GOOD PRACTICE GUIDE 125

Monitoring and Targeting in small and medium-sized companies

GOOD PRACTICE GUIDE 125

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

This Guide was part-funded under the SAVE programme.

SAVE (Specific Actions for Vigorous Energy Efficiency) was set up to encourage the more efficient use of energy in the European Union through 'organisational means' by:

- developing Standards/Specifications for energy efficiency;
- developing financial techniques to promote and encourage investment in energy efficiency (e.g. Third-party Financing);
- promoting training and awareness for the efficient use of energy.

Further details of SAVE activities in the UK can be obtained from:

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MONITORING AND TARGETING IN SMALL AND MEDIUM-SIZED COMPANIES

This Guide is No. 125 in the Good Practice Guide series. It provides advice for small and medium-sized companies to show how Monitoring and Targeting (M&T) can be used to better understand energy usage and to reduce energy costs.

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First published March 1998

LIST OF RELEVANT GOOD PRACTICE GUIDES

111. MONITORING AND TARGETING IN FOUNDRIES
112. MONITORING AND TARGETING IN LARGE COMPANIES
113. MONITORING AND TARGETING IN THE SEMI-MANUFACTURE OF NON-FERROUS METALS
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217. CUTTING ENERGY LOSSES THROUGH EFFECTIVE MAINTENANCE (TOTALLY PRODUCTIVE OPERATIONS)
231. INTRODUCING INFORMATION SYSTEMS FOR ENERGY MANAGEMENT

Copies of these Guides may be obtained from:

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FOREWORD

This Guide is part of a series produced by the Government under the Energy Efficiency Best Practice Programme. The aim of the programme is to advance and spread good practice in energy efficiency by providing independent, authoritative advice and information on good energy efficiency practices. Best Practice is a collaborative programme targeted towards energy users and decision makers in industry, the commercial and public sectors, and building sectors including housing. It comprises four inter-related elements identified by colour-coded strips for easy reference:

— *Energy Consumption Guides:* (blue) energy consumption data to enable users to establish their relative energy efficiency performance;

— *Good Practice Guides:* (red) and *Case Studies:* (mustard) independent information on proven energy-saving measures and techniques and what they are achieving;

— *New Practice projects:* (light green) independent monitoring of new energy efficiency measures which do not yet enjoy a wide market;

— *Future Practice R&D support:* (purple) help to develop tomorrow's energy efficiency good practice measures.

If you would like any further information on this document, or on the Energy Efficiency Best Practice Programme, please contact the Environment and Energy Helpline on 0800 585794. Alternatively, you may contact your local service deliverer – see contact details below.

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CONTENTS

INTRODUCTION

Objectives

Energy monitoring and target setting is the collection, interpretation and reporting of information on energy use in order to measure and maintain performance, and to identify opportunities for improvement.

The objectives of this Guide are:

- to show how small and medium-sized companies can make use of routinely available energy and business data to reduce their energy bills;
- to give practical guidance on how to set up a simple energy Monitoring and Targeting (M&T) system;
- to show how to interpret the energy data gathered through an M&T system and how to apply this information to improve energy performance.

This Guide is written for managers of small and medium-sized companies who have responsibility for energy use and are interested in analysing possibilities for reducing their energy bills through M&T. It is also designed for consultants and other external advisors who are assisting small and medium-sized companies in establishing and using M&T.

M&T Advice from the Energy Efficiency Best Practice Programme

This Guide has been written specifically for small and medium-sized companies, i.e. organisations whose energy bill is typically less than £250,000 per year. The Guide has been produced for those wishing to conserve energy, irrespective of the technology and processes employed in their industry. A number of complementary Guides and Case Studies have also been produced. Details of these publications and other sources of information available to you are provided in Appendix E. The Energy Efficiency Best Practice Programme operates the Energy Helpline which provides free advice to small and medium-sized companies on a range of issues to help them cut energy costs. You can call the Helpline on 0541 542541.

Energy M&T

There are many ways to set about identifying savings opportunities and improving energy performance. These include:

- an energy survey - which is a physical inspection of buildings and machinery to identify faults and measure efficiency;
- employee-focused activities - campaigns to increase awareness, motivation and involvement throughout the company;
- organisational considerations - the establishment of improvement teams, assigning energy responsibilities, providing specialist training, etc.

These are all well-tried and tested activities - proven to be effective in producing energy cost savings.

M&T is not a substitute for these actions. In fact, it can often provide useful information when implementing these other approaches, thus making them more effective. For example:

- in a survey, M&T indicates where to look for energy saving opportunities;
- by monitoring energy consumption, M&T shows deviations from expected patterns of energy use and highlights the need for closer managerial control.

Energy M&T has much in common with the information side of quality management. It uses many similar techniques of information gathering, analysis and reporting. In businesses where there is an information-based programme of quality improvement already operating, energy M&T will almost certainly share some information and management systems.

For organisations keen to reduce their environmental impact, energy efficiency has a key role to play. All formalised systems of environmental management have a requirement for an information system which M&T can provide for the energy component (and indeed much of the waste avoidance areas).

The aim of this Guide is to introduce the capabilities and benefits of M&T. The methods of data handling and reporting available are outlined to enable readers to maximise the benefits of the approach.

Energy Management and the Smaller Firm

The many differences between large and small firms affect the way in which they approach energy management. These include the management structure, the availability of specialist skills, organisational barriers and the scale of operation. In the larger firm, senior management can delegate energy management to people with specialist knowledge and skills. The interest of senior management in M&T is in the reporting systems as much as the management of the energy itself. Reporting systems provide a means of monitoring the performance of people who have been made responsible for energy use, and can be used to support aspects of management in hierarchies, e.g. budget control. In smaller firms; the interest in M&T is in the direct savings it produces, which is the emphasis of this Guide.

The most important differences between large and small firms, however, tend to be due to the scale of operation. In a large firm with an energy bill of over £1 million, the decision is not *whether* to install meters to provide insight into the breakdown of these costs, but *how many* meters and where to put them. The cost of a meter does not vary much with the amount of energy that goes through it and, for a smaller firm, the justification for investment in additional metering becomes much more difficult.

The Approach Used in this Guide

The approach used in this Guide is dominated by three themes:

1. What can be learned from information on energy consumption - how buildings and processes use energy and sources of energy wastage.
2. How to extract the maximum knowledge from information that is already routinely available - in particular by breaking down the overall energy use of a site to create a picture of where and how energy is used.
3. How to avoid investment in additional metering (as far as possible) by maximising the use of available information.

The Guide offers something to every level of readership - from those for whom M&T is a completely new activity, to those who have already gone some way and wish to do more. All calculations are clearly explained and presented as examples, and guidance is given on setting up simple spreadsheet systems.

The Role of Computers

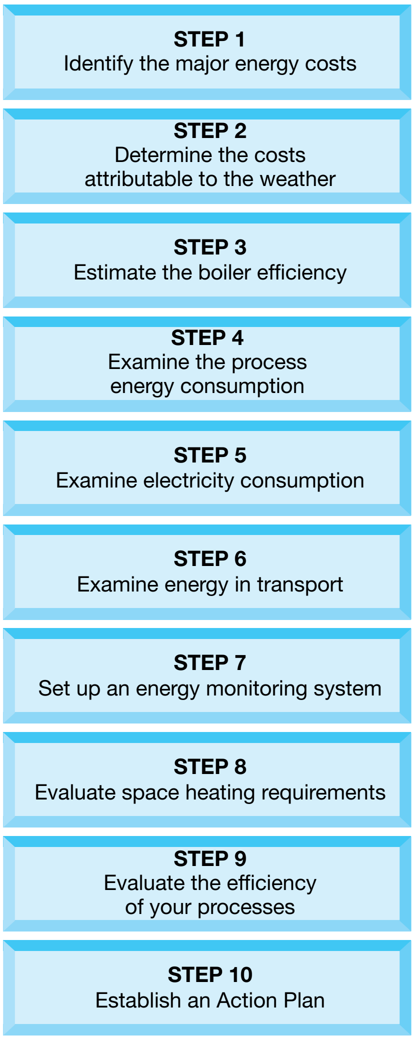
The procedures in this Guide can be carried out using paper, pencil and a hand calculator. However, all of the procedures are quicker and less error-prone when carried out using a computer equipped with spreadsheet software incorporating a graphics capability.

A number of commercial M&T software packages are available. A word of warning - they are usually designed on the basis of the philosophy that the designer believes is attractive to their main markets, i.e. the larger firms. Smaller firms should examine commercial software closely before purchase to ensure that it implements M&T in a style they wish to operate.

How to Use this Guide

The advice given in this Guide about implementing M&T in medium and smaller firms is described in a series of practical steps. These steps have been structured so that by starting from Step 1 and proceeding in sequence to Step 10, you will be provided with an increasing depth of analysis, insight and detail. The sequence of the steps can be varied with your requirements if you wish. Missing some of the later steps may be desirable, e.g. if transport is not a major issue for your company. However, it may still be useful to glance at each of the steps to make sure nothing useful is missed.

The ten steps are shown in the diagram below which is repeated throughout the Guide to help you locate the relevant activities. A summary box is also provided at the start of each section.



1

STEP 1 IDENTIFY THE MAJOR ENERGY COSTS

STEP 1
Identify the major energy costs

STEP 2
Determine the costs attributable to the weather

STEP 3
Estimate the boiler efficiency

STEP 4
Examine the process energy consumption

STEP 5
Examine electricity consumption

STEP 6
Examine energy in transport

STEP 7
Set up an energy monitoring system

STEP 8
Evaluate space heating requirements

STEP 9
Evaluate the efficiency of your processes

STEP 10
Establish an Action Plan

Step 1 shows you how to:

- compile summary charts of your energy use (cost and kWh);
- produce pie charts showing where the major sources of energy use and cost lie in your company (by energy type).

Any electricity or gas you use is metered into your premises by your supplier who will take regular meter readings and indicate these on the invoice. Your oil or coal supplier will have recorded the amounts delivered on the invoice.

The bills, therefore, are valuable information with which to start. You can supplement this with further readings from additional meters, if there are any. Boilerhouse records are also useful.

Gather together all of the bills for electricity and fuel for the past year and use the information they contain to complete the following two charts on energy costs and energy consumption. You may do this manually - directly onto the blank charts provided - or compile a simple computer spreadsheet to simplify the calculations.

Chart 1 - Energy Costs

Fill in Chart 1 (page 6) in the following way:

Write the name of each separately supplied heating fuel (oil, gas, firm gas, interruptible gas, coal, etc.) at the head of columns 2, 3 and 4.

Enter the cost of each fuel used in the month and add these together to find the total (column 5).

Enter the cost of transport fuels (column 6).

For *oil* and *coal* the invoices will carry information on deliveries. The information you are really interested in is consumption. To obtain this you need to take account of stocks. If stocks are not already routinely recorded, look at the suitability of your data before devoting a lot of time to it, and institute a system for recording the stock before delivery (for oil use a dipstick; for coal work out the volume from the geometry of the stockpile or bunker - assume the density of loose coal to be 0.82 te/m^3 if a figure is not available from your supplier).

For *gas* and *electricity*, the information that appears on the bill depends on the type of tariff you use. It is assumed that users of this Guide are using a monthly tariff, in which case, in addition to kWh, other indicators appear on the bill.

A letter 'E' after the meter reading indicates that the supplier has estimated the reading. If this happens frequently, institute a system of regular meter readings by your own staff - as close to the last day of the month as possible.

Enter the costs for electricity consumption (columns 7 and 8) showing the costs for day and night tariffs separately.

Electrical units may be recorded separately on the bills for night (low tariff) and day (normal tariff) - this will depend on the tariff structure being used. Enter the costs for each kWh element that is separately charged.

Enter maximum demand (column 9) and availability (column 10) taken from the monthly electricity bills.

Maximum demand is the highest kW or kVA used in any half-hour in the month. It tends to incur a charge only in a few months of the year, and information on the size of maximum demand may or may not be recorded when it is not charged for.

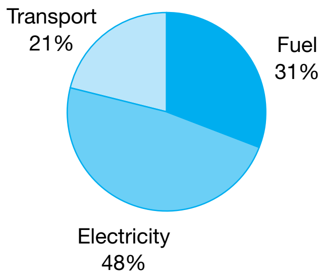
Enter all other electricity costs (column 11). These might include standing charges, power factor, etc. (do not include VAT).

Power factor is a concept that confuses many people. It is how much electric current you draw from the supply compared with the energy you take. It is a number between 0 and 1. If it is not shown separately but both kW and kVA are indicated on the bill, it can be calculated by dividing kW by kVA (power factor = kW/kVA). It is normally an avoidable cost - the supplier's tariff sheet indicates what the basis is for any charge. If the power factor is above 0.9 then there is little need to be concerned; if it is below 0.9 it is worth seeking the advice of your electricity distributor.

Add up the totals for each column and calculate the total energy cost for the year. Use this to calculate the percentage of each energy type as a proportion of total energy costs.

Draw up a pie chart showing the distribution of energy costs using the percentages you have just calculated.

Guidance on drawing up pie charts is given at the end of this section, and some blank charts have been provided for you to use if you wish.



Pie chart of basic energy costs by type

Chart 1 - Energy costs

1	2	3	4	5	6	7	8	9	10	11	
Fuels						Electricity					
Month	Fuel 1	Fuel 2	Fuel 3	Total	Transport fuel	Day kWh	Night kWh	Maximum demand	Availability kVA	All other	
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											TOTAL
Sub-totals											
%											

Chart 2 - Energy Consumption

Fill in Chart 2 (see page 8) in the following way: (Note that electricity and gas are both charged in kWh and it is advisable to work entirely in these units. Column 2 is for degree days data - this will be dealt with in Step 2.)

For each fuel type (including transport fuels), find the relevant conversion factor (from the billing unit to kWh) from the table below and enter it at the bottom of each column in Chart 2.

Enter the amount of fuel used in the month (in its original units) in the appropriate column.

Calculate the total heating and process fuel used each month in kWh and enter this in column 6. Do this by multiplying each of the monthly fuel data (columns 3, 4 and 5) by the conversion factor at the bottom of the column and adding them together.

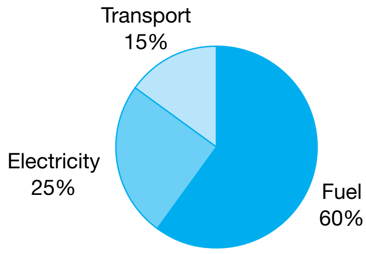
Calculate the transport fuel used each month in kWh and enter this in column 8.

Enter the amount of electricity consumed in the month in columns 10 and 11, showing day and night consumption separately. Also include maximum demand and availability (columns 12 and 13).

Note: maximum demand and availability are not measured in kWh and should not be included in the totals in this chart.

Add up the column totals and the total energy consumption of all fuels in kWh, then work out the corresponding percentages. There is also a box for you to work out your carbon dioxide (CO_2) emissions if these are of interest.

Draw up a pie chart showing the distribution of energy consumption using the percentages you have just calculated.



