Fig. 1 Changes in illuminance with time for different maintenance schedules.

TABLE 1. Luminaire / activity / location categories

	All air-conditioned buildings	Clean country area	City or town outsksirts	City or town centre	Dirty industrial area
Barelamp batten	A	A/B	B	B/C	C
Open ventilated reflector	A	A/B	B	B/C	C
Dusttight, dust-proof or reflec-tor lamp	A	A/B	B	B/C	B/C
Open nonventi-lated reflector, enclosed dif-fuser/controller	A/B	B	C	C/D	D
Open base dif-fuser or louver	A/B	B	B/C	C	C D
Recessed dif-fuser or louver, diffusing or lou-vered luminous ceiling	A	A/B	B	B/C	C
Indirect cornice	B	C/D	E	F/G	G

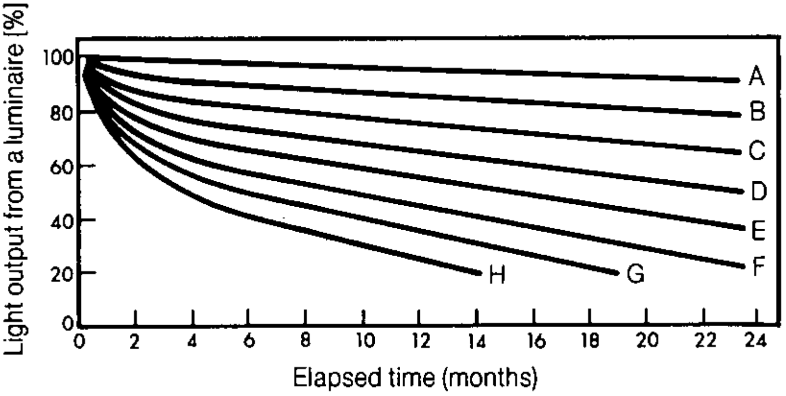


Fig. 2 Light output from a luminaire versus elapsed time for different luminaire/activity/location categories (Table 1).

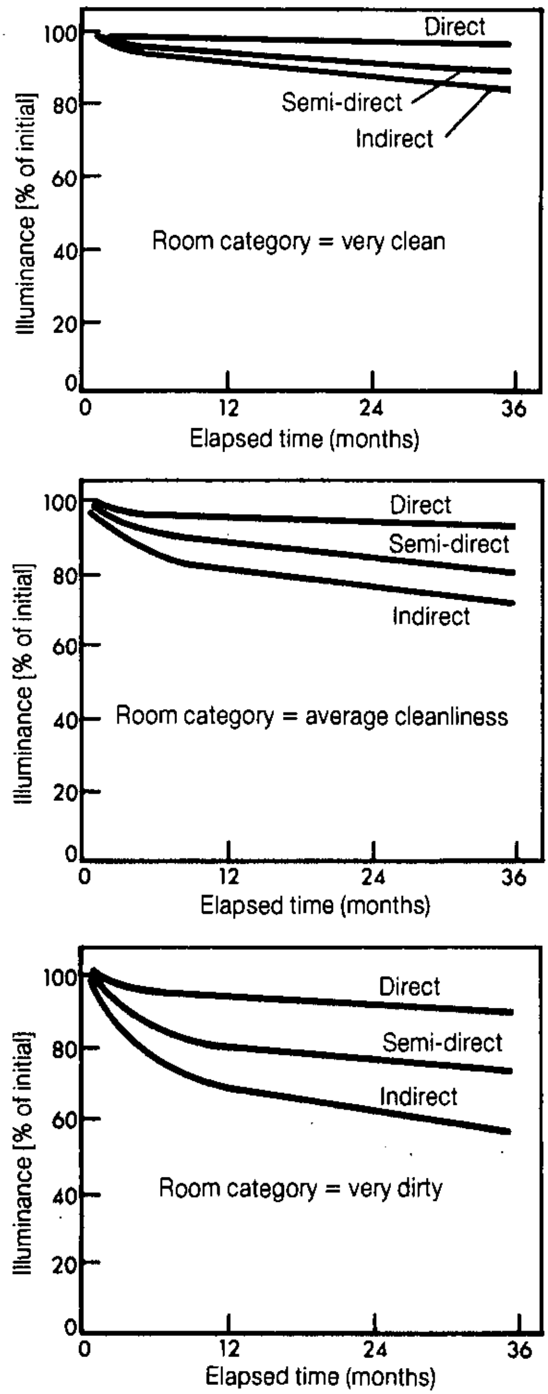


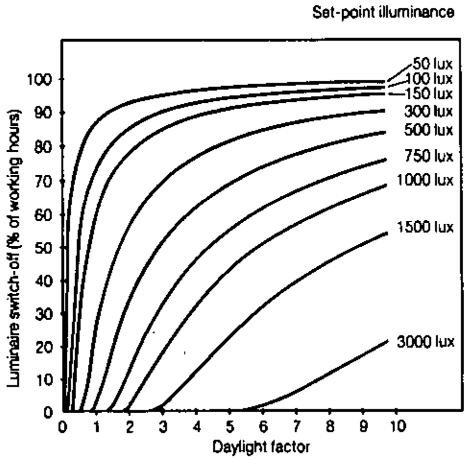
Fig. 3
Fraction of initial illuminance from an installation versus elapsed time for luminaires of different light distribution in rooms of different cleanliness.

reference values:	**application area:**	**referenced from:**
L.5	Lighting control	AT L.2

title:	**references to:**
OPERATING REDUCTION FOR PHOTO ELECTRIC CONTROL	

audit stage:

description:
Examples of reduction in operating time when photo-electric control is used can be found in Fig. 1 and 2. The presented values are valid for Great Britain (CIBS, 1984), but can be used for latitudes close to 50 degrees.



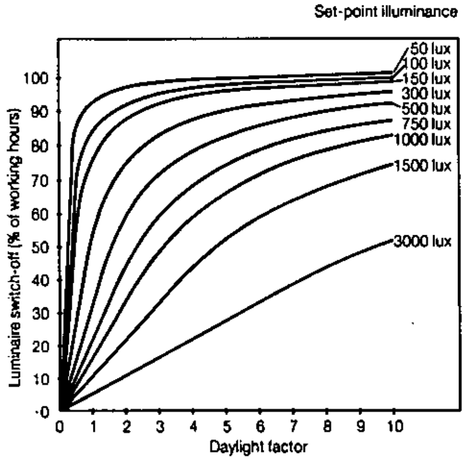


Fig. 1 Reduction in operating time for photo-electric Switching Control (left) and reduction in operating time for photo-electric Dimming Control (right). In the case of dimming control, the effect of decreasing lamps efficacy as a lamp is dimmed has been taken into account.

