Energy management principles and practice

This manual is based on the text of the book of the same name to be published by BSi in September 2009. Copies are not to be made without the written permission of the author or BSi.

Prepared by Vilnis Vesma
NIFES Consulting Group
Ref TRG 1997
Version 1.0
6 July 2009
Contents

0-1 Introduction ........................................................................................................................................... 1
0-2 Basics .................................................................................................................................................. 4
1-1 Monitoring energy consumption ........................................................................................................... 7
1-2 Understanding patterns of use ............................................................................................................ 13
1-3 Detecting and prioritising exceptions .................................................................................................. 17
1-4 Raising awareness and motivation ..................................................................................................... 20
2-1 Building fabric ................................................................................................................................... 23
2-2 Heating and ventilation ....................................................................................................................... 26
2-3 Combustion equipment ......................................................................................................................... 30
2-4 Air conditioning and refrigeration ....................................................................................................... 33
2-5 Lighting .............................................................................................................................................. 36
2-6 Hot water services ............................................................................................................................... 42
2-7 Catering ............................................................................................................................................. 44
2-8 Compressed air .................................................................................................................................. 46
2-9 Steam ................................................................................................................................................ 48
2-10 Process thermal insulation ................................................................................................................. 52
2-11 Motor driven equipment .................................................................................................................... 55
3-1 Managing energy saving opportunities ............................................................................................... 57
3-2 Energy audits and surveys ................................................................................................................... 59
3-3 Selecting and briefing consultants ..................................................................................................... 64
3-4 Making the case for capital projects ................................................................................................... 66
3-5 Evaluating savings achieved ............................................................................................................... 68
Further information ................................................................................................................................. 71
0-1 Introduction

Energy management is all about reducing the cost of energy used by the organisation, now with the added spin of minimising carbon emissions as well. Reducing energy costs has two facets: price and quantity. EN 16001 is exclusively concerned with the latter. It does not discuss competitive procurement or invoice validation. Nor does it discuss carbon emissions reduction, beyond what will be achieved incidentally through energy saving: so you will not find anything about alternative energy sources, renewables, carbon trading or fuel substitution.

The Standard regards meeting your organization’s energy policy as the defining objective. Why might the organization need a policy, and what should it look like? At the corporate or strategic level, an energy policy is a public commitment or undertaking which states, for the benefit of employees and contractors, what the organization expects of them in general terms, and what the organization’s objectives are in energy terms of its overall energy performance. It defines the scope and boundaries of the organisation’s energy management system and provides a framework for action. EN 16001 (s 3.2) adds that the policy needs to include three specific commitments:

• to continual improvement in energy efficiency;

• to ensure the availability of information and of all necessary resources to achieve objectives and targets; and

• to comply with all applicable requirements (legally required or voluntarily agreed to by the organization)

Of these commitments the first two are crucial, since they bind the senior management to creating the necessary environment and resources to make progress. There is no one policy that fits all possible scenarios but the following model is suggested as a starting point:
**(Name of organization)** is committed to continuous improvement in the efficiency with which energy is used, and the avoidance of energy waste.

<table>
<thead>
<tr>
<th>The scope of this policy covers all our buildings, processes, and transport operations</th>
<th>This will need to be customized to the particular organization, and might for example be extended to include business travel, raw materials, or even non-energy supplies. It may need to state explicitly that it includes outsourced operations and services.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our first objective is to reduce our total energy consumption each year by (x)% after taking account of changes in levels of activity, weather, and other relevant factors.</td>
<td>There is a danger here of setting a goal which is either unachievable or too easy. In some ways it may be preferable not to set a specific percentage, especially as the percentage which can be saved would usually be expected to decline year on year as the quick wins are exploited.</td>
</tr>
<tr>
<td>Our second objective is to reduce the carbon intensity of our energy purchases by (y)% year on year.</td>
<td></td>
</tr>
<tr>
<td>We undertake to comply not only with all relevant legislation relating to energy use but to additional voluntary requirements which may be agreed from time to time.</td>
<td></td>
</tr>
<tr>
<td>We undertake to provide the resources</td>
<td></td>
</tr>
<tr>
<td>• to plan and supervise the necessary projects and programmes;</td>
<td></td>
</tr>
<tr>
<td>• to maintain an energy management system compliant with EN 16001;</td>
<td></td>
</tr>
<tr>
<td>• to monitor energy performance; and</td>
<td></td>
</tr>
<tr>
<td>• subject to justification on reasonable criteria, to fund physical improvement projects</td>
<td></td>
</tr>
<tr>
<td>We undertake to carry out such awareness-raising, training, and maintenance optimization programmes as may be required in pursuit of improved energy efficiency and reduced losses</td>
<td></td>
</tr>
<tr>
<td>We expect staff and contractors alike to support our objectives and to cooperate actively in achieving them</td>
<td></td>
</tr>
<tr>
<td>We will publish the results each year</td>
<td></td>
</tr>
</tbody>
</table>
So much for the corporate policy. The energy manager will probably also want to develop technical policies defining in detail how things are to be done. For instance: what lighting levels will be provided in corridors? Will computer workstations be turned off at night? The idea is to define a common set of expectations and to remove the need for debate at the micro level. Technical policies provide ready-made answers to common everyday questions, and are the tactical counterpart of what the corporate policy does at a strategic level.
0-2 Basics

Improving energy efficiency is, in part, a technical pursuit with a scientific basis. However, although some aspects are undeniably highly specialised, the essential science should be familiar to most readers (perhaps dimly) from their school days and where BS EN 16001 (section 3.4.2) calls for the energy manager to be appropriately qualified. I read this as meaning that a basic grasp of physics and chemistry would be expected.

This chapter reviews some of the fundamental scientific concepts needed for the job, and other more specific topics are introduced in individual chapters where they may be helpful.

Energy and power

In BS EN16001 energy is defined as "electricity, fuel, steam, heat, compressed air and other like media" (your physics teacher probably defined it more rigorously as "capacity to do work" but the real-world definition is better for our purposes). When we buy or use energy it may be billed or reported in a variety of units of measurement, but all have their equivalents in kilowatt hours (kWh) which is how most practitioners commonly express energy consumption.

Some of the conversion factors are given in the following table:

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Measured units</th>
<th>To get kWh multiply by</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>kWh</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Natural gas</td>
<td>m3</td>
<td>10.7</td>
<td>1</td>
</tr>
<tr>
<td>Natural gas</td>
<td>hundred cu ft</td>
<td>30.3</td>
<td>1</td>
</tr>
<tr>
<td>Natural gas</td>
<td>kWh</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Natural gas</td>
<td>therm</td>
<td>29.31</td>
<td>1</td>
</tr>
<tr>
<td>Diesel or 35-second gas oil</td>
<td>litre</td>
<td>10.6</td>
<td></td>
</tr>
<tr>
<td>Heavy fuel oil</td>
<td>litre</td>
<td>11.4</td>
<td></td>
</tr>
<tr>
<td>Propane</td>
<td>tonne</td>
<td>13,780</td>
<td></td>
</tr>
<tr>
<td>Propane</td>
<td>kg</td>
<td>13.78</td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td>tonne</td>
<td>9,000</td>
<td>2</td>
</tr>
<tr>
<td>Coal</td>
<td>kg</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Steam</td>
<td>tonne</td>
<td>630</td>
<td>3</td>
</tr>
</tbody>
</table>

Notes
1. Depending on pressure, temperature, and calorific value
2. Highly variable between types
3. Dependent on pressure
"Power" has a quite specific meaning: it is the rate at which energy is delivered, commonly expressed in watts (W) or kilowatts (kW), although horsepower (HP) will also come to mind in some contexts. Because both are measures of power, there is a conversion factor between the two: 1 HP is equal to 0.746 kW.

The energy used by a piece of equipment running at fixed power for a certain time is the time multiplied by the power. A 3 kW heater running for two hours will use $3 \times 2 = 6$ kWh. A 55 HP diesel engine running flat out for two hours will deliver $55 \times 0.746 \times 2 = 82.06$ kWh

**Power factor**

In an electrical circuit, power is calculated by multiplying voltage and current together. In the case of mains power, where the current alternates, this relationship holds true at any given instant, so the *instantaneous* power will vary as the voltage and current continuously vary through the cycle. However, in order to deliver the maximum useful power, the current and voltage must be exactly in step. If they are not – for example if the load characteristics make the current waveform lag slightly behind the voltage waveform – then throughout the cycle either the voltage will coincide with a current that is less than it would have been, or the current coincides with a voltage that is lower than it would have been had they been in step. Indeed, there will be four occasions in each cycle when the instantaneous power is zero (two when the current is zero, and two when the voltage is zero). The result: less power will be developed for a given current. The *power factor* is the ratio between delivered useful power and what it would have been with perfect synchronisation of current and voltage.

Poor power factor means that a higher-than-necessary current must be drawn in order to deliver the required useful power. This increases the load on supply cables and switchgear, increases line losses, and (depending on the tariff) can impose higher supply-capacity and maximum-demand charges.

**Efficiency**

This is another word that has quite a narrow meaning in the context of energy management, where it refers to the ratio between useful energy output and energy input. Examples might be the useful heat output from a boiler, divided by the amount of fuel put in; or the work done by a car engine relative to diesel consumed. Take the earlier example of the engine which delivered 82.06 kWh over two hours. If it used 25 litres of fuel in the process, how efficient was it? from Table xxx we see that 25 litres of diesel contain $25 \times 10.6 = 265$ kWh. So the efficiency of the engine was $82.06 / 265 = 30.9\%$

In common parlance "efficiency" is often used interchangeably with "efficacy" or "effectiveness". If the occupants of a building tell one that its heating system is efficient, they usually mean that it keeps them warm, not that the boilers are well tuned and properly controlled to minimise standing losses. Beware also when promoting "efficiency savings" as this term has connotations of downsizing and redundancies.
Energy balance

Most people talk about "consuming" energy (be it in the form of gas, oil, electricity, heat, compressed air or steam) but purists would argue that we don't consume it: merely convert it from one form to another. Nobody seriously argues that we stop using the term "consume" but the point about conversion is important in a way. In the engine example, we used 265 kWh of chemical energy in the diesel fuel to generate about 82 kWh of useful mechanical work. But as energy cannot be destroyed, where did the missing 183 kWh go? It came out as heat in the exhaust and cooling system. There is an overall balance between what goes in and what comes out. We will encounter a similar argument when we discuss combustion efficiency in a later chapter.

Heat and temperature

Heat is one manifestation of energy. A flow of heat can be expressed in energy units (such as kWh). You can meter, buy, or use a quantity of it. The engine in the earlier example produced it by converting chemical fuel energy. Ten tonnes of steel at 300°C contains twice as much heat as five tonnes at 300°C.

Temperature, by contrast, is just a measure of how hot something is. You cannot buy or use temperature; it is not a form of energy. You can see how different heat and temperature are if you think about taking some ice from the freezer and adding heat to it. At first, starting from a temperature of -15°C (say), its temperature rises as it absorbs the heat. When it reaches melting point, it continues to absorb heat as it turns to water. During this process its temperature stays constant at 0°C but its heat content continues increasing (if you completely stop adding heat, the ice-water mix does not change). Once it is all melted, the liquid water continues to absorb heat and its temperature starts climbing again until it reaches the boiling point, whereupon the temperature again stops rising while the water evaporates. Only when there is no more liquid left can the water, now as vapour, start to increase in temperature (and become what is called 'superheated'). With a few odd exceptions that don't go through a liquid phase, as you add heat to any solid its temperature rises unevenly, remaining on plateaus while it is melting or vaporising, following the same trajectory back down as it first condenses to liquid and then solidifies when heat is removed from it. Common physical manifestations of this are (a) your drink with ice in it starts to warm abruptly once all the ice has melted; and (b) boiling a pan of water rapidly does not raise its temperature.

One finicky point you will need to know. When engineers and scientists talk about temperature differences they use a unit of measurement called a kelvin represented by a capital K. One kelvin is numerically equal to a one-degree difference between two temperatures in celsius (centigrade degree in the old nomenclature); when it is 19°C indoors and 5°C outside, the temperature difference is 14K.
1-1 Monitoring energy consumption

To manage energy successfully you need to measure how much you use, and that means taking your own meter readings rather than relying on figures provided by the utility companies. How frequently you get your meters read depends on your circumstances. EN16001 section 3.5.1 places an obligation on the organization to monitor, measure and record significant energy consumption ‘at defined intervals’. My usual guidance is to consider a weekly regime as the best starting point. Monthly monitoring, which has historically been the norm, is too blunt an instrument for major users while fine-grained data (30-minute intervals or less) brings attendant problems of data overload and difficulties in interpretation and analysis. EN16001 also calls for ‘energy factors’ to be recorded as well. By this it means weather data, usually in the form of degree-day figures (also discussed later), production statistics, and the like -- what in normal energy management terminology would have been called ‘driving factors’. When we come to discuss understanding patterns of energy consumption the value of this data will become clear but suffice it to say, for now, that both consumption and driving-factor information need to be synchronised and collected at intervals to match your required interval of assessment and reporting.

Energy metering technologies

Many readers will be happy to make do with existing metering, but some may need to install additional meters in order to separate out significant energy uses, or to measure flows of product. To get the best accuracy it is important to choose an appropriate measurement technology, but cost is always an issue. Fortunately, EN16001 does not lay down accuracy standards. Section 3.5.1 merely stipulates that accuracy and repeatability should be ‘appropriate’ and for routine energy management the requirement is actually quite relaxed, since you will mainly be interested in changes and trends.

Electricity meters

Modern electricity meters are solid-state electronic devices which are either directly connected in the supply cabling or (usually) where the measured current exceeds 100 amps indirectly through current transformers (CTs). A CT typically consists of a ring of magnetic material through which the power cable passes, the load current inducing a voltage in a secondary winding. It is this voltage which is sensed by the meter. The advantage of indirect connection is that the meter can be mounted in a convenient location remote from the power cable, where it may be easier to read; and multiple meters can be marshalled together.

For the sake of accuracy, CTs should be matched to the current they will be measuring. On a three-phase supply one CT per phase is needed and care must be taken that all are properly connected: having one disconnected will reduce the measurement by one-third, while one connect the wrong way around will reduce the measurement by two-thirds. Such faults may go undetected for years, giving incorrect results and ultimately causing embarrassment. More advanced meters nowadays include on-board diagnostics which aid
correct commissioning and prevent these problems; they can also report power quality, harmonics, power factor and other parameters.