Pie chart of energy consumption by type

Table of fuel conversion data

Fuel	Supply unit	Factor to kWh	Factor to tonnes of CO_2
Natural gas Natural gas	therm kWh	29.31 1	0.00573 0.000196
Electricity	kWh	1	0.00056 (for 1997 supply mix)
Gas oil Light fuel oil	litre litre	10.56 11.28	0.00263 0.00281
Medium fuel oil Heavy fuel oil	litre litre	11.33 11.44	0.287 0.00299
Propane Butane	tonne tonne	14,240 13,750	2.75 3.04
Coal	tonne	8,000	2.56
Derv Petrol	litre litre	10.56 9.71	0.00263 0.0024

Chart 2 - Energy consumption

1	2	3	4	5	6	7	8	9	10	11	12	13		14	15	16
		Heating and process fuels				Transport fuel		Electricity						Electricity		
Month	Degree days	Fuel 1 qty	Fuel 2 qty	Fuel 3 qty	Total kWh	litres	kWh	Reading date	Day kWh	Night kWh	Maximum demand	Availability kVA		Reading interval days	Day kWh per hour	Night kWh per hour
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
Sub-totals																
%																
Fuel factors to convert to kWh													TOTAL			
CO_2																
Fuel factors to convert to CO_2													TOTAL			

Producing Pie Charts

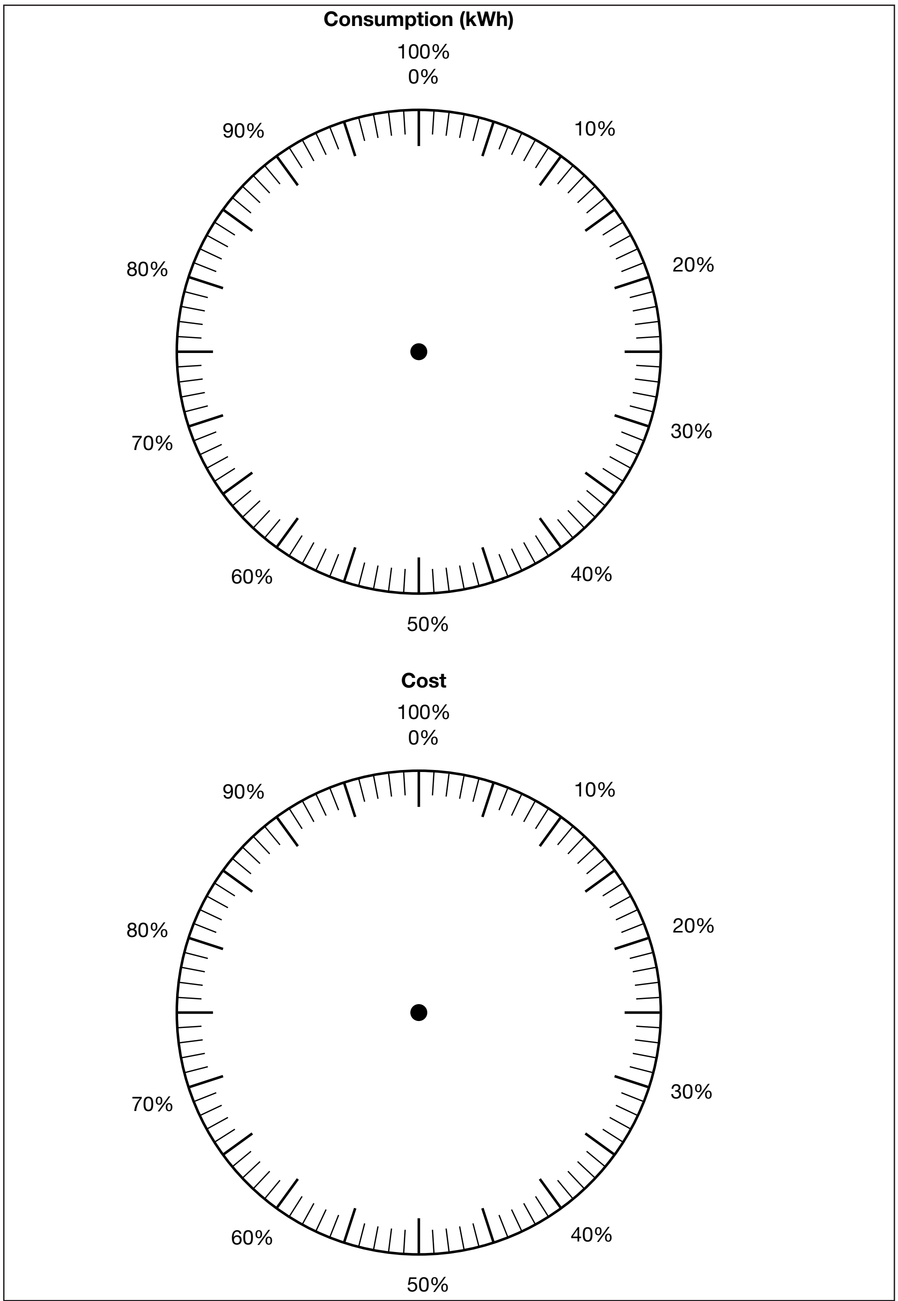


Fig 1 Blank pie charts

The blank pie charts in Fig 1 are provided for you to set out your energy consumption and costs in a way that will indicate how your energy is used and what this costs. There are two charts, one for consumption in kWh and one for costs. These are likely to look very different by the time they are complete because of the relative costs of electricity and fuel.

The whole pie chart represents your total energy use. At the end of each step you can show in greater detail the proportion of this total energy that can be attributed to different energy consuming activities.

The pie chart provides an immediate visual impression of the relative importance of each area of energy use and cost, and enables you to decide which areas to prioritise in any action plan.

Each of the 10 steps of the Guide shows an illustration of the form that the pie chart should take, and the part of the pie chart being dealt with at that stage.

2

STEP 2 DETERMINE THE COSTS ATTRIBUTABLE TO THE WEATHER

Step 2 shows you:

- the significance of 'degree days' to energy usage;
- how to plot an x-y graph of energy consumption against degree days;
- examples and interpretations of typical energy vs. degree day graphs;
- how to use your graph to calculate the proportion of energy use that relates to the weather, and to show this weather-related energy use in the pie charts.

Degree Days

Degree days are a measure of the variation of outside temperature and enable building designers and users to determine how the energy consumption of a building is related to the weather. They quantify how far, and for how long, the external temperature has fallen below set base temperatures (normally 15.5°C for heating applications). This daily data can then be totalled for any required period - a week, month, year, etc. and compared with energy data.

Figures for degree days are available from a variety of sources and are published bi-monthly in *Energy & Environmental Management*, a magazine published by the Department of the Environment, Transport and the Regions (DETR). Details of how to receive this free publication are given in Appendix E. Further guidance on the use of the degree day can be found in Fuel Efficiency Booklet 7, *Degree days*.

Comparison of heating energy with monthly degree days has several valuable applications:

- to determine what part of your energy use is for space heating;
- to determine whether the space heating is operating satisfactorily;
- to evaluate the potential impact of energy saving measures.

Creating the Energy vs. Degree Day Graph

Locate degree day data for your region and complete column 2 of Chart 2.

Decide which, if any, of the metered forms of energy you currently use for space heating. Plot a scatter diagram (x-y graph) of data from this meter against degree days - by hand or using a computer spreadsheet with graphics.

A range of sample graphs are shown (Fig 2). Compare the appearance of your graph with these and decide whether your pattern is best represented by a single straight line (Types 1 or 2), two straight lines (Types 3 or 5) or a curve (Type 4). If the points are too scattered to fit a specific line, the graph may most resemble Type 6.

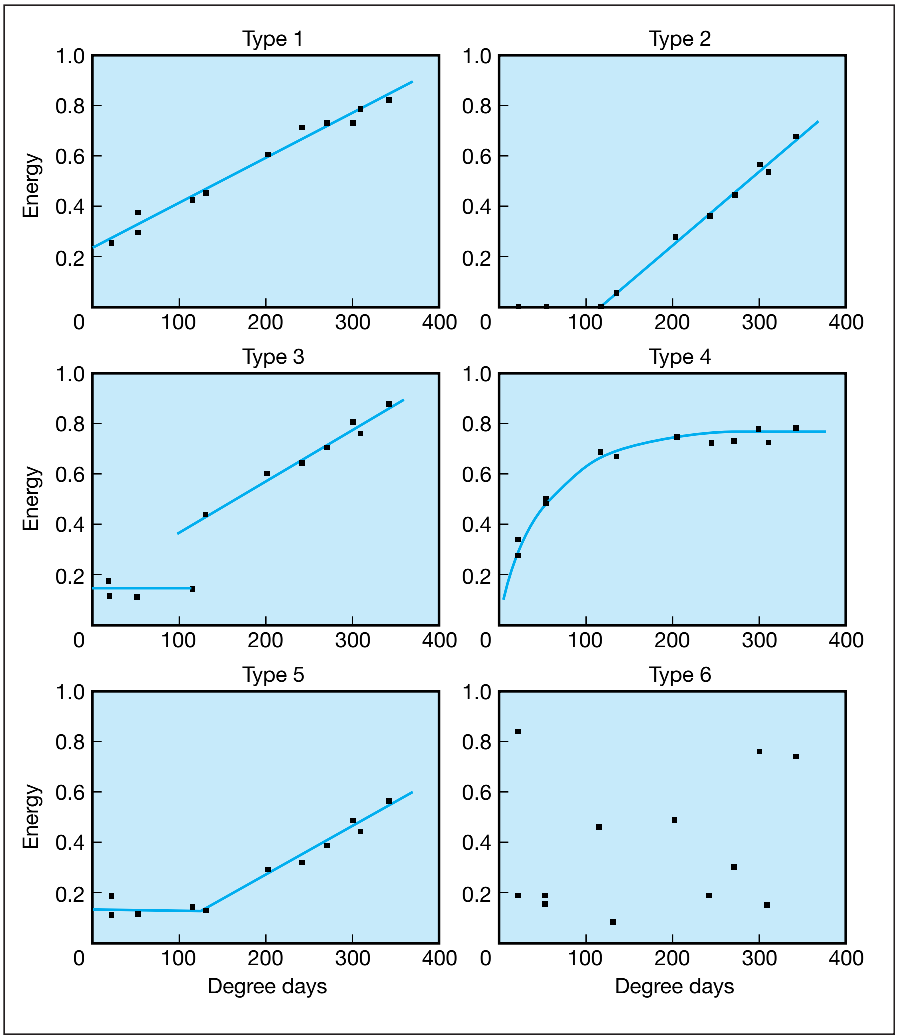


Fig 2 Energy vs. degree day plot variations

Types 1 - 5 are likely if the metered energy is used for:

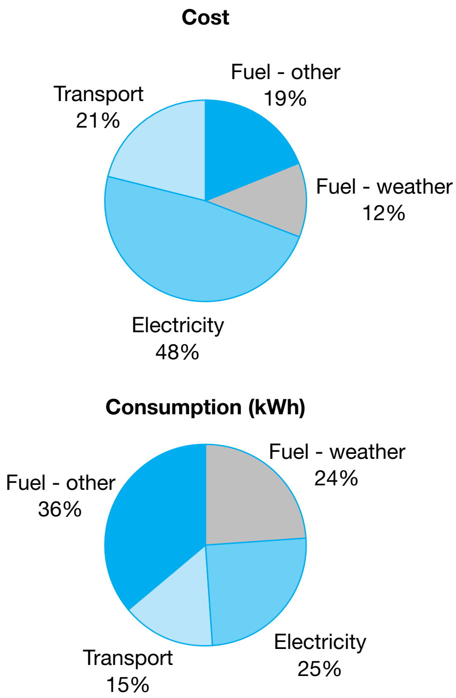
- space heating only;
- space heating and production where:
    - production does not vary much;
    - production varies but energy consumption remains steady.

Draw a best fit line through the points on the graph according to which type you think the points correspond. Extend the line as far as the border of the graph. If it cuts the energy axis, this intercept is the fuel consumption that does not relate to space heating.

By deducting this figure from the total energy consumption you can determine the proportion of fuel which is directly related to degree days, and hence to external weather conditions. (The box overleaf explains how to do this for each of the graph types.)

You may have a variable production process that is supplied with the same energy type as, and metered together with, your space heating system. In this case the procedure described in Appendix B will enable you to determine the proportion of consumption relating to space heating.

Now you can mark the space heating energy consumption and cost onto your pie charts. The charts now show how much of the fuel energy consumption is weather-related. In this example we have assured that electricity is not used for space heating.



Cost and energy consumption pie charts updated with space heating (weather) contribution

Calculating energy used for space heating from energy vs. degree day graphs

For Type 1, extend the sloping line back to zero degree days. Note the energy value at which the extended line cuts the energy axis. Subtract, from the total energy in one year, the number of data points in a year multiplied by this intercept value. The remainder is the energy used for space heating.

Example: The total energy use in a year is 21,900 GJ and the line cuts the energy axis at 560 GJ a month. 1 GJ = 1,000 MJ, 1 kWh = 3.6 MJ. Data is presented monthly so there are 12 data points. The space heating consumption is:

$$21{,}900 - (12 \times 560) = 15{,}180 \text{ GJ}$$

$$= 4{,}217{,}000 \text{ kWh}$$

$$\text{ratio} = \frac{15{,}180}{21{,}900} \times 100\%$$

$$= 69.3\%$$

For Type 2, all the fuel is for space heating.

For Type 3, extend both lines back to zero degree days. Note the energy value at which the higher line cuts the energy axis. Subtract, from the total energy in one year, the number of data points in a year multiplied by this intercept value. The remainder is the energy used for space heating, as for Type 1. The difference between the points where the two lines cut the axis represents energy used which is not related to the weather when the heating is on - usually losses in the distribution system. Multiply this difference by the number of points lying in the higher line and you have identified a use of energy you probably did not know the cost of before.

For Type 4, note the energy consumption in the months with the lowest degree days. The average of these is the energy use when the heating is probably not used. Subtract, from the total energy in one year, the number of data points in a whole year multiplied by this value. The remainder is the energy used for space heating, as described for Type 1.

For Type 5, note where the horizontal line cuts the energy axis. Subtract, from the total energy in one year, the number of data points in a year multiplied by this value. The remainder is the energy used for space heating.

For Type 6, consider the causes of scatter. There are usually two possibilities:

- problems in the data gathering - the energy and degree day data are not co-ordinated properly, i.e. energy and degree days are not measured in the same time interval - check this;
- variations in production, or some other variable, overwhelm the effect of weather - use the procedure in Appendix B.

What the Data Tell You About Energy Use

The line you have drawn on your graph can already tell you a lot about fuel use at your site. In this section the main characteristics of each of the graph types are highlighted. Consider whether the form of your chart is consistent with what you thought you knew about your buildings.

A straight sloping line, Types 1 and 2, and the straight sections of Types 3 and 5, indicate that the building is maintained at the same temperature over the part of the season where the line is straight. If the building is comfortable at any time, then it could reasonably be expected to be comfortable all through the year. It also means that the boiler efficiency is the same throughout this part of the year. This does not necessarily mean that the building is also efficient, but it is unlikely to be grossly inefficient. About 60% of all buildings fall into this category.

A curve (Type 4), indicates that constant temperature is not maintained in the building. There are two reasons for this:

1. limited heating capacity in the heating system, when the need is mainly just to take the chill off;

2. poor temperature control in the building, usually as a result of local imbalances of supply and demand for heat, resulting in overheating of some areas and underheating of others.

The curve may be slight or, in the extreme, could come close to levelling out at high degree days. If the heating is intended only to take the chill off (e.g. a warehouse, workshop, garage, greenhouse), this may be acceptable; where a stable temperature is the intention, it points to a building where very substantial savings in energy consumption can often be made. About 25% of buildings fall into this category.

Where the line cuts the border of the graph is significant. If tracing the line back to the border causes it to intercept the degree day axis (Type 2), this means that the weather has to turn quite cool before heating is needed at all. This will happen either because the building is maintained at a relatively low temperature or because heat from other sources contributes significantly to the building heating, e.g. the heat given off by lighting, machinery or processes.

If the line intercepts the energy border (Types 1 and 3) this indicates the energy which is not used for space heating.

A horizontal line (Types 3 and 5) means that, over this range of degree days, the energy use does not depend on the weather. This could be because of some other use of heat, e.g. production, or losses from an extensive energy distribution system.

If the line is broken it means that, when space heating is being used, it is associated with an increase in weather-unrelated energy as well - often attributable to inefficiencies in the heat distribution system. It is particularly common in sites with a centralised boilerhouse.

If the line bends upward from the horizontal (Type 5), this is the combination of a horizontal line and Type 2, and indicates that space heating is not required until the degree days reach a particular level. The reasons are the same as those given for Type 2 - a building maintained far below 15.5°C or a building which is receiving heat from some other source.

A graph of Type 6 means that the effect of weather variation on energy use is overwhelmed by variations in other factors.