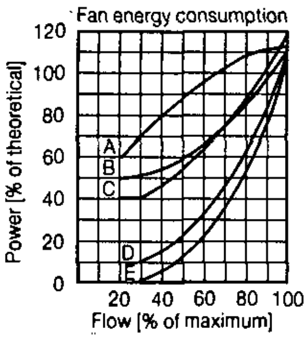
reference values:	application area:	referenced from:
RV EL.1	ELECTRIC MOTORS	ECO EL.3, EL.6, AT EL.3, (+ distribution ECOs)

title:	references to:
TYPICAL CHARACTERISTICS OF VARIOUS MOTOR SPEED CONTROL OPTIONS	

audit stage:
ECO Identification/ECO Delailed Evaluation

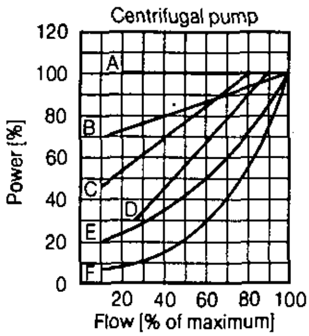
description:

In Fig. 1 through 3 is given the power versus the flow for fans, centrifugal pumps and positive displacement pumps (after Electrical Construction and Maintenance, 1983).



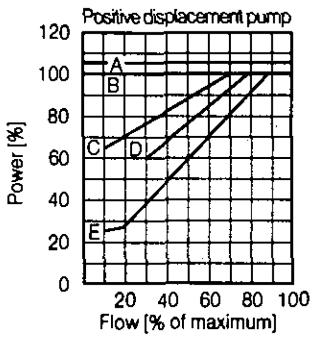
A Forward curved fans & discharge dampers
B Airfoil fans/variable inlet vanes
C Fan control/eddy current clutch
D Adjustable frequency AC motor control
E Theoretical fan curve

Fig. 1 Fan energy consumption.



A Adjustable frequency AC motor control
B Throttling control valve
C Hydrostatic control
D Mechanical control
E Eddy-current clutch
F No-flow control valve

Fig. 2 Centrifugal pump.



A Eddy-current clutch
B Bypass control valve
C Hydrostatic control
D Mechanical control
E Adjustable-frequency AC motor control

Fig. 3 Positive displacement pump.

reference values: RV EL.2	**application area:** ELECTRIC MOTORS	**referenced from:** ECO EL.9, AP EL.3
title: TYPICAL HIGH EFFICIENCY MOTOR IMPROVEMENTS		**references to:**

audit stage:
ECO Identification/ECO Detailed Evaluation

description:

Typical efficiencies for electric motors are shown in Fig. 1 and Fig. 2.

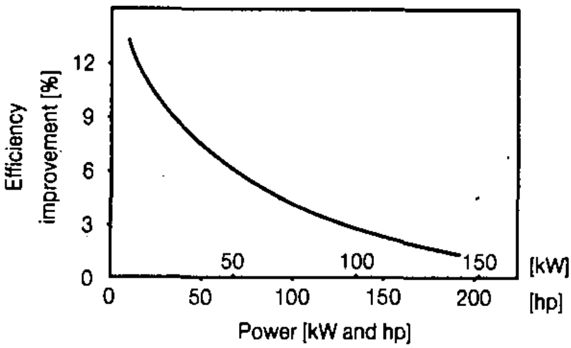


Fig. 1 Typical efficiency improvemen of high efficiency motors.

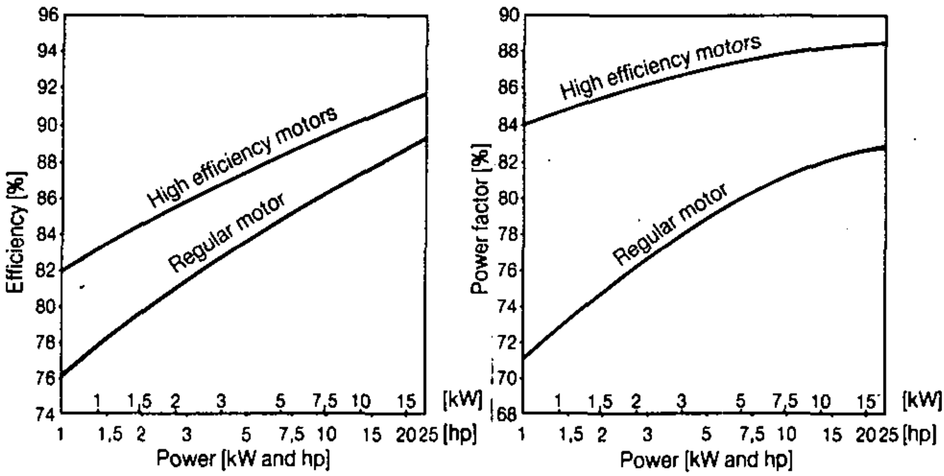


Fig. 2 Typical efficiency and power factor differences for small size range of high and normal efficiency motors.

reference values:	application area:	referenced from:
RV EL.3	ELECTRIC MOTORS	ECO EL.10, AP EL.3

title:
VARIATION OF EFFICIENCY AND POWER FACTOR WITH PART LOAD

references to:

audit stage:
ECO Identification/ECO Detailed Evaluation

description: Some typical motor characteristics are shown in Table 1 (Timpone, 1982).

TABLE 1 Typical motor characteristics for four motor sizes

Power kW	Full load [rpm]	Amperes at 460V: Full load	Amperes at 460V: Locked rotor (maximum)	Efficiency: Full load	Efficiency: 3/4 load	Efficiency: 1/2 load	Power factor: Full load	Power factor: 3/4 load	Power factor: 1/2 load
2	1160	5.0	32.0	76.0	74.0	70.0	79.0	70.0	57.0
7	3515	13.1	81.0	84.5	84.5	83.5	86.0	83.0	74.0
	1740	13.4	81.0	83.0	84.0	84.0	86.0	82.0	72.0
	1160	14.2	81.0	84.0	84.0	83.0	80.5	74.5	61.5
33	3555	59.5	362.0	89.0	89.0	89.0	88.0	85.0	79.0
	1770	63.1	362.0	89.5	89.5	89.5	83.0	79.0	70.0
75	3560	112.0	725.0	91.5	92.0	92.0	91.5	90.5	90.5
	1780	118.4	725.0	92.5	93.0	93.0	85.5	83.5	76.5

Typical efficiencies for electric motors versus load are shown in Fig. 1 (Freund, 1982).

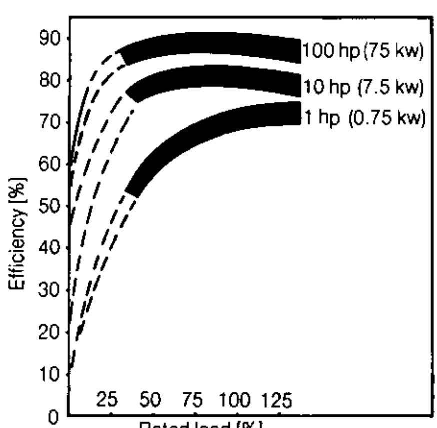


Fig. 1
Typical variation of motor efficiency with load for three motor sizes.

reference values: RV EL.4	application area: ELECTRIC MOTORS	referenced from: AP EL.3
title: VARIATION OF MOTOR EFFICIENCY WITH MOTOR SIZE		**references to:**

audit stage:
ECO Identification/ECO Detailed Evaluation

description:

Variation of motor efficiancy versus motor size is shown in Fig. 1 (ASHRAE Standard 100.3P).

