GOOD PRACTICE GUIDE 112

Monitoring and Targeting in large companies

GOOD PRACTICE GUIDE 112

SAVE

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:

Energy Efficiency Enquiries Bureau
ETSU
Harwell
Didcot
Oxfordshire
OX11 0RA
Tel: 01235 436747
Fax: 01235 433066
E-mail: etsuenq@aeat.co.uk

MONITORING AND TARGETING IN LARGE COMPANIES

This Guide is No. 112 in the Good Practice Guide series. It provides advice for large companies to show how Monitoring and Targeting (M&T) can be used to better understand energy usage and to reduce energy costs.

Prepared for the Department of the Environment, Transport and the Regions by:

ETSU
Harwell
Didcot
Oxfordshire
OX11 0RA

and

Cheriton Technology Management Ltd
PO Box 916
Swavesey
Cambridge
CB4 5UE

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ETSU
Harwell
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Oxfordshire
OX11 0RA
Tel: 01235 436747. Fax: 01235 433066. E-mail: etsuenq@aeat.co.uk

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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.

ENGLAND

London
Govt Office for London
6th Floor
Riverwalk House
157-161 Millbank
London
SW1P 4RR
Tel 020 7217 3435

East Midlands
The Sustainable Development Team
Govt Office for the East Midlands
The Belgrave Centre
Stanley Place
Talbot Street
Nottingham
NG1 5GG
Tel 0115 971 2476

North East
Sustainability and Environment Team
Govt Office for the North East
Wellbar House
Gallowgate
Newcastle-upon-Tyne
NE1 4TD
Tel 0191 202 3614

North West
Environment Team
Govt Office for the North West
Cunard Building
Pier Head
Water Street
Liverpool
L3 1QB
Tel 0151 224 6401

South East
Sustainable Development Team
Govt Office for the South East
Bridge House
1 Walnut Tree Close
Guildford
Surrey
GU1 4GA
Tel 01483 882532

East
Sustainable Development Awareness Team
Govt Office for the East of England
Heron House
49-53 Goldington Road
Bedford
MK40 3LL
Tel 01234 796194

South West
Environment and Energy Management Team
Govt Office for the South West
The Pithay
Bristol
Avon
BS1 2PB
Tel 0117 900 1700

West Midlands
Regional Sustainability Team
77 Paradise Circus
Queensway
Birmingham
B1 2DT
Tel 0121 212 5300

Yorkshire and the Humber
Sustainable Development Unit
Govt Office for Yorks and the Humber
PO Box 213
City House
New Station Street
Leeds
LS1 4US
Tel 0113 283 6376

NORTHERN IRELAND
IRTU Scientific Services
17 Antrim Road
Lisburn
Co Antrim
BT28 3AL
Tel 028 9262 3000

SCOTLAND
Energy Efficiency Office
Enterprise and Lifelong Learning Dept
2nd Floor
Meridian Court
5 Cadogan Street
Glasgow
G2 6AT
Tel 0141 242 5835

WALES
Business and Environment Branch
National Assembly for Wales
Cathays Park
Cardiff
CF10 3NQ
Tel 029 2082 5172

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INTRODUCTION

Objectives

Energy monitoring and target setting is the collection, interpretation and reporting of information on energy use. Its role within energy management is to measure and maintain performance and to locate opportunities for reducing energy consumption and cost.

The objectives of this Guide are:

- to show how large companies can make use of normally available energy and business management information to improve energy efficiency and to reduce their energy and utility bills;
- to give Energy Managers practical guidance on how to set up a Monitoring and Targeting (M&T) system for their company and how to interpret the information it provides.

This Guide is written for Energy Managers in large companies who are interested in analysing possibilities for reducing their energy bills through the application of M&T. It is also designed for consultants and other external advisors who are assisting industry to establish and use M&T.

M&T Advice from the Energy Efficiency Best Practice Programme

This Guide has been written specifically for companies whose energy bill is a significant amount, typically greater than £250,000 per year. It is particularly relevant to 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 the Appendix.

Energy M&T

Energy Monitoring and Targeting (M&T) is the predominant activity within energy management to use and interpret energy use information. It is therefore distinguishable from activities that depend mainly on physical inspection (surveys), engineering appraisal, inter-personal relations (motivation, improvement teams) and energy purchasing - although it is capable of providing important and valuable inputs to all of these.

Within the scope of M&T there is a wide range of styles and practices, but there are elements which are common to many of these. They all have the same overall objectives in mind: better accountability; better control and allocation of cost; improved performance; improved productivity; reduction in waste.

Energy M&T has much in common with the information side of quality management in that it it uses many similar techniques of data gathering, analysis and reporting, has to function within a management structure, and yields benefits that are similar in kind. In organisations where a programme of improvement in quality management is already operating, energy M&T will almost certainly share some information, and there are benefits in sharing reporting systems and management structures.

Energy is an important area of environmental impact. All formalised systems of environmental management have a requirement for an information system which, for the energy component, would encompass M&T. Some systems of environmental management are modelled on quality management systems, and the same considerations with regard to sharing data collection, analysis, and reporting apply.

Energy M&T also shares many of the quantitative techniques in the newer styles of management accounting, e.g. Activity Based Cost Management (ABCM), and many M&T systems are set up within an ABCM philosophy.

Styles of M&T

There are few formal conventions regarding energy M&T, what it is supposed to be, how it should be carried out, or how it should fit within the organisation. Development of the concept has allowed a number of different styles to emerge, all of which are outlined in this section.

The Energy Accountable Centre - is an approach introduced in the UK in the 1980s and is very much influenced by cost accounting principles.

It is based on the notion that, if a manager responsible for a department in a factory is made accountable for the energy costs of his/her department, and is suitably supplied with information on costs, there exists an incentive to find ways of improving performance.

It works by identifying areas of the organisation where management accountability is definable geographically, installing meters on energy and energy-based utilities (such as compressed air) at the point of entry to the area or department, and providing information on consumption on a routine (daily, weekly or monthly) basis. It is characterised by the way energy metering schemes map on to organisational structures. The lack of adequate metering and conflict with organisational structures have been significant reasons why the adoption of Energy Accountable Centres has been limited.

Avoidable Waste - is a more recent approach and has become prominent since about 1988. It is based on the observation that much of the potential for energy savings lies in two very specific areas:

- that part of energy use which might not be essential to production and is found by tracing the relationship between energy and production back to zero production;
- occasional actions taken by individuals or particular events causing an increase in energy consumption, which are avoidable.

Avoidable Waste tends to be more selective. It focuses on a limited range of core processes and tends to be applied in a more supervisory way - one part of the organisation has the analytical expertise and supervises and supports other parts of the organisation in their management of energy.

Quality-centred M&T - is based on the requirement within accredited quality and environmental management systems (BS 5750, ISO 9000, BS 7750, etc.) for an information system, and shares information with these. It is shaped by the information requirements, reporting chains and priorities of these systems, which, in turn, are influenced by the philosophy under which they have been established.

The advantage of applying energy M&T within quality systems is that it uses management structures that are already in place and is less likely to be marginalised as an activity.

Activity Based Costing (and Management) (ABC or ABCM) - is an accounting philosophy developed in the US in the 1980s. It recognises that income from manufacturing is determined by the price the market will accept - but income has to cover costs. Costs are added by ‘activities’, but some activities add value and others do not.

ABCM seeks to identify activities which add disproportionately to costs compared to value. **Activities** originally referred to what people did because of the way that overhead costs used to be assigned, by accountants, in proportion to direct labour costs. Now, 'activities' are taken to include all overhead costs which, for many firms, include energy.

Although developed independently, ABCM shares many of the techniques and tools which have been developed within energy M&T.

Statistical M&T - is the direct analogue of Statistical Process Control (SPC) in quality management. Developed in the 1940s in the UK sugar industry, it is now finding application within M&T due to the availability of modern computer software. Statistical M&T is not a distinct philosophy as such, but a means to enhance the performance of other approaches to M&T.

Data mining - is an approach to the analysis of very large bodies of data. It was developed to enable organisations that already carry out large numbers of computer-borne transactions (e.g. financial houses, large retailers, public administration, etc.) to make use of the very large arrays of data created by these systems. It uses very powerful (neural network) computers to pick out patterns and relationships in the data, but is characterised by adopting no preconceptions regarding the nature of the patterns themselves.

This Guide introduces the capabilities and benefits of M&T and outlines the different methods of data handling and reporting available. This will enable readers to maximise the opportunities for improving energy efficiency within their own organisation, whichever manufacturing management philosophy currently applies.

Approaches to M&T

The approach to energy M&T that an organisation adopts depends on:

- who, within the organisation, is taking the initiative - an engineer, accountant, statistician or scientist;
- external influences - energy consultant, software supplier or auditor;
- which formalised systems of information-based management already exist - BS 5750, Total Quality Management (TQM), ABCM, BS 7750, etc.;
- sources of external advice - e.g. the approach proposed by an energy consultancy will depend upon its strengths in survey work, software development or organisational issues.

An individual's professional background and training will have a strong bearing on the approach to M&T adopted. Different individuals will have been exposed to varied cultures of information use and have differently developed skills in working with information. Statisticians tend to place more emphasis on analysis than reporting, and may tend to centre the activity on themselves; accountants may be more likely to favour a style which circulates information and depends on interpretation by the recipient.

The approach taken will, in turn, influence:

- the structure of reporting systems;
- assignment of responsibilities;
- selection of software.

This Guide aims to give an appreciation of what M&T can achieve, and to show that its full potential can be realised in any of the circumstances likely to be found in the larger company.

Sustaining the System

Experience has shown that the greatest threat to M&T systems in industry is **marginalisation** - where the system may operate but no-one takes notice of it. There are four common circumstances under which marginalisation occurs:

1. Lack of accountability - no clear lines of responsibility between the faults/problems/anomalies identified by the system and the people in charge of the part of the organisation where they are found.

2. Lack of resolution - people are more likely to maintain faith in a system when it identifies at least some faults and/or problems that they are not aware of, or identifies them before they otherwise would become aware of them. The resolution of a system is the smallest deviation from expected consumption that can be confidently identified as exceptional; poor resolution can lead to a system in which people have no faith, either because it highlights problems that do not really exist or it seems never to raise a question even when faults are known to exist.

3. Lack of ownership of the result - people are more responsive when the information is seen to work for them in identifying problems and opportunities rather than create a situation where they become servants of the system.

4. Lack of authority - where the information system does not have the support of senior managers, who are perceived not to have belief in it or do not use it to support the supervision of activities under their control.

If energy M&T is to be applied successfully in an organisation, the system should:

- support lines of responsibility and identify where they are unclear;
- use methods of analysis appropriate to the process being monitored, to ensure adequate resolution;
- involve the people it serves, accommodating both their views and desires to offer solutions and have their performance judged on fair criteria;
- have the support and commitment of senior management.

Selecting Computer Software

Below the level of neural network computers, there are no procedures performed by computers within energy M&T that are not exact analogues of procedures that used to be carried out by hand. The role of the computer is mainly to enhance the speed of calculation and the quality of presentation, whilst reducing the cost of the operation and frequency of calculation errors.