It is worthwhile exploring one further aspect in all graphs that show high scatter by connecting the data points by lines in time series order. The presence of loops is a good diagnostic test for some building heating control faults. Loops appear when the energy consumption for a given level of degree days is different, according to whether the weather is getting warmer or colder. Degree days measure the outside temperature. All other things being equal, the energy consumption should be the same, irrespective of season. Loops are caused by poor temperature control and inconsistent operation of time clocks on heating plant. They can also be caused by effects of the sun, which are not common in industrial buildings.

3

STEP 3 ESTIMATE THE BOILER EFFICIENCY

Step 3 shows you how to:

- compile a graph of heat output vs. fuel use for your boiler and calculate efficiency from the slope;
- calculate boiler losses (combustion losses and blowdown/radiant losses);
- update pie charts to show the proportion of fuel use associated with boiler losses.

The pattern of energy vs. degree days, and the pattern of energy vs. production (to be examined later), contain valuable quantitative information on the efficiency of processes and losses relating to energy for space heating. Where processes and building heating are not direct-fired, an important ancillary piece of information is the boiler efficiency.

An important fact to remember is that boiler losses affect every unit of energy which passes through the boiler.

If you have a boiler, you should always carry out periodic maintenance to maintain efficiency and, as part of this, a combustion efficiency test should be carried out. If you have a boiler of any significant size, combustion tests should be carried out at even shorter intervals.

If information from these is not available immediately, use an estimate of the efficiency from the table below.

Approximate efficiencies of well-maintained boilers operated correctly between 50% and 100% of rated output, based on gross calorific value of the fuel to hot water or saturated steam

Boiler type	Efficiency (%)
Condensing	88 - 92
Shell boiler - hot water	78 - 80
Shell boiler - steam	75 - 77
Water tube with economiser	75 - 78
Cast iron - sectional	68 - 72
High efficiency modular	80 - 82
Steam generator	75 - 78

Measuring Boiler Efficiency

A boiler converts the energy in the fuel first into hot gases in the flame and then, by transferring the heat, to water or steam. Not all the heat from the fuel is, or even can be, transferred to the water or steam - the remainder passes up the flue as **flue losses.**

The ratio of the heat in the water or steam divided by the energy in the fuel is the **efficiency** of the boiler. It is usual to state this either as a percentage or as a number between 0 and 1. An efficiency of 75% or 0.75 means the same.

In addition to the flue losses, there are two common, possibly large, losses of heat from the boiler - radiant heat from the boiler shell and blowdown (*blowing down* is releasing water from the boiler, under pressure, to expel impurities which build up in the boiler water).

There are two ways to measure boiler efficiency: by measurement of flue gas composition or by calculation from fuel use and metered heat output.

Boiler combustion tests

In boiler combustion tests, either the carbon dioxide content or the oxygen content of the flue, and the flue gas temperature are measured. If you are currently using combustion tests you are probably already using charts which relate the gas analysis and temperature to efficiency; if not, these are provided in Fuel Efficiency Booklets 14, 15 and 17 - which also describe how to use them.

Comparison of the boiler fuel consumption with boiler output

A simple estimate of boiler efficiency can be calculated by dividing the total steam output by the fuel consumption over a long period. This method is possible only if there is a meter for both the fuel into the boiler and the output (steam is the only output which commonly has a meter).

If regular readings of boiler fuel and steam output are available, it is prudent to go further. Plot a scatter diagram with fuel as the x-axis and output as the y-axis - an example is given in Fig 3 at the end of this section. The result should be a good fit to a straight line with very little scatter, which, if extended back to zero output, either goes through the point 0,0 or as close as hardly matters. If this is verified, dividing the total output by the total fuel input represents the slope of the line, and from this the efficiency can be calculated - it should be very close to the combustion efficiency measured from the flue.

If the graph does not extend back to 0,0 but cuts the fuel axis, this is indicative of high losses from boiler blowdown or other losses from the boiler. Quantify these as a proportion of fuel consumption and costs by:

$$\text{non-flue losses} = \frac{\text{fixed fuel consumption}}{\text{average fuel consumption}} \times 100\%$$

If these losses are high you need to consider what remedial steps may be necessary - water purification (if it is high blowdown), improved boiler controls or a smaller boiler.

To calculate boiler efficiency (from the slope of the output vs. fuel graph) we need to convert the fuel and the output to the same units of energy. Use the fuel conversion factors in your own version of Chart 2 to convert fuel to kWh.

If the boiler output is metered as steam, it is measured as lb or kg and the output is at some particular pressure. Use the table overleaf to convert steam output to kWh. The table indicates the energy content of saturated steam at various pressures.

Energy content of saturated steam at various pressures

Gauge pressure (bar)	(psi)	Temperature (°C)	Total energy content (kWh/kg)	(kWh/lb)
1	14.5	100	0.7431	0.3371
2	29.0	120	0.7517	0.3410
3	43.5	134	0.7569	0.3433
4	58.0	144	0.7592	0.3444
5	72.5	152	0.7631	0.3461
6	87.0	159	0.7653	0.3471
7	101.5	165	0.7672	0.3480
8	116.0	170	0.7689	0.3488
9	130.5	175	0.7700	0.3493
10	145.0	180	0.7711	0.3498
11	159.5	184	0.7722	0.3503
12	174.0	188	0.7731	0.3507

Boiler losses can now be calculated using a known figure or an estimate of the boiler efficiency:

- as a percentage of total fuel use:

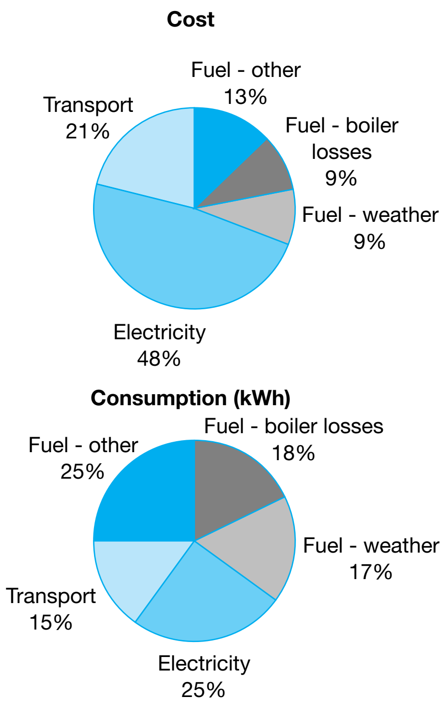
$$\text{boiler losses (\% total fuel)} = \text{boiler fuel (\% total fuel)} \times \frac{(100 - \text{boiler efficiency in \%})}{100}$$

- in kWh per year:

$$\text{boiler losses (kWh)} = \frac{(100 - \text{boiler efficiency \%})}{100} \times \text{annual boiler fuel use} \times \text{fuel conversion factor}$$

Mark the boiler losses on your pie charts. The charts now show how the fuel consumption element is composed of:

- weather-related energy use;
- boiler losses;
- other (e.g. production).



Pie charts updated for boiler losses

Worked example of efficiency calculation

Fig 3 shows the steam output and fuel consumption in a textile finishing works. The line almost passes through 0,0. The average steam production was 21 lbs steam per litre of oil. Steam pressure was 150 psi, the energy content at this pressure is 0.35 kWh/lb. The energy content of the oil is 11.33 kWh/litre.

The average efficiency is therefore:

$$\text{efficiency} = \frac{0.35 \times 21}{11.33} = 0.649 \text{ or } 65\%$$

Compared with the table given at the start of Step 3, this is not a particularly good performance.

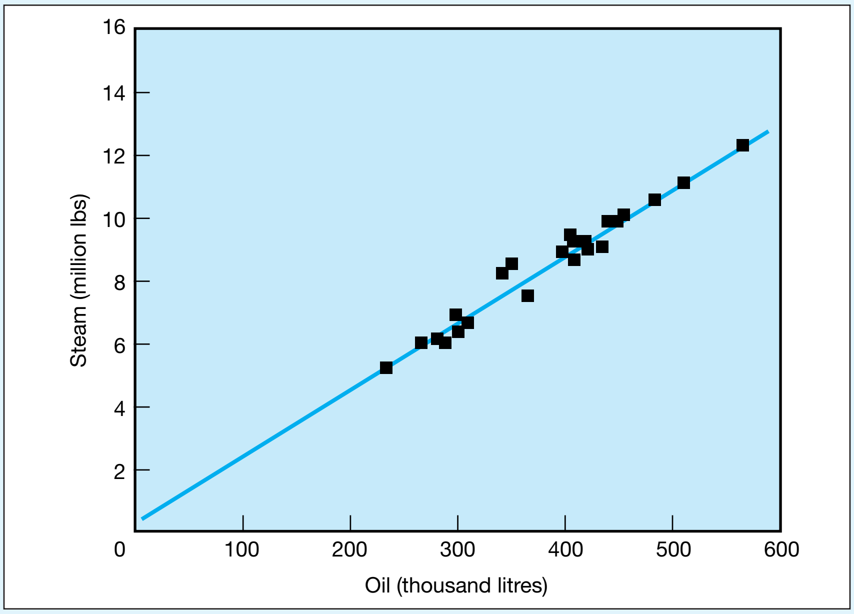


Fig 3 Steam output vs. oil use for a boiler in a textile works

4

STEP 4 EXAMINE THE PROCESS ENERGY CONSUMPTION

Step 4 shows you how to:

- plot a graph of fuel use against production;
- calculate non-productive fuel energy use for processes with a significant fixed fuel energy consumption, and show this as a proportion of total fuel use on the pie charts;
- interpret common forms of the graph and relate them to process characteristics.

Fixed and Variable Energy Costs

Most managers are very familiar with the idea of fixed and variable costs.

- Fixed costs are costs incurred irrespective of whether, or how much, you produce - they do not change as output changes.
- Variable costs are those costs that do change with production.

Fixed costs are often lumped together as overheads. The total cost is the fixed and variable costs added together. The total cost divided by the production output is the **unit cost.** The concept of fixed and variable costs is often used to calculate the **break-even point** - where unit selling price equals the unit production cost.

Energy costs also divide into fixed and variable costs, and separating these can provide a significant insight into the efficiency of energy use. There is, however, an important difference in the way these are determined compared to the normal accounting of production costs. Ordinarily, which costs are fixed and which are variable are more or less known already and are determined by the nature of the cost item. For example: rent, rates, salaries and capital costs are fixed, whereas raw materials and waste disposal are required in proportion to the amount of production, and so are variable. Total costs are arrived at by multiplying the variable costs by the amount of production and adding these to the fixed costs:

total costs = fixed costs + (production x unit variable cost)

In the case of energy, we usually know the total energy cost for given production levels and can work back to find the fixed energy cost:

fixed costs = total costs - (production x unit variable cost)

In this section we show how to determine fixed (non-productive) fuel energy consumption from a graph of fuel energy use vs. production.

Relating Energy to Production

If energy use for production in any one particular process is a significant part of your overall cost, you should ensure that the fuel used by that process is separately metered, and set up some sort of monitoring system for that process. This is to ensure that you can both control and allocate costs appropriately.

If you have a meter that enables you to record the energy use of a process separate from other demands, base your monitoring system on meter readings which are weekly rather than monthly.

Time the energy meter readings to coincide as closely as possible with the existing production log. For example, if production is recorded each week at the close of day on Friday, have the meter reading timed to coincide.

If the number of working hours varies significantly, record these too.

> If you do not have separate metering of energy for production and energy for space heating, use the procedure in Appendix B to determine whether there is a large enough dependence on production to warrant this analysis.

See if you can relate fuel energy to production in any meaningful way. Plot a scatter diagram of fuel energy against production (use a scale which has zero for both energy per week and production per week in the bottom left corner).

Compare it with the example graphs in Fig 4.

If you have a type in which there is a clear fixed energy consumption (i.e. a high intercept with the energy axis - Type 2) calculate this as a proportion of total energy use. To do this, multiply the energy at zero production by the number of data intervals in the year and by the fuel factor which converts your fuel to kWh (from the table in Step 2):

$$\text{energy}_{\text{non-productive}} \text{ (kWh/yr)} = \text{energy}_{\text{at zero production/week}} \times 52 \times \text{fuel factor}$$

Work out non-productive energy as a percentage of the total fuel energy use (in kWh).

Mark non-productive fuel energy on your pie charts.

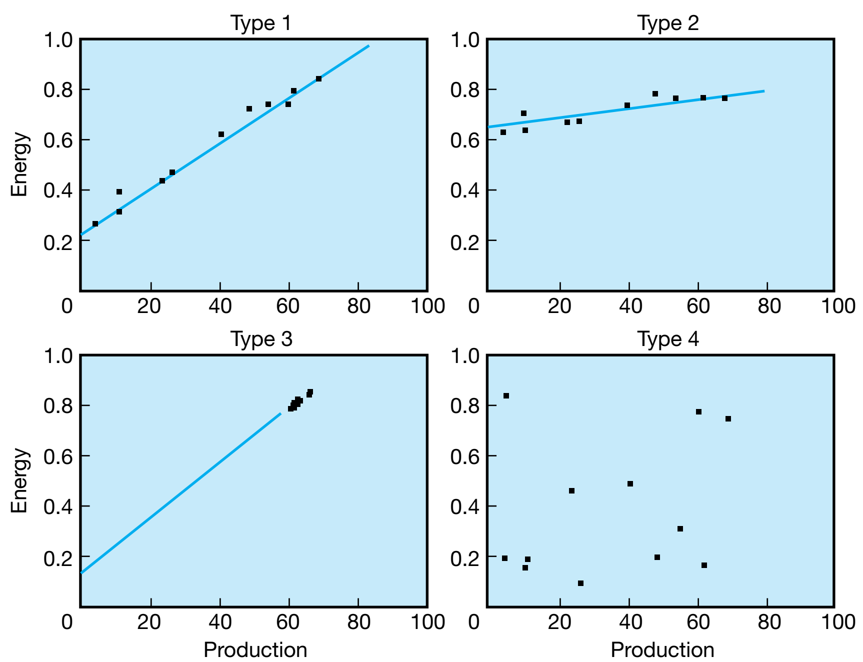
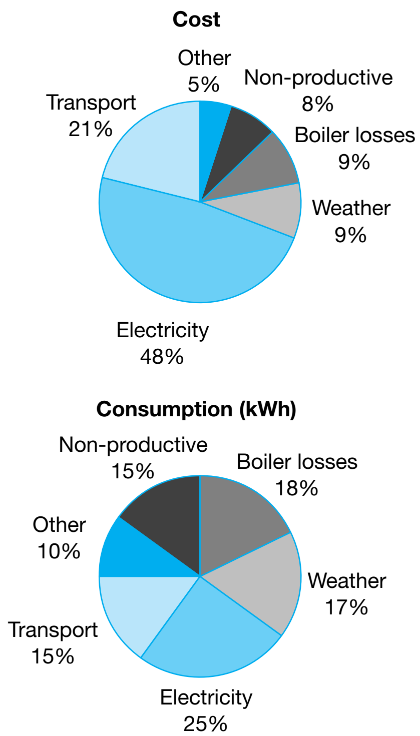


Fig 4 Typical graphs of fuel energy vs. production



Pie charts updated for non-productive fuel energy use

What the Data Tell You About Process Fuel Energy Use

Type 1 is the commonest type of process, where the line is straight with some energy use at zero production. The straight line means that the part of energy use which depends on production is equally efficient at all production rates.

Type 2 is the same as Type 1 but fixed consumption is a high proportion of total consumption. There are three common reasons for this:

a) High fixed energy consumption is inherent in some processes - extruders for plastics processing and some kinds of pottery kiln are examples.

b) A data problem where the measure of production used does not closely represent the duty of the process - a clue to this is a wide range of types of production of similar kind, e.g. papermakers producing many kinds of paper. In a drying process, what really determines your energy use is the water evaporated, not the product coming out at the end. Most factories which encounter this have the means to calculate the water evaporated, from the production data, when it tends to appear more like Type 3.

c) There is a large and avoidable loss in the system. Some areas to consider are:

- on steam heated plant, suspect faulty steam traps;
- if monitoring water, suspect a leak;
- on heating plant, suspect inadequate insulation.