TABLE 1. Suggested minimum motor efficiencies (3 phase).

Power [kW/hp]	Minimum Efficiency [%]
.75/1	80
2.2/3	84
3.7/5	85
7.5/10	88
18.54/25 (or greater)	90

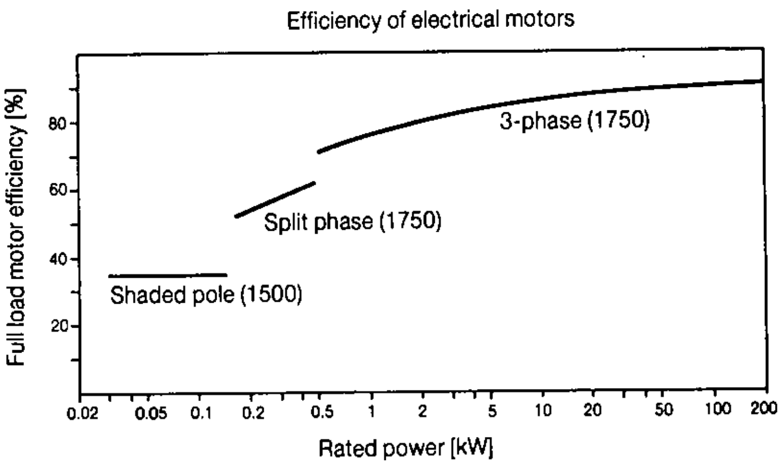


Fig. 1 Typical variation of efficiency with motor size. Numbers in brackets give the nominal rpm.

reference values:	**application area:**	**referenced from:**
RV EL.5		

title:	**references to:**
ELECTRICAL SYSTEM EQUIPMENT LIFE	

audit stage:
ECO Identification/ECO Detailed Evaluation

description:

Typical equipment life-times for electric equipment are given in Table 1. Values of moment of inertia for electric motors are given in Table 2. Bell and Hester, 1980; Barry Blower CO., 1981.

TABLE 1. Typical equipment life.

Equipment	Medium life yrs.
Motors except in	18-25 yrs.
fan coils	10 yrs.
Motor starters	17-20
Transformers	30
Generators	25-30
Main cables	25-30
Switchgear and distribution equipment	25-30
Branch circuit cables and outlets	20-25
Lighting	20-25
Controls electric	16
Controls electronic	15
Capacitors	10-20

TABLE 2. Approximate range of moment of inertia capability of electric motors.

Size [hp]	1750 rpm Minimum	1750 rpm Maximum	1150 rpm Minimum	1150 rpm Maximum
1	0.5	1.4	1.3	3.1
1 1/2	0.8	1.8	2.0	3.5
2	1.1	2.1	2.7	6.0
3	1.4	3.1	2.9	8.9
5	2.2	3.5	3.7	19.0
7 1/2	2.3	6.5	5.9	21.6
10	2.4	9.1	6.9	22.7
15	4.6	12.3	16.8	32.3
20	6.4	14.2	18.7	45.4
25	10.1	16.7	26.1	62.5
30	12.2	24.9	29.5	70.0
40	15.6	26.2	33.0	120.0
50	18.5	31.0	48.5	158.6
60	20.6	43.7	60.7	194.9
75	22.3	47.8	72.1	196.4
100	45.2	64.9	103.1	233.2
125	52.3	89.8	117.2	287.4

Note: Polar moment of inertia = mr^2,
where: m = mass of wheel [kg],
r = radius of gyration [m].

For fans, where the moment of inertia is not given in catalogue, use 65 to 75% of the tip radius dimension.

reference values: RV EL.6	**application area:** ELECTRICAL	**referenced from:** ECO EL.5, EL.10 and AP EL.1, EL.2

title: ELECTRIC MOTORS - MAXIMUM KVAR FOR PF CORRECTION AND MOMENT OF INERTIA CAPABILITIES	**references to:**

audit stage:
ECO Identificaion/Evaluation

description:

TABLE 1. Typical maximum correction capacitor kvar for a range of motor sizes.

kW	Power hp	Full Load rpm	Full Load Current	Maximum Correction Capacitor (kvar)
2	3	1160	5.0	2
7.5	10	3515	13.1	3
		1740	13.4	4
		1160	14.2	4
3.7	50	3555	59.5	10
		1740	63.1	15
7.5	100	3560	112.0	15
		1780	118.4	25

reference values:	**application area:**	**referenced from:**
RV EL.7		

title:	**references to:**
TYPICAL ELECTRICAL APPLIANCE LOADS AND USAGE	

audit stage:
Disaggregation/ECO Identification

description:
Energy consumption for domestic appliances varies widely depending on age of equipment, habits of residents, etc. The examples given here should only serve as an inclination of the magnitud of energy consumption by various appliances (Penner, 1974). For further examples of compilations of this kind, see Fracastoro-Lyberg, 1983.

TABLE 1. Typical power consumption, average annual use time, and average annual electrical energy consumption by appliances (based on U.S. usage).

		Average power, [W]	Assumed use [h/yr]	Energy use per year, [kWh/yr]
FOOD	Deep fryer	1,448	56	83
	Dishwasher	1,200	300	360
	Freezer (frostless, 450 l or 15 cft)	440	4,000	1,761
	Microwave oven	1,500	127	190
	Self-cleaning oven	4,800	157	750
	Range	8,200	55	455
	Refrigerator (frostless 350 l or 12 cft)*	321	3,800	1,217
LAUNDRY	Clothes dryer	4,856	204	993
	Iron (hand)	1,008	141	144
	Washing mashine	512	200	103
	Water heater (standard)	2,475	1,700	4,219
ENTER-TAINMENT	Television black & white	55	2,200	120
	color	200	2,200	440

* Energy use by refrigerator/freezers: 660 kWh/yr for a single-door, manual-defrost model (250 to 400 l or 9 to 13 cft): 1,180 kWh/yr for a two-door, cycle-defrost unit (350 to 450 l or 12 to 15 cft); 1.8 MWh/yr for a two-door, top-freezer, frost-free model (350 to 600 l or 12 to 20 cft); 2,200 kWh/yr for a side-by-side, frost-free unit (450 to 750 l or 16 to 25 cft).

REFERENCES

ACGIH (American Conf. on Governmental Industrial Hygiene). 1980. Industrial Ventilation. Edwards Brothers Inc.

ACIN, undated. Manufacturers catalogue. The Hague, the Netherlands.

Albern, W.F., 1983. "Simultaneous Heating and Cooling - The Undetected Energy Consumer". ASHRAE Journal, (Sept.), pp. 38-39.