Computer software tends to be designed around a philosophy which reflects the experience, preferences and approach of the designer. It is time-consuming and expensive to write new software, so it tends to be designed around:

- the designer’s perceptions of the market for the product;
- the designer’s background and experience in M&T.

Software differs as much in style as M&T itself. Designers who see errors in meter reading as a major threat to M&T tend to place emphasis on data acquisition. Designers with a background in Energy Accountable Centres tend to focus more on the re-organisation of data rather than statistical summaries.

M&T software products tend to include any feature which is straightforward to convert to software code - such as checking for a meter that has gone round the clock. However, the availability of such features should not be confused with the ultimate requirement for the system to work with the processes the organisation uses - **it is more important that a system does what the organisation needs, than do many things it does not require.**

As spreadsheets have become easier to use, as well as more powerful, many users of M&T in industry rely on spreadsheets they have designed themselves. This allows them to develop in sophistication, beginning with simple spreadsheets and then moving on to macro-driven spreadsheets versions as their confidence grows.

Benchmarking

A very simple way to use energy information as an aid to management is to compare the overall energy consumption of an enterprise, site or process with others of a similar kind. In its more general form this approach is known as **benchmarking.**

The Energy Efficiency Best Practice Programme encourages industry to adopt benchmarking of energy performance through its Energy Consumption Guides. These publications are based on questionnaire surveys, usually carried out with the involvement of trade and/or research associations, which gather information on the energy consumption, gross production and other key parameters that tend to affect energy requirements, e.g. water usage, types of process plant, classes of product and internal factory recycling.

There are already Energy Consumption Guides on industries such as liquid milk processing, brewing, glass containers, non-Fletton bricks, steel reheat furnaces, ferrous foundries, ceramic tableware, injection moulding and blow moulding of plastics, aluminium extrusion, cold storage, and others.

In some sectors these surveys have been carried out more than once and the results indicate the rate at which improvements in energy performance are being achieved, as well as provide a basic measure of performance.

2 IMPLEMENTING ENERGY M&T

After more than a decade of experience of energy M&T in industry, the ingredients of success and causes of failure are now reasonably well understood. The way M&T is implemented in an organisation, the resulting benefits, and the cost depend on the style of the current management, the business environment in which the organisation needs to function, its broader aims, and, to some extent, the sector of industry in which it works.

About one in five organisations that have adopted M&T in industry have abandoned it; reasons for this include lack of commitment or faith from senior management, lack of adequately trained people to operate and maintain the system, and competition from other activities for the time needed to establish the system.

Organisations that have persevered with M&T cite a range of difficulties:

- lack of capital for instrumentation or computer equipment;
- lack of interest from senior management;
- difficulty in siting meters;
- lack of influence over energy users whose activities the system is intended to monitor;
- lack of ability to index production;
- lack of management time to operate the system effectively;
- lack of in-house expertise, particularly in the use of computer software.

Despite the difficulties, there are many significant benefits that have been gained by organisations that have successfully implemented M&T. For example, sites using M&T:

- can improve their energy performance more quickly and to a greater extent than those without M&T;
- are better able to justify capital investment in energy efficiency;
- tend to have fared better in difficult economic conditions.

In addition to these benefits, sites with M&T tend to think it is a more effective way to control energy costs than other means, and are more likely to have a forward action plan than those without.

Broadly speaking, organisations which adopt M&T most readily already tend to have in place some other system of information-based management - ISO 9000, TQM or ABCM. In such cases the problems associated with the introduction of an information-based system of management have been encountered and overcome. Those that find capital cost a barrier tend to be those with smaller energy bills or with very diverse processes which require an investment in metering.

Applications for M&T

Whatever the reported experiences of users of M&T, there is nothing to indicate that failure is anything to do with inherent weaknesses of the activity. The nature of the sector and the processes it uses have some bearing, but otherwise the difficulties encountered tend to relate to application of M&T within the organisation, e.g. difficulties in obtaining accurate meter readings, inadequate training of staff, marginalisation of energy management within the organisation, and lack of investment.

Generally speaking, in any one sector of industry, the key features of M&T - what is measured, what other information is required, the type and depth of analysis required and the reporting channels and structures - tend to be broadly similar. If there are differences, these are greater between sectors than between sites within the sector. The more energy-intensive the sector and the more energy that is concentrated into a small number of processes, the more similar the sectors become.

Examples from the brick and paper industries

In the brick industry, energy is a high proportion of costs and value added; the kiln accounts for more than 90% of the total energy supplied, and M&T applied to the kiln can achieve a resolution of 2.5% based on the production tonnage alone. All of the information, including metered energy use, required to implement a basic system of M&T is probably already circulating within the organisation. Implementation may require only minor modifications to the way information is collected, a move toward more frequent energy meter readings, fairly basic analysis, and modification of existing reporting channels.

The paper industry is an internationally competitive industry in which energy costs are a high proportion of total costs and value added. Energy requirements are concentrated in one core process - the paper machine - but this might produce many varieties and gauges of paper, each of which has different energy requirements. All of the information required to implement energy M&T to a resolution of 1% is probably already being gathered and circulated. Implementation of M&T would not involve any changes to reporting channels, but may require minor modifications to the way information is collected and major changes in the way it is analysed and reported.

In some industries, particularly metals and plastics, there is a high degree of internal recycling of material on which energy is expended on each pass of the material through energy-intensive stages. In these industries the control of yield - how much material appears as product - is at least as important as improvements to the energy efficiency of individual processes.

There are many industries, e.g. textiles, food, engineering, where no one process dominates, and where the installation of sub-meters is necessary to bring a majority of energy consumption under management control. Production information to achieve a useful resolution may be difficult to specify or measure; in such circumstances, how much of the energy use is brought within the scope of M&T is an important consideration *before* the installation of meters.

Business Drivers

The type of industry, the nature of its markets and the company's principal business drivers have a significant effect on a company's requirements for M&T:

- Where cost is most important, the imperative is to reduce costs and minimise waste.
- In businesses working close to capacity, the requirement of M&T is to pre-empt failure and schedule maintenance.
- Where quality is paramount, M&T can contribute to quality management.
- In growing businesses, M&T provides an insight into the performance of processes to enable new capacity with improved performance to be specified.

In each case the strategy for implementation of M&T will be starting from a different point and seeking different outcomes.

Components of M&T

When considering the implementation of M&T it is important to look beyond the practical steps that need to occur. The support of management, availability of technical assistance and a culture of achieving results are just as necessary.

Senior management commitment

If the commitment of senior management can be achieved prior to adoption of energy M&T, this is almost certainly an advantage. Senior managers normally want to know what result they are going to get before committing themselves to a course of action.

In some industries, and in some approaches, M&T may call for a significant financial commitment for additional meters, software, etc. This can be difficult to support because only rarely is it possible to calculate the financial return on the installation of a meter - the savings are likely to be based on guesswork.

Apart from investment, top-level commitment often brings easier access to data and resources. It also brings authority when there is a need to challenge practices in areas of the company where performance could be improved. Experience shows that a large part of the benefits of M&T come from simple analysis, either of existing information or information easily gathered without a very large commitment of capital.

Anyone with access to basic historic data and a desktop computer, and who is prepared to co-operate with colleagues to pool information and explore the basic procedures outlined in this Guide, can produce a result that will justify the investment of time and resources in M&T as a formalised management activity.

Technical support

Technical support can be obtained internally in your organisation or, if not available, from consultants, training and computer software.

Consultancies vary widely in their preferences and expertise. Consultants with a detailed knowledge of a particular industry and its processes are probably already well known in the industry, although skill with the techniques of analysis may be your requirement more than specific industry knowledge. Among the community of energy consultants there is a wide spectrum of styles and specialisms, ranging from:

- consultants with a preference for the energy survey style of work, whose focus may be in the technology of data collection;

through to:

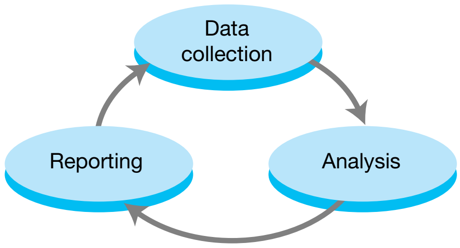
- consultants with an interest in computer systems whose focus is on information technology, software and, increasingly, on automatic data acquisition systems;
- consultants whose interest is in management systems and whose focus is likely to be on reporting systems and responsibility structures, and less on the analysis and acquisition of data.

When selecting a consultant it is important that his/her style and focus matches that of the organisation and the state of development of information-based approaches within it.

Training is an important source of support. Apart from general energy management training, there are many consultancies that offer in-company training in M&T, and there are some open courses that allow for delegates to base the training on their own data.

Computer software performs many of the analytical calculations without the need to understand the detail. The choice between software packages should be based on how well they handle relevant processes, as well as other factors such as cost or ability to handle large volumes of data.

Stages of M&T



The implementation of M&T requires three discrete tasks to be undertaken: data collection, analysis, and reporting.

Each component is dependent on the others. Without analysis there is nothing to report and without data there is nothing to analyse. Clearly, if no **ACTION** is taken on the information reported, then the whole exercise is a waste of effort.

Data collection

There are four stages in data collection:

- using data already being collected, without any form of modification;
- modifying the way data is presently being collected;
- collecting further data manually;
- automatic data acquisition.

Much of the core data on production is usually being gathered already for other purposes (e.g. cost and production control), and some analysis will already have been done to determine what information is gathered, by whom, how, and for what purpose. Sharing this information for M&T purposes may require modifications to the way it is gathered to enable M&T to perform more effectively. The impact of this on other management functions should be considered - it may, or may not, be beneficial.

For M&T purposes, production information can be divided into three types:

- information on production that relates to amount - weight, volume, number of items, area (waiting time and productive hours fall into this category, as does the weather measured as degree days);
- information on production that does not relate to amount - temperature, density, water content, ratios of constituents (e.g. fat to solid ratios in fried food);
- ancillary information - causes of breakdown, occasional notes and comments.

The first of these is distinguishable from the other two because items of information are additive - information for a week can be obtained by adding daily information. Information of the second type is not additive. In some cases M&T can achieve adequate resolution only if information of this second type is utilised.

Information which is not additive tends to be difficult to summarise and this is often reflected in the way it is handled in organisations. It is more likely to be hand-written, with few checks on its accuracy, and archived without being processed.

Proposals to incorporate such information into M&T systems tend to meet with resistance because of the work involved in handling it, and a false perception that, if it is difficult to use in the context in which it was gathered, it must be impossible to use in M&T. The handling of this information is better established in organisations already operating information-based quality management than in those which are not. This accounts for some of the resistance to M&T in organisations where quality management systems are poorly developed.

There is a perception that successful M&T requires the installation of very large numbers of meters. In 1992, a survey of M&T systems already in place showed that 40% were based on fewer than ten meters, and a similar proportion with between 11 and 50. Fewer than 20% have more than 50 meters.