Where it is not possible to disconnect the power cable to thread it through the CT, split-core types can be used which clip over the cable. There are even flexible types where space is limited.

Flow meters

There are numerous technologies available for measuring gas, steam, compressed air, oil and other fluids but even knowing what liquid or gas is being measured, other questions will have a bearing on the choice of metering technique:

- What is the expected temperature range?
- What is the maximum expected pressure?
- What maximum and minimum flow rates need to be accommodated?
- What is the maximum acceptable pressure drop?
- In some cases, how much straight pipe is there upstream and downstream?
- In some cases, is electrical power available?
- If measuring a liquid, what is its viscosity? Is the viscosity likely to vary significantly?
- What is the state of the measured liquid (dust, dirt, bubbles, etc.)?

This is definitely a case where advice from a consultant (or metering supplier with a wide product range) will be invaluable. But for now here is some very general guidance for the more common applications.

Firstly for gas supplies, turbine meters would be the usual choice for large meters (pipe sizes of 200mm and over). Otherwise rotary positive displacement or bellows types would normally be used. The latter are limited to low-pressure applications.

For oil, a positive-displacement type of meter would be the typical choice.

For compressed air submeters, turbine meters are unsuitable because they are easily damaged by sudden pressure fluctuations, and entrained dust or water droplets. Orifice plates are a robust solution where the flow rate is constant; otherwise either thermal-mass or vortex meters should be employed. Both of the latter impose relatively low pressure drop, making them attractive for retrofit applications. Pressure and temperature correction is likely to be needed.

For steam the best candidates are likely to be vortex meters and variable-area orifice meters such as the Spirax Gilflo, unless the flow rate is unlikely to vary, in which case a
fixed orifice might be an option. Pressure and temperature correction are definitely required in all cases.

For water and other clean liquids, positive-displacement and multi-jet meters are acceptable. Vortex and orifice meters are more tolerant of suspended contaminants but the latter are only accurate over a narrow range of flow rates. Electromagnetic meters may also be considered, as long as the fluid is conductive.

Data collection

You may collect the data automatically, manually, or both, but where manual readings are involved it is worth paying attention to the following points of policy, preparation and practice:

Policy

• Decide at what interval to read the meters – monthly or weekly, for example – and set a target reading time such as, say, the first working day of the month, or 7 a.m. each Monday morning.

• Make someone responsible for taking the readings and nominate a deputy to cover for absences.

• State how much leeway is allowed on meter-reading date and time.

• Make arrangements to collect driving factor information such as production, degree day figures, etc, at the same intervals as meter readings.

Preparation

• Create a checklist of meters to be read.

• In the case of multi-rate meters (those with day/night or normal/low registers), say which registers are to be read and recorded. Some electricity meters (such as 'Code 5' meters in the UK) may record consumption in several distinct time bands.

• Record the meters' attributes: what commodity they measure, their location, units of measurement (including any multiplier factor such as x10), number of readout digits, serial number and other salient facts.

• Consider fixing a durable label or tag near the meter to identify what it is measuring. Don't fix it to the meter itself in case it is later swapped out.

• If appropriate, prepare forms on which meter readings can be recorded. Include provision for time as well as date if readings are more frequent than once a month. It is useful to show the meter serial number if known and also any special access requirements (e.g. who holds the keys, swipe card or access codes)
• Take an initial set of readings for the record. This will help resolve ambiguous or suspect readings later.

• Brief the nominated meter readers and provide training, especially relating to meters with which they are not familiar.

• If possible, disable any 'reset-to-zero' buttons.

• Check the security of power supplies to meters and ancillaries (where relevant). If interruptions are a risk it may be necessary either to secure the supply, or read the meter more frequently.

• In the case of natural gas supplies, identify where on the bills the calorific value and the correction factor for temperature and pressure are shown. These will be needed to convert the volumetric gas measurement to energy terms.

**Practice**

When you, your staff or contractors read your meters they should:

• Do so as close as possible to the target day and time.

• Check each serial number or other unique identifier against that expected.

• Always record the date and time on which each meter reading is actually taken (the actual date and time as distinct from when it was supposed to be taken).

• Record the reading exactly as it appears on the meter. Show all the digits, including the decimal fraction if there is one (decimal fraction digits may be indicated by a contrasting colour scheme) and any fixed zero printed on the face of the meter. In Figure xx the gas meter reading should be written down as 10558840.

• Gas-meter readings are usually volumetric and must be corrected for temperature and pressure variations (unless the meter has a built-in corrector) and for calorific value.

• Remember that the register displayed on most half-hourly electricity meters is not the total units consumed, but rather the cumulative units for the rate band active at the time of reading. Use the button provided to step through the available readout registers to obtain the totals you want.

• On remote readouts with reset buttons, do not reset to zero after reading the meter.

• When meters are exchanged, take readings from both; note the date, and register the attributes of the new meter on the central record.

• For unmetered commodities held in bulk on site, record their stock levels at the same time as the readings are taken on meters, and the quantities of all deliveries received since the last stock-level entry.
For sites with numerous meters it may be cost effective to invest in a handheld electronic meter reading device to replace paper forms. This can be programmed to organise walk orders and check that reads are sensible as they are entered, reducing the risk of misreads and subsequent revisits or estimates. They can also save time by replacing manual data entry with digital data import.

Any device with an internet connection and a web browser can also be used as a meter data entry terminal by using the MeterPad web service. This provides a private, password-protected central database for the storage and retrieval of meter readings. Although it requires a little effort to set up, it then provides a highly organised framework within which meter readers can, for example, preview earlier readings or leave comments for other users sharing their data; it also creates an inventory of meters and their attributes.

**Automatic meter reading**

An automatic meter reading (AMR) system will fulfil two distinct requirements: facilitating remote readings, and providing fine-grained consumption histories. AMR is thus beneficial in the following circumstances:

- A dispersed estate of multiple sites
- Unattended outposts
- Areas with access restrictions (tenants' areas, hazardous areas)
- Where numerous readings need to be synchronised, even if only on a weekly or monthly basis
- Where information is required with minimum delay
- Where you want to monitor consumption within restricted time-bands, for example to enable time-of-day billing of tenants' supplies.

Some users will already have data collection capability in place, either through a building energy management system (BEMS) or, in an industrial context, a supervisory control and data acquisition (SCADA) system. Others will need to install some or all of the infrastructure from scratch and in some cases, new compatible metering may be required.

AMR technology is too complex and diverse to deal with here. The technical issues and options are outlined in an article at http://vesma.com/tutorial/art-amr.htm. Do not be paralysed by the seemingly overwhelming choice of communication options, and do not be tempted into thinking there is a 'one size fits all' solution. Most reputable providers of data collection systems will use a variety of techniques suited to the circumstances of individual meters.
Also, be skeptical of end-to-end solutions from single vendors. Companies that excel at data collection often lack the knowhow to analyse and present data effectively, a topic which is addressed in a later chapter. Split the project into two aspects:

- Metering, data collection and communications; and
- Analysis and reporting functions

The interface between the two is a database and that also is the place where diverse inputs such as manual meter readings and driving-factor data are merged with AMR data. This philosophy, furthermore, gives you the flexibility to have multiple AMR vendors if that is convenient.
1-2 Understanding patterns of use

A word of warning: this chapter contains some algebra, but don’t worry if it doesn’t go in first time. All I want you to appreciate is that there is often a way to calculate expected energy consumption from other independently-measured management data.

The point is that the overworked dictum ‘you cannot manage what you do not measure’ does not quite tell the whole story. It is all very well to measure and record precisely how much energy you have used: the big question is whether it was the appropriate amount.

That is a question we can’t answer unless we understand, and can explain, patterns of consumption in relation to prevailing circumstances by which I mean the weather, level of production activity or other external driving factor. Traditionally, consumption that varies because of such external factors has been treated as hard to manage, and the best treatment that many people achieve is to ‘adjust’ their consumption data to take account of what are seen as external disturbances that are somehow distorting the results. I suggest that this is wrong-headed.

Let us think about two simple scenarios: the heating system in a building, and factory which uses energy to process a homogeneous product. Start with the factory first. It should be evident that the more product they make, the more energy they will require, and it is quite plausible that each unit quantity of product requires a certain amount of energy so that there is a simple proportionality between the two. We could say that the production energy requirement $E$ is linked to production output $P$ by the formula

$$ E = mP $$

where $m$ is a constant specific to the process in question. However, in real life things are not so simple. Usually, there is some constant background demand for energy in addition to what goes directly into the product. This might be heat losses in the case of gas, or other uses like lighting and extract ventilation in the case of electricity. Whether the constant background energy requirement is associated with the process equipment or just other continuous uses sharing the same meter, we can allow for it in the formula by adding an extra term:

$$ E = c + mP $$

where $c$ represents the fixed demand in a given interval of time (one week, say). Readers may recognize this formula as the equation of a straight line and one of the things we can try, when developing a model of how energy consumption relates to a driving factor like production throughput, is to plot our data on a scatter diagram of weekly energy against weekly production to see if such a straight-line relationship seems to apply. This has been done in Figure 1-2-1.
In a case like this, where we do indeed see a relationship, we can superimpose a best-fit line and this gives us numbers for \( c \) (the intercept on the vertical axis) and \( m \), the gradient of the line, in energy units per unit of output. This straight-line ‘performance characteristic’ enables us to estimate what the energy demand ought to have been, given what the output was. In Figure 1-2-2 we see this illustrated. We draw a vertical line at the prevailing production output and where this crosses the performance characteristic we can read off the expected consumption. This will later come in useful because it gives us a yardstick against which to assess what we have actually used. We can detect exceptions (chapter 1-3) and evaluate savings relative to where we would otherwise have been (chapter 3-5).
Could we have done the same thing for the building heating system? As it turns out, the answer is yes. Figure 1-2-3 shows the weekly gas demand in a building: it is higher in winter weeks than at other times. Figure 1-2-4 meanwhile shows something called the ‘degree-day’ value. This is a number, calculated each week from the recorded outside air temperature, representing how cold each week was. The exact methods need not concern us: the important thing is that the annual profile of degree-day values resembles the profile of gas consumption:

**Figure 1-2-3**  
Weekly gas consumption

![Weekly gas consumption graph](image1)

**Figure 1-2-4**  
Corresponding weekly weather expressed as degree-day values

![Degree-day values graph](image2)

If we plot weekly gas consumption against the weekly degree-day values on a scatter diagram, as in Figure 1-2-5, we see the familiar straight-line relationship. If the weather measured in degree days for any given week is assigned the symbol \( W \), we can write the formula:

\[ E = c + mW \]

to describe the relationship. This is exactly analogous to the production example and if we know how cold the weather was (in degree days) for a particular week, we can now estimate the expected energy consumption.
Figure 1.2.5

Expected weekly gas consumption for space heating can be predicted from degree-day values

Simple straight-line relationships of this sort will be found to apply in many circumstances but naturally there will be cases which are more complex. One of the common complications is where several products with different energy intensities are made on a shared facility. Here it is necessary to measure or estimate what each product’s energy intensity is, and build a slightly more elaborate equation. For example a commercial bakery might produce loaves of bread, pancakes and rolls. If bread loaves are found to need $m_1$ kWh per tonne, croissants $m_2$ kWh per tonne, and rolls $m_3$ kWh per tonne, expected energy consumption in a given week can be deduced from the formula

$$E = c + m_1.B + m_2.P + m_3.R$$

Where $B$, $P$, and $R$ represent the known tonnages that week of bread loaves, pancakes and rolls respectively. We can elaborate further and allow for the weather: if the heating is on the same meter and its requirement is found to be $m_4$ kWh per degree day, the formula would be extended thus

$$E = c + m_1.B + m_2.P + m_3.R + m_4.W$$

In fact there is no limit to how many factors one might wish to take into account, nor how complex the formula might turn out to be, although obviously one prefers to keep things as simple as possible. But however simple or elaborate the formula, the underlying point is this: having measured the relevant driving factors, we can use the formula to calculate expected consumption. In other words, we can explain consumption and thereby detect deviations from expected values. EN 16001 (para 3.5.1) places an obligation on the compliant organisation to do exactly that.

16
1-3 Detecting and prioritising exceptions

It is good practice (and an explicit requirement of EN16001) to keep a register of opportunities for saving energy. Opportunities will originate from energy surveys, from suggestions made by staff or contractors, and from the detection of what EN 16001 calls 'accidental excess consumption' caused by minor faults, human error, and so on: what we would call 'exceptions'.

Figure 1-3-1

This intermittent mechanism started running continuously when a limit switch in its control circuit came loose

Figure 1-3-2

Control valve on a heating system jammed open with a lump of wood

Figure 1-3-3

Failed non-return valve on a nitrogen compressor cost hundreds of pounds a year in extra electricity for the compressor

The energy manager in a large organisation could have hundreds or even thousands of metered streams of consumption to deal with and the traditional method of detecting exceptions was to assess the monthly consumption through each against some yardstick
(maybe the consumption in the same month the year before) and set a percentage variation limit on the deviation, which triggers an alarm. The results are very often reported simply by flagging the supposed exceptions on general summary tabulations, or at best by extracting a list of those streams which are supposedly out of limits. Leaving aside the use of a monthly assessment interval (which I would regard as too long) this methodology, which has unfortunately become the basis of some energy-management software products, is crude, unreliable and inefficient.

A much better approach can be found in better commercial M&T packages and can readily be implemented in a home-grown spreadsheet-based energy monitoring scheme. It simply requires that you have, in each practicable case, a formula for calculating expected consumption from the known values of the driving factors (‘energy factors’ in EN 16001) as outlined in the previous chapter. Given the driving-factor data for the week in question your software can thus assess the deviation (in energy-unit terms) from expected consumption and it is the size, and more specifically the cost, of this deviation which determines its importance. Percentage is secondary: a big percentage deviation on a minor consumption stream could be less significant than a moderate deviation on a large one. A small absolute deviation on an expensive commodity may be more important than a bigger deviation in something cheaper.

Once we have a cash value for the deviation for every targeted stream for the week we are reporting, we need to find an efficient way to present the information to the user and the best method -- which will seem obvious when I say it -- is simply to rank the report in descending order of the costs of deviations. Such a report is called an Overspend League Table and it has the following attributes and advantages:

• The most important deviations are always at the top of page 1;

• It will immediately clear which, if any, consumption streams are worth pursuing. If the biggest deviation is not costing too much, you can get on with other work and not waste time;

• No specialist energy knowledge or computer skills are needed;

• Other consumables like water, chemicals, and so on, can be integrated into the same management report;

• There is no limit to the number of streams reported (because of the way the important cases float to the top).