Albern, W.F., and Lacey, R.D., 1984. "Use Chilled Water Preheat Coils". ASHRAE Journal, (May), pp. 28-30.

Alexander, L.G., 1984 "Weather Compensation with Room Reset", Building Services Engineer (U.K.), (March), p. 53.

ANSI/ASHRAE/IES, 1981. 100 Series 1981. "Energy Conservation in Existing Buildings". Atlanta: American Society of Heating, Refrigerating and Air Conditioning Engineers.

Arasteh, D. et al., 1980. "Performance of a Selective Surfaced Water Wall Retrofit". Proceedings of the 5th Passive Solar Conference, Amherst, MA.

ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers Inc., New York).

ASHRAE, 1975. ASHRAE Standard 17-1975. "Method of Testing for Capacity Rating of Thermostatic Refrigerant Expansion Valves".

ASHRAE, 1979 ASHRAE Handbook -- 1979 equipment

ASHRAE, 1980 ASHRAE Handbook -- 1980 systems.

ASHRAE, 1980 (C) ANSI/ASHRAE/IES 90A-1980, ASHRAE/IES 90B-1975, ASHRAE 90C-1977. "Energy Conservation in New Building Design".

ASHRAE, 1981, (A) ANSI/ASHRAE 55-1981 "Thermal Environmental Conditions for Human Occupancy".

ASHRAE, 1981, (B) ANSI/ASHRAE 62-1981 "Ventilation for Acceptable Indoor Air Quality".

ASHRAE, 1983 ASHRAE Handbook -- 1983 equipment.

REFERENCES

ASHRAE, 1984
ASHRAE Handbook -- 1984 systems.

ASHRAE, 1985
ASHRAE Handbook -- 1985 fundamentals.

ASTM (American Society of Testing and Materials)

ASTM, 1981
ASTM Standard E-779-1981. "Standard Practices for Measuring Air Leakage by the Fan Pressurization Method".

ASTM, 1985
ASTM Standard E-741-1985. "Practice for Measuring Air Leakage Rate by the Tracer Dilution Method", (*1985 Annual Book of ASTM Standards, Vol. 04.07*, pp. 749-760).

Azer, N.Z., 1985.
"A Design Procedure, Spot Cooling Systems", ASHRAE Journal, (June), pp. 40-45.

Backus, A.O., 1982
"Energy Savings Through Improved Control of Heat Pump Setback", ASHRAE Journal, (February), pp. 24-28.

Baillie, J.D., and Langford, Ph. L., 1985
"Microprocessor Control of a System", ASHRAE Journal, (September), pp. 22-27.

Baltimore Air Coil Company Inc., 1984
"A Guide to Ice Storage System", ASHRAE Journal, (July), (Bulletin E140/1-0A, Baltimore Air Coil, Maryland, U.S.A.)

Baraniak, D.W., 1980.
"Practical Applications Using a High Resolution Infrared Imaging System", SPIE, Vol 254 Thermosense III, pp. 57-62.

Barry Blower Company, 1981.
"Engineering Data Bulletin 100-107", Barry Blower Co., Canada.

Batherman, R.E., 1982.
"Steam Traps", *Heating / Piping / Air Conditioning*, (Nov.), pp. 45-60.

Beier, R., and Gorton, R.L., 1978.
"Thermal Statification in Factories - Cooling Loads and Temperature Profiles", ASHRAE Transactions, Vol. 84, part 1.

Bell, C.J. and Hester, L.R., 1980.
"Power Factor Correction", Heating / Piping / Air Conditioning, (December), pp. 31-34.

Bentsen, L., 1985.
"New VAV Controls for Fume Hoods", Heating / Piping / Air Conditioning, (Feb.), pp. 67-69.

REFERENCES

Bergstrom, U., 1985.
"Franluftsvarmepumpar i flerbostadshus", The National Swedish Testing Institute, Boras, Sweden.

Berglund, L.G., and Gonzalez, R.R., 1978.
"Human Response to Temperature Drifts", ASHRAE Journal, (August), pp. 38-41.

Berutti, A., 1984.
"Cycling of Motors for Energy Conservation", Electrical Construction & Maintenance, (January).

Beyea, J. and Harrie, D., 1977.
"Energy Conservation in an Old 3-Story Apartment Complex", Proceedings of the International Conference on Energy Use Management, Fazzolare and Smith (eds), Pergamon, N.Y., pp. 457-464, Vol 1.

Birtles, A.B., John, R.W., and Smith, T.H., 1984.
"Study of the Performance of an Energy Management System", Building Services Engineering Research & Technology, Vol. 5, No. 4.

British Gas, 1983
The British Gas Guide to hot water plant sizing for commercial buildings, (June).

Bruel and Kjaer, undated.
Manufacturers Manual, Copenhagen, Denmark.

BSI (British Standard Institution), 1982.
"Basic Data for the design of buildings: daylight", BSI Document DD73:1982.

BRE (Building Research Establishment) Garston, Watford, U.K.

BRE, 1972.
BRE Digest 140.

BRE, 1976.
BRE Digest 190.

BRE, 1977.
BRE Digest 205.

BRE, 1978.
CP 44178.

BRE, 1979.
BRE Digest 232.

BRE, 1980.
BRE Digest 236.

BRE, 1981.
BRE Digest 253.
BRE Digest 256.

REFERENCES

BRE, IP 2/81.
BRE, 14/81.
BRE, IP 26/81.

BRE, 1983,
BRE Digest 270.
"Lighting Controls & Daylight Use", BRE Digest 272, (April).
BRE, IP 2/83.

BRE, 1984,
BRE Digest 289.

BRE, 1985,
BRE, IP 2/85.

BSRIA, 1983
"Kitchen Ventilation", BSRIA Library Bibliography.

Bullock, C.E., 1978,
"Thermostat Setback & Residental Heat Pumps", ASHRAE Journal, (Sept.), pp. 38-43.

Burger, Robert, 1980,
"Cooling Tower: Energy Conservation Workhorses", ASHRAE Journal, (April), pp. 33-35.

Burgess, C.K., 1985,
"Energy systems for commercial & industrial building", British Gas Corporation, Midland Research Station Symposium, October 15-16, 1985.

CMHC (Canadian Mortgage & Housing Corporation), 1982.
Energy Efficiency in Multi-Unit Residential Building. A Handbook for Owners and Operators, CHMC.

Chauan, R.B., 1985,
"Field Test on an Exhaust Air Heat Recovery Heat Pump", Building Research Note No. 226, (Feb.), National Research Council Canada.

Choi, S., Hirsch J. & Birdsall, B., 1982.
"Peak Saving in Buildings Through Use of Diesel Engine Driven Emergency Power Generation System", ASHRAE Journal, (Jan.), pp. 33-37.

CIBS (Chartered Institution of Building Services Engineers) London, U.K.,

CIBS, 1980,
Guide A3

CIBS, 1982,
Measurement of energy consumption and comparison with targets for existing buildings and services, part 4, London: CIBS.