Analysis

Analysis is the key weakness in most under-performing M&T systems. Arguably, all the benefits from M&T ultimately derive from the analysis and interpretation of the data - if this is weak it makes the whole system weak.

The first requirement of analysis is that it is capable of providing a useful insight into the process, enabling decisions to be taken and achieving a resolution such that faults are detected to achieve a worthwhile return on the activity. The optimum forms of analysis tend to be dictated by the nature of the process rather than the preferences of the individual manager. It is essential, therefore, that:

- either adequate training is provided; or
- any software utilised has adequate analytical capability.

Many successful industrial M&T installations are based on computer spreadsheets written within the organisation rather than dedicated software (the reverse is the case for monitoring estates of buildings).

The area where a computer spreadsheet encounters the earliest limitation is in the analysis of electricity half-hour profiles provided by utilities. Analysis on a day-by-day basis can be achieved very rapidly without reorganising the data from the format supplied. However, to produce a half-hourly profile (such as shown in Fig 14) the data will need reorganisation which, in the case of a spreadsheet, requires someone trained in the use of macro language. Before purchasing dedicated software, it is important to examine how much additional analysis is provided, as distinct from mere presentation.

Reporting

The forms of data reporting tend to be dominated by the preferences of individual managers, and can cover widely differing management styles. These range between extremes of:

● Providing users, department managers and supervisors with reports that summarise all the information perceived to be of value,	or	only supplying them with notice of exceptional consumption.
● Tabular presentation of numerical summary information delivered to the in-tray of department heads,	or	graphical charts in full colour posted on notice boards.
● Dedicated reporting as a separate communication channel for energy,	or	incorporation of energy information in existing report documentation used by other management information systems.

The broad principle of reporting is that:

- the right information should reach the person who has control of the resource to which it refers;
- they should be able to understand what it means to them;
- there should be a minimum of extraneous information that prevents them from noticing what they need to see;
- there is some means of ensuring that action is taken when it is needed.

It is becoming increasingly common practice within industrial enterprises to process production information for routine reports and briefing meetings by using computer spreadsheets. In many cases all the information required for energy M&T is already present on such a spreadsheet. Implementation of energy M&T may only require the addition of a few cells that combine information already present - although it may require the inclusion of a formula arrived at by analysis outside the spreadsheet itself.

Dedicated energy M&T software tends to be designed on the **Energy Accountable Centre** philosophy (discussed in Section 1), i.e. it requires definable units to be set up for which energy consumption and/or costs can be identified. As a dedicated system, such software tends to deal exclusively with energy information, and reporting is often entirely separate from other information systems. **A stand-alone energy reporting system needs to be carefully fostered to protect it from marginalisation when these reports compete with other pressures on managers' time.**

On the positive side, such systems are designed to enable the distribution of information to be very selective and focused, and to allow it to be tailored to the level of the organisation at which it is targeted. This comes into its own particularly for monitoring performance in multi-site organisations.

WHAT M&T INFORMATION CAN TELL YOU ABOUT ENERGY-USING PROCESSES

3

When energy is needed in industrial processes or buildings, it is used for a purpose, e.g. heating, melting, vaporisation, compression, chemical transformation, moving materials and semi-finished goods, and size reduction. The idea that energy can be managed by collecting information on energy use is based on the notion that the energy used to achieve a given amount of production on one occasion can be related to the amount of energy needed to produce either the same, or some other, amount of production on another occasion. A key factor in the success of M&T is experience in establishing the relationships that justify this extrapolation.

M&T works on the same basic principle as most other information-based management systems and includes:

- establishing a basis for predicting from past energy consumption data;
- using this to establish the expected energy use in the immediate past management period (day, week, month);
- calculating the difference between actual and predicted consumption;
- deciding whether or not this variation is acceptable;
- determining the cause of isolated unacceptable differences;
- implementing actions to improve the energy consumption prediction.

Characteristics of Processes Determined from M&T Data

From an M&T standpoint, industrial processes divide into two groups:

1. **Processes where energy use is largely determined by the physics of the process,** i.e. how much energy is used and to what extent the process transforms the product. This group comprises all heat-based processes (heating, melting, evaporation); all chemical and electrochemical processes; and some work-based processes (in the physics sense) such as compression of compressible fluids (refrigeration, compressed air and evaporation under vapour recompression).

2. **Processes in which physics provides a poor indication of the energy needs or of the extent of the process** - most of these processes are mechanical in nature and comprise processes such as cutting, size reduction, mixing, conveying, etc.

All the processes in the first group are sufficiently consistent in their energy behaviour to make M&T easily applicable; success depends mainly on the skill with which it is applied. In the second group, whether or not M&T has a place depends on how far energy consumption can be meaningfully related to some measure of production, or whether another system of performance evaluation can be found.

Fortunately, a very large proportion of industrial energy use comes into the first group, and much of the Statistical Process Control (SPC) element of quality management has been developed to handle processes in the second group. So, for a very wide range of processes there is already some established basis on which measured energy use can be used for management control.

Within the second group there are three forms of energy which are difficult to handle:

- energy consumption associated with activities linked to time rather than production - this applies to many of the non-production uses of electricity;
- energy consumption which is not linked to production but to the weather - space heating and space cooling;
- vehicle fuel.

Process energy linked to production

In processes where there is a strong link to production, the first requirement is to establish the nature of the link. This is easiest to consider in the form of an energy vs. production scatter graph (Fig 1).

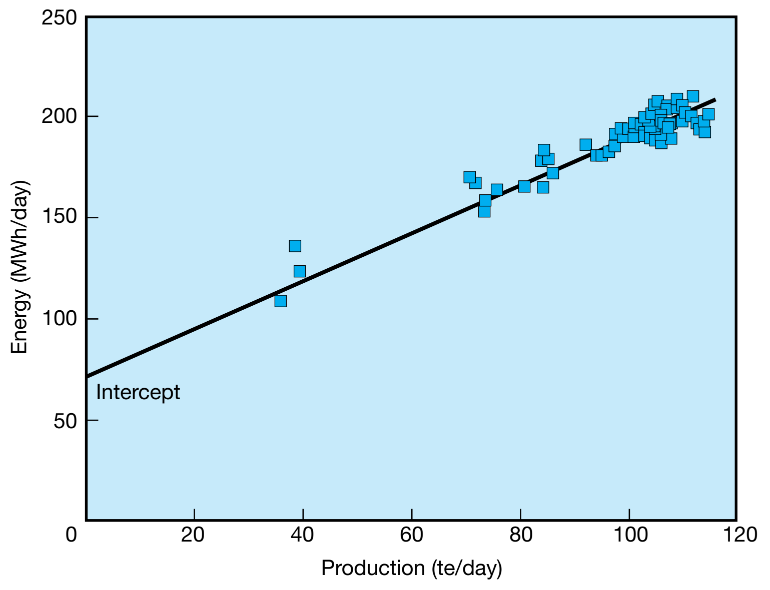


Fig 1 Energy vs. production for a glass melting furnace - the common form of graph

Fig 1 represents a basic pattern to which the behaviour of most processes can be related. Such a graph contains three elements:

1. An intercept (the point where a best fit line through the data cuts the energy axis at zero production) - this is the energy that would be required if this process ran but did not produce anything. It is also energy consumption that continues while production is in progress but does not contribute to production.
2. A slope - the amount of energy required at any given level of production to process each additional unit of production. The efficiency of the process can be established from the slope.
3. The scatter - the amount by which the energy used for any one level of production varies from one period to another. This tends to be governed by operational factors.

The pattern of Fig 1 is the most commonly observed, although this does not imply that it is the most likely for any specific factory or sector. The type of pattern found in a given factory is determined mainly by the industry sector. Figs 2 - 8 show examples of other common types of pattern.

Fig 1 is taken from a glass furnace. It has an intercept on the energy axis, the line is straight over the whole range of production, there is not much scatter, and production covers a wide range. The best fit line to the data can be formulated as:

$$\text{energy} = (m \times \text{production}) + c$$

where c and m are **empirical** coefficients (empirical means they are determined from the data, by either fitting a line to the data by eye or calculating it from the data).

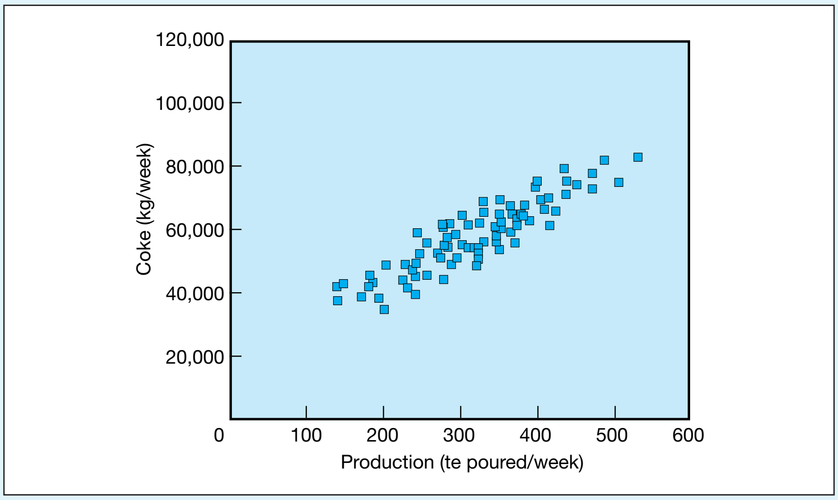
In this case c is 71.5 MWh/day and m is 1.185 MWh/te so the pattern is:

energy (MWh/day) = {1.185 x production (te/day)} + 71.5

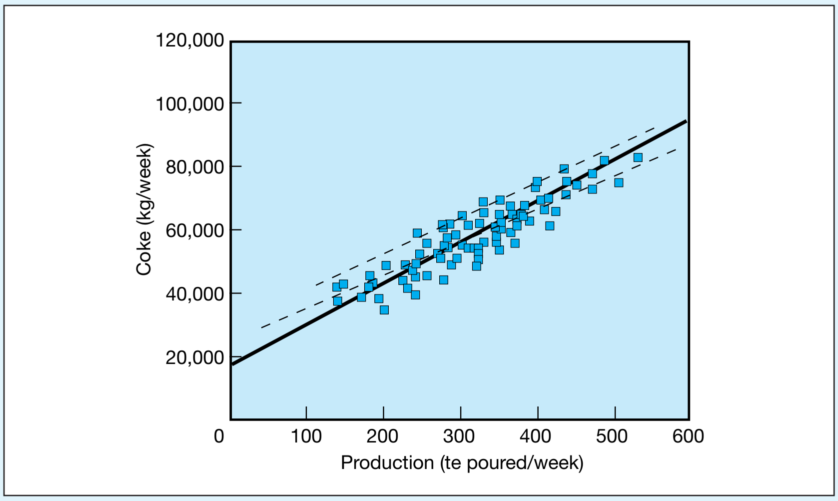
Similar patterns are found for most furnaces (for heating or melting), ovens, kilns, some dryers and many more processes. In the absence of any other indications, it is usual to assume a relationship of this kind.