There is one final refinement that I would suggest, and that is to have within your M&T scheme a way of recording typical variability for each monitored stream; in other words, the limits of normal deviation in unit terms. Some streams will exhibit more variability than others because in some cases the formula for calculating expected consumption will work well with only a small error under normal conditions, while in others the uncertainty will be much greater. Suppose for example you had two electricity-consumption streams, one which normally varied by plus or minus 500 kWh in the week and the other plus or minus 7,000 kWh. If both experience excess consumption
of 2,500 kWh the apparent cash loss would be the same in both cases, but only the first would be treated as a significant deviation. We want to avoid both spurious alerts and the possibility of missing things, so we must tune our assessments of individual streams’ behaviour and filter the results accordingly.

Figure 1-3-5 is an overspend league table implemented in Excel and including traffic-light symbols to indicate significance. Amber shows a deviation within normal bounds, red indicates unusually high excess consumption, and green would indicate consumption significantly below expectations. Where data-gathering has been taken care of, it takes only a few moments a week to generate this report. It does not need to be published or circulated: its purpose is to support a decision about what (if anything) needs pursuing. It is all about enabling the energy manager to ask the right question of the right person at the right time.

Figure 1-3-5

<table>
<thead>
<tr>
<th>Stream</th>
<th>Apparent overspend</th>
<th>Actual units</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>North factory - treatment plant electricity</td>
<td>£396, 1977, 597</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 1 - milling and grinding electricity</td>
<td>£279, 22776, 5614</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 3 - air compressor electricity</td>
<td>£216, 63888, 2038</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery - cooling tower makeup water</td>
<td>£174, 55, 136</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 3 - refrigeration</td>
<td>£109, 28, 1100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>North factory - EK/IRIS</td>
<td>£140, 50, 7954</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary processing - office - elec</td>
<td>£70, 1080, 4108</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary processing - HVAC - elec</td>
<td>£60, 8900, 6200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 1 - effluent</td>
<td>£44, 2984, 3026</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 1 - lighting elec</td>
<td>£33, 28180, 2574</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 3 - cooling tower electricity</td>
<td>-50, 50495, 45143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 1 - diamonds electricity</td>
<td>£11, 7601, 7301</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Refinery - fuel oil - steam - water</td>
<td>£81, 478, 273</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 1 - main inlet water</td>
<td>£62, 10723, 1103</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 1 - chillers electricity</td>
<td>£74, 38945, 3032</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 1 - air compressor electricity</td>
<td>£72, 44834, 4921</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 1 - blowers - gas</td>
<td>£626, 15680, 2590</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Building 1 - LV feeders</td>
<td>£756, 5057, 2700</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It is good practice to keep a record of any significant excess consumptions that you detect, and to track them through to resolution. In fact EN 16001 makes this a requirement. A word of caution, however: check the data before doing so, and not just the consumption data. Remember that an error in degree-day figures, production, or other driving factor could equally be to blame for spurious reports.
1-4 Raising awareness and motivation

Although energy efficiency is a technical topic, the solutions are not all technological. Human factors -- attitudes, knowledge, awareness and skills -- will be a significant energy aspect for most organisations because while it is true that people cause some energy waste they also hold three keys to improvement:

1. changing their own behaviour;
2. being vigilant for waste;
3. suggesting improved working methods or technical innovations.

But improvements will not happen spontaneously. People need help and guidance. We need to think about their levels of energy awareness; about their attitudes; about what motivates them; and about what knowledge (or even practical skills) they might need.

Figure 1-4-1

Energy awareness materials for the BBC, designed for NIFES by Purple Circle

What motivates people? A good way to start finding out is by asking them. The very act of pounding the beat, chatting with folk informally about their views on energy and the environment, will itself start to raise the profile of the subject. Some will mention problems you did not realise existed: obstacles that perhaps can readily be corrected ("I never turn any of these lights off because I don't know which switch controls which area"). Others will volunteer ideas which up until that moment they have kept to themselves. If you let the conversation roam, you will find clues about things which might act as motivators ("I wish they'd plant some trees around the car park"). Of course you will get moans and grumbles as well: "It's always freezing in here on Monday mornings". This is important. You need to be in a position to do something about genuine minor grievances like this. The complaints you hear will have been made many times before and -- as far as the complainer can see -- ignored. If the problem is one which can be solved, it will be important for you to resolve it, because otherwise it will be a
demotivator. But sometimes the problem itself is not what de-motivates: *it is the fact of the complaint being ignored*. If you follow up an issue and then go back to explain why it can't be resolved, that in itself may be such an improvement on earlier responses that your dissatisfied occupant becomes an ally.

For medium to large organisations, a questionnaire can then be designed using some of the clues that face-to-face interviews reveal. NIFES Consulting has done a lot of these, both paper-based and on-line, and uses a scoring technique that allows the workforce's profile to be plotted on a grid of motivation against awareness. The aim is to move people towards the high-motivation, high-awareness zone and out of the others. It is not always a question of people scoring low in both dimensions: those who are aware but unmotivated need different treatment from those who are highly motivated but lack awareness of what to do. Some people in that category present a perverse risk that they may take initiatives which, being ill-informed, are counter-productive. Over the years a pattern has emerged from these studies which is that people are motivated most by having a top person from the organisation visit their department on a walk-about energy survey. The things they value least are electronic communications.

The Web needs to be used with caution. My colleagues at NIFES have tried it for on-line questionnaires and found that exclusive reliance on web surveys can skew the response by excluding those workers (such as domestics and catering staff in hospitals, or machine operators in factories) who do not have access to the internet or intranet, and who paradoxically may be among the most important people to target. So they now provide paper questionnaires as a complementary input channel.

Fostering positive attitudes is not easy, but my experience has generally been that unless morale is rock-bottom, people will usually engage in a helpful way with something as worthy as environmental improvement. Motivation comes in many forms, of which money is perhaps the least effective and the most risky. People value learning about energy saving in the home, for instance, as a by-product of being trained about energy in the workplace. Reduced energy use, when it is achieved by avoiding operating equipment needlessly, also means reduced wear and tear, fewer breakdowns, and even in some cases reduced noise nuisance.

Awareness-raising will be the least of your problems because everything you do (including asking people about their attitudes) will automatically improve it. Just bear in mind that there are at least two categories of awareness that you will want to test. One is awareness of how and where the organisation uses energy; the other is awareness of what individuals can and should be doing to minimise consumption. Historically, we have also tested awareness of climate change and its causes, but this is much less important because people today are either aware of the issue through media exposure, or want to argue the toss, which does not help us.

Providing training (even very brief sessions) can help enormously not just by helping people to work in an energy-conscious way, but also by creating a break from normal routine and even providing a bit of fun. For some key workers, that essential bit of skills training may contribute directly to energy saving. In 1986 when I was working for Gloucestershire County Council, we spent just under £12,000 on off-the-job energy...
training days for school caretakers. Not only did we raise their awareness; we found we had (quite accidentally) improved their attitudes and motivation by providing them with the first training most had ever had. They enjoyed meeting each other, and several went on to make valuable energy-saving suggestions. One moved to a large college where he single-handedly saved two-thirds of the cost of the programme. Three years later (and after I had left) the County was still attributing those training courses with energy savings worth over £80,000 a year. They had recouped their investment 20 times over; now that's what I call a payback.

The benefits of improved awareness fade with time, so how often should you refresh an awareness campaign? Twice a year? Every three years? The answer is to use your energy monitoring and targeting scheme to detect loss of momentum. You will also find that it produces charts that can be used to provide feedback to staff.
2-1 Building fabric

The significance of building fabric to the energy manager lies in the opportunities that could present themselves to reduce heat loss from buildings in cold weather. By ‘heat loss’ I mean the flow of thermal energy, not a decline in temperature. With the internal temperature held constant above outside-air temperature, heat continually flows out (a) by thermal conduction through the walls, roof, floors, doors, and window glass and (b) in the warm air displaced by colder outside air, which is introduced either deliberately for ventilation or incidentally through gaps in the fabric.

All the heat that flows out through conduction and air-displacement has to be balanced by heat input from the heating system (assisted by incidental gains from lighting, equipment and people within the space). Insulating to reduce conduction losses, and draught-sealing to reduce air displacement, both have a direct beneficial impact on the amount of fuel that needs to be purchased (similar arguments apply to the need for cooling. Insulation, especially of roofs, can help to reduce heat inflows in hot weather, reducing discomfort and the need for air conditioning).

Thermal comfort is an important issue and insulation has an interesting effect. Only about half of our perception of comfort indoors is attributable to the temperature of the air in the room; half is attributable to the temperatures of the walls and ceiling surrounding us. This is because some of our body heat escapes by radiation to these cold surfaces. Poorly-insulated walls and ceilings have significantly lower surface temperatures than those with even a small insulating layer, whose thermal resistance causes the internal surface temperature to rise towards the air temperature. By reducing the discomfort attributable to cold surrounding surfaces, insulation enables us to maintain the same level of comfort with a lower air temperature than was previously needed. This further reduces the heat loss, including the heat loss through air displacement.

Opportunities to build new premises will not often arise, and when they do, regulations will dictate the thermal performance of what you build; the big issue as far as this book is concerned is what one can do through discretionary improvements to existing buildings. Improving air-tightness is generally the easier route. Partly it is about applying suitable draught-sealing products to openable elements like doors and window, or repairing them so that they fit properly, or both. But it could also entail plugging up holes in the fabric such as the gaps that will often be found where door and window frames are set into the walls, or at the junctions between walls and roofs, or around penetrations for piped services and cabling. Very often, straightforward measures will suffice like caulking with mastic, filling with expanding foam, replacing loose mortar, or repairing damaged cladding or blockwork.

A leaky building could easily be losing the majority of its heat through air displacement, so the improvement may be significant. As is often the case, there will be incidental benefits as well; discomfort from cold draughts, noise transmission from outside, and dust ingress could all be reduced.

Thermal insulation tends to be more problematic. It is generally likely to be less cost-effective and (with the possible exceptions of cavity filling, loft insulation and external roof treatments) is usually disruptive. However, it should not be overlooked.
When a print works in Gloucester expanded into the neighbouring industrial unit, they took the opportunity to insulate the space before occupying it, and they have found it works without a heating system.

The effectiveness of insulation is gauged by the ‘U-value’ of the wall or other element of the building envelope in which it is fitted. The U-value is the heat flow in watts through a square metre of the surface, per degree Kelvin of temperature difference. Halving the U-value halves the heat flow at a given temperature difference. The following table provides a few examples:

<table>
<thead>
<tr>
<th>Construction</th>
<th>U (W/m²K) approx.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-glazed window</td>
<td>5.5</td>
</tr>
<tr>
<td>Double-glazed window</td>
<td>3.0</td>
</tr>
<tr>
<td>Brick cavity wall (50mm cavity)</td>
<td>1.4</td>
</tr>
<tr>
<td>Ditto filled with mineral fibre</td>
<td>0.6</td>
</tr>
<tr>
<td>Uninsulated ceiling under pitched roof</td>
<td>3.0</td>
</tr>
<tr>
<td>Ditto with 50mm mineral fibre</td>
<td>0.7</td>
</tr>
<tr>
<td>Ditto with 150mm mineral fibre</td>
<td>0.3</td>
</tr>
</tbody>
</table>

There is a huge range of techniques and materials for insulating walls, roofs and floors, and every situation is different. Fortunately, there are a number of very good specialist installation contractors who can be found in the UK through trade associations such as Eurisol and the Association for the Conservation of Energy. Choose one that offers a big range of products and techniques, and can provide comprehensive and objective advisory literature.

*Figure 2-1*  
*Thermal imaging to locate defective insulation*
**Figure 2-1-2**

*Laying insulating panels over a flat roof*

**Figure 2-1-3**

‘Punkah’ fan prevents hot air pooling under the ceiling and increasing heat transmission through the roof

If you would like to know more about the theory and how to estimate savings, or find further contacts, visit www.vesma.com/tutorial/fabric.htm
2-2 Heating and ventilation

Space-heating systems come in many forms. At the lower end sit the individual gas radiant-tube, electric infra-red, or gas or oil-fired cabinet air heaters often found in smaller industrial premises. At the upper end there are multi-boiler systems with ducted air supply, generally with air-handling units supplied with hot water in a circulation system. In between are central systems with radiators, natural convectors or fan-convectors. Central boiler plant may use gas, oil, coal (rarely) or (increasingly) biomass. Electric heating is still encountered, either off-peak storage heaters or on-peak portable heaters. Heat pumps could also be added to the list but to make this chapter manageable I will focus on central-boiler systems and point out in passing anything that is relevant to other technologies.

Control is a critical issue when looking for efficiency improvements. The aspects to be considered include:

1. time;
2. temperatures;
3. zoning;
4. frost prevention;
5. boiler sequencing; and
6. in ducted-air systems, the ventilation make-up and recirculation rate

The first thing to check is that time control is flexible enough to match heat supply to patterns of occupation. In most places that means the ability to set different occupied periods depending on the day of the week, to provide for occasional out-of-hours use, and to schedule public holidays and the like. Today, wireless digital programmable thermostats that can achieve this are cheap enough for domestic use, meaning that there is no excuse for soldiering on with fixed 24-hour timeswitches. With a computerised building energy management system, it may just be a question of starting to use its features properly.

A further opportunity, particularly applicable to buildings with poor thermal characteristics, is ‘optimum-start’ control. Whereas you would set a conventional heating timer to start the boilers at some fixed time in the early hours of the morning to preheat the building, an optimiser is smarter. You tell it what time the building should be ready, and the device itself decides, day by day, how late it can start the heating. It will moreover train itself by monitoring how the building responds and in this way ensure that the building is never maintained at occupied temperature longer than necessary. Optimum start is a feature of building energy management systems and of stand-alone heating controllers alike. It can be applied to almost any kind of heating.

The other significant feature to look for in an effective time-control regime is the ability
to set extra time occasionally (for evening lettings, overtime working at weekends, and so on) without the risk of permanently altering the schedule.

Regarding temperature control, there are numerous methods. Thermostatic radiator valves (TRV) are a common choice and can if required be fitted with remote sensing heads. This gives some advantage over the integral sensor, which can be affected by the heat emitted from nearby pipework. TRVs can be retrofitted to existing radiator systems and can be locked to limit their range of control; some are even available with their own wireless digital temperature and time programmer.