CIBS, 1982,
"Measurement of Energy Comsuption", CIBS Building Energy Code, part 4.

REFFRFNCES

CIBS, 1984,
Code for Interior Liahtina, part 2. London: CIBS.

CIBS, 1985.
Guide B11.

CIBS, 1986.
Guide A4.
Guide 81.
Guide B2.
Guide B3.
Guide B4.
Guide 87.
Guide B16.

Coad, W.J., 1975.
"Enerav Audits I - Components of Enerav Use", Heatina / Pipina / Air Conditionina, (July), pp. 105-106.

Coad, W.J., 1975.
"Energy Audits II - Components of Enerav Use", Heatina / Pipina / Air Conditionina, (Aug.), pp. 93-97.

Coad, W.J., 1979.
"Enerav Audits III: Components of Enerav Use", Heatina / Pipina / Air Conditionina, (Sept.).

Coad, W.J., 1979.
"Enerav Audits 1V: The Use of Audits", Heatina / Pipina / Air Conditionina, (Oct.).

Cole, R.A., 1984.
"Reduced Head Pressure Operation of Industrial Refriaeration Systems", Heatina / Pipina / Air Conditionina, (July), pp. 119-132.

Conti, F. and Helcke, G., 1985.
"Enerav Audit Data Bases", Commission of the European Communities, Join Research Centre, ISPRA, Italv, Report EUR 8795.

Conti, F. and Helcke, G., 1986.
"Enerav Audit Data Bases: The situation in the European Community and some EA Member States", Commission of the European Communities Joint Research Centre, Ispra Establishment, Varese, EUR 9795.

Controlled Air Manufacturina Inc., 1982.
"Steel Control Damper Trade Cataloque SC-4B-82", Mississauaa, Ontario.

Coulsson, K.L., 1975.
Solar and Terrestrial Radiation, Academic Press, New York.

Courville, G.E., 1981.
"Assesment of Buildina Diaanosties", Oak Ridae National Lab Report ORNL/546-80/61602/1, Oak Ridae, TN, U.S.A.

REFERENCES

Dalrymple, M., 1984.
"PM Programs Reduce Motor Failures", Electrical Construction & Maintenance, (Oct.), p. 34.

Darley, M.F., et al., 1980 (updated).
"*Scorekeeping for Retrofits: Issues Pertinent to the Management of the 1000-House Pilot Project in Lakewood, NJ*", (Aug.). Princeton Univ. Report PU/CEES 106.

Dautovich, D.R., 1980.
"Motor Efficiency Study at Ontario Hydro", Engineering Digest (Association of Professional Engineers of Ontario, Canada), (Jan.), p. 15.

Dietz, R., 1985.
"Multi-tracer gas studies", reported in ASHRAE Seminar, Chicago.

Dombroski, L. and Nelson, W.I., 1984.
Heating / Piping / Air Conditioning, (May), pp. 877-892.

Duhal, L. and Sauov, B., 1983.
Building Rating for Audit; OFFN Berne, Switzerland.

Dubin, F.S. 1975.
"Guidelines for Saving Energy in Existing Buildings", Engineers, Architects *and Operator Manual ECM-2, U.S. Federal Energy Administration.*

Dubin, F.S., Mindell, H.L., and Bloome, S., 1976.
How to Save Energy and Cut Costs in Existing Industrial and Commercial Buildings, Noyes Data Corporation, Park Ridge, NJ.

Duffie, J.A., and Beckman, W.A., 1980.
Solar Engineering of Thermal Processes, John Wiley & Sons.

Dutt, G.S. and Beyea, J., 1979 (A).
"Hidden Heat Losses in Attics - Their Detection and Reduction", Princeton University Center for Energy and Environmental Studies Report PU/CEES R-77.

Dutt, G.S., 1979 (B).
"Condensation in Attics: Are Vapor Barriers Really the Answer?", Energy and Buildings 2, 251.

Dutt, G.S., Harrje, D.T., Gadsby, K.J., 1986.
"Convective Loop Losses in Buildings", Proc. of Thermal Performance of the *Exterior Envelopes of Buildings III, ASHRAE: Atlanta.*

EAM (Energy Audits Manual), 1981.
Government Institutes Inc.

ECM (Electrical Construction and Maintenance).

ECM, 1983.
"Adjustable Frequency Control Systems for AC Motors", (Feb.), p. 40.

REFERENCES

ECM, 1984, (A)
"Selecting Energy Efficient Motors", (March), p. 38.

ECM, 1984, (B).
"What's the Story? Factors Affecting Accuracy of Digital Multimeters", (March), p. 52.

Ellison, R.D., 1977.
"The Effects of Reduced Indoor Temperature & Night Setback on Energy Consumption of Residential Heat Pumps", ASHRAE Journal, (Feb.), pp. 21-25.

Elmroth, A., and Levin, P., 1983.
Air Infiltration Control in Housing: A Guide to International Practice, IEA Annex V, Swedish Council for Building Research Document D2:1983.

EMC (Energy Management Canada), 1983.
"Steam Traps - Energy in Steam Form can be Recycled for Maximum Savings", (June/July).

Energy Efficiency Office, London, U.K.,
Booklets 6, 8 and 9.

Erbs, D.G., Klein, S.A., Beckman, W.A., 1983.
"Estimation of Degree-Days and Ambient Temperature Bin Data from Monthly-Average Temperatures", ASHRAE Journal, (June), pp. 60-66.

Erth, R.A., 1980.
"Power Inverters and Off-Design Chiller Performance", Heating / Piping / Air Conditioning, (Nov.), pp. 63-67.

Eskra, N., 1980.
"Indirect/Direct Evaporative Cooling Systems", ASHRAE Journal, (May), pp. 21-25.

Eurovent, 1977.
Eurovent 7/3, "Forced Flow Air Heaters and Air Coolers - Test Code for Heat Exchangers".

Eurovent, 1977.
Eurovent 10/2, "Heat Recovery Devices - Methods of Testing Heat Recovery Devices for HVAC Systems".

Exett Sales, 1985.
Manufacturers Manual, Gavle, Sweden.

FATRA, 1982.
Diagnostic-Signature Energétique, OFEN Berne, Switzerland.

Feldman, E.J., 1983.
"Nameplate Data - For Better Motor Installation and Maintenance", Electrical Construction & Maintenance, (December).

REFERENCES

Fels. M.F., (Ed.). 1986,
Enerav and Buildinas. 9 (1986).

Fels, M.F. and Goldbera. M.L.. 1982,
"Measurina Household Fuel Consumption on the Standard Livina Cycle",
Enerav 7. 6. pp. 489-504.

Fitzaerald. D., 1983,
"Does Warm Air Heatina Use Less Enerav than Radiant- A Clear Answer".
Buildina Services Enaineerina. Research and Technoloav, Vol. 4, No. 1. pp. 26-28.

Fizzel. J.A.. 1977.
"Analysina Vertical Temperature Gradient", Heatina / Pipina / Air Conditionina, (Nov.), pp. 81-84.