Type 3 is a cluster of points and will result if you operate a narrow range of production rates. Examine which stage of the process decides your overall production rate. If the role of energy here is central to the process, which is commonly the case (e.g. in the way an oven is central to bread-making), improvements to the energy efficiency of this stage can increase your productive capacity. Improved energy efficiency will then produce benefits substantially over and above the direct reduction in energy costs.

Type 4 is a widely scattered graph where it is difficult to draw a line at all. It can be due to the following:

- the measure used for production bears insufficient relation to energy use[1] - seek another measure which does;
- collection of the data on production and energy is inadequately synchronised - data do not relate to the same time interval;
- there are factors which also affect energy use other than the measure of production you have chosen.

You should investigate all these possibilities as Type 4 would seem to indicate that you have poor control over costs and, unless some sense can be made of the scatter, there seems to be little prospect of being able to improve control.

There are other patterns which can occur but they are less common. These are dealt with in GPG 112, *Monitoring and Targeting in large companies*.

[1] Check that this has not occurred simply because you have not set the graph scale at 0,0 in the left-hand corner and are, in fact, dealing with Type 3.

STEP 5 EXAMINE ELECTRICITY CONSUMPTION

5

STEP 1
Identify the major energy costs

STEP 2
Determine the costs attributable to the weather

STEP 3
Estimate the boiler efficiency

STEP 4
Examine the process energy consumption

STEP 5
Examine electricity consumption

STEP 6
Examine energy in transport

STEP 7
Set up an energy monitoring system

STEP 8
Evaluate space heating requirements

STEP 9
Evaluate the efficiency of your processes

STEP 10
Establish an Action Plan

Step 5 shows you how to:

- complete Chart 2 (from Step 1) and generate a seasonal pattern of electricity consumption over a 12-month period;
- establish fixed and variable costs associated with production using electricity;
- create a half-hourly electricity demand profile;
- update the pie charts with day/night cost and consumption data.

Complete the part of Chart 2 for Step 5 and plot a graph of seasonal electricity consumption (as shown in Fig 5). This should include hourly consumption averages for each month for both day and night tariffs. If the supply is billed monthly, include on the chart the availability and maximum demand.

The day and night averages (columns 15 and 16, kWh per hour i.e. kW) can be determined from the days between the meter readings (column 14) and the number of hours in the day (usually 16 or 17) or night tariff period (usually 7 or 8), indicated in the supplier's tariff leaflet.

Maximum demand is the highest use of electricity in any one half-hour.

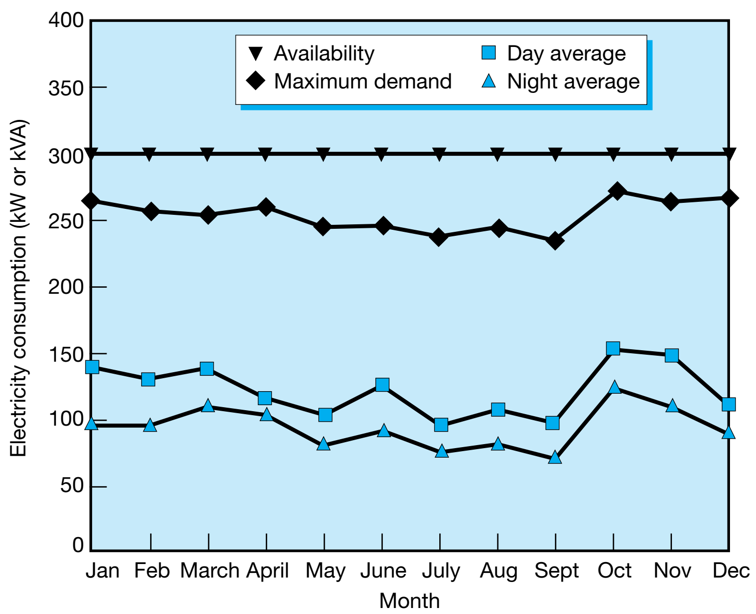
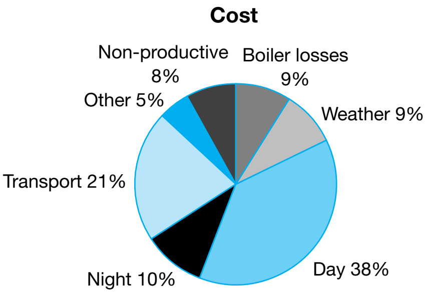
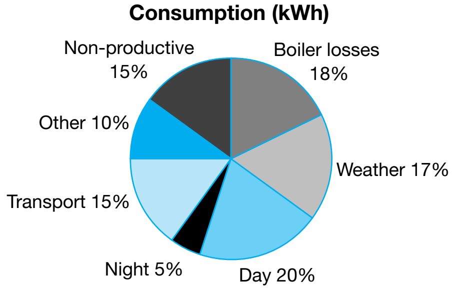


Fig 5 Seasonal pattern of electricity consumption





Pie charts updated for night/day energy consumption and cost

Mark the split of day and night electricity consumption on your pie charts and add non-kWh-related charges on your cost pie chart.

Having gathered this data from the electricity bill, it is worth considering the following:

- Is the proportion of kWh used during 'night' periods defined in your tariff contract reasonable for your pattern of operations?
- Is the maximum demand indicated on the bill, and its variation through the year, about what you expect? Is there an indication how this may be reduced? Is maximum demand a large part of total costs?
- Is the relationship between the average day demand and the maximum demand about what you expect?
- Is the level of availability set at a reasonable level (it should provide a modest headroom over maximum demand - in kVA - both for now and for foreseeable changes in consumption)?

Electricity and Degree Days

Unless you know that electricity is used for some purpose in which weather has an effect, do not plot graphs of electricity vs. degree days. This is because, in some circumstances, electricity consumption takes on a seasonal pattern, mainly owing to the seasonal impact of daylight which seems to mimic degree days and might be misleading.

Electricity and Production

If you use electricity for production processes, repeat the procedures of Step 4 to establish the fixed and variable costs. Do not be surprised if the fixed consumption appears to be a large proportion of the total.

The Demand Profile

If you currently buy electricity from a supplier other than your regional distribution franchise holder, you may already receive information on your half-hourly consumption pattern. If you are not already supplied with this information, your electricity supplier may be prepared to measure it for you - you can hire a demand profile recorder or, alternatively, ask a consultant to measure it for you.

The volume of information is too great to handle without a computer. If you do not have one, ask your supplier to print the profile as graphs. If you have a computer consider the following:

- If the data are only available as hard copy, key them into a spreadsheet, using a week to a column (preferably a full week).
- If the data are already in a spreadsheet leave them in their original format (normally a day to a row) but produce averages of weekdays and weekends (vertical columns), and compute the daily maximum demand and daily day and night consumption. (The spreadsheet SUM() and MAX() facilities will enable you to do this.)

Print out your half-hourly electricity profile as shown in Fig 6. Examine the profile in the following way:

- Look at the demand, especially over what you regard as silent hours - night time and weekends. Can you account for the plant which is running - is it necessary?
- Look at the time when consumption starts each day, when the staff are expected to be at lunch, and at the end of the working day.

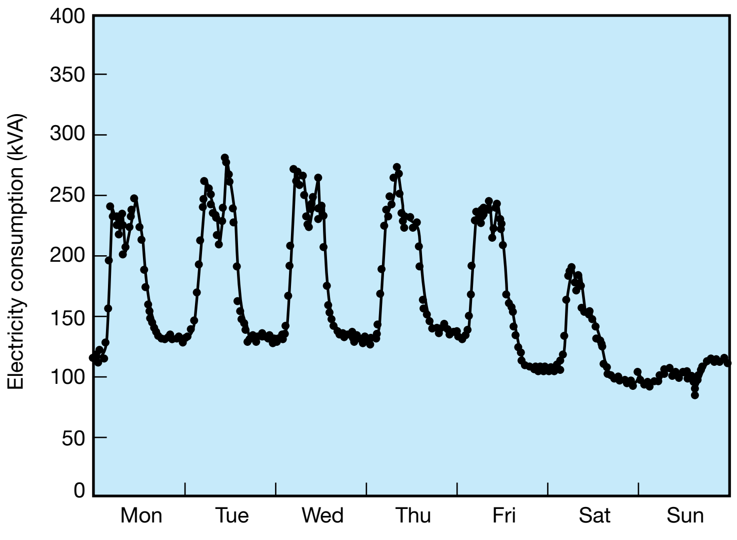


Fig 6 Half-hourly electricity profile

6

STEP 6 EXAMINE ENERGY IN TRANSPORT

Step 6 shows you:

- how mileage data and fuel usage can be used to compare vehicle efficiencies or to assess which categories of the fleet consume the most energy.

Energy consumption in vehicles depends mainly on the distance travelled, but it is also affected by how the vehicle is driven and how far the vehicle is into the maintenance cycle. (It often has a seasonal element - due partly to air temperature and partly to road conditions.)

The overall cost and consumption of vehicles is already recorded as part of the fuel component on your pie charts. If your fleet divides naturally into categories, it is worthwhile showing the breakdown. When fuel is dispensed into vehicles, it is always metered. Every vehicle carries an odometer (mileometer). It is straightforward to establish which vehicles account for the major fuel use or to compare the consumption of vehicles in distance per litre.

Distance per litre depends on a complex interaction of driver behaviour and factors associated with the route (numbers of stops, congestion, etc.). Over a year a seasonal variation is also often observed.

The Best Practice Programme produces several Guides which can help you reduce energy consumption in freight and other vehicles (see Appendix E).

7

STEP 7 SET UP AN ENERGY MONITORING SYSTEM

Step 7 shows you how to:

- use the energy vs. production (or degree days) graph to predict future energy consumptions;
- develop a control chart tracking the difference between actual and predicted consumption, with control limits to alert you to exceptional behaviour;
- apply monitoring and control to different types of energy use.

STEP 1
Identify the major energy costs

STEP 2
Determine the costs attributable to the weather

STEP 3
Estimate the boiler efficiency

STEP 4
Examine the process energy consumption

STEP 5
Examine electricity consumption

STEP 6
Examine energy in transport

STEP 7
Set up an energy monitoring system

STEP 8
Evaluate space heating requirements

STEP 9
Evaluate the efficiency of your processes

STEP 10
Establish an Action Plan

The formula of the best fit line on a graph of energy vs. production and energy vs. degree days provides you with the means to predict the energy consumption for any given level of production or degree days. This was shown in Steps 2 and 4.

By taking the difference between the actual consumption and this prediction, and charting this over time, you can detect changes in the pattern and faults. In short, you then have a monitoring system.

Monitoring Fuel and Steam

Use the line you have drawn on your graph of energy vs. production (or energy vs. degree days) as a benchmark against which to compare energy use each week into the future, and display this as a monitoring **control chart.** This is easiest if the line on your chart can be converted to a formula. The usual formula for a straight line is:

energy = energy at zero production + (slope of line x production)

or

energy = energy at zero degree days + (slope of line x degree days)

These are the most common formulae and can be used for graph Types 1 and 2 of either buildings or processes. Formulae for lines with breaks, bends and curves are described more fully in Appendix A.

If you have only one meter serving both production and space heating, the formula is modified to:

energy = fixed energy + ($constant_1$ x production) + ($constant_2$ x degree days)

and the constants are evaluated by one of the procedures set out in Appendix B.

Set up a production and energy log sheet in the form of Fig 7. For each week, write in the production, degree days, energy used and the predicted consumption (obtained from the line on your chart or from the formula). Subtract the predicted consumption from the actual and plot the differences on Fig 8.

Week	Production	Degree days	Energy used (kWh)	Predicted energy (kWh)	Difference
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Fig 7 Production fuel log sheet

Draw control lines on the chart based on previous performance. If energy goes outside these limits in future, you will know to look for exceptional factors to explain the greater deviation. This analysis will help you to avoid high consumption and learn from experience when consumption is low.

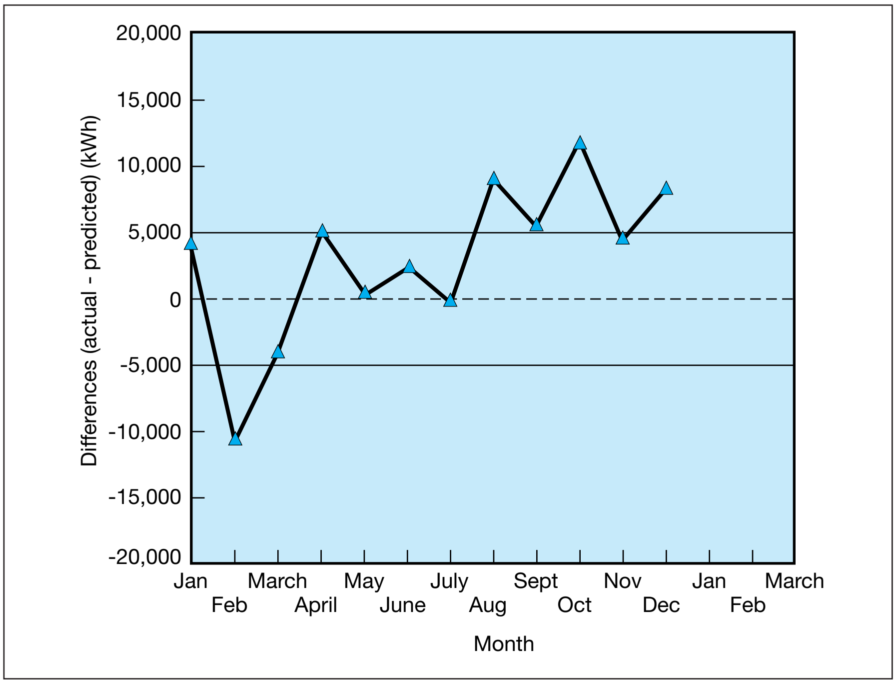


Fig 8 A control chart (this control chart is from the worked example in Appendix B)

Monitoring Boiler Efficiency

For boilers, if the fuel input and steam output are both recorded, log and chart exactly as described for fuel previously.

If the boiler is monitored only as combustion efficiency and there is no meter for boiler output, use the average % efficiency as the prediction and chart the differences between measured efficiency and this figure.

Monitoring Electricity

Electricity differs from heat (fuel) in several important respects. Although electricity consumption tends not to be linked closely to production or weather, it does tend to adhere closely to cycles over time. There are usually three cycles: daily, weekly and seasonal.

Which cycle you monitor depends on the way data are made available to you. The preliminary analysis in Fig 5 picks up the seasonal cycle. If you have access to continuous half-hour demand information, you can monitor the daily cycle; otherwise, work on a weekly cycle from your own meter readings. In general, the meter reading interval should be shorter than the cycle over which electricity consumption varies - monthly readings will pick up the seasonal cycle, daily readings will pick up the weekly cycle and half-hourly readings will pick up the daily cycle.

Set up a log sheet of the kind shown in Fig 9 (if using a computer spreadsheet, work with the data in whichever form is appropriate to your spreadsheet skills). Set up a column in which to compute an average electricity consumption from past data for each interval.

If the data are monthly, for January calculate, as a prediction, the average of the Januarys, for February calculate the average of the Februarys and so on.

If the data are daily, for Monday calculate, as a prediction, the average of the Mondays, for Tuesdays calculate the average of the Tuesdays and so on.

If the data are half-hourly, you have a range of possibilities. Because you have all the data to refer back to for detail, all you need is a system that can summarise the data and alert you to anything of potential interest. Use the spreadsheet functions to help analyse half-hourly data:

- Use the spreadsheet SUM() formula to total the data for each day and compare with the average for that day - Sundays with the average of Sundays, etc.
- Use the spreadsheet MAX() formula to find the maximum demand for each day and compare with the average maximum demand for that day - Sundays with the average of Sundays, etc.
- Use the spreadsheet SUM() formula to find the average of a block of periods during the night - e.g. the average of three hours - for each day and compare the total for each day with the average for that day - Mondays with the average of Mondays, etc.