Procedure for manually calculating the best fit line

1. Plot the data points as an x-y scatter diagram with production on the x-axis and energy consumption on the y-axis. Remember the data points should be for the same periods - it is no good recording energy weekly and production monthly. Also, the energy and production measurements should be at the same time, e.g. at the end of the same day, or 10 a.m. on a Friday. You will get a chart of the following general form:



2. By eye, draw on a straight line to give a visual best fit through all the data points, as shown below. It is best to use a transparent rule and a pencil for this - you may want to rethink your 'guess'. Don't try to force the line through the 'origin', i.e. the point where the x and y axes meet as this is unlikely to be a true representation of the relationship.



3. The formula that you must determine takes the form 'Y = m X + c'. For our relationship, 'X' is the production parameter, 'Y' is the energy parameter, 'c' is the intercept on the 'y' or energy axis (i.e. at zero production) and 'm' is the slope of the line (i.e. the energy required to process each unit of production).

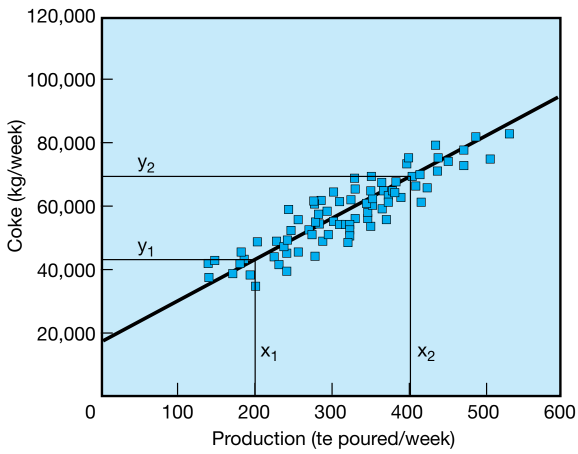
   'c' can easily be found as the value of 'Y' where the best fit line crosses the y-axis (see graph above).

'm' is calculated by the following:

Find two convenient values of the 'X' variable, x_1 and x_2, draw two vertical lines from these points to the best fit line. (It is often convenient to choose x_1 and x_2 so that the difference between them is a round number, e.g. 100, 400, 12,000 etc.)

Draw two horizontal lines from where the verticals cut the best fit line back to the y-axis at y_1 and y_2. You now have two pairs of numbers (x_1, y_1) and (x_2, y_2).

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



4. Now, for any value of production (X) you can predict a value of energy consumption (Y) from the formula, Y = m X + c.

Fig 2 is similar to Fig 1 but has no intercept, i.e. it is a straight line that, when extrapolated, passes through the origin (0 production, 0 energy). It is generally rare for this to be the case.

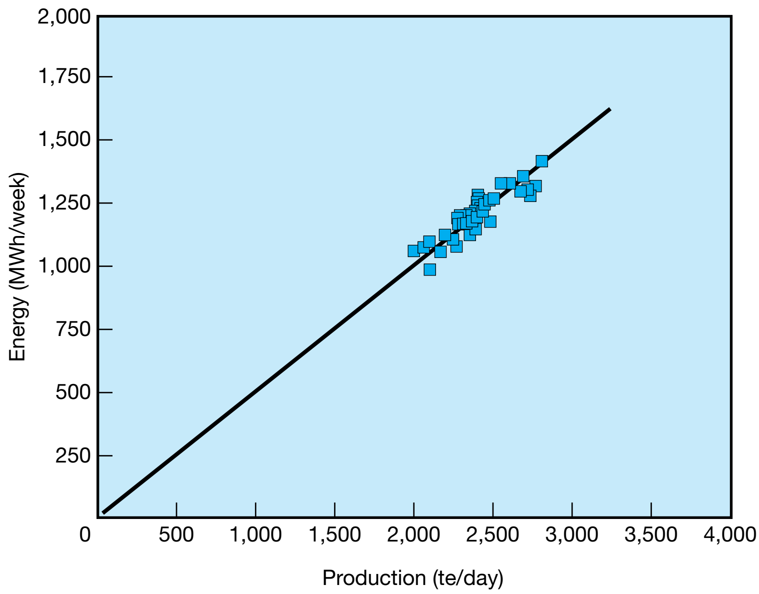


Fig 2 Energy vs. production for an electric arc furnace - a special case where the line passes through 0,0

This example is for an electric arc furnace melting steel for continuous casting. Our knowledge of physics leads us to expect the line to pass through the origin. It would be possible to represent this pattern by the formula:

energy = m x production

where m is an empirical constant and the c coefficient from the previous example is 0. In general, this should not be assumed unless there is a good physical case for it.

It happens to be an important case because rearranging the formula leads to:

$$\frac{\text{energy}}{\text{production}} = m$$

In other words, the expected value of energy/production (specific energy) is a constant, in this case 0.511 MWh/te. This is true *for this and only one other of the known patterns*. In all other cases, specific energy depends on the level of production, and statement of the specific energy without reference to the production rate is meaningless in management terms.

In Fig 3, the intercept is overwhelmingly more important than the slope of the line. This example is for a machine for extrusion-blow moulding of thermoplastic resins.

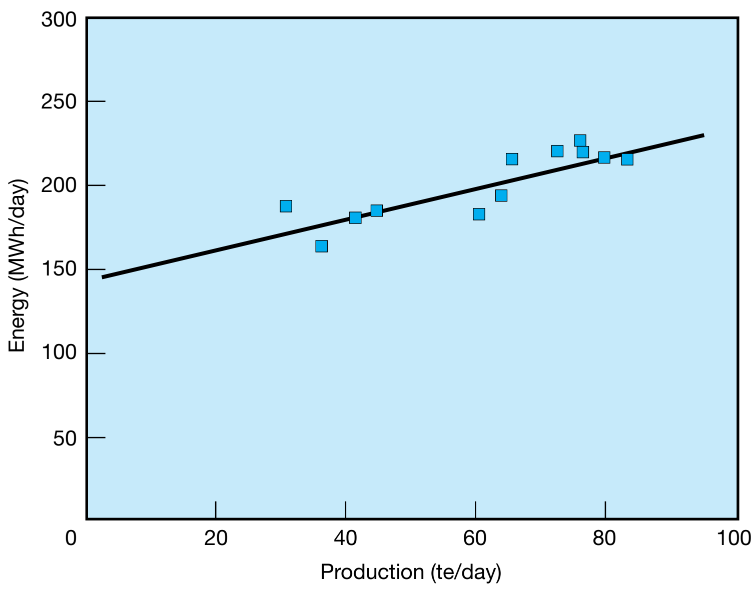


Fig 3 Energy vs. production for an extrusion-blow moulding machine - an example of a very high production-unrelated demand

There are three common circumstances which give rise to this pattern:

1. The process has innate characteristics that give it a high standing consumption but low additional consumption for each unit of production. Work-based processes in the production of plastic extrusions are a good example. In addition, processes with variable output driven by fixed-speed motors also often show a high intercept (although the line may be curved).

2. The process does not have a naturally high standing consumption but a fault is causing a high and continuous energy loss, e.g. faulty steam traps on steam-heated equipment such as sterilisers or rubber tyre moulding presses.

3. Processes where the energy consumption is representative of a fixed duty and the production variable used does not take adequate account of the real duty. An example is paper production where this shape of graph appears when steam is plotted against weight of paper produced. In paper machines, the actual process is the evaporation of water and the machine has an essentially fixed evaporative capacity. Variations in production rate represent the different amounts of water that are evaporated for the range of paper types produced on the same machine.

For the first two cases, the simple intercept formula, energy = (m x production) + c, is appropriate, although in the second case the cause of the high standing loss needs investigation. In the third case, monitoring will be worthwhile only if there is a change in the way the production variable is measured.

Note that, in this case, the specific energy is more closely related to production rate than is energy consumption.

Fig 4 is similar to the third variant of the previous case. It is a process with a fixed productive capacity producing an essentially uniform product, so both the energy use and production fall consistently within a narrow range.

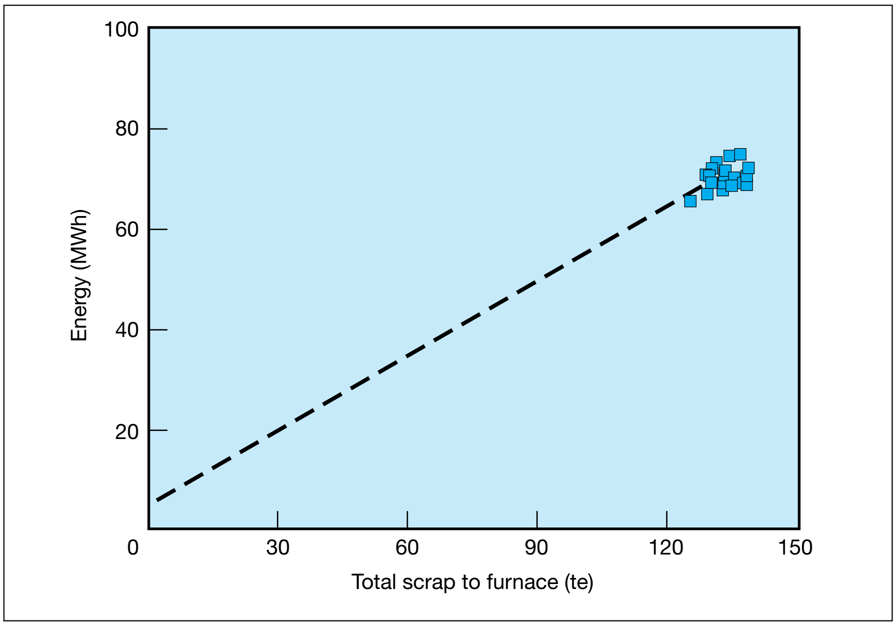


Fig 4 Energy vs. production for an electric arc furnace - an example of the impact of a very narrow range of production

This example is for another arc furnace for steel. In this case, although the data should fit a straight line of the form energy = (m x production) + c, c may be difficult to determine empirically from the data - the long extrapolation back to zero production makes any error in the slope too significant in determining the value of the intercept by purely statistical means. The dotted line can only be established either by specific tests to establish c and find m, or by calculation of m, and using this to estimate c. If there is significant scatter, consideration may need to be given as to whether the variables being used, especially for production, are appropriate.

Fig 5 is a pattern in which the line is curved, with the slope rising as consumption increases. This is for a milk manufacturing plant making butter and milk powder. Increasing slope means that the energy consumption per additional unit of output rises with production.