Fracastoro, G.V. and Lvbera, M.D., 1983,
"Guidina Principles Concernina Desian of Experiments, Instrumentation and Measurina Techniques". Report from International Enerav Aaency (IEA), Task III, Swedish Council for Buildina Research, Document D11:1983.

Francis. E.. 1985,
"Annual Ice Storaae for Coolina". SOLAR AGE, (April), pp. 67-70.

Freeborn, M., 1980,
"Cut Your Enerav Bill Throuah Power Factor Correction", Electrical Contractor & Maintenance Supervisor, (July); pp. 18-21.

Freund. A., 1981,
"Reducina Motor Losses". Electrical Construction & Maintenance, (March), p. 69.

Fullman, C., and Helm. B.M.. 1981.
"Deadband Thermostats Pro & Con", ASHRAE Journal, (July). pp. 51-53.

Gardener. P., 1984, "Enerav Manaaement Systems in Buildinas", Enerav Publications (UK).

Garland, Milton W.. 1980,
"Compressor Capacity Control for Air-Conditionina Systems", ASHRAE Journal, (April). pp. 37-39.

Gatts, R.R. Massey, R.G., and Robertsson, C., 1974,
Enerav Conservation *Proaram Guide for Industry and Commerce. National Bureau* of Standards, Washinaton DC, NBS Handbook 115.

Goldfield. J.. 1985.
"Contamination Reduction: General vs Local Exhaust Ventilation", Heatina / Pipina / Air Conditionina, (Feb.), pp. 47-51.

Griaa, P.F.. 1984.
"An Assessment of the Cost Effectiveness and Potential of Heat Pumps for Domestic Hot Water (only) Heatina", Buildina Research Establishment, U.K.

REFERENCES

Haines. R.W., 1980,
"Stratification", Heatina / Pipina / Air Conditioning. (Nov.), pp. 70-71.
Haines. R.W., 1981,
"Economy Cycle Controls", Heating / Piping / Air Conditioning. (March), pp. 70-71.

Haines, R.W., 1981.
"Economy Cycle Controls", Heating / Piping / Air Conditioning. (April), pp. 111-113.

Haines, R.W., 1982-1983.
"Roger Haines on Controls - Series of Articles", Heating / Piping / Air Conditioning. (Aug. -82 to March -83).

Haines. R.W., 1984,
"Retrofitting Re-Heat Type Systems", ASHRAE Journal. (Sept.), pp. 35-38.

Hamgtonq and Loyd. S., 1984,
"Heat Recovery from Buildings - An Annotated Bibliography". BSRIA Library. Bibliography LB 104/84, BSRIA.

Hansson, T., Nilsson. A. and Stadler. C.G., 1984.
Swedish Council for Building Research, rapport R139:1984.

Harrje, D. and Cooper, 1979.
"Instrumenting Energy Audits", Princeton University Center of Energy & Environmental Studies Report PU-CEES 91.

Harrje. O.T., Buckley. C.E., and Heissler, G.M., 1982.
"Building Energy Reductions: Windbreak Optimization", ASCE Energy Journal.

Harrje. O.T., and Cerceo. J.A., 1983 (B),
"Recommened Retrofit Actions Based on Air Infiltration Evaluations in a Variety of Buildings", 4th AIC Conference - Air Infiltration Reduction in Existing Buildings. Annex V Air Infiltration Centre Doc AIC-PROC-11-83.

Harrje. D.T., Murphy, W.J., Schoen. L.J., Gadsby. K.J., 1983 (C).
"Energy Diagnosis of the More Complex Building", Proceedings from CIB 83, National Inst. for Building Research. Gavle Sweden.

Hensley. John C., 1981.
"Cooling Tower Energy", Heating / Piping / Air Conditioning. (Oct.), pp. 51-57.

Hensley. John C., 1983.
"External Influences on Cooling Tower Performance", ASHRAE Journal. (Jan.). pp. 86-89.

Hill. C.R., 1984.
"Integration of Cooling Storage with Chiller Plant Operation", Heating / Piping / Air Conditioning. (May), pp. 105-113.

Hirst. E., White. D., Goerlitz. R., and McKingstry. M., 1985.

"Actual Electricity Saving and Audit Predictions for Residential Retrofit in the Pacific Northwest", Energy and Building, Vol. 8, pp. 83-91.

Holmer, I., 1984.
"Manniska och klimat: problempaverkan och utvardering", VVS & Energi, No. 4, pp. 45-48.

Holmes, L., 1982.
"Energy Saving Motor Controllers - Background and Update", Electronics & Power, IEE (UK), (March), pp. 232-235.

Honeywell, 1976.
Variable Air Volume Systems Manual, Honeywell, Minneapolis, U.S.A.

IES (UK), 1972.
"Daytime Lighting in Buildings", Technical Report 4.

IES (Illuminating Engineering Society of North America)

IES, 1982.
IES LEM-1-1982 "IES Recommended Procedure for Lighting Power Limit Determination", Lighting Energy Management Series, New York.

IES, 1984.
IES LEM-2-1984 "IES Recommended Procedure for Lighting Energy Limit Determination", Lighting Energy Management Series, New York.

IES, 1984.
IES LEM-4-1984 "IES Recommended Procedure for Energy Analysis of Building Lighting Design and Installations", Lighting Energy Management Series, New York.

ISO (International Organization for Standardization)

ISO, 1982.
ISO/DIS 7726 - 1982, "Thermal Environments - Specifications relating to appliances and methods for measuring physical characteristics of the environment".

ISO, 1983.
ISO Standards Handbook 15, "Measurement of fluid flow in closed conduits".

ISO, 1984.
ISO Standard 7730-1984, "Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort".

Jack Dale & Associates, Inc., 1984.
Governments Institutes Inc., Energy Audits Manual, Rockville, U.S.A.

Jackson, D., Harrje, D.T. and Dutt, G.S., 1985
"Measurement of Air Leakage Properties of Common Residential Insulation Materials", Proceedings of ASTM Conference on Thermal Insulation Materials and Systems, Dallas 1984. Philadelphia: ASTM.

REFERENCES

Johnson, G.L., and Jones, L., 1980.
"A Low Cost Data Logging System", DBR/NRC Building Research Note No. 166, (Aug.), Ottawa: National Research Council of Canada.

Johnson Controls, 1982.
"Energy Conservation Control", EC2, (Dec.), Johnson Controls Company, Milwaukee.

Johnson, G.A., 1985
"From Constant Air to Variable", ASHRAE Journal, (Jan.), pp. 107-114.

Jones, L., 1980,
"Hot Water Consumption and Performance of an Automatic Storage Type Water Heating Installation in a School Building", ASHRAE Transactions, 1980.

Jones, L., 1981,
"Computers for Building Architecture and Engineering Design", Dept. of Energy, Mines and Resources, Ottawa, Ontario, Canada, 1981.

Jones, Leslie & Associates, 1983.
"Review of the Potential of Passive Solar Strategies for Office Buildings - Report No. Passive-7", (Aug.), National Research Council Canada, Solar Energy Program.