	Day units			Night units			Maximum demand		
Month	**kWh**	**predicted**	**difference**	**kWh**	**predicted**	**difference**	**kWh**	**predicted**	**difference**
January									
February									
March									
April									
May									
June									
July									
August									
September									
October									
November									
December									
January									
February									
March									
April									
May									
June									

Fig 9 Electricity consumption log sheet

Monitoring Transport

From past records, note how much seasonal variation there is in performance - is the variation between summer and winter greater than from month to month? If there is no clear dependence on season, monitor the differences between actual consumption and the average over a fixed period, e.g. a year. If it does depend on season, monitor differences calculated in the same way as for electricity.

STEP 8 EVALUATE SPACE HEATING REQUIREMENTS

8

Step 8 shows you how to:

- calculate the energy losses associated with the fabric of the building;
- calculate ventilation rates and energy losses for the building;
- update pie charts for weather-related energy loss (from building fabric and ventilation).

In Step 2 you were able to separate the space heating from other energy uses. One further step will enable you to determine which aspects of building heating might yield greatest potential for savings.

The following procedure applies only if a graph of energy vs. degree days contains a straight section from which you have been able to obtain a value for a slope. If the line is curved the temperature is not closely controlled, and the most immediate requirement is to find out why that is (in industrial buildings a useful line of investigation is to establish the route taken by air entering the building to make up for air extracted by fans).

The slope of the line of energy vs. degree days isolates the energy which depends solely on the weather from other uses. This energy comprises two parts:

1. fabric losses (the heat lost through the windows, roof and walls);
2. ventilation.

You can evaluate the fabric losses from knowledge of the constructional details of your building and the hours over which it is heated. If your graph of energy vs. degree days has a straight section in it, you can use the slope of the graph, the fabric losses and the boiler efficiency (if relevant) to work out the ventilation rate. Ventilation in industrial buildings is a major source of heat loss.

Fabric Losses

The fabric losses comprise the heat lost from the building through the solid structure of the walls, roof, window glass, etc. To work out the fabric heat loss you need to know:

- the area - in m^2 - of each part of the outermost skin of the building;
- the U-value for the construction materials for each component of the building[2];
- the average daily heating hours for the building.

[2] The U-value is a simplified measure of the rate at which heat passes through solid materials.

You can base these figures on estimates to start with and refine them later. The energy loss from each element of fabric is given by the following formula which must be applied to all of the building's different elements and then aggregated:

$$\text{fabric loss}^3 \text{ (kWh/degree day)} = 0.024 \times I \times U \times A \times \frac{1}{B}$$

where:

- U is the U-value measured in watts/m^2/°C;
- 0.024 is the conversion factor from watts/°C to kWh/degree day;
- A is the area in m^2;
- B is the boiler efficiency expressed as a number between 0 and 1;
- I is an intermittency factor related to the number of hours in a day over which the building is maintained at a controlled temperature (this approach measures fabric loss in energy per degree day which means that the inside building temperature does not matter).

For a building with many different structural elements, since the factor 0.024, boiler efficiency and intermittency factor are the same for each element, this calculation becomes:

$$\text{fabric loss}^3 \text{ (kWh/degree day)} = 0.024 \times I \times \frac{(U \times A)_{walls} + (U \times A)_{windows} + (U \times A)_{roof}}{B}$$

The energy loss in kWh is this figure multiplied by the total number of degree days in the year over which your energy vs. degree day graph has a straight section with a positive slope. Calculate this for all elements of the building fabric - walls, windows, roof (Fig 10).

Structure	**Dimensions**	**Area (A)**	**U-value (U)**	**U x A**
Windows				
Wall 1				
Wall 2				
Wall 3				
Wall 4				
Wall 5				
Wall 6				
Roof skylights				
Wall fabric[3]				
Wall 1				
Wall 2				
Wall 3				
Wall 4				
Wall 5				
Wall 6				
Roof fabric[4]				
			Total U x A	
			kWh/degree day = U x A x 0.024 x I x 1/B =	
			Total kWh =	
				= 100%
			kWh	%
Windows				
in walls				
in roof skylights				
Wall fabric				
Roof fabric				

Fig 10 Calculating the fabric losses from your building

[3] Adjusted for boiler efficiency.

[4] It is usually easier to calculate the window area first and subtract this from the gross area of each wall to find the area of non-window wall fabric. (Also applies to skylights and roof area.)

For the intermittency factor, a crude estimate is provided by the following table. A high inertia building is one in which the temperature falls slowly when the heating is turned off; a low inertia building is one where the temperature drops rapidly when the heating is turned off.

Intermittency factors for industrial buildings

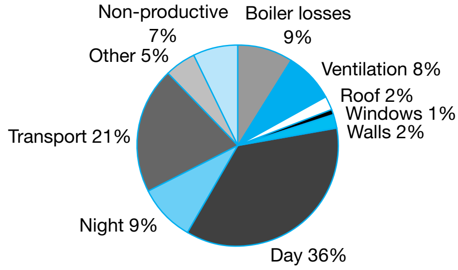
Hours heating per day	**4**	**8**	**12**	**16**	**20**	**24**
High inertia	0.43	0.56	0.67	0.78	0.90	1.0
Low inertia	0.29	0.45	0.59	0.73	0.87	1.0

If the working week is less than seven days, multiply this factor by the number of working days divided by seven.

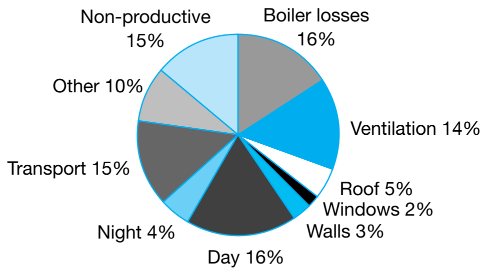
A list of U-values appropriate to industrial buildings is given in Appendix C.

Now work out your building fabric losses using Fig 10 and mark these on your pie charts.

Cost



Consumption (kWh)



Pie charts updated for building fabric losses

Ventilation Losses

For the building heating, your pie chart now shows the weather-related energy distinct from weather-unrelated energy, and that part of the weather-related consumption which is due to fabric losses. The rest of the weather-related consumption are losses due to ventilation.

It is possible to work out whether the ventilation rate is reasonable for the building:

The loss of heat due to ventilation is the number of air changes per hour multiplied by the specific heat capacity of air multiplied by the temperature difference between inside and out. This is related to the boiler fuel by the efficiency so that:

ventilation loss (kWh/degree day) = total weather-related fuel energy - fabric loss

$$\text{ventilation rate (air changes per hour)} = \frac{\text{ventilation loss (kWh/degree day)} \times B}{I \times V \times 0.024 \times 0.33}$$

where:

I is the intermittency factor as for fabric losses;

V is the volume of the building in m^3;

0.33 is the specific heat capacity of air expressed on a volume basis (0.33 $Wh/m^3/°C$);

0.024 is the conversion factor from Wh/°C to kWh/degree day;

B is the efficiency of the boiler expressed as a number between 0 and 1.

The ventilation rate you need for industrial buildings depends on the kind of process you operate and whether this is designed to:

- provide fresh air requirements to occupants, who require about 8 litres per person per second;
- rely mainly on natural ventilation through doors and gaps in the building fabric, which should be between 1 and 1.5[5] complete air changes per hour;
- use extraction fans;
- be based on the floor area, for which a standard allowance[6] is 1.3 litres/ second/m^2.

Compare your ventilation rate with these standards. If your ventilation losses are very large compared to what you expect, a priority is to examine the way air moves through the building to see whether you can account for it.

[5] Chartered Institution of Building Services Engineers (CIBSE) Guide, Section A4.

[6] Chartered Institution of Building Services Engineers (CIBSE) Guide, Section A1.

If you use extraction fans, ask whether the rate of extraction is more than you need *and* from where the make-up air is drawn. (Is it being inadvertently drawn from heated areas within the building when it could be unheated air taken from outside?)

Note: Ventilation rates of much less than 0.5 air changes per hour are unlikely in reality. The procedure just described assumes that a constant air temperature of between about 15°C and 25°C is maintained in the building throughout heated hours. If the procedure produces a ventilation rate below 0.5 or a fabric loss greater than the slope of your energy vs. degree day line, this is probably because this assumption does not hold. This would happen if you:

- depend mainly on radiant heating;
- heat only part of the building.

STEP 9 EVALUATE THE EFFICIENCY OF YOUR PROCESSES FROM THE GRAPH OF ENERGY VS. PRODUCTION

9

Step 9 shows you how to:

- use the slope of the energy vs. production graph to calculate process efficiencies (examples are given for aluminium melting and bread-baking).

The best fit line for a straight line on a graph of energy vs. production has the form:

energy = m x production + c

where m and c are constants. m is the slope and has units of energy per unit of production. If production is measured in tonnes, m has units of energy per tonne; if production is measured in kg, m has units of energy per kg.

For many processes the energy requirements of the process are governed very precisely by the laws of physics - the most important of which are those that govern changes in the temperature of materials, melting, evaporation and chemical reactions.

A straight line graph with a low scatter results only when the material being processed passes through a similar cycle, i.e. the same or similar materials, with the same starting and finishing temperatures and the same proportion always melting or evaporating. If this is the case, and providing you know what the cycle is, it is a fairly simple matter to evaluate the energy efficiency, calculate what the energy requirements are and compare these with the slope of the line of energy vs. production.

Heating and Melting

The slope of the line of energy vs. production has units of energy per weight of product (e.g. per te or per kg). If the units are different, they need to be converted to one of these. The energy required (per te or per kg) to heat a material is:

energy per unit weight = specific heat capacity x temperature rise

The specific heat capacity of a material is often denoted by Cp, which can vary over a large temperature change. So if you are dealing with high temperature processes such as melting glass, firing pottery or melting metals, ensure the specific heat capacity you use takes account of this. The energy required to melt a material is called its specific latent heat of melting and is expressed in energy per unit weight.

Specific heats and latent heats are available in reference books (see Appendix E for details).

STEP 1
Identify the major energy costs

STEP 2
Determine the costs attributable to the weather

STEP 3
Estimate the boiler efficiency

STEP 4
Examine the process energy consumption

STEP 5
Examine electricity consumption

STEP 6
Examine energy in transport

STEP 7
Set up an energy monitoring system

STEP 8
Evaluate space heating requirements

STEP 9
Evaluate the efficiency of your processes

STEP 10
Establish an Action Plan

For a process that only heats material but does not melt or vaporise it the efficiency of the process is:

$$\text{efficiency} = \frac{Cp \times (T_{final} - T_{start})}{\text{slope}} \times 100\%$$

If the process melts a material, it generally has to heat it to the melting point, T_{melt}, first, melt it and then heat the liquid above the melting point. The specific heat of the liquid tends to be slightly different from the solid. Latent heat (the energy required to change the state of a material, e.g. from solid to liquid, or liquid to gas) is often represented as L. In this case the efficiency of the process is:

$$\text{efficiency} = \frac{\{Cp_{solid} \times (T_{melt} - T_{start})\} + L + \{Cp_{liq} \times (T_{final} - T_{melt})\}}{\text{slope}} \times 100\%$$

Example

A small foundry melting aluminium alloys found that the best fit of weekly energy and production was:

$$\text{energy (GJ)} = 2.585 \times \text{tonnes}_{\text{poured per week}} + 75$$

and average production was 60 tonnes per week. The average proportion of energy which was not related to production was, therefore:

$$\text{non-productive energy} = \frac{75}{75 + (2.585 \times 60)} \times 100 = 32\%$$

The slope is 2.585 GJ/tonne (= 2,585 MJ/tonne). The starting temperature was the ambient temperature of about 25°C, the usual pouring temperature was 730°C. The average specific heat of solid aluminium from ambient temperature to the melting point at 661°C is 1.061 MJ/tonne/°C and for the liquid is 1.177 MJ/tonne/°C. The latent heat of melting is 396 MJ/tonne. Therefore:

$$\text{efficiency} = \frac{\{1.061 \times (661 - 25) + 396 + 1.177 \times (730 - 661)\}}{2{,}585} \times 100\%$$

$$= (1{,}152/2{,}585) \times 100\%$$

$$= 44.6\%$$

Evaporation and Drying

The procedure is the same for evaporation processes but special care is needed to ensure that the measure of production is appropriate. Drying is the most common process where material is evaporated. In this case the material which is vaporised is water, but the usual measure of production is either what is left behind or, less commonly, the weight of material put into the dryer. To establish the efficiency it is necessary to work out how much water has been evaporated per unit of product.

The energy required to heat liquid water to the boiling point is 4.18 kJ/kg/°C. The energy required to evaporate water is given in steam tables, which are widely published. The energy required depends on the pressure; most drying processes are carried out at atmospheric pressure, in which case the appropriate steam table is the one for superheated steam (where the water vapour is heated to far above the temperature at which it will condense). Metric steam tables are usually presented in units of kJ/kg. To convert from kJ/kg to kWh/kg, multiply by 0.0002778.

If the process is carried out at atmospheric pressure, the energy requirements (taken from steam tables) to vaporise water from 0°C are given below.

Energy required to evaporate water at 100°C and heat the vapour at atmospheric pressure to T_{final}

T_{final}(°C)	160	180	200	250	300	350	400
kJ/kg	2,796	2,836	2,875	2,975	3,075	3,176	3,278
kWh/kg	0.777	0.788	0.799	0.826	0.854	0.882	0.911

If the input to the process is at a higher temperature, deduct the heat required to raise the water from 0°C to that temperature.

The table indicates the energy required to evaporate the water; there is also the energy required to heat the material left behind to the evaporation temperature. This is given by:

energy to heat solids = mass x specific heat x temperature rise

Most users of drying processes know the water contents of the input material and the output material because they have to control these to achieve a satisfactory quality.

Example

This example is chosen because, although it is about as complex a calculation as most users in small and medium-sized firms are ever likely to meet, it is also a familiar process which is easy to follow.

In a bakery, production is measured as the numbers of loaves of a standard weight leaving the oven (another bakery might measure the flour used each week). The energy vs. production graph had a best fit of:

GJ/week = 155.7 + 0.543 x production ('000 800 g loaves/week)

So the production-related energy use is 0.543 GJ per 1,000 loaves, each loaf weighing 800 g.

The process consists of mixing flour with water and yeast (and other minor ingredients). This is put into a prover at 47°C to allow the dough to rise, after which the bread is passed direct to an oven.

The process in the oven is:

- heating all the ingredients in the loaf to the final temperature (at the end of baking) - the main ingredients are the solid constituents of the bread, (carbohydrates), and the water content (moisture from the flour and added water);
- vaporising some of the water;
- heating the water vapour to the oven temperature.

The water content of the flour is about 14% (it is often listed in the nutritional information on the flour provided by the supplier). The 'recipe' used requires 575 ml of water to be added to each kg of flour. Water content of the final loaf is 40% (if this is not known it can be measured by weighing a loaf, baking it completely dry in an ordinary domestic oven, and weighing it again).

In the oven, the only loss of weight is the water lost as vapour; the solids content of the flour is the solids content in the output loaf. Therefore:

The water content of an 800 g loaf is typically 40%:	0.4 x 800 g =	320 g
The solids content is therefore:		480 g
The flour used to make the bread contains 14% water, and therefore the flour used to make an 800 g loaf is:	$\frac{480}{(1 - 0.14)}$ =	558 g
The water content of the original flour is therefore:		78 g
The water added to the flour is, typically, 575 ml per kg of flour, or per 800 g loaf (i.e. per 558 g of flour):	$\frac{575}{1000}$ x 558 =	321 g
The water lost in baking is: water in flour + added water - water still in bread	78 + 321 - 320 =	79 g/loaf

The starting temperature for the process in the oven is the prover temperature of 47°C.

Sticking a thermometer into a loaf immediately on removal from the oven indicates the temperature inside the loaf to be as close to 100°C as makes no difference. (This is true of any product which retains a high proportion of water.)

Part of the energy is required to heat the water which does not evaporate and therefore reaches no more than 100°C:

$$\text{energy to heat water in loaf to 100°C} = \frac{320}{1{,}000} \times 4.18 \times (100 - 47)$$

$$= 71 \text{ kJ/loaf}$$

The oven temperature is 240°C; any water released from the loaf has to be heated to this temperature.