Radiator systems can also use a control technique called compensation, in which the circulating water temperature varies according to the weather. The colder it is outside, the hotter the radiators run; in mild conditions they run cooler. This strategy, which dates from the era before TRVs, matches heat output to expected demand. It has the great advantage that if the occupants open the windows, their rooms get cold and the heating does not respond. With TRVs or other local thermostatic control on a system running at fixed circulation temperature, the heaters would respond by delivering more heat, which is obviously wasteful and does nothing to encourage people to close the windows again. Compensation can be used in combination with TRVs and is particularly beneficial where there are significant runs of uninsulated pipework, since these will no longer wastefully overheat the spaces they pass through.

**Figure 2-2-1**

*Extensive bare pipework on a radiator system calls for compensated-temperature control*

Compensation is not compatible with fan-assisted convector heaters. The water circuits feeding these must always be run at constant temperature or the air flow from them will be perceived as cold (a manifestation of the wind-chill effect). Temperature control for such heaters is often achieved by a thermostat turning the fan on and off. This may, however, leave unwanted heat output due to natural convection, particularly where there is significant vertical distance between the inlet and outlet grilles of the heater cabinet. Where this is a problem, it may be feasible to fit a motorised valve to stop the water flow through the heater coil when there is no heat demand.

In buildings with central ducted air supply, the inlet air may be partially preheated and then delivered to the space through a ‘terminal reheat’ unit which operates under local thermostatic control. With this arrangement, as with fan-convectors, greater economy may be achieved by attention to the positioning of the temperature sensor or thermostat and, in the case of thermostats, the use of electronic types with a narrow switching differential. The older electromechanical thermostat may switch on and off over a band of two degrees, allowing temperature swings which cause waste since they result in a higher-than-necessary average temperature being maintained in order to satisfy
the required minimum. In areas such as stores and loading bays where it is impossible to prevent high air-exchange rates, direct-fired radiant heaters will often be found. They have the advantage of keeping people feeling warm in a lower air temperature but they demand a special kind of thermostat or sensor called a ‘black bulb’, which is designed to respond to the prevailing radiant temperature and not the air temperature in the usual sense.

Figure 2-2-2

Radiant heating is appropriate in very draughty buildings

Frost protection is a critical weak point in most temperature-control systems. It is a prevalent cause of energy waste including, in my personal experience, electrically-heated front steps and vehicle access ramps. These are oddities of course: most frost protection is designed to protect heated spaces. One facilities manager discovered that 40% of his headquarters’ electricity costs were attributable to frost-protection preheaters running continuously on its ventilation air-handling units. But even in the absence of faults there may be scope for improvement. For example, triggering the frost protection on low internal (rather than outside) temperature is more rational and less likely to result in needless heating, so a review of control strategies may be profitable.

Figure 1-3-1

These electrically-heated steps were found to be running continuously

Moving on from temperature control, it may be beneficial to be able to heat some parts of a building but not others at certain times. This is very easy if you have independent direct-fired space heaters, and subject to pipework layouts and pumping arrangements, it may also be feasible to introduce it in a central-boiler system, either by means of motorised valves or by fitting zone pumps. It is highly unlikely to be feasible as a retrofit measure in a ducted-air system.

Next we come to boiler sequencing. This means ensuring that only the minimum number of boilers is allowed to run commensurate with the demand for heat, while any surplus capacity is isolated thermally to prevent heat loss. An idle boiler in circuit in parallel with a working one will receive half the system’s water flow, and will dump heat from that
water up the chimney. Heat will be wasted but—just as importantly—the combined flow from the two boilers will be a 50/50 blend of heated water from one and slightly cooled water from the other. This could actually prevent the connected heating and hot-water system from working as it should. An effective sequencing control will enable full output during the morning preheat period (to make it as short as possible) but will then trim back the available capacity to match what is necessary for maintaining steady conditions through the day. It is like accelerating your car away from traffic lights and then easing back on the throttle to cruise at a steady speed, with more or less throttle depending on the gradient.

The difference can be significant. In one instance I visited two office buildings belonging to the same organisation when it was about 12°C outside to find one using virtually no gas while its more modern sister building’s boiler were running at 20% of rated maximum output. The difference was that the second building had ineffective sequence control and all its boilers were taking turns to feed each other’s standing losses. Effective sequence control demands two things:

1. an appropriate control strategy applied to suitable sensor measurements; and
2. effective means of physically isolating idle boilers. This may be valves or dampers.

One or both of these factors may be absent, in which case there will be an opportunity to reduce energy waste.

Finally we need to think about controlling the ventilation rate, which is most easily done when the building has ducted air supply. Simple time control can make a significant difference, remembering that even during the pre-occupation morning boost period the ventilation can be minimised. Not only does this directly reduce heat loss: it reduces the warm-up time which itself yields a small gain in efficiency. In some buildings with ducted air supply, there is provision for recirculating a proportion of the extract air. You need to check that the control strategy is maximising the recirculation rate because that minimises the amount of cold outside air that needs to be drawn in and heated.

The recommended method for monitoring the health of a heating system is to assess the building’s weekly fuel consumption against heating degree days, either calculated from local outside air temperatures or obtained on subscription from a nearby observing station. For substantial installations it may be worthwhile installing a heat meter, assessing fuel used against heat generated and heat generated against degree days. This will enable you to discriminate between faults within the boilerhouse and waste in the delivery of heat.
2-3 Combustion equipment

In all combustion equipment, there are inevitable energy losses. Not all the energy in the fuel can be effectively used. The losses can however be minimized by appropriate maintenance, and this represents a small but very cost-effective contribution to the enterprise’s energy saving programme.

The principles can be illustrated by reference to a piece of energy conversion equipment that almost every reader will have responsibility for – a heating boiler. Most of the heat released from the fuel is absorbed by the water in the boiler, but some escapes in the exhaust gases. Some heat is also lost from the casing of the boiler. Figure 2-3-1 shows the energy balance: energy arrives in the fuel at F units per hour; heat is lost up the stack at S units per hour; and heat is lost from the casing at C units per hour. The difference, F-S-C, leaves the system as useful energy, U units per hour (strictly speaking this is the net useful heat: what leaves in the circulating water flow minus what comes back in the return).

Figure 2-3-1

Energy balance for a heating boiler

The stack loss S is a certain percentage of the fuel input F, and the ratio (F-S)/F is called the ‘combustion efficiency’. S can never be zero because the exhaust gases have to be maintained above a certain temperature to ensure that the chimney works effectively and to prevent corrosive condensation (condensing boilers are an exception – see below). How high or low the actual efficiency is depends on various factors that affect S, including how well the burner is tuned. Excessively-high exhaust temperature will increase losses because of the exhaust gases carrying more energy away. Excessive exhaust-gas volumes will also waste energy (even if the temperature is OK) and this will occur if the fuel:air ratio is too “lean” – that is to say, if more air is fed in than is necessary for complete combustion. Conversely if too little air is supplied for complete combustion, some unburned fuel will escape up the chimney (as smoke, soot or carbon monoxide depending on the fuel). Damaged burners can cause incomplete combustion even with considerable excess air.

Different burners can achieve different efficiencies, but a figure of about 80% - 85% would be typical in a heating boiler. The burner in a condensing boiler can achieve close to 100% because the exhaust gas is discharged at low temperature and latent heat is recovered from the water vapour, in the exhaust. By contrast, a burner on a high-temperature furnace would usually be much less efficient because of the high temperature at which heat is exhausted up the chimney.

Correct adjustment of air:fuel ratio, combined with measures to minimise the exhaust temperature (like keeping the boiler internals clean, Figure 2-3-2) will between them ensure that the maximum useful heat is extracted from the fuel. This could yield a saving
of several percent on boiler fuel, depending on how bad the situation is to start with - perhaps of the order of 20-30% in the worst cases. Moreover, these savings could be achieved at little or no cost since combustion testing and adjustment of burners ought to be part of good routine maintenance. Every boiler maintenance visit should include a combustion test, which can be done by sampling the exhaust gases (figure 3) and its results should be reported.

*Figure 2-3-2*

*Combustion analysis equipment in use*

Combustion efficiency can be tested by taking the following measurements:

- Stack temperature
- Ambient temperature
- Percent of either oxygen or carbon dioxide in the exhaust gas
- Carbon monoxide level (for gas) or smoke number (for oil)

It is always worthwhile comparing each successive result with earlier tests. Set the best achieved efficiency as the target, and query any result which is less than the previous best. You may be able to compare similar installations (bearing in mind that particular features, such as chimney height, may affect achievable efficiency).

If you don't do the tests yourself, you should check that the reported percentage combustion efficiency is consistent with the recorded 'raw' measurements. A spreadsheet is available that can help you do this (http://vesma.com/tutorial/combust05.xls). It is based on something I did when I was energy manager for a large organisation, and had checked through a batch of test reports from our boiler maintenance contractor to find about half of them somewhat suspect. I went out and did some spot checks with my own equipment, and stumbled over evidence of falsification: in some cases, previous test results were chalked up on the boiler, obviously with the intention of saving the technician the bother or doing a real test next time around. But the most surprising evidence of cheating was that flue-gas tests has been reported on some installations where there wasn't a probe hole in the boiler flue.

In summary: poor maintenance of burner equipment will cause avoidable losses.
Minimising costs is just a question of getting the maintenance right: and that will only happen if you monitor performance and insist that things are done as they should be.

Figure 2.3.3

Boiler cleaning
2-4 Air conditioning and refrigeration

Refrigeration equipment is found in air-conditioning, food-storage, and process applications, and is the basis of ground-source and air-source heat pumps. There are two main classes of machine to generate the cooling effect: absorption chillers (in which heat is used as the power source) and the more commonplace vapour-compression chiller which uses mechanical power, usually from an electric motor.

In the latter case an organic vapour in a closed loop is first compressed, which raises its temperature. Heat is then removed from it in a heat exchanger cooled by ambient air or cold water, which causes it to condense to liquid form. It then passes through a throttle valve to a region of low pressure. At this reduced pressure, its boiling point is below the temperature of the air or water that needs cooling. The two pass through another heat exchanger where heat from the air or water boils the refrigerant, losing heat in the process and dropping in temperature. The refrigerant, having now returned to vapour, goes back around the circuit to the compressor.

Absorption machines operate on a somewhat more complex principle in which vapour is absorbed by a liquid in one part of the circuit and then boiled out of solution in another. Being driven by heat rather than mechanical power, it is an attractive option where waste heat is available as an energy source.

Whichever type of refrigeration cycle is used, the overall picture is the same: heat is extracted from the chilled medium in one heat exchanger (the evaporator) and dumped to atmosphere, either directly or indirectly via a cooling circuit, in another (the condenser). The efficient supply of cooling service can be ensured by taking the following precautions:

1. Make sure that nothing impedes the transfer of heat in condensers or evaporators, by keeping them clean, unobstructed, and free of ice.

2. Ensure that the condenser coolant is supplied at the lowest possible temperature. Air-cooled condensers should not for example be allowed to draw air which has picked up heat elsewhere. On an air-conditioning system that might include ventilation extract air; in the context of a refrigerator, standing it in a hot kitchen.

Figure 2-4-1

*Having this condenser unit indoors decreases its energy efficiency and could contribute to summertime overheating*
3.. Monitor temperatures and pressures in refrigerant circuits. Abnormal readings will indicate loss or contamination of refrigerant charge, compressor faults, blocked strainers, or other conditions that are likely to have an adverse impact on efficiency (cooling power divided by input power).

4.. On multi-chiller installations, check that the control system is only running the minimum number of chillers required at any given time.

Ensuring an efficient, least-cost source of cooling power is not of course the whole story. You will also need to ensure that good use is made of the cooling supplied. Let us take air conditioning first. Here, from my experience, the prevalent problem is simultaneous heating and cooling of the same space. This is a classic example of avoidable waste because it is superficially symptomless but, once detected, may require little more than a change to temperature control set-points (the usual mistake being that the cooling and heating target temperatures are set too close to each other; the slightest overshoot on one or other causes them to lock in contention). The biggest risk is naturally where the two control systems are independent, but failure of a valve or damper, or of a frost-protection thermostat, can cause simultaneous heating and cooling in the best-designed installation. Otherwise in air-conditioned premises you should check that

1.. the conditioned space is not drawing in too much fresh air;

2.. there is no exchange of air with untreated spaces;

3.. time and temperature controls are appropriately set; and

4.. the target space temperature is reasonable.

Enlightened organisations these days prohibit the use of cooling below a certain internal temperature, generally around 26°C.

We should at this point mention humidity control, which is an aspect of some air-conditioning systems that increases the demand for cooling power. Water vapour is present in the air and, in the right quantities, contributes to comfort. Too little causes itchy eyes; too much will make it feel muggy.

Our bodies perceive the relative humidity (RH), which is a measure of the degree to which the air is saturated with water vapour, there being a maximum quantity of vapour which air can hold at any given temperature.

Generally speaking, relative humidities in the range 30%–70% are acceptable. In temperate climes such as the UK, buildings without humidity control naturally achieve these conditions most of the time.

Some buildings do however have equipment for regulating the internal relative humidity. This can be provided at two levels:

- Humidification only, to counteract the low relative humidity which can occur when cold outside air is introduced and heated. Cold air cannot hold much water vapour, and therefore has a very low RH after being heated.
• Full humidity control: this is where dehumidification is available to deal with high RH, as may occur in summer in buildings with a high percentage of air recirculation. The recirculated air will have picked up water vapour from the building occupants, catering, potted plants and so on.

Both humidification and dehumidification require energy. Humidification needs heat to evaporate liquid water. Dehumidification requires chilling and heating: the air must first be cooled sufficiently to condense out the excess water vapour, and then reheated.

Energy demand can be reduced by relaxing the specification for internal RH. If the target is 50% RH, the system will always be humidifying or dehumidifying, whereas if the permitted range were extended to 40%–70%, then the building’s air supply would need neither form of conditioning much of the time.

In process cooling applications it is usual to use a medium such as water, glycol or brine circulating in a closed loop between the chiller plant and the various apparatus that needs cooling. Depending on what the cooling uses are, there may be an opportunity to raise the circulating temperature. Operating at an excessively-low circuit temperature has two adverse effects. It reduces the thermodynamic efficiency of the chiller plant, since it has to pump heat across a wider temperature differential; and it increases unwanted heat gains in the distribution circuit since they are that much further below ambient temperature. This incidentally raises another issue: the need to keep the pipework and fittings well insulated.