Jones, P.J. & O'Sullivan, P.F., 1985,
"Low energy factories", British Gas Corporation Midland Research Station Symposium, Oct. 15-16, 1985.

Kallblad, K., 1983.
"Calculation Methods to Predict Energy Savings in Residential Buildings", IEA Annex III Residential Buildings Energy Analysis, Swedish Council for Building Research, Document D4:1983.

Kallen, Howard P., 1982.
"Analysis: Off-Peak Cooling Methods to Reduce Energy Consumption", ASHRAE Journal, (Dec.), pp. 28-30.

Kao, J.Y., and Pierce, E.T., 1983,
"A Study of Sensor Error on Building Energy Consumption", ASHRAE Journal, Vol. 25, No. 12.

Kao, J.Y., 1985,
"Sensor Errors", ASHRAE Journal, (Jan.), pp. 100-106.

Kelly, J.F. and Didion, D.A., 1975,
"Energy conservation potential for modular gas fired systems", NBS Buildings Service Services No. 79.

Kinsey, R.A., 1979,
"Power and Fuel Savings with Central A/C and Furnaces", ASHRAE Journal, (June), pp. 58-62.

RFFERFNCES

Klassen. J.. 1981.
"Proiect Icebox - An Annual Fnerav Storage System", ASHRAE Journal, (May), p. 48-50.

Kinqler, R., 1980.
"Efficiencv Considerations for Two Staae Svstems", ASHRAE Journal, (Dec.), pp. 33-37.

Korte, B., 1976.
"Retrofitting & Replacina Enerav Intensive Rooftops", Heating / Piping / Air Conditionina. (Oct.), pp. 31-41.

Kraah. R. W.. 1976.
"Brush Cleanina of Condenser Tubes Saves Power. Cost", Heating / Piping / Air Conditionina, (Sept.). pp. 60-64.

Kusuda. T.. 1981.
"A Comparison of Enerav Calculation Procedures, ASHRAE Journal. 23, pp. 21-24.

Landman, W. J.. 1976.
"Chilled Water Storaae". Heatina / Pipina / Air Conditionina. (Nov.), pp. 73-75.

Landman, W.. 1983.
"The Search for Chiller Efficiencv". Heatina / Pipina / Air Conditionina. (July), pp. 77-81.

Leitner, G.. 1980.
"Controllina Chiller Tube Foulina". ASHRAE Journal. (Feb.). pp. 40-43.

Levine. M.. Moll. L.W.. 1981.
"Beyond Setback: Enerav Efficiency Through Adaptive Control", ASHRAE Journal. (July), pp. 37-39.

Liptak, B.G., 1979.
"Savinas Throuah CO Based Ventilation". ASHRAE Journal. (Julv), pp. 38-41.

Llovd. S., 1985.
"Garaaes & Car Parks", BSRIA Librarv Biblioaraphv LB88/85, BSRIA (UK).

Lunde, P.J. 1980.
Solar Thermal Fnaineerina. John Wilev & Sons.

Macriss. R.A. and Zawacki. T.S.. 1985.
"Effect of retrofit on combustion characteristics & seasonal efficiency of aas fired furnaces & boilers". Westinahouse, Combustion Control News. Winter (Feb.). 1985.

Mattinalv. G.E.. Harrie. O.T.. Heissler, G.M.. 1979.
"The Effectiveness of an Everareen Windbreak for Reducing Residential Enerav Consumption". ASHRAE Transactions. Vol. 85. pt. 2.

REFERENCES

Meyer, J.R., 1983.
"Evaporative Cooling for Energy Conservation", Heating / Piping / Air Conditioning, (Sept.), pp. 111-118.

MITEC Electronic, 1981,
Manufacturers Manual, Saffle, Sweden.

Munk, M., Oct. 1979,
Energy Auditing Theory and Practice, World of Energy Engineers Congress.

National Electric Contractors Association (NECA), 1975,
Electric Load Management, Electrical Design Library Series.

Nelson, L.W., and MacArthur, J.W., 1978,
"Energy Savings Through Setback", ASHRAE Journal, Vol. 20, No. 9, pp. 49-54, and ASHRAE Transactions, Vol. 84, pt. 2, 1978, pp. 319-334.

Nelson L.W., and Beckey, T., 1982.
"Computer Prediction and Test Verification of Cooling Energy Savings with Thermostat Setup", ASHRAE Transactions, Vol. 24, No. 1, pp. 44-48.

Nordtest, 1983,
NT VVS 021, "Heat Recovery Units: External Leakage".

Nordtest, 1983,
NT VVS 022, "Heat Recovery Units: Internal Leakage".

Nordtest, 1983,
NT VVS 024, "Heat Recovery Units: Temperature Efficiency".

Nordtest, 1983,
NT VVS 025, "Heat Recovery Units Functioning at low outdoor temperatures".

Norlen, U., and Holgersson, N., 1982,
"Estimating Effects of Energy Conservation Measures: A Swedish Study", New Energy Conservation Technologies, ed. J.P. Milohone and E.M. Willies, Springer Verlag.

NVG, (Nordic Ventilation Group), 1982,
"Methods for measurement of airflow rates in ventilation systems", Svensson, A., Swedish Institute for Building Research, Bulletin M83:11.

OFAC, 1983,
(Office Féderal des Affaires Conjoncturelles), Manuel: Etudes et Projets, EDMZ, Berne, Switzerland.

Ogasawary, S., Taniguchi, H., and Sukehira, C., 1979,
"Effect of Energy Conservation by Controlled Ventilation - Case Study in a Department Store", Energy & Buildings, Vol. 2, pp. 3-8.

Olesen, B.W., 1982,"Thermal Comfort", Technical Review, No. 2, Bruel & Kiaer,

OML (Ontario Ministry of Labour), 1982,

"Occupational Health & Safety Act & Regulations for Industrial Establishments", Ontario Regulation 692 and 714/82.

OBC (Ontario Ministry of Municipal Affairs), 1984,
"The Building Code Regulation 583/83 and 549/84.

Oven, M., 1983
"Automatic blowdown with heat recovery", Heating / Piping / Air Conditioning, (Aug.), pp. 68-73.

Pannkoke, T. 1980, (A).
"Air Terminal Units", Heating / Piping / Air Conditioning, (Dec.).

Pannkoke, T. 1980, (B),
"Air Terminal Devices: What's Available", Heating / Piping / Air Conditioning, (Nov.), pp. 31-37.

Paoluccio, J.P. and Burfield, J.A., 1981,
"University Evaluates Dead Band Control Strategy", ASHRAE Transactions, Vol. 87, part 1.

Pearson, R.J., 1982,
"Evaporate Cooling", Heating / Piping / Air Conditioning, (Dec.), pp. 80-89.

Pearson, F.J., 1985,
VAV System Retrofit in an Industrial Building", Heating / Piping / Air Conditioning, (Aug.), pp. 109-113.