Steam tables give the energy required to vaporise water at 0°C to vapour at 200°C as 2,875 kJ/kg, and to vapour at 250°C as 2,975 kJ/kg. So, the value at 240°C is approximately 2,955 kJ/kg.

To take 1 kg of water at 47°C and vaporise it at 240°C is 2,955 kJ less the energy required to heat the water from 0 to 47°C (which is 47 x 4.18 kJ):

$$= 2{,}955 - (47 \times 4.18)$$

$$= 2{,}759 \text{ kJ/kg.}$$

Therefore, the energy required to evaporate water from the loaf is:

$$= \frac{79}{1{,}000} \times 2{,}759$$

$$= 218 \text{ kJ/loaf}$$

The bread solids are carbohydrates. We do not know the specific heat of these, but the specific heat of wood, which is a not dissimilar substance chemically, is often quoted in books as 2 kJ/kg/°C. Most of the 480 g bread solids are in the interior of the bread and, like the water, we assume reach about 100°C, so:

$$\text{energy to heat bread solids} = \frac{480}{1{,}000} \times 2 \times (100 - 47)$$

$$= 51 \text{ kJ/loaf}$$

$$\text{Total energy} = 71 + 218 + 51$$

$$= 340 \text{ kJ per loaf}$$

1 GJ = 1 million kJ so 340 kJ per loaf is 340/1,000,000 x 1,000 = 0.34 GJ per 1,000 loaves. So the oven efficiency is given by:

$$\text{efficiency} = \frac{\text{energy required}}{\text{energy used}} = \frac{0.34}{0.543} \times 100\% = 63\%$$

STEP 10 ESTABLISH AN ACTION PLAN

10

Step 10 shows you how to:

- develop an Action Plan to help you manage your energy use and maintain M&T;
- involve colleagues in improving energy usage through Energy Teams;
- begin to gather more detailed energy information through auditing.

Steps 1 to 9 of this Guide will have helped you identify your major costs. They may have helped you to identify some early savings.

You should now be developing an Action Plan to carry the benefits of the actions taken into the future:

- decide how you are going to manage energy on three timescales - from day to day, month to month and year to year;
- consider how you will implement decisions through employees, energy suppliers and outside help on three levels - for their co-operation, for their knowledge and for their skills.

In establishing an Action Plan it is useful to consider the cycle of data collection, data analysis, analysis reporting, and action. In Appendix D you will find checklists to steer you in each of these areas.

Energy Teams

An effective way to work is through key people meeting on a regular basis - quarterly or monthly, as necessary - to discuss problems, opportunities and actions.

Your agenda will depend largely on what you have found already, how much work you still have to do, and the nature of your business:

- Consider implementing weekly, monthly and quarterly checklists for the site to ensure that faults you have identified and put right do not recur or are intercepted early. Some ideas on items for checklists are provided in Appendix D.
- Continue monitoring energy use and establish a procedure to review any changes which occur from what you have established as the current pattern.
- Ensure that you are up to date regarding changes in the energy supply industry, i.e. the introduction of competition in electricity and gas markets. Ensure that you are gathering all necessary and appropriate information on your energy use pattern to take advantage of these changes.
- Obtain and review any advice or literature from the Energy Efficiency Best Practice Programme (EEBPP) relevant to your industrial or commercial sector.

- Draw up a list of measures you can implement in terms of short-, medium- and long-term investments. Examine the impact on your cash flow if you were to implement these wholly or in part. Draw up an energy saving investment strategy.
- Consider ways in which you can make your energy management initiative the basis for a wider programme of environmental awareness and management.

Energy Survey

None of the steps in setting up M&T has required more than deskwork. You now have enough information to justify looking for energy saving opportunities and to gather some of the information you may still need. This can be done in an energy survey.

The purpose of the energy survey is three-fold:

- to relate what goes on around the site to what you have found out from the bills and meter readings;
- to look for areas of visible energy waste which can be acted on quickly and at low cost;
- to gather information to refine the estimates made and guide future management and strategy.

If you use a consultant, he or she will probably want to conduct an energy survey in a single tour of the site because of the cost of his/her time, in which case the analysis of any already existing routinely gathered data should be carried out before the survey.

It is important before starting the survey that you have at least attempted Steps 1 to 6, because you will then know more about what to look for in the survey. Very few forms of energy waste are as visible as steam leaks or open doors. The information from the preceding steps will guide you to where the greatest savings potential is to be found.

A note on energy management

This ten-step process will provide you with a great deal of information to help you understand how energy is used and wasted within your site. However, achieving better energy performance means taking action through implementing energy saving practices and techniques in priority areas. If this is to have a significant and lasting effect, you will need to consider training, awareness campaigns, and improving energy information systems (and integrating them with normal business information systems). You may well choose to contract specialist advice or make proposals for investment in new technologies.

These energy management issues are outside the scope of this Guide and we encourage you to make use of the other material available from the EEBPP to help you do this. See Appendix E for details of further information available to you.

APPENDIX A CONVERTING A LINE ON A GRAPH TO A FORMULA

Straight Lines

A straight line on a graph of y against x, where y and x are measured quantities, has the formula:

$$y = m\,x + c$$

where m and c are constants.

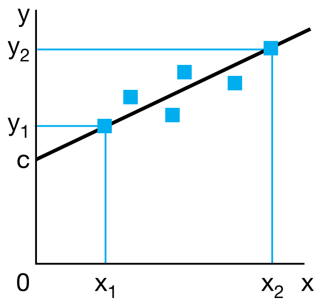
y is plotted on the vertical axis and x is plotted on the horizontal axis. When plotting a graph which involves energy, use the convention that energy is plotted on the vertical axis (and is therefore represented by y) and production or degree days is plotted on the horizontal axis (and is therefore represented by x).

If the graph is for a boiler, the fuel input is the x-variable and the output (steam or hot water) is the y-variable.

c is the value of the variable y when x = 0

m is the slope of the line.

Exactly how the values of m and c are determined depends on how the user prefers to carry out calculations, but the broad principle is as follows:



Plot an x-y graph of the data. Draw a best fit line by eye. Choose two values of x which are easy to determine the values of; we will call these x_1 and x_2. If the line goes through two data points, then choose x-values corresponding to these, otherwise choose round numbers. The accuracy of the calculation is helped if these points are as far apart as possible.

Now find the corresponding values of y. If you have chosen data points on the line, look up the y values from the original data. If you have chosen round numbers, draw a vertical line from the x-axis to the line and, at the point where each vertical touches the line, draw a horizontal line back to the y-axis and read off the corresponding values of y - call these y_1 and y_2.

Calculate the slope as:

$$m = \frac{(y_2 - y_1)}{(x_2 - x_1)}$$

The intercept, c, can then be found by using this value of m in the equation of the straight line 'y = m x + c', and using the x and y values of any point on the line.

$$c = y_1 - m\,x_1$$

or

$$c = y_2 - m\,x_2$$

There is a useful mathematical rule of thumb that the best fit line should always pass through the point which is the average of the 'x's and average of the 'y's:

$$c = y_{average} - m\,x_{average}$$

On some graphs (which appear in the procedure in Appendix B) a line sometimes cuts through the x-axis, if the value of x here is x_0, then:

$$c = 0 - m\,x_0$$

If using pencil and paper

Always draw your graph to include zero for the x- and y-axes. Find the average value of x and y and plot the point corresponding to this on the graph. Draw the best fit line by eye, but make sure that it passes through the average point and is traced right back to the y-axis.

If the line passes through a pair of points, use these as in the above procedure, otherwise, it is easier to measure off c first. Use the x and y average values for x_2 and y_2. Then, with c already known:

$$m = \frac{y_2 - c}{x_2}$$

If using a computer spreadsheet without (or avoiding) the linear regression facility

(This method of setting up a computer spreadsheet column - with a spreadsheet formula accessing constants from cells at the head of a column - is useful for a wide range of business spreadsheet applications, not just energy M&T.)

In the following description the spreadsheet cell locations from the table below are used. In your own version the cell references may differ - please ensure that you adjust references accordingly.

Set up the data for energy and production or energy and degree days in columns, leaving a few spare rows at the top of the spreadsheet. (There are advantages in having the energy column to the right of the other variable in most spreadsheets.) Set up another column, to compute the best fit line, to the right of the energy column. Head this column ‘prediction’. In the cell corresponding to the first row of data, enter the following formula (in the correct syntax for the spreadsheet you are using):

=D$2 + D$3*B.row

where D$2 here refers to the cell location holding the estimate of ‘c’ and D$3 refers to the cell location holding the estimate of ‘m’ - both of these are estimated by the process described below. (Note: $ is a formula device that absolutely fixes a cell reference so that when the cell contents are copied, the 2 and 3 row references are retained.) B.row refers to the value of the ‘x’ variable in column ‘B’ and the row given in the formula (i.e. B4 if the formula is in D4). The formula should be included for each row where there is a value for ‘x’. The table shows the formula display for the spreadsheet.

The formula presentation of a computer spreadsheet set up to compute a prediction from a line of best fit

	A	B	C	D
1				
2				0
3		=sum(B7:B20)	=sum(C7:C20)	=(C3/A20-D2)/(B3/A20)
4				
5	Week no.	Production (tonnes)	Actual energy (litres of fuel)	Prediction energy (litres of fuel)
6				
7	1	358.1	14291	=D$2+D$3*B7
8	2	376.4	17211	=D$2+D$3*B8
9	3	492.9	20827	=D$2+D$3*B9
10	4	435.0	16640	=D$2+D$3*B10
.	.	.	.	.
.	.	.	.	.
20	14	450.4	16733	=D$2+D$3*B20

Set up an x-y scatter diagram showing the x-variable (production or degree days), with ‘energy’ and ‘prediction’ as two different y-variables (on the same axis). If in doubt, refer to your spreadsheet manual or ‘help’ files for further instruction.

In cell B3 write: =sum(B7:B20)

Copy this to cell C3 which will appear as: =sum(C7:C20)

In cell D2 write 0 to start with.

In cell D3 write the formula (in the correct syntax for the spreadsheet you are using):

=(C3/A20 - D2)/(B3/A20)

where A20 indicates the number of data points. If this column carries text, use the actual number or use a further column to number the time periods. Sum(C7:C20) given in cell C3 is the summation of all the entries in the energy data column, and sum(B7:B20) given in cell B3 is the corresponding summation for the entries in the variable column. Since A20 defines the number of rows covered by the summation, the sum(..)/A20 value is an average of the values in that column. The cell D3 therefore calculates the slope from the first estimate of the c value (0) in cell D2 and the average of all the data points.

The graph you are plotting should show two sets of data. The first is the scatter diagram of the actual energy points against production; the second is the points representing the prediction values - these should lie on a straight line, based on the estimate of the value of c=0. Now, in cell D2 enter a new estimate value for c, given the best estimate you can make by eye of the point where the best fit line would cut the energy axis at zero energy. Changing D2 results in a new set of points for the best fit - the trick now is to adjust c accurately enough so that your value in D2 looks like the value on the graph, i.e. until you are satisfied with the fit. (Note: If the best fit line cuts the x-axis, which is rare in processes but is common in industrial buildings, your c value in cell D2 will be negative.)

The number values in the cells corresponding to D2 and D3 are c and m respectively.

If the line has a negative value for c, modify the formula using an IF statement to make the prediction equal to zero when x is less than the intercept on the x-axis. For example, in row 7 the prediction formula becomes:

=IF(B7<0,0, D$2 + D$3 x B7)

(Once again, use the correct syntax for your spreadsheet.)

If using a computer spreadsheet with a regression facility

Many computer spreadsheets offer a facility for finding the best fit line through data. Follow the instructions provided with your spreadsheet software package.

The spreadsheet instructions may describe this procedure as a ‘line estimate’, ‘regression’, ‘least squares’ or ‘trend line’. These all mean the same and ultimately involve the same procedure.

There are three notes of caution which should apply whenever this procedure is used:

1. The computer finds the best fit line by minimising the total sum of the *square* of the distance of each point from the line, and the procedure has to assume the line is straight.

2. Using the square of the distance means that the procedure attaches more significance to a point a long way from the line than to one which is close to it - a point 3 kWh from the line counts as $3^2 = 9$ in this calculation whereas a point 1 kWh from the line counts as only $1^2 = 1$. Data errors tend to give rise to points further from the line than operational factors, and it is important when using this procedure to eliminate all data errors first.

3. The procedure does not know that the line could be bent. Apply it only to data where the graph indicates strongly that a straight line applies.

(Note: Some spreadsheets offer the facility where the user can elect to force the best fit line through the origin (x=0, y=0). **Never use this for energy work**.)

Broken and Bent Lines

Broken and bent lines are handled in the same way as straight lines except that the straight line formula is used over straight sloping segments and constants used over the horizontal segments.

If using pencil and paper

Draw the best fit line as two lines with either a bend or a break. The formula for each sloping line segment follows the 'y = m x + c' formula already described.

A horizontal segment is a constant value of y.

In a line with two sloping segments you will need two formulae, each with a different value of c and m. In a line with a horizontal segment, the sloping segment will need one formula with a c and m value, whilst the horizontal segment will have one value throughout, just c. You will need to note the value of x at the bend or break. This defines the range over which the formula is valid, i.e. the line segment for x values lower than the 'break value' of x and the line segment for x values greater than the break value of x. Simply use the formula appropriate to the value of x when the need arises.

If using a computer spreadsheet without (or avoiding) the linear regression facility

For a bent line with two sloping segments, use an IF statement that switches between two y = m x + c formulae at the appropriate value of X_{break}. The values of m and c for the two lines must be calculated separately and stored in different cells (e.g. D$1, D$2 and D$3, D$4 respectively for the two lines). The prediction for row 7 becomes:

$$=IF(B7<X_{break},D\$1 + D\$2 * B7, D\$3 + D\$4 * B7)$$

If using a computer spreadsheet with a regression facility

If the line has a break or bend, regression is an inherently misleading procedure applied to the whole data set - because of the problem of using squares. You must sort the data into two sets either side of the break value of x, then apply regression to the two separate subsets.

When using the formula, use an IF statement which decides whether the x-variable is above or below the point where the bend or break lies.

Curves

If using pencil and paper

To formulate a curve, draw the best fit curve by eye. Then, when you need values from the curve, read them direct from the graph (this can never be very precise).

If using a computer spreadsheet without (or avoiding) the linear regression facility

Curves are most important when using degree days. Experience shows that the common curve which reduces in slope with increasing degree days to become horizontal, is best represented by the formula:

$$\text{energy} = (E_{max} - c) \times (1 - e^{-k \times \text{degree days}})$$

E_{max} is the level of degree days at which the curve either becomes horizontal or would do if the degree day axis were extended far enough; c is the intercept as before; k is a constant which determines how sharp the curvature is. If you cannot make a good guess at a value for E_{max} you can take the approach that the curve is reasonably well represented by two straight lines joined at a kink in the middle. You can then proceed as in the previous section.

If you can make a reasonable guess at E_{max} and c (it does not have to be precise), then use the following:

Set up the data for energy and degree days in columns as for the straight line, but with at least three cells at the top of the column for predicted energy.

Enter the formula in the cell corresponding to the first row of data (in the correct syntax for the spreadsheet you are using), e.g. for row 7:

=(D$1-D$2)*(1-EXP(-D$3*B7))

Where the coefficients are estimated in D1, D2 and D3 (for first estimates see below), EXP() is the exponential function and the data in column B are usually degree days. The set-up of the spreadsheet should be similar to the table on page 40, but with three coefficients instead of two.

Set up an x-y scatter graph showing the x-variable (production or degree days), energy and prediction column.

In cell D$1 write your best guess at the energy at which the curve levels out.

In cell D$2 write your best guess at where the line cuts the energy axis.

In cell D$3 write the value 0.003 (this is a value of k which gives a curve within a degree day range of 0 - 500).

Look at the graph, which should now show the estimate of the line based on these values. Adjust the values of the constants until you get a good fit (you may need to try negative values of c, D$2).