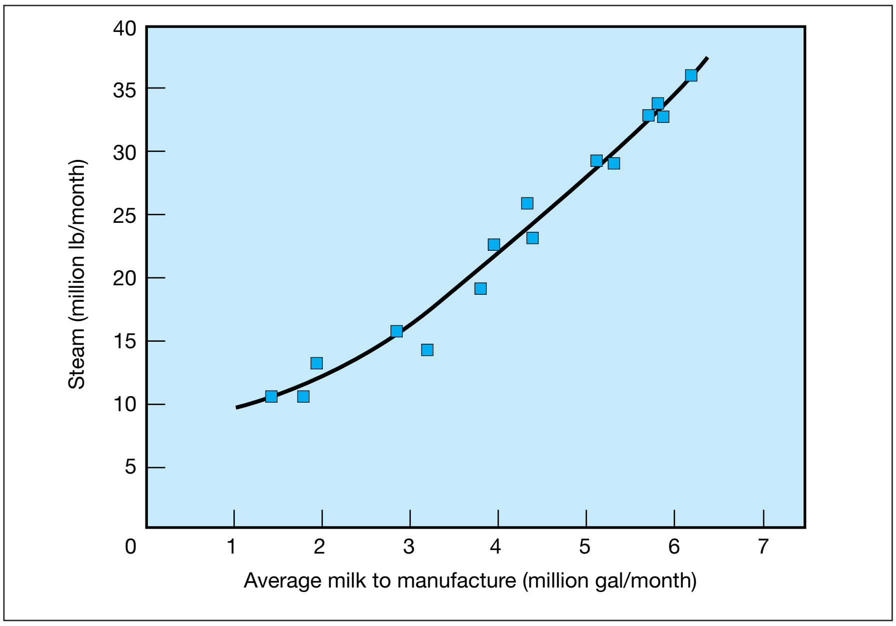


Fig 5 Energy vs. production for a milk manufacturing depot - an example of a curved chart created by plant with different efficiencies being operated in a merit order

The most common causes of this shape of chart are when:

- as in this example, the data refer to the whole factory and production at different levels is achieved by a changing mix of plant of different efficiencies;
- the data refer to a part of the factory or accounting centre which covers more than one use of energy, and there is a relationship between these which is not a simple ratio, e.g. a combination of a seasonally dependent production rate and space heating, which is common in breweries.

A suitable formulation of the pattern is then:

$$\text{energy} = \{(m_1F_1 + m_2F_2 + m_3F_3 \ldots) \times \text{production}\} + c$$

where F_1, F_2, etc. are the fractions of the production in each period, accounted for by each item of plant, and m_1, m_2, etc. are empirical constants specific to those items.

In Fig 6 the graph curves with reducing slope to become straight at higher production rates. This tends to be rather unusual. In a single process, the range of production that produces this effect is rarely encountered in practice, and in multiple processes it implies that most inefficient plant has priority. This data is taken from a shaft furnace used for melting aluminium. A feature of the process is the way heat in the exhaust is recovered to preheat the material entering the process; this is less effective at low throughput. In the straight section of the line, the relationship is exactly the same as for Fig 1.

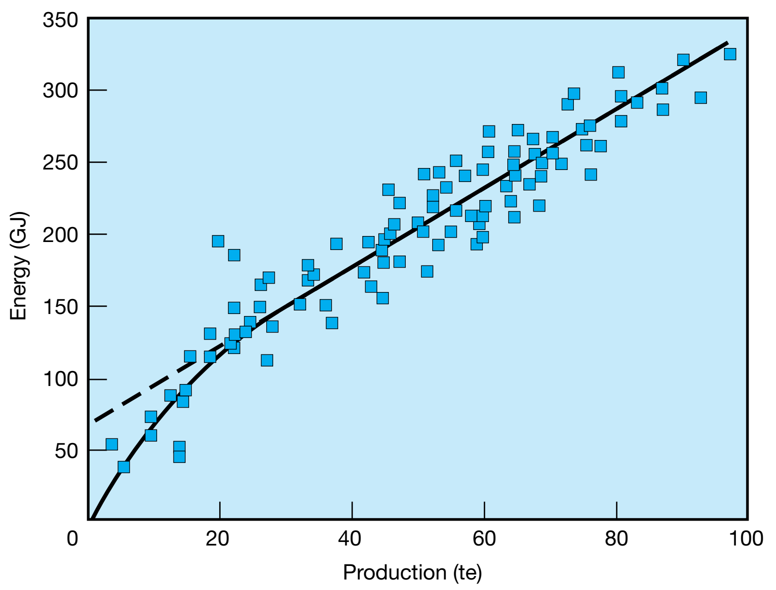


Fig 6 Energy vs. production for a shaft furnace - an example of a curved chart caused by efficiency varying with throughput due to internal recycling of heat

The precise relationship in the curved section is usually not known, or not easily calculated. A useful modification of the formula that achieves a good empirical fit for most circumstances is:

$$\text{energy} = (1 - \exp^{-k \times \text{production}}) \times (m \times \text{production} + c)$$

where m is the slope of the straight section of the chart, c is the intercept found by extrapolating the straight section to zero production and k is an empirical constant (sometimes called an **approach coefficient**). Note: $(1 - \exp^{-k \times \text{production}})$ is a common mathematical expression for approximating curves.

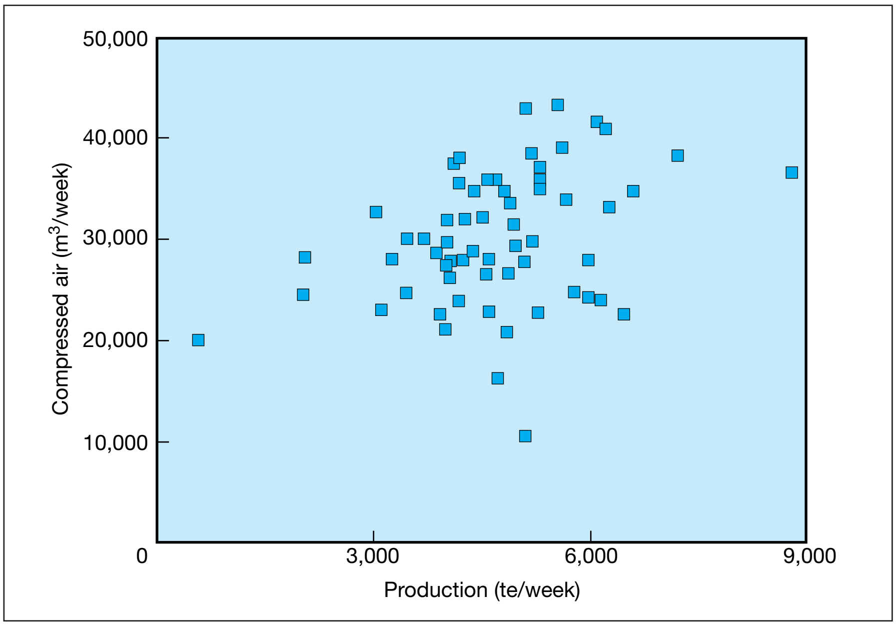


Fig 7 Compressor power vs. volume of compressed air in a hot rolling steel mill - an example of poor control

In Fig 7 the scatter is so great that it overwhelms any underlying pattern.

There are five common reasons for this type of chart:

1. The variable used to represent production is entirely inappropriate - explore other variables.

2. More commonly, the times at which energy meter readings and production records are taken are different, so there is a mismatch in the periods covered by the data; the shorter the data collection interval, the greater the impact, so it is most common in systems that use daily or weekly data.

3. The metered energy is serving more uses than just that measured by the production variable chosen - this is not unusual when energy includes building heating as well as production-related energy.

4. It has not been noticed that the energy and/or production scale does not extend to the origin (0,0) and the process is really the type shown in Fig 4.

5. The data cover a long period of time and there has been a steady change in the energy required for a given range of production over time, which has not been taken into account.

The data (Fig 7) are actually for compressed air compared to production in a steel rolling mill. A combination of the above factors is involved. It is usually possible, by further analysis, to obtain a clearer picture of the factors at work and attribute the chart to another type.

The characteristic feature of Fig 8 is a negative slope. In terms of a mathematical fit, this is much the same as the case of Fig 1 with a negative slope. In physical terms, however, it is far more significant because of the interpretation of the slope. As production increases, less energy is required and it appears, therefore, that marginal increases of production could be producing energy. This is the clue to understanding this behaviour - it normally involves some heat recovery or recycling of heat, although it can involve a reduction in the extent of processing as production throughput increases. This example is for a brewery and shows the total fuel used compared to total throughput. Similar behaviour is found in the injection moulding of polymers.

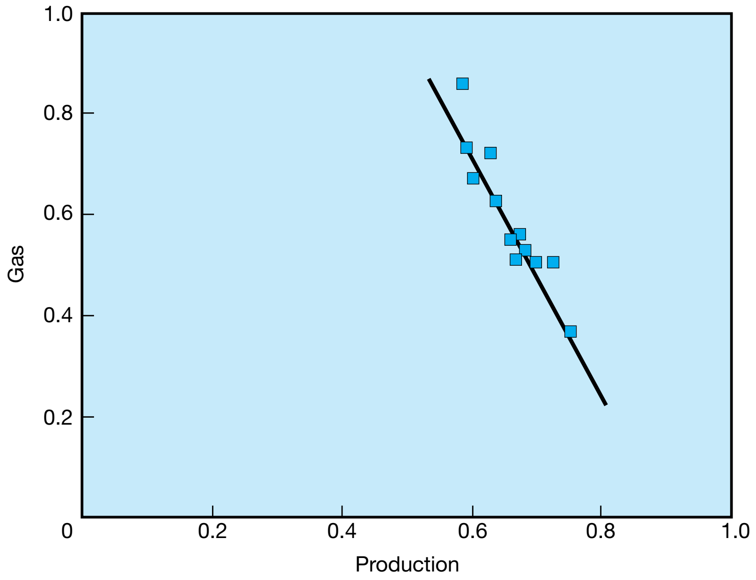


Fig 8 Energy vs. production for a brewery - an example of a line of negative slope

Approximating multivariable situations

If there are more variables controlling the energy use than are incorporated in the x-variable then it is not possible to represent these adequately on a two-dimensional graph. It is, however, still possible to formulate energy mathematically as:

$$\text{energy} = (m_1 \times P_1) + (m_2 \times P_2) + (m_3 \times P_3) + c$$

where P_1, P_2, etc. refer to the other production or other parameters and m_1, m_2 etc. are constants related to these parameters. A common, more generally representative, formulation is:

$$\text{energy} = (h \times H) + (m_1 \times P_1) + (m_2 \times P_2) + (m_3 \times P_3) + \ldots + (d \times DD) + c$$

where H is the productive hours in the period and h is an empirical coefficient, m_1 and P_1 have the same meanings as before, DD stands for degree days (a measure of the weather) and d is an empirical coefficient. If the usage pattern of plant is very variable, it may even be worthwhile extending this formulation to:

$$\text{energy} = (h_1 \times H_1) + (m_1 \times P_1) + (h_2 \times H_2) + (m_2 \times P_2) + \ldots + (d \times DD) + c$$

where the h_1 and H_1 refer to individual processes. Approaches of this kind have been developed for textile finishing. These coefficients can be determined by multiple regression, the method of residuals or sometimes by statistical factorisation methods. They may also be based on standard values - an approach used successfully in the Flowline method in textile finishing, and in the paper industry where one machine produces many grades of paper.