Penner, S. and Icerman, L. 1974,
"Demand, Resources, Impact, Technology and Policy", Energy Vol. 2, Wesley Publishing Company Inc.

Pettersson, B., and Axen, B., 1980,
Thermography - Testing of the Thermal Insulation of Air tightness of Buildings, Swedish Council for Building Research, Document D5:1980.

PM & E, 1984,
"Peak Power Shaving with On-Site Generators", Plant Management & Engineering, (June).

Prasad, M., 1981,
"Optimum Interstage Pressure for 2-Stage Refrigeration Systems", ASHRAE Journal, (Jan), pp. 58-60.

Public Works Canada, undated,
"Advanced Seminar on Energy Systems Analysis".

Reav, D., 1980,
"Heat Recovery", Building Services Engineer, (Aug.), pp. 35-43.

Reed, M.A., 1983,
"Control Changes Enable VAV Conversion", Heating / Piping / Air Conditioning, (March), pp. 109-110.

REFERENCES

Rise, J.A., 1985,
The VOM-VTM Handbook, Tab Books Inc., U.S.A.

Roulet, C., 1987,
Office Fédéral des Affaires Conjoncturelles, Mesures in situ en énergétique du batiment, EDMZ, Berne, Switzerland.

Saugy, B., 1985,
Abaques de prestation des procédés énergétiques du batiment; OFEN, Berne, Switzerland.

Shaw, C.Y., 1981,
"Air tightness: Supermarkets and Shopping Malls", ASHRAE Journal, Vol 23., No. 3, pp. 44-46.

Shavit, G., 1974,
"Enthalpy Control Systems Increased Energy Conservation", Heating / Piping / Air Conditioning, (Jan.), pp. 117-122.

SIA, 1982,
(Societe Suisse des Ingenieurs et Architectes), Recommandation SIA 180-4, SIA Zurich, Switzerland.

Silvers, J.P. and Tye, R.P., 1985,
"A Survey of Building Envelope Thermal Anomolies and Assessment of Thermal Break Materials for Anomoly Correction - Vol. II", Proceedings of Federal Workshop on Building Envelope Thermal Anomalies, ORNL/SUB-83/70376/2.

SMS, 1986,
SS 2095, "Heating Equipment - Laboratory Testing of Heat Pumps", Draft Swedish Standard, Stockholm: Swedish Organization for Mechanical Standardization.

SP (National Swedish Testing Institute), 1985,
SP MET ET - 001, "Garantikontroll av villavarmepumpar, matmetoder, (Warranty control of residential heat pumps, measuring techniques)".

Spethmann, D.H., 1977,
"Load Reset, A Basic Optimization Tool", Heating / Piping / Air Conditioning, (Dec.), pp. 35-40.

Spethmann, D.H., 1981,
"Electrical Energy Mangement", ASHRAE Transactions, V. 87, part 1.

Spirax Sarco, 1985,
"Steam Utilisation Course", Spirax Sarco Inc., Pennsylvania.

STWA (Severn Trent Water Authority), 1983,
Energy Conservation Demonstration Projects Scheme, Coventry City Council, Coventry, Canada.

Stamm, R. H., 1978,

REFERENCES

"Recirculated Refrigerant Systems and HVAC Energy Conservation", Heating / Piping / Air Conditioning, (Feb.), pp. 51-56.

Stamm, R. H., 1984.
"Industrial Refrigeration: Compressors", Heating / Piping / Air Conditioning, (July), pp. 93-111.

Stoecker, N.F., and Daber, R.P., 1978.
"Conserving Energy in Dual Duct Systems by Reducing the Throttling Ranges of Air - Temperature Controllers", ASHRAE Transactions, Vol. 84.

Stoecker, W.F., 1980.
"Refrigeration Control with Enhanced Microcomputers", Heating / Piping / Air Conditioning, (Nov.), pp. 48.

Sullivan, H.F., 1982.
"A Review of Energy Calculation Methods", Buildings Energy Technology Transfer Program, publ No. 82.03, Ottawa, Ontario, Canada.

Sun, T.Y., 1979.
"Heat Recovery vs Economiser Cycle", Heating / Piping / Air Conditioning, (Feb.), pp. 81-87.

Supple, R.G., 1982.
"Evaporative Cooling for Comfort", ASHRAE Journal, (Aug.), pp. 36-42.

Tamblyn, R. T., 1977.
"Thermal Storage: A Sleeping Giant", ASHRAE Journal, (June), pp. 53-57.

Tao, W. and Janis, R., 1985,
"Modern Cooling Plant Design", Heating / Piping / Air Conditioning, (May), pp. 51-56.

Tedrow, L.E., 1984.
"How to Grease Motors", Electrical Construction & Maintenance (Apr.), p. 50.

Thielman, O. E., 1983.
"Chiller Optimization by Energy Management Control Systems", ASHRAE Journal, (Nov.), pp. 60-62.

Timpone, R.E., 1982.
"Consider Practical Aspects when Buying High Efficiency Motors", Electrical Construction & Maintenance, (Aug.), p. 24.

Trane Company of Canada, 1977,
"Coil Control - Part II", TRANE Engineers Newsletter, (Oct.).

Trane Company of Canada, 1978,
"*Large Chillers: Series or Parallel Flow?*", TRANE Engineers Newsletter, (May).

Trane Company of Canada, 1979.

"Fan Selection & Control in Variable Air Volume Systems", TRANE Engineers Newsletter, (Oct.).

UNI CTI 8065.
Trattamento delle acque negli impianti termici ad uso civile: Manutenzione degli impianti.

Ure, J.W., 14th - 15th April, 1983.
"Small air source heat pumps for hot water supply in commercial premises", CICC Ltd., Nottingham University.

WECS (Wendes Engineering & Contracting Services), undated.
"Energy Retrofit Savings Made Easy", Illinois.

Weinman, C.H., 1986.
Office Fédéral des Affaires Conjoncturelles, Planification intégrale des installations techniques, EDMZ, Berne, Switzerland.

Welsh, J.W., 1984.
"Chilled-Water Free Cooling", ASHRAE Journal, (March), pp. 49-50.

Wendes, H.C., 1983.
"Estimating VAV Retrofit Cost", Heating / Piping / Air Conditioning, (Aug.), p. 93.

Wiggin, M.E., and Morris, R.H., 1985.
"Electronic Control for Fume Hoods", Heating / Piping / Air Conditioning, (Feb.), pp. 59-64.

Winger, Ph., 1983.
"Atmospheric Cooling Retrofit", Heating / Piping / Air Conditioning, (Nov.), pp. 64-65.

Woods, J.E., Winakur, G., Maldonadoz, F. and Kipp, S., 1982.
"Subjective and Objective Evaluation of CO-Control Variable Ventilation System", ASHRAE Transactions, Vol. 88, part 1.

Wulfinghoff, D.R., 1984.
"Common Sense about Building Energy Consumption Analysis", ASHRAE Transactions, Vol. 90, part 1.

Analytical Index

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-effectiveness.

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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