There are two other possible opportunities in the context of central chiller plant, perhaps more related to the chapter on motor-driven equipment, but worth mentioning here. The first concerns the flow rate in the distribution loop. If demand is highly variable, there may be scope to use variable-speed drives to minimise pumping energy requirements. Secondly, where there is a bank of fan-assisted cooling towers, consideration should be given to how they are controlled. If the fans run at fixed speed, schedule them so that only the minimum number run at any one time to satisfy the condensers’ demand. But if they have variable-speed fans, keep them all running and modulate the fan speed.

Refrigeration in food storage will be covered under the chapter on catering.

Finally, the usual recommendation for monitoring the energy used in air conditioning is to relate weekly electricity consumption to cooling degree days (either measured locally or obtained on subscription). Ideally, chillers should be separately metered, but even if they are not their effect on overall building consumption should still be perceptible. When monitoring process loads, the ideal arrangement is to use a heat meter to measure the total cooling supply, using that as the driving factor for chiller energy use. Cooling supply can then be assessed in relation to production activity or weather (or a combination of the two); breaking the cooling supply chain in this fashion enables you to discriminate between waste that occurs in the chiller plant and the downstream applications respectively.
2-5 Lighting

Lighting in itself is not always a major energy use, but it is disproportionately important because of the visual cues it sends to the occupants of buildings. Very often when training staff or interviewing them about their attitudes to energy, I have heard them complain about the buildings where they can see lights being left on unnecessarily. Conversely, working in a building with automatic lighting control, one is constantly reminded, in effect, that the organisation cares.

There are a number of easy and inexpensive steps that you can take. There are some workplaces, for example, where people may not even know where the light switches are, or if they do, it may not be clear which of a bank of switches controls which area. Clearer labeling is simple: it need not be flashy, and combined with motivation and awareness, it will help to cut costs.

Figure 2-5-1

Well-labeled light switches

I will cover low-energy lighting technologies later, but suffice it to say for now that tungsten-filament bulbs should just be replaced without further consideration. Replacing a 60W bulb with a compact fluorescent lamp (CFL) will save something of the order of £50 (at 2009 prices) over the life of the lamp, not counting the savings in maintenance costs, CFLs are available in sizes and styles to suit almost every application including spotlights and chandeliers, and start-up delays are a thing of the past.

Another important consideration is the level of illumination that is provided. The CIBSE (Chartered Institution of Building Services Engineers) recommendation for offices, for example, is 400 lux but a survey with an inexpensive light meter could reveal that this is exceeded. You are very likely to find that corridors and staircases are overlit compared with the CIBSE recommended level of 200 lux. You may conclude that it is possible to disconnect some light fittings. In fact in the absence of glare from windows or other light sources, 200 lux is perfectly comfortable for office work, and I am writing this with an
ambient light level of 32 lux on my desk which is adequate for reading paperwork (but makes the room look too gloomy for most people's tastes).

Figure 2-5-2
Light meter

Some building managers have successfully reduced the number of tubes in existing multi-tube fittings, after replacing their reflectors to improve light delivery from the luminaire. This can be done without detriment to light levels provided on working surfaces.

Daylight

When daylight is available, it makes sense to use it in preference to artificial lighting. Paradoxically, large windows are counter-productive, because they cause huge contrasts in light level within the space, creating the impression that areas away from the window are dark. The best results will be obtained when spaces are evenly lit. Having windows -- even small ones -- on both sides of a room, or using rooflights (or 'sun pipes' when there is an intervening roof void) will help. Even though absolute light levels may be lower, the space will feel better lit. When designing accommodation, remind the architect that tricks like light-coloured sloping ceilings, splayed window reveals, and wide window-sills will help to distribute natural light through the space. For an existing space, an external 'light shelf' or properly-configured slatted blinds can be used to bounce incident light up onto the ceiling.

Figure 2-5-3
Natural lighting from above and angled reflective surfaces create a well-lit appearance
The things which make spaces costly to light are some of the same things that make them dispiriting to work in: dirty windows and rooflights, piles of clutter, and dark decor and furnishings.

**Controls**

To make most effective use of natural light, photocell controls may be appropriate, but this is just one aspect of the subject. The objectives of a lighting control regime are to provide illumination

1. At the times it is required
2. Where it is required
3. At an appropriate level of illumination
4. Without causing distractions
5. Without compromising safety

The broad recommendations for various indoor lighting scenarios are as follows:

<table>
<thead>
<tr>
<th>Circumstances</th>
<th>Possible strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>No daylight available</td>
<td>Time switching where occupation patterns are predictable (for example, department stores). Occupancy sensing, where space is occupied at unpredictable times (for example, locker rooms). More localised manual switching could also be considered if there is a risk of nuisance switching from an automated system.</td>
</tr>
<tr>
<td>Daylight available, low occupation</td>
<td>Because the lights are only rarely needed, daylight-sensing is unlikely to be worth paying extra for. Occupancy linking should be considered, perhaps using a “manual on, auto off” strategy.</td>
</tr>
<tr>
<td>Daylight available; one or two occupants</td>
<td>More localised switching should be beneficial, perhaps using a “manual on, auto off” strategy if occupation is irregular and intermittent. Daylight sensing may be warranted if the space is continuously occupied. Timed “off” control may be worthwhile if working hours are regular. (see below)</td>
</tr>
<tr>
<td>Daylight available; multiple occupation</td>
<td>Timed “off” control is likely to be worth considering under all circumstances. This is a regime whereby a signalling pulse is sent out at key times (during lunch, after close of business etc.) to turn off lights at work stations. A local reset switch (often a pull-cord) is provided at each work station to allow those still at work to restore their local lighting. Photoelectric (PE) daylight linking may be</td>
</tr>
<tr>
<td>Area</td>
<td>Control Method</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>-------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Worthwhile for spaces which are fully occupied during working hours, and which therefore need continuous lighting. PE control can be restricted to perimeter zones in deep-plan spaces.</td>
<td></td>
</tr>
<tr>
<td>Corridors, unmanned reception areas</td>
<td>Fully automatic on/off control using presence detectors, but leaving some residual light for safety (which may itself be photocell-controlled if there are windows)</td>
</tr>
<tr>
<td>Store rooms</td>
<td>Time-delay manual switches can be a good option if users will not necessarily want the lights on. Otherwise, occupancy sensors.</td>
</tr>
</tbody>
</table>

A simple scheme which works reliably and saves a moderate fraction of the energy required is preferable to a scheme which saves more energy but is temperamental or difficult to maintain and operate. Because of the risk of unintended adverse consequences, expert advice should always be sought in each case. The history of energy management is littered with cases where automatic lighting control has irritated and alienated the users of buildings.

*Figure 2-5-4*

*Motion-sensor switch as a replacement for a standard light switch*

**Lighting technologies**

For a given level of illumination, different lamp technologies will require different amounts of electric power.

Where T12 (one-and-a-half inch) fluorescent tubes are fitted and have switch-start ballasts, slimline T8 (one-inch) tubes can almost always be used instead. These are more efficient in terms of light output per unit of electrical power, and are no more expensive to buy.
Fluorescent-tube installations can benefit from the introduction of high-frequency (HF) ballasts in place of mains-frequency control gear. HF gear typically reduces electricity consumption by 20%, gives quick startup and prevents the stroboscopic effect which can be hazardous where there is rotating machinery. Furthermore, a fluorescent tube with HF gear does not flicker near the end of its working life; it just stops working, and moreover stops using energy whereas mains-frequency fluorescent lamps actually draw more power when they have failed than when they are working.

The quality of light service is critical to the user and must not be compromised. Factors which need to be taken into account are:

- Colour temperature: do the users want a 'warm' or 'cool' light?
- Colour rendering: this determines how well the user can identify and discriminate between different hues. Low-pressure sodium lamps (the very yellow lights used in street lighting) are among the worst, since everything illuminated by them appears monochrome, but they are very energy-efficient.
- Glare: using a small number of high-output lamps creates concentrated light sources that may cause difficulties.
- The aesthetic need for ‘sparkle’

Display lighting presents particular challenges. Spotlights still tend to be of the filament variety since discharge (fluorescent) lamps cannot usually be focussed sufficiently well. Low-voltage (LV) tungsten halogen ‘dichroic’ parabolic reflector lamps have an efficiency advantage over mains-voltage reflector bulbs (such as the ubiquitous PAR38) and additionally are designed to project light while not projecting heat to the same extent. When lighting small subjects the LV lamp can usually provide a more concentrated beam, allowing the required level of illumination to be provided on the subject with less total light output and hence less energy input.

LV lamps must however be installed and used correctly. Their service life is critically influenced by supply voltage, and where several are fed from a common transformer without voltage regulation, the failure of one lamp will allow the voltage on the others to rise, accelerating their failure. Failed lamps must be replaced immediately, or a voltage-regulated power supply should be fitted to prevent the problem of cascade failures.

An alternative to low voltage tungsten halogen lamps for display lighting is metal halide discharge lamps. As a general guide, replacement of conventional sealed-beam reflector lamps will give savings of 30-70% for the equivalent lighting.

For outdoor lighting applications, filament bulbs in bulkhead fittings can be replaced with high pressure sodium, low pressure sodium, or compact fluorescent bulbs, yielding savings of 75-85% on energy and significantly reducing maintenance costs. Meanwhile for high-wattage floodlighting (filament lamps, including tungsten halogen floodlights)
the most appropriate energy-saving substitutes are high-pressure sodium or mercury discharge lighting.

For a more thorough treatment of the comparison between lamp technologies, visit www.vesma.com/tutorial/lampchart.htm.
2-6 Hot water services

In theory, domestic hot water services (those needed for hygiene and catering) should not impose major costs. The daily requirements for an average office or factory worker is in the order of 4 litres per day which (if delivered at 60°C) ought to cost under £2 per person per year if heated by gas (£6 if electric). In the much higher-consumption environment of, say, a general hospital, one would expect the daily consumption per occupant to be 10 litres per day which, bearing in mind that it is also required seven days a week, implies annual costs of £70 per occupant with gas-fired boilers.

The causes of energy loss in hot-water provision are twofold. There are those related to excess consumption of water – leaks, taps left running to overflow, hot water being used in excessive quantities, or where lower temperatures or even cold water would suffice – and those which cause high standing heat loss independent of the quantity of hot water drawn off. Such routes for standing heat loss obviously include long runs of uninsulated hot water pipework, and poor insulation on hot water storage vessels. A more subtle cause is the heat loss from a large heating boiler being run at very low load factor purely to service hot-water requirements in the summer. This is a problem which in some installations will have been addressed by providing electric immersion heaters to substitute for boilers during the summer, but that in itself creates a new risk, which is that the electric heaters may inadvertently be left running during the winter. This does not exactly waste energy, but it does impose extra costs because of the price differential between electricity and gas or oil.

Naturally, one should not rule out the unexpected. Some workmen painting the inside of a hospital cold-water header tank were held up because after they had isolated and emptied it, it began to refill from the outlet. It transpired that hot water was entering the cold water pipework via defective mixer taps. This problem was of course completely hidden during normal operation, when draw-off of cold water was sufficient to prevent the leaking hot water from filling the tank past the overflow.

A common opportunity for reducing standing heat loss is to fit point-of-use water heaters in order to dispense with central storage and long distribution runs. These may be wall-mounted electric types in washrooms, or direct gas fired for catering, locker-room showers and other larger users. Time controls can be fitted to local water heaters. A secondary reason for eliminating long distribution runs for hot water from central storage is that, in England at least, building codes require that they be kept charged with hot water by pumping the hot water around a closed recirculation loop. This measure is designed to conserve hot water by obviating the need to run the hot tap to purge the line of cold water. But it increases both standing heat loss and electricity consumption.

Hot water may, of course, be needed in large quantities for process lines and cleaning duties including laundries and kitchens. Here there may be little choice but to retain central provision. In these circumstances it may be possible to recover heat from water-cooled equipment (such as chillers) and processes, or even from hot process drains if there is no contamination risk.
It is not usually possible or practical to monitor separately the energy used for dometic hot water provision. In the majority of cases one can do little more than infer the scale of energy use from the intercept on the energy-versus-degree-days scatter diagram. For industrial uses, it may be possible to meter the consumption and assess it against production activity, but the picture will not always be clear because often water is used in short bursts for cleaning which only takes place at irregular intervals dictated by batch or product changes and will probably bear no relation to product throughput. If you are in this situation, either try relating consumption to the number of cleaning cycles, or monitor subjectively by studying charts of consumption at intervals of (say) five to 15 minutes.
2-7 Catering
In the majority of organizations catering is not a major user of energy, although there may be worthwhile gains in large kitchens in hospitals, hotels and educational establishments. Having said this there are also minor opportunities such as fitting night blinds to chilled display cabinets (applicable also in food retail generally) and timeswitches on vending machines which are refrigerated for purely aesthetic reasons rather than to preserve the contents.

Many of the energy requirements in kitchens and restaurants are dealt with elsewhere in this book. They have refrigeration equipment and are major users of hot water. They also have space heating, ventilation and lighting requirements to which the same principles apply as in the building at large, with the following possible additions:

- Because demand for ventilation air is likely to be very peaky, there would be more scope for time controls, including in all likelihood separate schedules for the kitchens and seating areas respectively;

- It may be possible to regulate air supply dynamically by means of more sophisticated controls which sense the demand for fresh air;

- It may be necessary to provide fresh air supply fans to balance the extract air and prevent the kitchen from scavenging heated air from the rest of the building;

- There may be scope for heat recovery from the extract air, albeit with complications because of the need for filtration and the necessity of piping the heat to other parts of the building (since kitchens themselves are probably the last places that need the extra heat)

Energy requirements specifically for catering are likely to include gas and electricity for cooking, hot water for sinks sterilisers and dishwashers, and electricity for dishwashers, refrigerators, freezers, heated and chilled display cabinets in the primary catering area. In principle one should also include electricity used for vending machines, kettles, water boilers, cookers, refrigerators etc. distributed around the building.

Thinking about cooking appliances, the big gains will come from awareness and training. Staff should be discouraged from leaving gas rings, grills, hotplates and ovens running when they are not required. They should be trained not to turn on ovens to warm up unnecessarily early, nor to set pans to boil before they are needed, nor to let pans boil rapidly when gentle boiling will do (remembering that the water temperature will be 100C regardless of the rate of boiling). They should be taught to use lids on boiling pans at least while coming to the boil, and during cooking for those foods where it is not essential to leave the pan open. All these measures will save fuel and electricity and – as importantly – will help counteract the overheating and excessive humidity that make a kitchen uncomfortable. One chef in a major commercial kitchen who let his staff have this training had a pleasant surprise. Not only did he save enough to fund the purchase of the latest combi oven: he found that tempers were less frayed and staff turnover reduced.
Training will also help reduce consumption of hot water. For instance, staff can be discouraged from leaving soiled pans under a running hot tap. Just leaving them to soak will be just as effective, and the likelihood of running out of hot water (a major problem) will be reduced. Likewise with lighting: service counters may have high-power lamps to help keep food warm on display. Illuminating an empty counter is a wasteful habit that can be avoided.