Building heating linked to degree days

The most appropriate measure of the weather for monitoring the heating and cooling needs of buildings is the degree day.

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 18°C or 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.

Further guidance on the use of the degree day is to be found in Fuel Efficiency Booklet 7, *Degree days.* Figures for degree days are published bimonthly in the DETR's *Energy & Environmental Management* magazine (see Appendix).

There are four common base patterns found in industrial buildings, shown in Figs 9 to 12.

The basic pattern is shown in Fig 9. This is exactly analogous to the process case of a straight line with a positive intercept, but with heating degree days as the x-variable. This example is for a textile spinning mill with close control of the environmental conditions, and therefore shows little scatter.

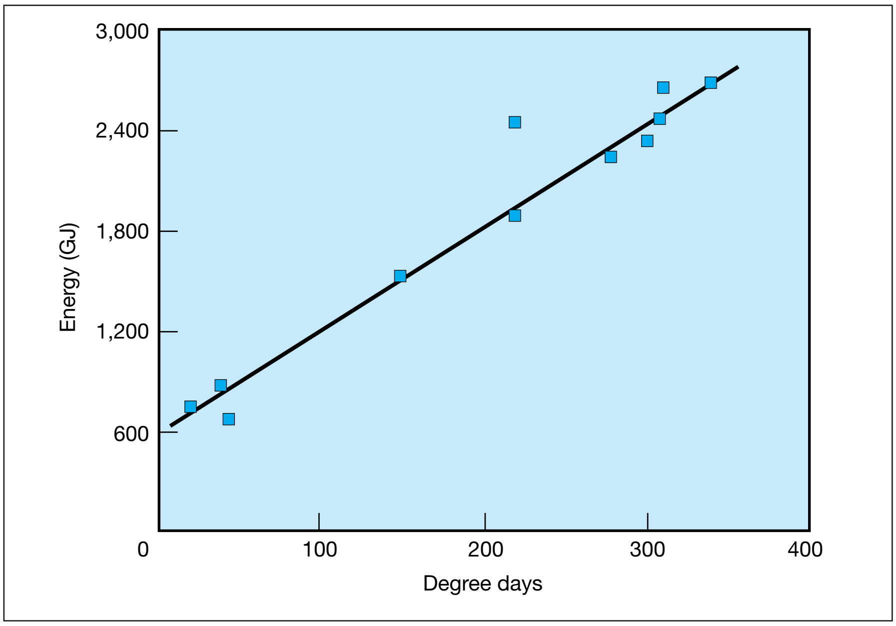


Fig 9 Energy vs. degree days for a textile spinning mill - an example of a chart for well-controlled heating

It is adequately represented by the expression:

energy = (m x degree days) + c

The pattern in Fig 10 is a variant which has the intercept on the degree day axis.

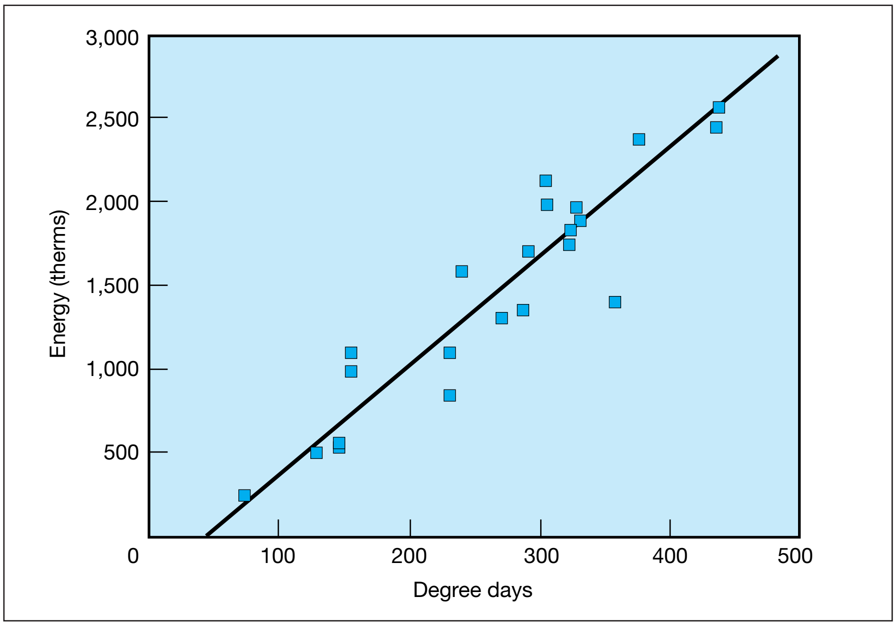


Fig 10 Energy vs. degree days for an engineering works - an example of the effect of an internal temperature maintained below the degree day base temperature or where the building gains heat from elsewhere, e.g. process plant or other machinery

This is interpreted as indicating that energy is not required until the outside temperature falls to a certain level of degree days. In this case, either:

- the building is maintained at a lower internal temperature than the degree day base temperature; or
- the building is receiving heat from elsewhere, e.g. process plant, which maintains the temperature.

Both of these are common circumstances in buildings and this is a frequently encountered pattern. For M&T purposes it is represented by the expression:

for degree days < DD_0 energy = 0

for degree days > DD_0 energy = (m x degree days) + c

where DD_0 is the intercept on the degree day axis and c will be negative.

Fig 11 shows energy vs. degree days for a building in which the line is curved and levels out to horizontal at extreme degree days.

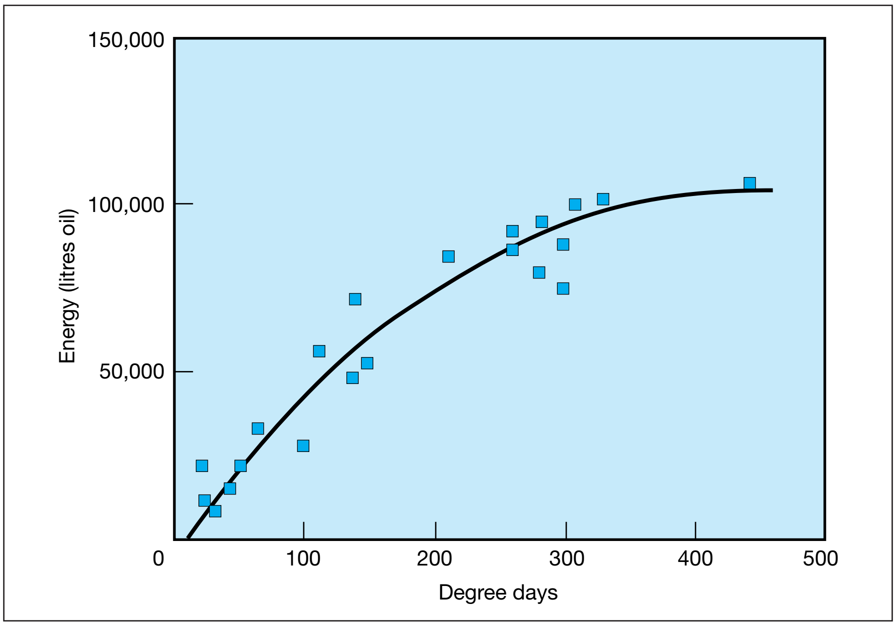


Fig 11 Energy vs. degree days for a building with limited heating capacity

At the point where the line is horizontal, the heating system is not accepting more fuel, despite falling outside temperatures (usually because it is working at full capacity). As degree days increase, no more heat is added which results in a fall in internal temperature. The simplest mathematical representation of this pattern is:

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

which is easily formulated on computer spreadsheets. It is a convenient formula because it contains only three empirical constants. E_{max} and c are interpolated directly from the chart. k is obtainable either by successive approximations on a spreadsheet (to produce a curvature recognisable as this case within a range of 500 degree days, k tends to have a value between 0.002 and 0.01) or directly by mathematical techniques. (This curve is not amenable to evaluation by least squares regression. To use this formulation in an M&T system it must be programmed into the software.)

Fig 12 shows curvature in the opposite direction.

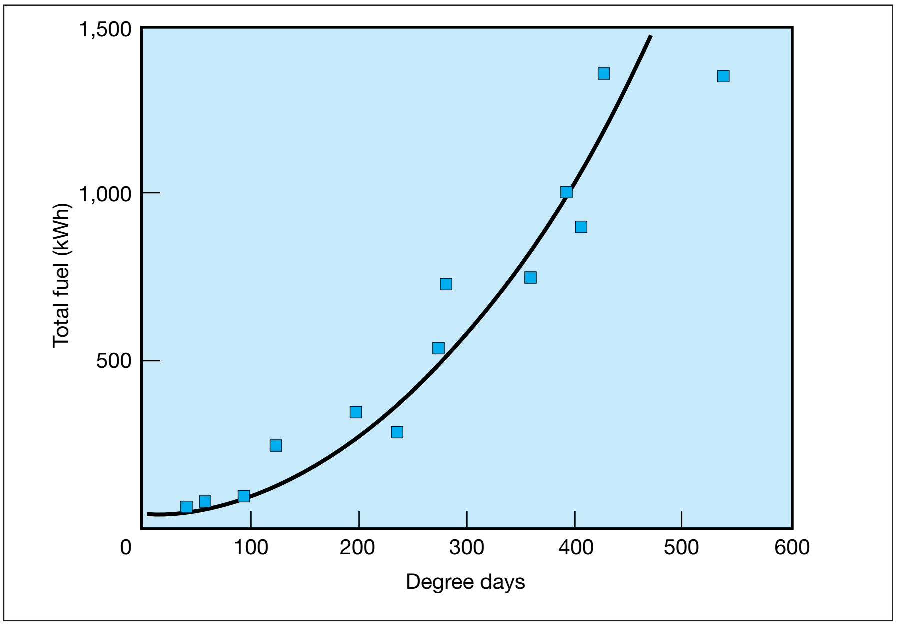


Fig 12 Energy vs. degree days for a building in which temperature stratification is occurring

In this particular case, which is the commonest form of curvature in this direction, energy is a good fit to:

$$\text{energy} = c + m \times (\text{degree days})^2$$

and is due to temperature stratification in the building - cold air ingress forcing warm air to rise and temperatures in the roof of the building becoming much warmer than at floor level. It is common in dispatch warehouses.

There are other patterns relating to building heating and degree days. Detailed discussion of these is beyond the scope of this Guide. Broadly, these divide into two groups:

- patterns which arise from a combination of a weather-unrelated demand and one of the patterns already discussed;
- patterns in which the line followed by the points on the graph changes with season - so that the line moving from winter to summer or summer to winter produces loops when the individual points are joined up in time series order.

Building cooling linked to degree days

For cooled buildings, behaviour is not quite the same as for heated buildings. At precisely the right cooling degree day base temperature, solar gain causes a curve which can be shown to be a good fit to:

$$\text{energy} = (1 - \exp^{-k \times \text{degree days}}) \times (c + m \times \text{degree days})$$

This is exactly analogous to the curve in Fig 6 but with cooling degree days substituted for production. A fortunate coincidence in this relationship and a rule associated with changes in the base temperature for degree days, however, means that this curve can be straightened by the simple expedient of using degree days to a different base temperature.