There are methods for refining this procedure mathematically, but they are beyond the scope of this Guide.

If using a computer spreadsheet with a regression facility

There are methods for making mathematical substitutions to make curves amenable to regression, but they are far beyond the scope of this Guide.

B

APPENDIX B SEPARATING BUILDING HEATING AND PRODUCTION ENERGY USING A SINGLE METER

(or separating the impact of any two variables on energy consumption)

A substantial hurdle for smaller firms applying energy M&T is the cost of metering. Where the scale of energy use in a large factory might justify installing a meter on each of the major items of plant and on the space heating load, the small firm may not have enough confidence in the outcome to be able to justify such an expense. It is then worthwhile considering how much information can be gleaned from one meter serving two uses.

Before going into detail, it is worthwhile making the point that these procedures are really only needed where the two separate uses of energy are split more evenly than about 80:20 (i.e. of the two uses, the smaller is at least 20% of the total), or where there is some other indication that energy to one process depends on two parameters, e.g. production and standing time, or two measures of production.

Consider the example shown in the table below, which shows one year of degree days, production and energy data for a factory (the data are real although originally they came from two installed meters and have been combined for this example).

Degree day, production and energy data for a factory

	Degree days	**Production (tonnes)**	**Fuel (kWh)**
Jan	284	186	153,081
Feb	280	215	153,081
March	277	280	193,925
April	192	290	196,475
May	150	300	191,250
June	79	225	143,344
July	59	267	160,275
Aug	66	248	160,400
Sept	94	236	154,375
Oct	215	267	194,250
Nov	298	238	183,050
Dec	285	189	158,950
Total	**2,279**	**2,941**	**2,042,456**
Average	**189.9**	**245**	**170,205**

The energy consumption of the building heating and production are assumed, initially, to be represented by two relationships:

$$energy_b = c_b + (m_b \times \text{degree days})$$

$$energy_p = c_p + (m_p \times \text{production})$$

b refers to buildings and p to production;

m_b and m_p are the slopes of the two lines;

c_b and c_p are the intercepts.

When the energy is added together, as it is when we try to use one meter instead of two:

$$\text{total energy} = c + (m_b \times \text{degree days}) + (m_p \times \text{production})$$

where c is the result of combining c_b and c_p. This is the important disadvantage of using one meter instead of two. If the energy which is not related to either degree days or production is significant, you cannot tell whether it is the processes or building heating which harbours it!

Now what is needed is a means of working out c, m_b and m_p from the data.

There are two ways to do this:

- by hand calculation (with the help of a computer spreadsheet if you wish);
- using a computer spreadsheet with a multi-variate regression facility.

Production and degree days are described here as **variables**. The term can be used to mean degree days and production or production in two processes. (If two variables affect energy use in the same process, it can apply to these, too.)

The Hand Calculation

Although this procedure looks time-consuming, it is not difficult. A key point in its favour is that, being so close to the data, you may notice things that simply do not show in an automatic computer routine - and computers have the disadvantage of having to work with the least squares rule.

The procedure is:

1. Start with three columns of data - $variable_1$, $variable_2$ and energy.
2. Plot a graph of $variable_1$ against $variable_2$, connecting the points in time series order (Fig 11). This is simply to check out the data. Note two things:

- the variable that covers the widest range of values;
- if there is any noticeable pattern in the graph (especially circles and figures of 8) as this indicates that the two variables are not behaving independently e.g. production is seasonal. If they are not independent this might be carried through the analysis and confuse the interpretation later.

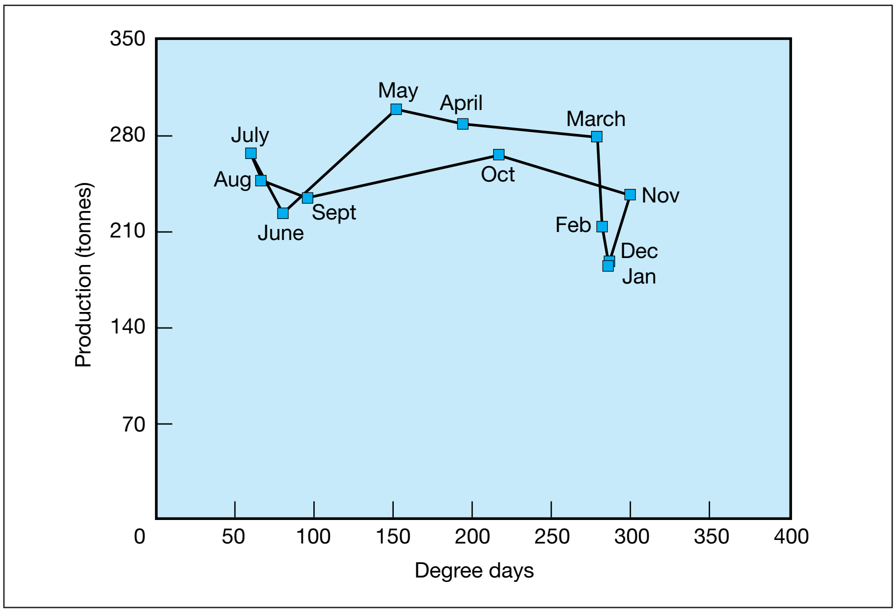


Fig 11 Production vs. degree days showing how to decide which variable to use first

(Steps 3 - 6 below show how to calculate the values of c and m for variable$_1$.)

3. Take the variable that covers the widest range of values first (we will call this variable$_1$). Plot energy as an x-y graph against this variable (Fig 12).

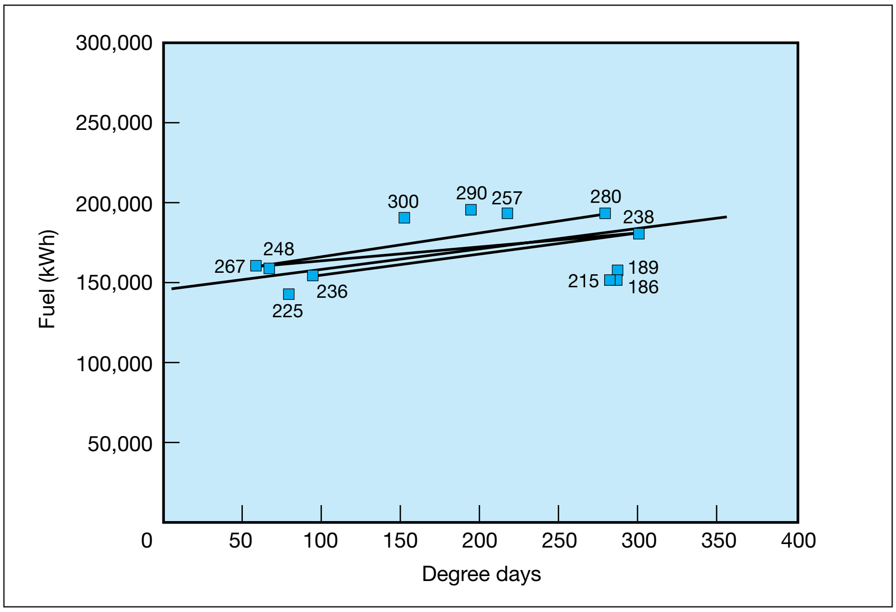


Fig 12 Energy vs. degree days

4. In drawing a best fit line by eye, you will find that deciding where to draw the line is much more difficult than when there is only one other variable involved. A useful tip is to mark the point for the average of variable$_1$ and average energy.

5. Mark each point with the value of variable$_2$. See if you can find pairs of points that are far apart on this graph but have similar values for the other variable, and join these by lines. Make the best fit line parallel to these, but pass through the average point.

6. Calculate the formula of the line:

$$\text{energy} = c_1 + (m_1 \times \text{variable}_1)$$

by one of the methods in Appendix A.

(Steps 7 - 12 below show how to calculate the values of c and m for variable$_2$.)

7. Plot the graph of energy against variable$_2$ (Fig 13). Deciding where to draw the best fit line here, especially the slope, is likely to be more difficult than on the previous graph. If straightforward, proceed as before to calculate the line, energy = c_2 + (m_2 x variable$_2$), and then to step 13 overleaf.

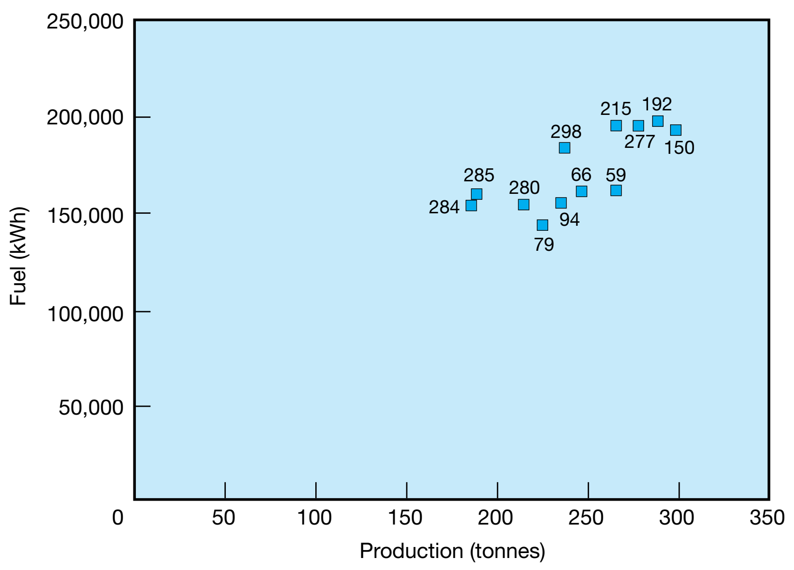


Fig 13 Energy vs. production

8. If not straightforward, you need to use the procedure called the 'method of residuals'. Use the formula:

$$\text{energy} = c_1 + (m_1 \times \text{variable}_1)$$

from the first graph (Fig 12) to calculate the predicted energy for each period from the value of variable$_1$ (see table below).

Calculating a prediction and differences

	Degree days	**Production (tonnes)**	**Fuel (kWh)**	**Predicted (kWh)**	**Residual (kWh)**	**Predicted (kWh)**	**Difference**
Jan	284	186	153,081	183,412	-30,331	151,965	1,116
Feb	280	215	53,081	182,850	-29,769	166,860	-13,779
March	277	280	193,925	182,428.5	11,496.5	201,083.5	-7,158.5
April	192	290	196,475	170,486	25,989	194,471	2,004
May	150	300	191,250	164,585	26,665	193,900	-2,650
June	79	225	143,344	154,609.5	-11,265.5	143,949.5	-605.5
July	59	267	160,275	151,799.5	8,475.5	163,525.5	-3,250.5
Aug	66	248	160,400	152,783	7,617	154,382	6,018
Sept	94	236	154,375	156,717	-2,342	151,920	2,455
Oct	215	267	194,250	173,717.5	20,532.5	185,443.5	8,806.5
Nov	298	238	183,050	185,379	-2,329	181,648	1,402
Dec	285	189	158,950	183,552.5	-24,602.5	153,704.5	5,245.5
Total	**2,279**	**2,941**	**2,042,456**		**136.5**		
Average	**189.9**	**245**	**170,205**				

9. Calculate the difference between the actual energy use and this predicted energy (taking predicted away from actual) - these differences are called the **residuals**.

10. Check how good a fit you obtained by adding up the residuals (see previous table). If the best fit line passed through the average point, this should be zero. In practice this may not be zero but will be small compared to the residual values.

11. Plot a graph of the residuals against the other variable and draw a best fit line (Fig 14). If the best fit line in the previous graph went through the average point, this line will pass through zero at the average value of $variable_2$.

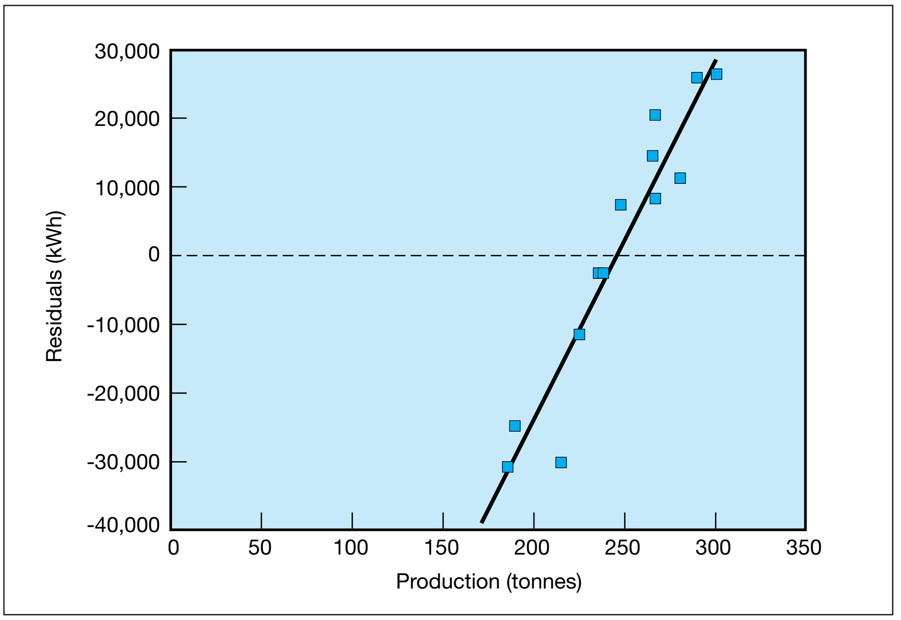


Fig 14 Residuals vs. production

12. By using one of the methods in Appendix A, find the formula of this line as:

$$difference = c_{res1} + (m_2 \times variable_2)$$

(Steps 13 - 15 below establish the multivariate equation and generate a control chart.)

13. According to the route used, the best fit line to the data overall is:

$$energy = (c_1 + c_2) + (m_1 \times variable_1) + (m_2 \times variable_2)$$

or

$$energy = (c_1 + c_{res1}) + (m_1 \times variable_1) + (m_2 \times variable_2)$$

14. Calculate a predicted energy from this formula using the average values of variables 1 and 2. The amounts in each term of the formula indicate the relative proportions of energy going into these three areas of use.

15. Calculate the differences and set up a control chart showing differences between actual and predicted consumption (Fig 15).

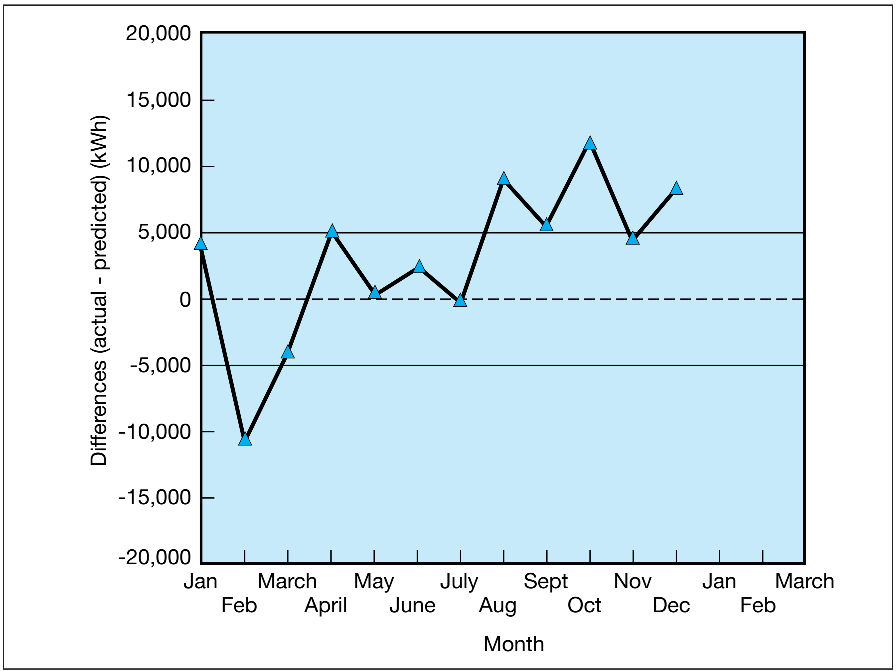


Fig 15 A control chart showing differences between actual and predicted consumption

Worked example

The data for the example are given in the table on page 44.