Figure 2-7-1

Empty foodservice trolleys with the lights (and perhaps heaters) left on

In the chapter on air-conditioning and refrigeration we learned that it is important for the condenser to have access to plentiful cold air. The majority of refrigerators and freezers have condensers consisting of tubes on the back of the unit through which the heat is dumped. They will have lower running costs if located away from the heat of the kitchen with plenty of air-circulation space. This is a layout planning issue. But the condenser coils should also be kept clean, which is a maintenance issue, as is checking that appliances are not frosting up internally. Training will help here as well. Staff need to understand that leaving appliance doors open wastes energy.

What about the idea that a full freezer is more efficient than a part-loaded one? In fact, probably the opposite is true. Why? Firstly, the freezer is just an insulated box whose contents are maintained at a temperature below the surroundings. What defines its energy requirement is the rate at which heat leaks back into the box through the insulation, and that is purely a function of the box’s characteristics and the temperature differential. All other things being equal, the freezer will use the same power regardless how full it is. What in fact tends to happen is that a full freezer has its door open for longer (increasing its energy use) because it is that much more difficult to locate a desired item among the contents. Having said that, it is better to run one freezer moderately full than two almost empty, so occasionally there may be scope to redistribute contents and turn one off. Certainly there is no point in deliberately filling a freezer with loaves of bread (or plastic bags of crumpled newspaper: I have heard both recommended).
2-8 Compressed air

The main use of compressed air is as a medium for delivering mechanical power, although there are other applications such as pneumatic controls (as a safe alternative to electrical actuators in hazardous environments), for sorting and separating small items on production lines, blowing dust or swarf in manufacturing workshops, transporting powder, atomising water in humidification systems and agitating the contents of tanks and vats – to name but a few.

What every application has in common is compressors (be they reciprocating piston types, screw, vane or centrifugal), ancillary driers and filters, receivers (storage cylinders) and distribution pipework. This supply infrastructure may consist of small local units or be centralised.

Air leaks are the most obvious aspect of energy waste. Because it is not always possible or convenient to repair them as soon as they are found, some organisations have a regime whereby staff have a supply of serial-numbered tags that they can hang on leaking pipes, joints, fittings or equipment, each with a tear-off counterfoil they can send to the maintenance office. This facilitates a coordinated assault on the problem during the next shutdown or other opportunity. Remember, however, that some air loss can be stopped immediately, for example when it arises because a drain valve has been left open or excessive pressure is lifting safety valves. At one establishment I even found they were deliberately (and quite unnecessarily) emptying the air receiver at the end of each day.

Reducing the supply pressure (of which more later), minimising service hours, and fitting automatically-controlled zone isolation valves will all limit the loss through leaks that have not yet been attended to; even better is removing and capping-off redundant branches of pipework.

It can be quite instructive to measure or estimate the air consumption during quiet hours and compare it to working hours. Even if the factory lacks air meters, the compressors probably have hours-run counters which will give an indication of the difference. I did this at one factory and found that the compressors ran as long on a stock-taking day as they did on a normal working day, implying that the bulk of the air consumption was uncontrolled.

In that instance, some of the air was being used to agitate tanks of liquid. Using costly dry filtered air piped at high pressure from a central system is not always appropriate for agitation, air knives, blow guns, and other such low-grade duties; it may be economical to supply these from local blowers which (furthermore) can be run on demand.

Whenever you eliminate a use of central compressed air by substituting an alternative solution, you may create an opportunity to eliminate sections of distribution pipework, reduce the daily service hours, or reduce the central supply pressure. Supply pressure may also be reducible if its level is dictated by one or two critical uses. Consider providing local boosters for these so that general pressures can be taken down.

Once the consumption of compressed air has been minimised, attention can turn to the efficiency of centralised air supply. This has several aspects, one of the most important being how multiple compressors are controlled to share the load. A ready assessment can be made again with the use of their built-in run-hours counters; simple arithmetic will
show to what extent more capacity was on-line than was strictly needed. Some compressors are designed to run continuously but switch between loaded and unloaded modes. These will usually have separate run-hours counters for loaded and unloaded running, which is important because they are wasteful at low load factor, using a substantial percentage of their rated power while producing no air. Considerable savings in both energy and maintenance costs can sometimes be achieved by improving the control of compressor sequencing such that (as far as possible) each unit runs close to its rated output or not at all, rather than cycling on and off in combination with the others. Where air demand is very variable, one possibility may be to use a variable-speed machine alongside a bank of fixed-output compressors.

One point worth mentioning is that it matters where the compressor draws its air from. Outside is preferable, since you will get roughly a 1% increase in output for each 3°C drop in inlet temperature.

It is sometimes suggested that as compressed air is about ten times the price of electricity when used as a source of motive power, it may pay to replace air tools with electric equivalents. This assumes that the replacement tools are equally effective and not attractive targets for theft. In practice replacement is not likely to be cost-effective unless it enables compressed air to be dispensed with completely.

The recommended technique for monitoring a substantial compressed-air installation for energy efficiency is to treat it as two processes:

1. Track air quantity delivered against some suitable driving factor such as production throughput (or other index of activity if that is not feasible);

2. Track electricity used in each compressor against the quantity of air it delivers.

If compressors are not separately metered, they will need to be treated as a group, and you will be less able to pick up faults and less able to pinpoint them. You will also be unable to minimise costs by running the machines in order of merit.

If there is no air meter at all, you will have to track electricity used against the driving factor for air consumption and if excess electricity consumption is detected you will not be able to discriminate between the compressors and downstream uses as the cause of the problem. If there is no dedicated electricity meter on the compressors it will not be possible to manage them, nor to discriminate between the compressed-air system and other users of power as the culprits if excess consumption occurs.

*Figure 2-8-1*

*Location of a run-hours counter on an air compressor*
2-9 Steam

In thermal processes that need to operate up to say 200°C, such as drying and distillation, steam is a convenient medium for transporting the heat. Water could be used (pressurised, otherwise it would boil) but compared with steam it cannot carry anything like the same amount of energy per kilogramme. This is because of water's relatively high latent heat of evaporation: if you condense a given mass of steam in a heat exchanger at atmospheric pressure, it yields about fifty times as much heat as the same quantity of liquid water delivered at 100°C and leaving at 90°C. Steam at different pressures condenses at different temperatures (170°C at eight times atmospheric pressure, for instance) and controlling the steam supply pressure effectively controls the temperature of operation very tightly. This is in contrast to the use of hot water, which falls in temperature as it gives up its heat (meaning that at high loads the average heat-exchange temperature is reduced). Added to which, surface heat transfer from water is poorer than is achieved by condensing steam.

The typical steam installation consists of a tank (the 'hotwell') containing hot treated feedwater which is pumped into one or more boilers. The boilers generate steam at the desired pressure and this is distributed via pipework (possibly through pressure-reducing stations for some users) to the dryers, tanks, vats, presses, air heaters or other heated equipment. The steam condenses back to liquid water within the heated equipment -- giving up its latent heat -- and the condensate passes out through steam traps whose job is to prevent steam escaping but to allow the free passage of water. The condensate then returns to the hotwell. Ideally, the steam system is a closed loop, but this is not always the case; for example, in some plants steam may be directly injected into tanks and vats, while in others the condensate may be diverted because of the risk that it contains contaminants that could compromise product quality. In such cases (and in the more common cases where there are steam leaks or condensate is lost en route back to the boiler) makeup water has to be added to top up the system. This makeup water requires expensive chemical treatment. Steam leaks cause a gradual increase in the amount of dissolved solids in the boiler water, since the chemical treatment of it just converts one form of impurity into another necessitating periodic 'blowdown' to regulate their concentration. Blowdown, which is also necessary to remove sludge and scale from the bottom of the boiler, inevitably entails energy loss.
Steam will not only be lost in leaks. Condensate is generated at the prevailing steam pressure and temperature (potentially around 170°C or more) and therefore when released at atmospheric temperature it finds itself well above boiling point. Inevitably, some of it must boil off to leave liquid water at 100°C. What boils off is called 'flash' steam. Flash steam can potentially be utilised (albeit for lower-temperature applications) and for some factories its recovery and use represents an energy-saving opportunity.

Even just the way condensate is piped back to the hotwell could be significant. Delivering it through a submerged sparge pipe will prevent the vapour loss that occurs if it drops through the open air. It may pay to review the steam supply pressure and reduce it, because this will reduce the amount of flash steam, the rate of loss through leaks, and the temperature of the distribution pipework.

Even in cases where it is felt to be necessary to dump condensate, heat could potentially be extracted, for example by passing it through a heating coil in the cold feedwater supply. A fuel saving of about 1% will result from increasing the feedwater temperature by 6°C.

Steam leaks are costly not just because of the energy lost in the steam. There is the additional cost of treating the makeup water to replace it. Faulty steam traps may also cause losses by allowing steam to escape through the condensate return system (itself a potentially hazardous situation). The other way steam traps can fail is by not letting condensate pass out. This wastes energy because the retained condensate will form an insulating layer in the heat exchanger, reducing the efficiency of heat transfer. Routine checking of traps by means of sight glasses, three-way test cocks, or specialist devices is part of effective energy-conscious maintenance. If traps are fitted with bypass valves it is important to ensure that they are not accidentally left open. Such bypasses are sometimes justified on the grounds that they assist air removal during startup (air in the system is bad because it reduces heat-exchanger efficiency) but a better solution is to fit thermostatic air vents which will close automatically once all the air has been purged. If two or more pieces of equipment share one trap, that is also a recipe for problems. Very rarely the problem may be that the trap is too small.
Blowdown needs to be monitored to ensure that it is not excessive. The risk here is either that automatic regulation is fitted, but malfunctions or is incorrectly set, or that manual blowdown valves are opened too often, or for too long, or -- worse still -- left open. Another route for water loss is condensate overflowing at the collection point during startup when the rate of condensate return will be at its peak.

Distribution pipework should be reviewed to see if it is still appropriate for current conditions, given that steam loads may have been significantly reduced over the years and the system might originally have been conservatively designed. Oversized pipes and those that take circuitous routes lose more heat than necessary; the worst offenders (and those that may be easiest to deal with) are dead lengths of pipework, or long runs of pipework with very small users at the end which could be provided with heat by some other means. Even if it is not possible to replace or reroute pipework, its insulation can be kept in good order. Check for wet or missing sections; look for opportunities to fit jackets to valves, flanges and other fittings. A flange can be reckoned equivalent to about a third of a metre of pipe and a valve considerably more. Getting steam pipework right is something of an art. For example, because some steam will condense in the pipes, they themselves need to be fitted with collection pockets and steam traps, and laid to slope towards these collection points in the direction of steam flow.

One inexpensive way to save steam, although it requires a little experimentation and investigation, is reducing warm-up times to the minimum. Often a conservative policy will have been inherited which leaves the plant in hot standby for too long. Worrying about startup times may also inhibit operators from standing the plant down at all during protracted idle periods. As in many similar situations, attention to one or two minor technical constraints (air venting is an obvious example here) can facilitate a beneficial change to operating practice.
It will be evident that steam technology is a highly specialised subject where expertise is needed even for routine operation, let alone for improving performance. The engineer who wishes to improve his or her knowledge should visit the web site of the Cheltenham-based equipment supplier Spirax Sarco (www.spiraxsarco.com), and follow the 'Resources' link.

Recommended practice for monitoring steam systems starts with providing feedwater meters and steam meters on each boiler. This at least facilitates a mass balance by means of which excessive blowdown can be detected, and in combination with individual fuel metering gives very good visibility of most aspects of boiler performance. A makeup water meter meanwhile, even if shared by all boilers, will enable monitoring for changes in condensate and steam losses throughout the steam system. Next it will be beneficial to monitor major branches or groups of steam-using plant items. The key is to group items as far as possible according to what drives the variation in steam consumption, so that a meaningful targeting model can be developed. Thus for example a group of dryers used interchangeably for the same product stream could be grouped together, as might the space-heating system.
2-10 Process thermal insulation

Unwanted heat transfer not only wastes money but can prevent things from working properly. Uninsulated buildings are uncomfortable even with the heating turned up (because of the physiological effect of cold surfaces). Kilns would be unable to reach their required operating temperature, and unlagged steam systems would be perpetually water-logged with condensate. For each application there is a range of technical solutions and sometimes it may pay to add insulation beyond the minimum required for effective operation, or to change the insulating material for one with superior characteristics. An example of this last point is where heavy refractory lining is used in an intermittent furnace. It may be possible to replace the inner face with ceramic-fibre insulation blanket or tiles which, since their own heat capacity is lower, allow the furnace to heat up more rapidly and thereby reduce preheat times.

Let us think about pipework. Ten metres of uninsulated 50mm-diameter pipe at 190°C emits about 6kW, for example, which at 2009 fuel prices would cost something of the order £1,500 per year to supply continuously. Adding thermal insulation not only saves money and improves the operation of equipment, it also reduces the discomfort that can be caused by excessive heat release into occupied spaces. Generally speaking, the more insulation the better, but there are diminishing returns. Each additional percentage-point of energy saving costs more to achieve, there are trade-offs between thermal performance of different materials and their installation costs, and as a result the calculation of the economic optimum thickness is not straightforward. To simplify things I would suggest using standard recommended thicknesses such as those from BS EN 5422:2009, an abstract of which is shown in Table 2-10-1. In the example cited above, the reduction in heat loss would exceed 90%.