Processes linked to time through activities

For some processes it is difficult to establish an independent variable (such as production or degree days) against which to monitor energy consumption. Some processes, however, are associated with activities that are strongly linked to time. Time can therefore be used as the comparator to identify characteristic patterns. It is not necessary to know what the activity is in order to use time as a basis for monitoring.

Example

Fig 13 shows the fuel use in a large vehicle fleet. The fuel consumption of vehicles depends on environmental conditions, on the nature of the load and on road conditions. It is not necessarily very easy to establish all of these. In Fig 13 there is clearly a pattern which is seasonally dependent and which offers a basis for comparison of one period with another in a previous year.

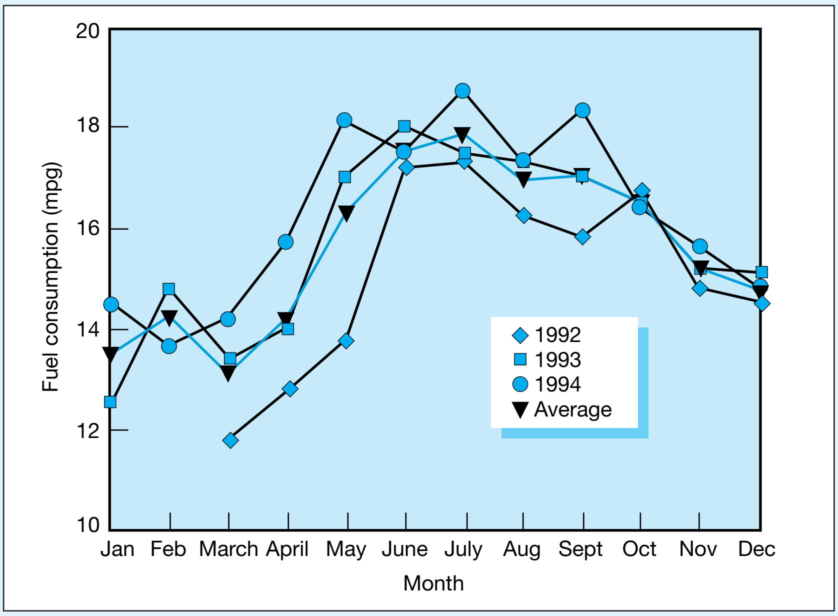


Fig 13 Fuel consumption in vehicles as an example of a seasonal pattern which is not related directly to temperature

Fig 14 shows a half-hour electricity demand profile for a factory producing domestic consumables. There are clear features in the profile on weekdays which are repeated each day without much variation. This kind of information is now available routinely at the whole-site level for large numbers of industrial sites, and there is justification in extending it selectively to the sub-meter level now that the cost of metering technology has reduced.

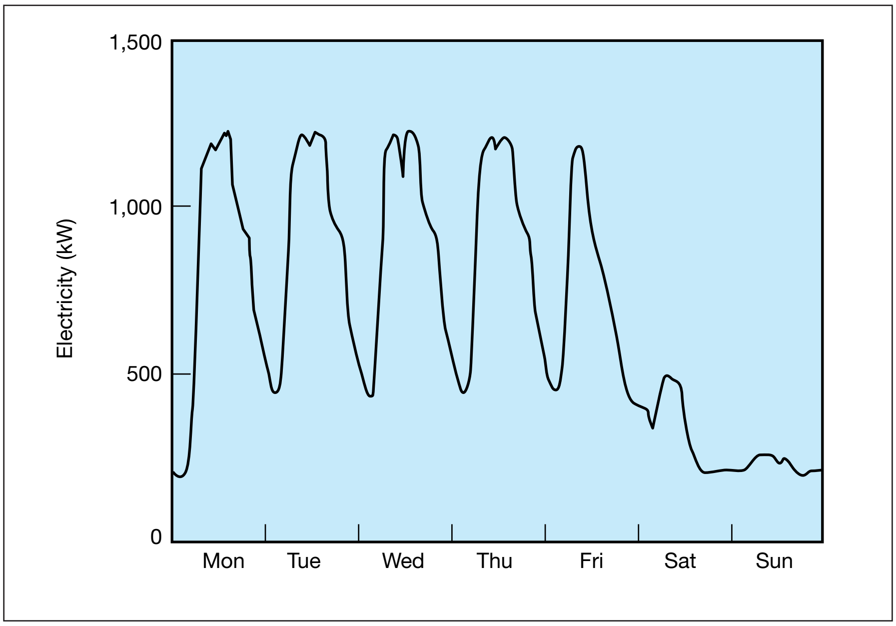


Fig 14 The half-hour electricity demand profile of a factory making domestic consumables

In the specific case of Fig 14, a range of questions of interest to management are raised by the profile:

- What causes the differences from day to day?
- Why does the afternoon demand on Friday tail off early?

- Why is the lunchtime dip not more noticeable?
- What activities are being supported by the load at night and over weekends?

There is a wide range of techniques for handling this information and this is only one form of presentation of data for one week. The normal format for this information at the whole-site level is as a 48 x 365 array (365 days and half-hourly energy data - sometimes shown pictorially as ‘contour mapping’). Without restructuring the array in any way it is possible to compare one day with another, compare one time over many days and compute averages on an hourly, daily or weekly basis. However, the data require processing to produce a chart like Fig 14.

Processes with no relation to other variables or time

Processes which seem to have no relation to other variables or time lead to an expectation of the same value each time they are measured. There is no need to discuss the analysis of these in detail in this Guide; they are a standard case within the scope of SPC and can be treated as an extreme case of Fig 3 but with zero slope.

True examples of this type of behaviour are found from time to time in energy management. **They are usually due to machinery that is running uncontrolled, and therefore left running when not needed - a source of immense waste.** On/off controls and simple alarms are usually cheaper than fitting meters and collecting data.

Example

In a textile spinning mill, measurement of the electricity consumption of vacuum pumps, used to remove stray fibre from the machines, was found not to vary at all. Timers to shut down pumps reduced running hours of 20 kW motors from 90 to 55 hours a week, reducing annual consumption by 35,000 kWh - worth £1,580 a year.

Monitoring Data as an Indicator of Efficiency

Monitoring data is both a useful indicator of the efficiency of processes and a means to gauge the scale of potential savings.

Non-productive and activity-unrelated energy consumption

The intercept on a chart of energy vs. production, i.e. the point where the line is extrapolated back to zero production, represents energy which the process uses even though it produces nothing. It is a fair question to ask how much of this is necessary. The same applies to night-time electricity loads in factories that do not operate at night.

The first step is to quantify non-productive energy. On a chart of the form:

$$\text{energy} = (\text{m x production}) + \text{c}$$

the non-productive energy is the intercept divided by the total for average production:

$$\text{proportion of non-productive energy} = \frac{\text{c}}{(\text{m x average production}) + \text{c}} \text{ x } 100\%$$

In Fig 1 the best fit to the data is:

$$\text{energy} = (1.185 \text{ x production}) + 71.5$$

and the average production is 107 te a day.

$$\text{So proportion of non-productive energy} = \frac{71.5}{71.5 + (1.185 \text{ x } 107)} = 0.360 = 36\%$$

This is a key element of the **Avoidable Waste** style of approach.

Example

A glass melting furnace comprises a refractory-lined insulated tank of molten glass which is kept constantly topped up with raw material as molten glass is pulled from one end, and a system of large tower regenerators for recovering heat from the hot exhaust gases. In this furnace, the ducts between the glass furnace and the regenerators were found to be contributors to non-productive heat loss. Insulating the ducts reduced heat loss by 1.3 MWh/week.

Fig 15 shows an example of electricity use in a combustion air fan. Extrapolation of electricity consumption shows a production-unrelated demand of 300 kW. This is because, although this is a variable load application, the motor attached to the fan is a fixed-speed motor in which variable air flow was achieved by throttling using a damper. Installing variable-speed control on the motor matches the speed to the load and, in this case, achieved a reduction in standing consumption of 100 kW.

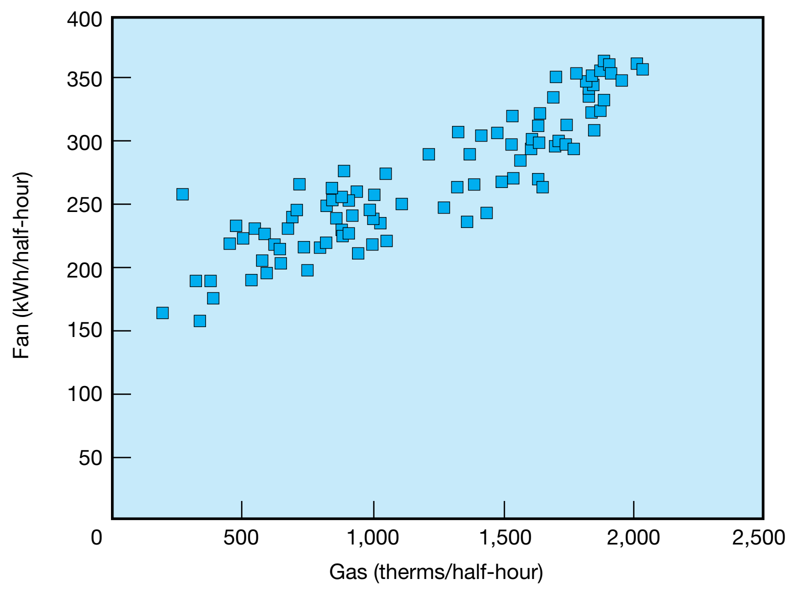


Fig 15 Combustion air fan power compared to gas consumption for a steel reheat furnace showing the high production-unrelated demand of a fixed-speed drive

In Fig 14 the total electricity consumption for the week was 227,850 kWh. The night baseload on weekdays was 450 kW and 200 kW over the weekend. It is unreasonable to assume that the whole baseload can be eliminated, but it is fair to ask what is the difference in activity that accounts for the difference in baseload and why it takes so long to run down on Saturday.

Production-related efficiency

A straight line energy vs. production chart means the energy required to process one additional unit weight of material is the same over the whole range of output. This can be used to estimate the efficiency of the process.

Straight lines with low scatter are encountered frequently because, for most industrial processes, the particular transformation from raw material to product is very much the same for every kilogram or tonne of material passing through, and the efficiency with which this is achieved is the same - irrespective of the rate of throughput.

The slope of such a straight-line chart can be used to calculate the process efficiency (as shown in the box).

The shaft furnace in Fig 6 is used for melting aluminium alloys. The metal that enters the furnace is always aluminium at about ambient temperature. This temperature varies a little but variations between 5°C and 30°C are small compared to the 600°C rise to melt it. The output is molten alloy for gravity die casting which requires a melt at a consistent temperature for its pouring and solidification characteristics; so, the input temperature, output temperature and composition of the metal are always the same.