Fig 11 (page 46) shows production vs. degree days. Degree days from January into summer fall and then rise again. There is a slight pattern here, in that the spring seems to have had higher production than the rest of the year, but it otherwise only indicates that degree days vary between about 50 and 300 - a span of 300/50 = 6, while production has a span of 300/180 = 1.66. Start by looking at the effect of degree days.

The graph of energy vs. degree days is shown in Fig 12, with all the points marked with the production in the same month. It is not easy to draw a line because variations in production have quite a large effect on energy use. There is one pair of points far apart with similar production (236 and 238). Two other pairs are 267 and 280 which are joined by a slightly steeper line (this is expected because production is higher on the higher degree days), and 248 and 238 which are joined by a less steep line. This gives us some confidence that a line parallel to one joining the pair 236 and 238 will have a slope very close to the right value. If it is drawn through the average point it will be good for a best fit line.

Because these two points are so convenient, instead of trying to read anything off the graph, calculate a formula using the data for these points (September and November) and the averages of fuel and production.

$$\text{slope} = m_1$$

$$= \frac{(\text{fuel}_{\text{Sept}} - \text{fuel}_{\text{Nov}})}{\text{degree days}_{\text{Sept}} - \text{degree days}_{\text{Nov}}}$$

$$= \frac{(154{,}375 - 183{,}050)}{(94 - 298)}$$

$$= 140.56$$

$$\text{intercept} = c_1$$

$$= \text{fuel}_{\text{av}} - (\text{degree days}_{\text{av}} \times m_1)$$

$$= 170{,}205 - (190 \times 140.5)$$

$$= 143{,}510$$

so: $$\text{fuel} = 143{,}510 + (140.5 \times \text{degree days})$$

A graph of energy vs. production is shown in Fig 13. There are two points far apart with degree day values of 280 and 277, but, comparing the points at 284 and 285 with 280 is confusing enough to make it advisable to try something else.

Use the formula already determined to calculate a predicted energy consumption based on degree days alone (see column 5 of the table on page 47). Then calculate the residuals (column 6) between the predicted fuel and the actual. Add up the residuals.

A graph of the residuals against production is shown in Fig 14.

The best fit line can be calculated from the graph. You can see that this line cuts -40,000 kWh for the residuals at 170 tonnes. The sum of the differences is 136.5, which is practically zero compared to the 40,000 in the scale, so we expect the line to pass through the average of the production, which is 245 tonnes. The best fit line is therefore:

$$\text{slope} = m_2$$

$$= \frac{(-40{,}000 - 0)}{(170 - 245)} = 533$$

$$\text{intercept} = 0 - (\text{production}_{average} \times m_2)$$

$$= -245 \times 533$$

$$= -130{,}585$$

$$\text{so,} \quad \text{fuel} = (c_1 + c_{res1}) + (m_1 \times \text{variable}_1) + (m_2 \times \text{variable}_2)$$

$$= (143{,}510 - 130{,}585) + (140.5 \times \text{degree days}) + (533 \times \text{production})$$

$$= 12{,}925 + (140.5 \times \text{degree days}) + (533 \times \text{production})$$

This formula was used to calculate the control chart in Fig 15. This control chart shows a low consumption in February and then differences close to the lower control level between January and June, and close to the upper control level from July onwards.

Since we have access to the separately metered data for this example, we can verify what the analysis has found. The low energy use in February is known, from the separately metered supplies, to be an unexplained one-off event in the process. The change in July, that affected all the months after this date, is known, from the separately metered supplies, to be an event concerning space heating energy use. The prediction after this event was therefore low by 2,500 kWh per month, which caused the whole period after July to lie outside of the control band in Fig 15.

Taking the average fuel of 170,205 kWh per month, average degree days of 190 per month and average production of 245 tonnes per month, the proportions of consumption are:

		kWh	**%**
Total fuel		170,205	100
Fixed consumption		12,925	7.6
Degree-day-related	140.5 x 190 =	26,695	15.7
Production-related	533 x 245 =	130,585	76.7

These can then be marked on the pie chart.

Using a Computer Spreadsheet with a Multi-variate Regression Facility

Using a computer spreadsheet with this facility for the example just illustrated produces the result:

monthly fuel = 21,077 + (125.25 x degree days) + (511.42 x production)

and the breakdown:

		kWh	%
Total fuel		170,172	100
Fixed consumption		21,077	12.4
Degree-day-related	125.25 x 190	23,797	14.0
Production-related	511.42 x 245	125,298	73.6

The spreadsheet facility estimates the weather-related consumption and the production-related consumption slightly lower and attributes the difference mainly to fixed consumption. The main differences between this result and the hand calculation is that the hand calculation was less influenced by the data for February which is further from the average than any other month.

C

APPENDIX C
U-VALUES OF COMMON STRUCTURES IN INDUSTRIAL BUILDINGS

	U-value (W/m^2/°C)
Masonry walls	
212 mm (8.5 in.) solid brick	
unplastered and uninsulated	2.30
with 13 mm internal dense plaster	2.17
with 19 mm external render	2.17
with 9.5 mm plasterboard lining	1.50
with 9.5 mm foil-backed plasterboard	1.18
212 mm (8.5 in.) dense block wall	
unplastered and uninsulated	3.30
with 13 mm internal dense plaster	3.00
with 19 mm external render	3.00
with 9.5 mm plasterboard lining	1.80
with 9.5 mm foil-backed plasterboard	1.50
212 mm (8.5 in.) lightweight block wall	
unplastered and uninsulated	0.80
with 13 mm internal dense plaster	0.77
with 19 mm external render	0.73
with 9.5 mm plasterboard lining	0.67
with 9.5 mm foil-backed plasterboard	0.59
103 mm brick outer and 100 mm dense block inner leaves, 50 mm air cavity	
unplastered and uninsulated	1.84
with 13 mm internal dense plaster	1.60
103 mm brick outer and 100 mm lightweight block inner leaves, 50 mm air cavity	
unplastered and uninsulated	0.99
with 13 mm internal dense plaster	0.92
Roofs	
Tiled or slated pitched roofs	
uninsulated	6.62
glass or rock fibre insulated 80 mm	0.42
glass or rock fibre insulated 100 mm	0.35
with 75 mm rigid glass fibre slab + Al foil	0.39
with 40 mm polyurethane foam + Al foil	0.46
Flat metal deck	
uninsulated	3.25
with 70 mm rigid glass or rock fibre roofboard	0.42
with 80 mm cellular glass insulating board	0.52

	U-value (W/m^2/°C)
Flat concrete deck, 3 layers felt and 10 mm chippings	
uninsulated	2.60
with 70 mm rigid glass or rock fibre roofboard	0.41
with 80 mm cellular glass insulating board	0.50
Flat aerated concrete deck (less than 600 kg/m^3)	
with 60 mm rigid glass or rock fibre roofboard	0.40
with 70 mm cellular glass insulating board	0.49
Flat timber deck, 3 layers felt and 10 mm chippings	
uninsulated	1.54
with 70 mm rigid glass or rock fibre roofboard	0.37
with 80 mm cellular glass insulating board	0.39
Lightweight pitched roofs and steel or fibrous cement clad walls	
Under- or over-purlin or inside rail lining	
uninsulated roof	6.7
uninsulated wall	5.7
glass or rock fibre insulated 80 mm	0.42
glass or rock fibre insulated 100 mm	0.34
with 75 mm rigid glass fibre slab + Al foil	0.38
with 40 mm polyurethane foam + Al foil	0.45
Windows	
Without frames	
single-glazed	5.6
doubled-glazed, air gap 25+ mm	2.9
air gap 12+ mm	3.0
air gap 3+ mm	4.0
roof glazing skylight	6.6
With frames (frame 10% of window area)	
single-glazed	
wood frame	5.3
aluminium frame	6.0
double-glazed	
wood frame	3.0
aluminium frame	3.6

U-values for a wider range of structures are provided in Fuel Efficiency Booklet 16, *Economic thickness of insulation for existing industrial buildings*, and the CIBSE Guide.

D

APPENDIX D
CHECKLISTS

In this section you will find helpful tips for getting started with managing your energy (or other resources). Earlier we referred to the cycle of data collection, data analysis, analysis reporting, and action. Below you will find checklists for each of these.

Checklists for Energy Management Procedures

The following checklists will assist you in implementing energy management (including M&T) in your organisation. For further practical advice refer to the FOCUS publication referenced in Appendix E. For details of technical solutions to energy waste, other publications, e.g. the Fuel Efficiency Booklets, are available from your Regional Government Office, ETSU and BRECSU (contact details are provided in Appendix E).

Data collection checklist

1. Ensure that production/climatic factors and energy measurement periods coincide (take particular care with utility invoices - use physical meter readings instead).

2. Read the meters at the same time each day/week/month, as appropriate.

3. Make sure that the meter reader is adequately trained for the job; design some simple forms to make the task easy (see Section 7).

4. Train more than one person in how to read the meters.

5. Only collect data that will be used.

6. Ensure that degree day information is collected as soon as it is available. It is normally available within a few days of the month end from your Regional Government Office, the Meteorological Office, various other commercial sources or, at a later date, from the DETR's magazine, *Energy & Environmental Management.*

Data analysis checklist

1. When setting up your energy standards make sure that you are happy with the relationship derived.

2. Analyse the data for each time period; avoid batch processing, where data from a number of time periods are collected and analysed at the same time.

3. Perform simple checks to test data quality and validity. In particular, check that the meter reading has the correct number of digits recorded on the sheet.

4. Where appropriate, use personal computers to make the analysis easier. Use in-house spreadsheets or bespoke energy management software, as appropriate.

5. If manual analysis is unavoidable, use simple forms to make it as straightforward as possible.

6. Use familiar units for energy and production.

7. If energy costs are to be reported, use a ‘budget energy cost’ to avoid the distortions caused by fuel price changes.

8. Ensure that more than one person is capable of performing the analysis.

9. Keep the analysis simple and to a minimum that is consistent with the needs of the company.

Analysis reporting checklist

1. Integrate the reports with the existing management information systems.

2. Prepare and issue reports in a timely fashion for each time period; avoid batch processing a number of time periods together.

3. Issue reports either on an exception basis or according to need (i.e. do not overload people with unnecessary information).

4. Use variance reporting to show improvements or deterioration in performance.

Action checklists

1. Discuss the reports informally with the relevant staff after each time period.

2. Agree a way forward, planning activities in each period.

3. Encourage discussion about how energy savings may be made in the future.

4. Include energy in other management information discussions (e.g. team briefings).

5. Motivate those responsible for energy use and increase the level of awareness so that they act positively (rather than react) to save energy.

E

APPENDIX E
FURTHER INFORMATION

The Energy Efficiency Best Practice Programme

The Department of the Environment, Transport and the Regions (DETR) provides a wide range of information and other support to help companies reduce their energy bills via its Energy Efficiency Best Practice Programme (EEBPP).

Below is a list of information designed to support small and medium-sized companies, particularly in the general area of Monitoring and Targeting. This material is available to you, free of charge, from the EEBPP. Details of how to receive this material are given on the back cover of this document.

Information specifically for small and medium-sized companies

FOCUS - The managers guide to reducing energy bills. This is a practical guide for small businesses to show the reader how to save money on gas, electricity and other utility bills. It provides a series of simple checklist questions and practical suggestions for no-cost and low-cost actions.

EMMA - The Energy ManageMent Advisor. A simple, interactive Windows-based software package, designed to help businesses reduce energy costs. It is ideal as an introduction to energy management.

Energy Saving Guide for Small Businesses. A step-by-step approach to help readers improve the energy efficiency and profitability of their company. It complements the energy saving tips contained in FOCUS.

The Bottom Line. A video that shows where the main sources of energy wastage are in small businesses, and how to tackle them.

Good Practice Guides (GPGs)

The following Guides give additional information on M&T:

GPG 111, *Monitoring and Targeting in foundries*
GPG 112, *Monitoring and Targeting in large companies*
GPG 113, *Monitoring and Targeting in the semi-manufacture of non-ferrous metals*
GPG 131, *Monitoring and Targeting in the glass manufacturing industries*
GPG 147, *Monitoring and Targeting in the steel industry*
GPG 148, *Monitoring and Targeting in the textiles industry*

The following Guides are useful in improving other aspects of energy management:

GPG 69, *Investment appraisal for industrial energy efficiency*
GPG 165, *Financial aspects of energy management in buildings*
GPG 213, *Successful project management for energy efficiency*
GPG 214, *Making use of Business Standards*
GPG 217, *Cutting energy losses through effective maintenance (Totally Productive Operations)*
GPG 231, *Introducing energy information systems for energy management*

The following Guides are useful in reducing energy costs of transport and vehicles:

ECG 59, *Fuel consumption in freight haulage fleets*
ECG 64, *Fuel consumption in UK car and van fleets*

Fuel management guide for freight haulage fleets
Fuel management guide for car and van fleets

Fuel Efficiency Booklets (FEBs)

FEB 1, *Energy audits (1A for industry, 1B for buildings)*
FEB 7, *Degree days*
FEB 14, *Economic use of oil-fired boiler plant*
FEB 15, *Economic use of gas-fired boiler plant*
FEB 16, *The economic thickness of insulation for existing industrial buildings*
FEB 17, *Economic use of coal-fired boiler plant*

Good Practice Case Studies (GPCSs)

Particular Case Studies demonstrating energy management and M&T principles in small and medium-sized companies are:

GPCS 71, *Energy management training enables savings in small firms*
GPCS 134, *Decentralisation of steam supply on a small industrial site*
GPCS 207, *Monitoring and Targeting in a multi-site company*
GPCS 221, *Monitoring and Targeting in a hospital laundry*
GPCS 265, *Energy savings in a small company through management commitment and staff involvement*
GPCS 273, *Monitoring and Targeting at a brewery*
GPCS 332, *Corporate commitment to saving energy at a small site*

Other Useful Information

Energy and Environmental Management - a free bimonthly journal published by the DETR giving information on UK energy efficiency and environmental issues. It is an interesting journal with topical articles and notification of events. It is also a useful source of degree day data. You can subscribe to the journal by contacting Energy & Environmental Management, Readerlink Ltd, 260 Field End Road, Ruislip, Middlesex, HA4 9BR.

Specification for Environmental Management Systems BS 7750. British Standards Institution (BSI), 1992. ISBN 0-5802-0644-0.

Energy Monitoring and Targeting using CUSUM. Peter Harris. Cheriton Technology Publications, 1989. ISBN 1-872157-00-9.

Statistical Process Control, A Practical Guide. J S Oakland and R F Followell, 2nd Ed., Heinemann Newnes, 1990.

Materials Thermochemistry. O Kubaschewski, C B Alcock and P J Spencer, Pergamon Press, 6th Ed. 1993.

The Government's Energy Efficiency Best Practice Programme provides impartial, authoritative information on energy efficiency techniques and technologies in industry, transport and buildings. This information is disseminated through publications, videos and software, together with seminars, workshops and other events. Publications within the Best Practice Programme are shown opposite.

Further information

For buildings-related publications please contact:
Enquiries Bureau
BRECSU
Building Research Establishment
Garston, Watford, WD2 7JR
Tel 01923 664258
Fax 01923 664787
E-mail brecsuenq@bre.co.uk

For industrial and transport publications please contact:
Energy Efficiency Enquiries Bureau
ETSU
Harwell, Didcot, Oxfordshire,
OX11 0RA
Fax 01235 433066
Helpline Tel 0800 585794
Helpline E-mail etbppenvhelp@aeat.co.uk

Energy Consumption Guides: compare energy use in specific processes, operations, plant and building types.

Good Practice: promotes proven energy efficient techniques through Guides and Case Studies.

New Practice: monitors first commercial applications of new energy efficiency measures.

Future Practice: reports on joint R & D ventures into new energy efficiency measures.

General Information: describes concepts and approaches yet to be fully established as good practice.

Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Energy Efficiency in Buildings: helps new energy managers understand the use and costs of heating, lighting etc.