Table 2-10-1: Recommended pipe insulation thicknesses (mm)

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Pipe temperature (°C)</th>
<th>Insulation thermal conductivity (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.025</td>
</tr>
<tr>
<td>17</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>42</td>
<td>100</td>
<td>15</td>
</tr>
<tr>
<td>89</td>
<td>100</td>
<td>19</td>
</tr>
<tr>
<td>219</td>
<td>100</td>
<td>23</td>
</tr>
<tr>
<td>17</td>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>42</td>
<td>200</td>
<td>28</td>
</tr>
<tr>
<td>89</td>
<td>200</td>
<td>36</td>
</tr>
<tr>
<td>219</td>
<td>200</td>
<td>44</td>
</tr>
<tr>
<td>17</td>
<td>300</td>
<td>30</td>
</tr>
<tr>
<td>42</td>
<td>300</td>
<td>41</td>
</tr>
</tbody>
</table>
Insulation for process plant, pipes and fittings can be obtained in both rigid and flexible formats in a wide range of foam and fibrous materials suitable for different applications. Valves, flanges, strainers orifice plates and other fittings will need to be insulated as well and this can be achieved either with preformed kits for standard components or with flexible jackets. Good installation contractors will be able to advise you and will have methods of estimating the reduction in heat loss that you can expect. When specifying the installation, allow for protective cladding to protect the insulation from mechanical damage and water ingress, paying particular attention to the insulation on fittings where access for maintenance may be needed: if the insulation is not easy to remove and refit properly, it is likely not to get replaced after being taken off.

*Figure 2-10-1*

*A valve insulated with a flexible jacket*

Open water surfaces in process vats or boiler feedwater tanks are a route for heat loss. At 60 °C water temperature in typical ambient conditions the loss is about 3kW per square metre. The loss can be reduced by fitting a lid or using a blanket of floating plastic balls. This can be important even for a low-temperature fluid surface like a swimming pool. The main mechanism for heat loss from a liquid surface is evaporation (latent heat). A lid
has two effects: it reduces air movement over the surface and it allows the vapour pressure of water above the surface to rise. Both these effects reduce the evaporation rate. A ball blanket reduces the exposed surface area through which evaporation can occur but anything which causes the balls to roll will have an adverse effect by increasing the wetted surface. This includes current induced by agitator paddles or things being dipped in the fluid. When designing a lid for a dipping tank, make sure that it is easy to remove and replace and that operators understand the importance of using it.

The effectiveness of new or additional process-plant or pipework insulation ought to be easy to verify because it is likely in the majority of cases to result in a fixed weekly reduction in fuel consumption regardless of production throughput or other variables. Even the weather will not be a factor if the process is not exposed to the elements, and where it is, you would expect to see a reduction which is partly to prevailing degree-day values. Ongoing monitoring should reveal any substantial deterioration in insulation performance. For high-temperature process plant such as kilns and melting furnaces regular measurement of external surface temperature will indicate loss of insulation effectiveness. Spot checks with a surface-temperature thermocouple or non-contact thermometer may suffice but thermal imaging will reveal isolated hot spots that isolated checks could miss. Localised insulation failure is not necessarily a big problem in terms of energy saving but of course it could have a dramatic impact on reliability and availability.
2-11 Motor driven equipment

In an industrial plant a very substantial fraction of electricity demand will be due to electric motors. The first thing to check is that all the driven equipment is doing a useful job: cases have been known, for example, of circulation pumps which were found not to be necessary. A more subtle aspect is the mechanical efficiency of the driven equipment. In stirring and mixing applications, for instance, there may be low-loss paddle designs which do the same job with less power.

Then there is the ever-present risk of intermittent unnecessary running, for example in conveyor systems; an unloaded motor may still draw about a third of its rated power, and it will also adversely affect the supply power factor, increasing the peak demand current. Sometimes operators are reluctant to switch off ancillary equipment because they fear, perhaps with some justification, that it will not start again when required. A classic case occurred at a plant making wide rolls of plastics film. A number of 90 kW chopper fans were provided for disposing of the scrap film that was generated when there were problems on the line. It transpired that these fans would indeed sometimes fail to start, and they were therefore left running. The reason was traced to accumulations of scrap plastic in the fan casing. However, when one of the operators remarked that fouling increased the current drawn by the fan motor when it was running idle, the management realised that the ammeter could be used as a condition check. They instituted a regime whereby the fans would be opened up and cleaned when their minimum current draw exceeded a certain threshold. This ensured that they never got into such a state that they might not start reliably.

Oversized motors operate less efficiently (and at worse power factor) than ones well-matched to the intended duty. If permanently lightly-loaded, it may be possible to switch to permanent star connection or fit a smaller motor.

The transmission of mechanical power can also cause losses. The engineer needs to look for unusually hot or noisy gearboxes, worn or slack V-belts, individual belts broken on multi-belt drives, misaligned pulleys or couplings, and worn bearings in motors, driven equipment, or intermediate drive train. When V-belt pulleys need replacing, opt for wedge belts (2% improvement) or flat or ribbed belts (5-6% improvement). Consider high-performance lubricants for gearboxes, while on part-loaded multi-belt drives, consider removing one or more belts to leave only the minimum required for the power actually being transmitted.

In some circumstances it may pay to introduce time switching, or to fit automatic stop/start control which might include motor load sensing.

It is often possible to substitute a high-efficiency motor, when replacement is necessary; the lifetime cost of the motor is dominated by the electricity it uses. Rewinds reduce efficiency and may be a false economy. Standards for the efficiency of motors have recently been tightened with the introduction of IEC 60034-30, replacing the EFF1, EFF2
and EFF3 bandings which some readers may be familiar with. IE1 (standard efficiency) corresponds to the old EFF2, IE2 (high efficiency) to EFF1, while IE3 (premium efficiency) exceeds any previous standard. A super premium rating, IE4, which will have 15% lower losses than IE3, is expected.

In some circumstances where output is variable (typically with pumps and fans) variable-speed drives (VSD) are economical. Take for example a motor driving a fan. If it is necessary to reduce flow to 50%, a damper might typically be used to restrict the air flow; but the motor will still be drawing 80-90% of its rated power. Using speed control instead of a damper reduces the motor power requirement to one-eighth of its rated power. It also reduces noise, which may be an important consideration if the fan is part of a building ventilation system. Some applications which do not initially appear to offer this potential, because they have always been run at fixed outputs, may in fact turn out to lend themselves to variable-speed control. For example with a central chilled water supply you could sense the return temperature, which will tend to drop when demand is low but rise when it is high: by varying the pump speed to hit a target return temperature you could reduce the pumping power drawn during periods of low cooling demand.

Fully variable speed is not always the answer. Multi-speed motors provide substantial savings where stepwise changes in speed are acceptable. Where a fixed (but lower) speed is appropriate, a change of pulley ratios may be all that is needed, and could pay for itself in days.
3-1 Managing energy saving opportunities

When you have a healthy energy-management programme, you will be faced with a continual stream of opportunities. Increased awareness and motivation will generate suggestions from staff; exceptions detected by your monitoring and targeting scheme will expose instances of avoidable waste which will need to be attended to; and the reports from any energy audits that you commission will include recommendations that need to be evaluated and maybe pursued further. This is without including your own ideas and initiatives prompted by reading your way into the subject, using common sense, or responding to sales pitches.

Given that they usually have other duties and conflicting priorities, energy managers understandably sometimes fail to follow up on energy-saving opportunities. They just get sidelined or forgotten, which is particularly bad if they originate from staff suggestions, as failure to get a response is a major demotivator. So EN 16001’s 3.3.1 calls for a register of energy-saving opportunities to be maintained.

There is no hard-and-fast rule about what the register should comprise but here are some suggestions:

- A descriptive title
- Which energy aspect the opportunity comes under
- How it originated: if as a staff suggestion, from whom?
- Who is responsible for resolving it
- Its status: is it just an idea? Has it been costed and evaluated? Has it become a project, and if so what stage has the project reached?
- What it is worth (either in annual cash terms or net present value)
- Who is responsible for doing what next, and by when
- If resolved the outcome, including if possible an objective cost/benefit report

Opportunities which have been resolved should remain on the register for two simple reasons. Firstly the energy manager needs to be able to justify his or her existence, and having a library of achievements readily to hand is important. Secondly, the organisation needs to retain knowledge of what works and what doesn’t.

Identifying which energy aspect an opportunity belongs to is more important than it might seem. If you discover that it does not naturally fit in any of your existing aspects, you are then obliged to add a new one. This in turn may prompt the realisation that there may be a whole family of similar opportunities. The example I give is of an organisation that had already recognised heating, lighting, large motors, and staff awareness and training as significant energy aspects. It subsequently emerged that poor maintenance of
combustion plant was wasting money. This gave them an insight: that maintenance was an energy aspect, and once they looked at their operations from that perspective they began to uncover further opportunities. One in particular was significant, namely that by rewriting one of their contract specifications they could achieve energy-conscious repair and maintenance.

Prioritising follow-up on opportunities becomes easier if you have a tracking system which does two things: list the unresolved opportunities in descending order of cash value; and list outstanding actions in chronological order, identifying the person responsible. If time is pressing, these strategies enable you to focus on the things which most need attention. You can chase the people whose tasks are most overdue, and in progress meetings you can order the agenda with the big prizes first.
3-2 Energy audits and surveys

An energy survey is one method of finding opportunities for energy cost reductions. Although primarily thought of as being concerned with technical opportunities, surveys can be made more valuable by addressing the issues of staff awareness and motivation.

The traditional energy survey revolves around a physical inspection of buildings, plant, processes and systems, augmented by key measurements. The usual output is a report recommending a package of improvements, with costs and paybacks assigned to each recommended measure. Although often carried out by outside consultants (discussed in the next chapter) energy surveys can be conducted in-house by the energy manager if he or she feels confident to try it. The advantage is that the home-grown survey does not have to generate definite solutions and can be more open-ended. The other benefits of home-grown surveys are:

1. Greater site familiarity makes the process more efficient
2. Easier access to sensitive or hazardous areas
3. Possibility of spreading the survey over an extended period
4. Possibility of parcelling out aspects of the survey to better-qualified colleagues
5. More leverage to extract data not readily available to outsiders
6. Discretion to omit whole topics or areas
7. No obligation to report in a prescribed format
8. Ability to experiment, for example with alternative operating strategies
9. Greater cooperation from potential suppliers when seeking project budget estimates

With some assistance from suppliers anxious to sell energy-saving solutions, and from maintenance contractors keen to provide value-added extras, the energy manager is often in a better position to carry out an effective energy survey than he or she might think.

Whoever carries it out, the effectiveness of an energy survey can be enhanced by using M&T analysis as a precursor. By exposing anomalies in patterns of consumption, such analysis can point the surveyor in profitable directions.

Because energy surveys often result in spend-to-save opportunities, they call for financial viability to be calculated. The raw material for such a calculation is:

1. An estimate of the energy savings expected
2. Projected unit prices of saved energy
3. An estimate of the project capital cost (and ongoing operation/maintenance costs, if applicable)

Project costs can be estimated by consulting appropriate suppliers. Projected unit prices normally have to be guessed at, unless the energy manager or consultant subscribes to an energy market information service. Estimated energy savings can be speculative as well,
but the key requirement is to be able to quantify the existing consumption incurred in a particular zone, service, or piece of equipment. Some of the commonly-used methods of estimation are as follows:

1. Nameplate rating methods can be used on any equipment which has a fixed power demand, and which either runs continuously or runs intermittently for measurable periods. Look for run hours counters which allow the annual running time to be estimated from readings taken at a few days’ interval, or use a stopwatch to gauge the percentage of time for which the equipment runs. The annual kilowatt-hour consumption is then simply the nameplate rating multiplied by the estimated annual running hours.

   On three-phase electrical equipment where the instantaneous power requirement is not known, but an ammeter is fitted in the supply distribution board, the power in kilowatts can be calculated from the indicated current and nominal voltage. As before, the power figure should be multiplied by the estimated annual running hours to arrive at an annual energy figure.

2. Direct estimates of power requirement can be arrived at, where it is practicable to do so, by deliberately switching the equipment in question on and off, and observing the effect on the supply meter. This is most conveniently done by two people in radio or telephone communication: one switching and the other taking spot meter readings. The rate of meter advance during the test will differ from that immediately before and after, and the difference indicates the power requirement of the switched load.

3. For those occasions where steam-heated equipment or heating systems are to be assessed, steam consumption can be estimated by diverting its condensate into a barrel on weighing scales and registering the rate of increase of weight. This is a process which should only be undertaken by experienced and competent personnel working to an agreed method statement.

4. Temporary metering can be installed. For electricity, oil and water it is possible to use non-invasive clamp-on metering.
What equipment will you need?

For the purposes of energy surveys, it is not usually necessary to have traceable calibrated instruments because approximate measures usually suffice.

- **Digital thermometers with type K thermocouple probes.** You will need one instrument operating in the range –50 to 200°C, ideally with 0.1 °C resolution, and another for 0-500 °C with 1 °C precision. For high-temperature applications a robust probe is needed. For lower-temperature work, a ‘band’ probe designed for surface measurements makes a good general-purpose instrument capable also of measuring air temperatures. Even a bare thermocouple junction can be used. Thermocouples can be left in place and read manually by connecting the instrument when required. Compensating extension cable is necessary if the probe will need to be used at a distance (on the end of a pole), for instance.

  ![Digital thermometer with thermocouple probe](image)

- **A sling hygrometer** enables a spot check to be made on wet and dry bulb air temperatures. Alternatively, use a digital relative humidity probe, especially if moisture contents of product need to be measured.

- **Non-contact thermometers** can be useful to give approximate temperatures of inaccessible surfaces, or to scan for hot spots.

- **An infra-red camera** can be hired if large areas need to be assessed in detail. Results of infra-red thermography must be interpreted with caution.

- **Miniature data loggers** which record temperature, relative humidity, voltage, or pulses, may be useful for extended tests. Pulses may be logged from a variety of sources including PIR sensors (logging occupancy levels) or even improvised temporary contacts on valve linkages and other moving equipment.

- **A light meter.** An inexpensive unit will suffice, capable of working over the 100-2000 lux range. Photographic light meters are not suitable.

- **Plug-in power meters** can be used to check the consumption of appliances under 3kW rating.
• **An electrical demand profile analyser** would normally be used for assessing the total intake to a building. Domestic power displays such as the Efergy, Electrisave Owl or Wattson may be used for spot checks in smaller premises or on subcircuits where there is safe access to separate supply conductors.

![Portable power logger with flexible current transformers](Photo: Kane International)

**Figure 3-2-2**

*Portable power logger with flexible current transformers*

**A digital camera**

**Pressure/vacuum gauges**

**Combustion analysis kit.** This is one instrument which ought to be calibrated against a traceable standard. Although relatively expensive, this is a good long-term investment because it enables poor combustion to be detected through regular checks. Always choose one with carbon monoxide measurement. If using oil or solid fuel, you will also need a **smoke pump**.

![Combustion analyzer](Photo: Elcomponent)

**Figure 3-2-3**

*Combustion analyzer*

**Anemometer** to measure air velocities especially in supply and extract ducts

**Smoke generator** to detect air leaks. Alternatively, improvise with tissue-paper tell-tales or a child’s bubble maker.
• **Torch** (for reading meters and equipment rating plates)

• **Stopwatch**

• **Pocket tape measure**

• **Manhole lid lifter** (for access to water meter)

• **Meter compartment keys**

• **Walkie-talkie radio** or mobile telephones to coordinate ‘drop tests’ when one party is reading meters while another starts and stops equipment.

Lastly, do not forget your own eyes and ears. There is often a great deal to be gleaned by talking to, and more importantly listening to, people within the organization. They will not necessarily be able to articulate their ideas in technically rigorous terms, but the fact is that they do know what is going on, and what they say can be full of useful clues.
3-3 Selecting and briefing consultants

If you do not feel confident about conducting your own energy audit, or you lack the time, you may want to consider bringing in a consultant to help and advise you. An outside specialist should enjoy a number of advantages anyway:

1. Broader experience of similar installations;
2. Greater technical knowledge, essential if you are pursuing a specific project in depth;
3. Disinterested viewpoint (compared with what you would get by way of free advice from a technology supplier);
4. A fresh pair of eyes and ears

Energy-management consultants can of course help with things other than energy audits. They can design and conduct attitude and awareness studies, motivation campaigns, and training courses.

If you need outside help, one of your first problems will be knowing where to find it. Other than word-of-mouth recommendations from contacts in similar businesses, you could consider asking your trade body or industry research association; such organisations often use one or more energy consultants who will enjoy the advantage of knowing your industry. However, bearing in mind that industry-specific knowledge is not always essential (many opportunities are generic - take for example space heating, lighting, or compressed air) another avenue would be an organisation such as the Energy Institute (EI) or the Energy Services and Technology Association (ESTA), whose contact details are given under the 'further information' section. In both cases, membership is selective, giving reassurance as to quality and independence; the EI furthermore has an explicit code of conduct for consultants. Some will be members of both.

While there are a few larger energy-management practices (including my own employer, NIFES) the majority of consultants in energy operate as sole practitioners. Do not be put off by this; many of these are extremely well-qualified and experienced in particular aspects of the subject, and it is relatively rare for an energy survey to be such a big undertaking that one person could not carry it out. Even if the assignment is very general and wide-ranging, when you hire a sole practitioner you know exactly who will be doing the work and you will be assured of continuity. Larger firms are always an option but they come into their own particularly when you are starting with a general survey to find opportunities, but expect this to progress to one or more technically-specialised follow-on projects. The bigger the consultancy, the wider its staff's experience will be and the more likely it will be able to estimate the likely capital costs of projects based on their own recent experience. A larger practice will also have the edge for motivation, awareness and training campaigns which call for intense bursts of activity from a specialist team embracing two or more disciplines, including for example those where there is spill-over into related topics such as environmental management or maintenance improvement.
 Needless to say, you should check the credentials of any consultant that you are considering. Ask for recent relevant references, but only if it really is important that they have worked in your industry should you make that a criterion. Follow the references up. Ask for proof of professional indemnity insurance, and find out what professional qualifying body he or she belongs to, and whether membership requires adherence to a code of conduct. The EI's code of conduct for example stipulates that the consultant must not offer advice outside his or her sphere of competence, must respect confidentiality, and must declare any commercial interest at the outset. Commercial links are not necessarily bad, but they must be in the open.

It is prudent to ask the consultant to sign a confidentiality agreement, all the more so if he or she is a specialist in your industry. Consultants inevitably see sensitive information and analysis of energy data can reveal things about your operations that perhaps even you did not know, as in one instance where I discovered that shift workers in a factory were under-declaring production during the week so that they could pretend to be working full shifts on Sundays.

How much is it worth spending on an initial energy survey? We can work this out roughly by saying that we would like to recoup the cost in six months through measures which cost little or nothing to implement, and which might save, say, 5% of your energy costs. This sets a budget limit for the preliminary survey of 2.5% of annual energy spend. Thus if your spend is £50,000 a year, the budget would be £1,250 or about two days of a consultant's time -- just enough for a half-day survey and a report. Over the years there have been a succession of government-funded schemes which subsidise energy surveys, but a subsidy is a mixed blessing:

1. The funding body usually has its own agenda and a proportion of the work will be to satisfy their requirements, not yours.
2. The scope of work may be prescriptive and wider than you really need; in particular, it may call for a certain minimum number of recommendations, but the consultant acting independently may think that there are only one or two things worth pursuing.
3. The consultant may have to spend longer than is strictly necessary producing a report that meets the funder's specification when something simpler or different may be needed.
4. The funding body may have a for-profit arm to which it is feeding commercial information.

Finally, be cautious about entering arrangements in which the savings are shared between you and the consultant. There are ethical companies operating in this manner but the history of shared-savings schemes is littered with litigation, ill feeling and resentment. The consultant is the more powerful party in such contracts because they are on familiar territory. You will not be: do not take the risk.
3-4 Making the case for capital projects

EN 16001 tries to place an obligation on the top management of organisations to provide the necessary resources for the energy-saving programme, and while they may vote funds to support the essential sustaining activities, they are not likely to support proposals for energy-saving projects regardless of the strength of the business case. In fact, quite the opposite. Because energy projects are (a) somewhat technical and (b) unfamiliar territory, they suffer from being perceived as risky. They are also not business-critical, but fall into the discretionary category of investment which will always be trumped by projects such as those supporting environmental compliance (keeping directors out of jail) or marketing (maintaining or extending market share). It does not matter that a marketing campaign might be vastly more costly and more risky than an energy project, because a successful ad campaign has a huge up-side benefits.

So what are the ingredients for success against such odds? The first is to recognise that making the case for a project is not a one-off activity but is better viewed as part of a continuous ongoing process. Developing your reputation is key. A good way to start is to find one project that can be executed with complete certainty with the minimum or resources and a good return. People-based initiatives such as awareness-raising and training are usually excellent in this regard and are among the things you need to start with anyway; but sometimes there is an obvious technical project (one small pharmaceutical packing company saved £12,000 a year by putting a £250 hood over their shrink-wrapping machine). Use your monitoring and targeting scheme to confirm the savings that this first project achieves, and use it as an example of what you can do. Learn up about relevant legislation and regulation (which EN 16001 obliges you to track anyway) and about the world energy scene, climate change, emissions trading, and anything else that will help to make you the organisation's energy guru. Develop a view on the future of energy prices.

You should cultivate an ally among your top management. Find a director who is likely to see a successful energy-saving campaign as a feather in his or her personal cap, and involve them in your plans. This person will be able to act as your advocate, and give you guidance as to how best to position and present your ideas. It may be that they, rather than you, would make any final presentation of your request to the board.

Be very cautious about evaluating the cost-effectiveness of the projects you put forward. A bad project will quickly damage your hard-won reputation. Use appropriate evaluation tools such as discounted cash flow techniques (details of which can be found in management-accounting textbooks and on the web) with conservative assumptions, and pay particular attention to risk. Risks include not only price risk (the project costing more than anticipated) but the risk that it does not yield the expected savings. There may also be incidental risks like interruption to service or an adverse impact on quality, and circumstantial risks, such as impending closure of the facility which you are not aware of. You need to show that you have at least understood what the risks are, quantified them as
much as possible, and developed strategies for minimising their impact. Thorough treatment of risk will help to offset the board’s possible negative perceptions.

Take care about how you present your proposals, both in written form and as a live pitch. Preface your written proposal with a half-page summary (few board members have the time or inclination to read everything they receive for consideration) and, most important of all, give a single clear recommendation or request which they can accept or reject. Giving choices is to invite delay. If there were other options, describe them and explain why you rejected them. If appropriate, use pictures, models, or even samples of equipment to illustrate your suggested project. Find out what interests and motivates the people you are trying to influence, and align your request with their interests.

Once you have been given the go-ahead for your project, get on with it. Few things could be worse for your reputation and your relationship with your mentor than failing to implement an idea for which you were given support and resources.

Successful energy managers not only find it easy to get support for projects, but often find themselves being asked to suggest more. When you get there, it is a great position to be in, so always have additional plans in the pipeline.
3-5 Evaluating savings achieved

In chapter 1-2 I introduced the concept of having a model -- a mathematical formula -- for calculating expected consumption from known values of production, degree-day value or other driving factor ('energy factor' in EN 16001). One simple but widely-applicable model is the straight-line relationship between consumption E and driving factor P:

\[ E = c + mP \] (i)

For simplicity and clarity this chapter will refer exclusively to straight-line models and I will call the straight line the 'performance characteristic'. But do bear in mind that other more complex models could be used.

In chapter 1-3, I showed how the performance characteristic is used to compute the size and hence the cost of deviations from expected behaviour, evaluating all monitored streams across the board for an individual week. It was implicit, but now needs to be stated explicitly, that the performance characteristics used for overspend calculations are set at an aggressive-but-achievable level. This is because we want to assess every consumption stream against its best past performance. It follows that as time goes by and improvements are achieved (by whatever means) these target performance characteristics must continually be revised downwards to make sure they continue to represent best achieved performance.

Now in order to evaluate the savings that have been achieved we need to answer the question 'how much less have I used than I would have used in the absence of my energy-saving measures?'. The easiest way to answer this is first to calculate an expected consumption using not the target performance characteristic but the characteristic that applied before the measure were taken. This we designate as the historical baseline performance characteristic. A numerical example may help. Suppose a process historically used to operate on a characteristic of 1,000 kWh per week plus 30 kWh per unit of production. Let us say that in the last week production throughput were 100 units and energy consumption 3,500 kWh. How much energy was saved that week?

Expected consumption on the basis of the historical baseline would have been 1,000 + 30x100 = 4,000 kWh; thus the saving that week was 4,000-3,500 = 500 kWh.

Of course we usually need to compute the aggregate savings over an extended period, often 52 weeks. The mathematics is easy: we just need to account for the fact that there will be 52 lots of fixed consumption (c in equation (i) above). More generally, over an interval of t weeks, we would write the equation for expected consumption as

\[ E = tc + mP \] (ii)
Where $c$ is the intercept and $m$ the slope of the historical baseline characteristic. Let me illustrate this with another numerical example based on the same hypothetical process as before. This time I want an assessment for a 13-week period. Suppose that total production over the whole period had been 1,100 units and energy consumption 42,500 kWh. Substituting in equation (ii) we get an expected consumption of $13 \times 1,000 + 30 \times 1,100 = 46,000$ kWh and the aggregate saving is thus $46,000 - 42,500 = 3,500$ kWh.

Sometimes the energy manager wants to forecast, soon after implementation, the future savings that will accrue from a project. This is not a problem because as soon as the new target performance characteristic can be established with reasonable certainty, we can use a formula like equation (ii) to estimate the new expected consumption over any period of $t$ weeks. If the new performance characteristic has an intercept of $k$ (originally $c$) and a slope of $n$ (originally $m$) the saving $S$ over a year ($t = 52$) would be given by $S = 52(c-k) + (m-n)P$ where $P$ represents the budgeted total production for the year.

Figure 3-5-2 shows an actual case where a heating system's boilers and controls were replaced. Weekly fixed consumption dropped from 9,867 to 2,480 kWh, the slope of the line changed from 107 to 154 kWh per degree day and as the typical annual degree-day count in their region is 2,300, their annual gas saving is $(9,867 - 2,480) \times 52$ plus $(107-154) \times 2,300 = 276,024$ kWh.

Finally a word of warning. There is a lingering tradition of trying to use parameters called energy performance indicators (EPI) which are usually the simple ratio of kWh per unit of output or kWh per degree day. There are various reasons why EPIs cannot be used for assessing savings.
They are only ratios: the change in an EPI from one date to another tells you nothing about the absolute quantity of energy saved.

Whenever there is a fixed element of consumption (that is, in almost all cases) the EPI will vary with changes in the driving factor as well as with energy efficiency, and it is impossible to disentangle the two without complex corrections. Periods of high output flatter the EPI of an energy-intensive process while cold weather flatters the EPI of a heating system and vice versa.

An EPI cannot even be calculated at all if more than one factor influences consumption.

For these reasons EN 16001 does not require EPIs to be calculated (and although one mention of them leaked into the Standard's explanatory annex, it carries a health warning). My advice is simple: do not try to use them. You may reply that your senior management like them 'because they are simple and easy to understand', or you may be under the yoke of a government reporting scheme that requires them. Fine; continue reporting them if that is what you have been told to do. It does not matter that they never really meant anything and never will; regardless of that, with the advice contained in this book you will be much better equipped, on a day-to-day basis, to manage energy.
## Further information

<table>
<thead>
<tr>
<th>Organisation</th>
<th>How they can help</th>
<th>Contact details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Association for the Conservation of Energy</td>
<td>Trade body for suppliers of some energy-saving products</td>
<td><a href="http://www.ukace.org">www.ukace.org</a></td>
</tr>
<tr>
<td>Degree Days Direct</td>
<td>Summarised data relating to outside air temperature</td>
<td><a href="http://www.DegreeDaysDirect.com">www.DegreeDaysDirect.com</a></td>
</tr>
<tr>
<td>Energy in Buildings and Industry</td>
<td>Free journal</td>
<td>01889 577222</td>
</tr>
<tr>
<td>Energy Management Register</td>
<td>Free on-line advice, guidance and information on the practicalities of energy management</td>
<td><a href="http://www.vesma.com">www.vesma.com</a></td>
</tr>
<tr>
<td>Energy Services and Technology Association</td>
<td>Trade body for (a) energy consultants and (b) suppliers of some energy-saving technologies and services</td>
<td><a href="http://www.ESTA.org.uk">www.ESTA.org.uk</a></td>
</tr>
<tr>
<td>NIFES</td>
<td>Consultancy specialising in energy training, surveys, audits, and related engineering design and project management</td>
<td><a href="http://www.NIFES.co.uk">www.NIFES.co.uk</a></td>
</tr>
<tr>
<td>Spirax Sarco</td>
<td>Learning resources on every aspect of steam generation and utilisation</td>
<td><a href="http://www.SpiraxSarco.com/resources">www.SpiraxSarco.com/resources</a></td>
</tr>
<tr>
<td>Water, Energy and Environment</td>
<td>Free journal</td>
<td>01342 316390</td>
</tr>
<tr>
<td>Wolters Kluwer</td>
<td>Publisher of Croner’s Energy Management, a loose-leaf technical manual on the subject</td>
<td><a href="http://www.croner.co.uk">www.croner.co.uk</a></td>
</tr>
</tbody>
</table>