Thermodynamics of heating and melting

The energy required to heat any material is given by the mass, M, multiplied by the specific heat, Cp, multiplied by the temperature rise. The energy required to heat a solid with specific heat Cp_s from T_{os} to some final temperature T_{fs} is therefore:

$$\text{energy to heat solid} = M\, Cp_s\, (T_{fs} - T_{os})$$

The energy required to melt a material at its melting temperature is the mass, M, multiplied by the latent heat of melting, L_m:

$$\text{energy}_{\text{to melt material at melting temperature}} = M\, L_m$$

The energy required to raise the temperature of a liquid is analogous to that of the solid and is the mass, M, multiplied by the specific heat of the liquid, Cp_l, multiplied by the temperature rise from the starting temperature, T_{ol}, to the final liquid temperature, T_{fl}. So:

$$\text{energy}_{\text{melt to final temperature}} = M\, Cp_l\, (T_{fl} - T_{ol})$$

Calculating the process efficiency:

Energy is delivered at some efficiency which, because this is a straight line, clearly is not dependent on the amount of material being processed and can be expressed as a constant, e.

If the process, as in the aluminium melting furnace, is taking the material through from solid to liquid, the temperature range is continuous and the final solid temperature T_{fs} and the starting liquid temperature, T_{ol} are both the melting temperature, T_m. The overall energy requirement to heat from solid at temperature T_{os} to liquid at T_{fl} is:

$$\text{energy} = \frac{M\, Cp_s\, (T_m - T_{os}) + M\, L_m + M\, Cp_l\, (T_{fl} - T_m)}{e}$$

M is a common term and a graph of energy vs. production is expected to be a straight line of slope, m, where:

$$m = \frac{Cp_s\, (T_m - T_{os}) + L_m + Cp_l\, (T_{fl} - T_m)}{e}$$

A value of m can be determined from the graph. Cp_s, T_m, L_m and Cp_l are characteristics of the material and can be looked up in reference books. T_{os} and T_{fl}, the initial and final temperatures, are process parameters of which management should already be aware.

Everything in this expression except the efficiency, e, is known.

The slope of the line in Fig 6 is 2.585 GJ/te. Take the pouring temperature to be 730°C. The specific heat capacity of aluminium from ambient temperature to the melting point at 661°C is 1.061 kJ/kg/°C and for the liquid is 1.177 kJ/kg/°C. The latent heat of melting is 396 kJ/kg.

$$\text{slope} = \frac{1.061 \times (661 - 25) + 396 + 1.177\,(730 - 661)}{e} = \frac{1{,}152}{e}$$

The efficiency of the furnace is therefore:

$$e = \frac{1{,}152}{2{,}585} = 45\%$$

This level of efficiency is quite good for a gas-fired furnace in this application.

Selecting specific heat data

It is important to select the right data on specific heats. Specific heats vary with temperature and, where not specified, tend to be quoted in reference texts at, or around, 25°C (298°K). This can be rather misleading - particularly in high temperature processes. Heat capacity is often quoted in reference texts as the **molar** heat capacity, which is the energy required to raise one gram-molecular weight (the molecular weight expressed in grams) by 1°C. So, to convert this to a kg basis, divide by the molecular weight and multiply by 1,000. To calculate the molecular weight of a material, add the atomic weights of its constituent elements in the proportions of its chemical formula.

Note: Very precise information (which is usually the best to use) on heat capacities, and the temperature ranges over which they are valid, is often provided in reference texts as the numerical values of coefficients A, B, C and D in an equation of the form:

$$Cp = A + BT + \frac{C}{T^2} + DT^2$$

For some materials it may be necessary to use several such formulae to cover the range of temperatures required. For comprehensive information on specific heats, latent heats of fusion and evaporation, see Kubaschewski, Alcock and Spencer's *Materials Thermochemistry* (see Appendix). Specialist textbooks on the processes in use in specific industries usually also provide this information.

In some industrial processes there is a need to include other energy inputs. In bricks, glass, chemicals and some other processes there are chemical reactions to take into account. These are usually described in specialist texts on the industry. (Full data on nearly all reactions of common interest are also given in Kubaschewski, Alcock and Spencer's *Materials Thermochemistry.*)

In processes which involve heat recovery, the efficiency 'e' may be greater than 1 and provides a measure of the amount of heat being recycled.

The same evaluation procedure can be applied to evaporation and distillation processes. This includes all processes that start with a liquid and involve vaporisation, e.g. drying. Two particular considerations are that:

- the specific heat capacity of a vapour (or gas) depends on its pressure;
- evaporation processes are often engineered to recycle heat, over a number of *effects*, or to use mechanical vapour or thermo-recompression.

Two of the most important vaporisation processes occur in boilers and drying, both of which involve vaporisation of water. Boiler efficiency can be evaluated from a graph of steam output vs. boiler fuel. This is an adjunct to monitoring the efficiency from tests on the boiler flue composition and temperature, and not a substitute. The energy-related properties of water vapour are given steam tables. Steam tables are widely published in textbooks on mechanical engineering and some energy management reference works. A summary steam table is available in Fuel Efficiency Booklet 2, *Steam*. (See Section 4 for evaluating the efficiency of a drying process.)

Building heating efficiency

The slope of the line of energy vs. degree days is also an important indicator. It is possible to show, although the detail is beyond the scope of this Guide, that the slope m of a line of energy vs. degree days is equivalent to:

$$m = F \frac{\sum U A + \sum N V Cp \rho}{e}$$

where:

- e is the marginal efficiency of conversion of the energy recorded on the y-axis to heat (marginal means that standing losses are discounted - in the case of fuel-fired systems this essentially means the combustion efficiency); for steam heating it acknowledges the residual heat in condensate.
- F is a dimensionless number known as the **degree day correspondence factor.** It is a measure of how far the degree days used as the indicator of the weather on the x-axis represent the difference between the building internal temperature and the outside temperature expressed as degree days.

- $\sum$ U A means multiply the area, A, and the U-value, U, of each element of the outer fabric of the building - walls, roof, windows, etc. - in turn and add up all the results.

- $\sum$ N V Cp ρ means multiply the volume, V, number of air changes, N, and the heat capacity of air, Cp, for each element of the volume of the building by the density of air, ρ, and add up all the results.

The U-value is a measure of the thermal conductivity of a structure. It can be looked up in standard reference sources for all common fabric types - for a first estimate, the values in the table below can be used. The slope is measurable from the chart, e is measurable from the standard combustion tests on boilers (which should be measured routinely, anyway), A and V are measurable or estimable from the dimensions of the building and Cp ρ has the value 0.33 kWh/m^3/hour/°C or 0.00792 kWh/m^3/hour/degree day. The commonly used units of U-values - W/m^2/°C - can be converted to kWh/m^2/degree day by multiplying by 0.024.

U-values for common structures in an industrial building (source: Textiles industry)

	U-values	
	W/m^2/°C	**kWh/m^2/degree day**
Single-glazed windows	4.6	0.11
Roof skylights	6.6	0.16
Solid brick unplastered	3.3	0.08
Brick cavity (brick unlined)	1.4	0.03
Well-insulated wall	0.5	0.01
Pitched tiled roof plaster-board ceiling	1.5	0.04
Roof with fibreglass lining	0.4	0.01

The degree days used by most industrial energy managers are those published for regional observing stations using a formula which measures how long in parts of a day and by how much, in °C, the outside temperature is below a fixed base temperature. For buildings that are intermittently heated it over-estimates the heat requirements. How much less energy is required by an intermittently heated building depends on the number of hours a day it is heated and what is called its **heating inertia** - how fast its internal temperature falls in °C/hour for a given temperature difference between inside and out; the faster the temperature falls, the lower the inertia.

Fig 16 provides a chart for finding a value for F (degree day correspondence factor) as a function of the number of hours of heating, and a value for the heating inertia. (F = 1 for a continuously heated building). If required, the inertia can be measured using a thermograph, but as long as the working day is more than eight hours, F is not very sensitive to the inertia and can be estimated:

- A building with a heavy structure, many internal barriers to air movement and considerable internal mass (product in a warehouse) has a high inertia, i.e. a low value approaching 0°C/hour/°C. Therefore, find the value of F on the left-hand axis for the requisite heating hours per day.

- A light building with few barriers to air movement, perhaps some mechanical ventilation and little internal mass would have a low inertia, i.e. a higher value, say around 0.3°C/hour/°C; for this the value of F is read on the right-hand axis. In the fortunate position of knowing the value of the heating inertia, the appropriate value of F can be found from Fig 16.

In practice, the most difficult factor to estimate in industrial buildings is the number of air changes (N). It is usual to simplify the calculation by assuming a common air exchange rate over the entire building volume.

In principle, everything is now known except N, and the formula becomes a method for estimating the ventilation rate, which is commonly the highest component of building heat loss and, after stratification, is the most cost-effective element of significant heat loss to correct in industrial buildings.

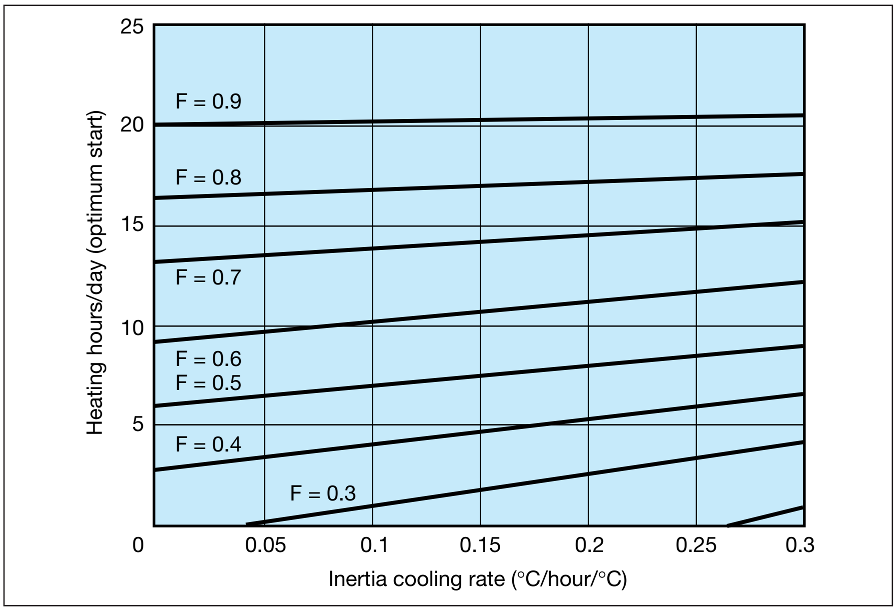


Fig 16 Degree day correspondence factor isopleths for the appraisal of the heat balance of intermittently heated buildings

Example

The slope of energy vs. degree days for the building in Fig 9 has a slope of 6.5 GJ/degree day (1,807 kWh/degree day).

The building is 200 feet long, 120 feet wide and 60 feet high and windows represent 40% of the wall area. One foot is 0.3048 m. U-values are estimated as 0.024 kWh/m^2/degree day for the walls, 0.11 for the windows and 0.03 for the roof. The boiler efficiency is known to be 75%. The building is heated continuously, therefore F = 1.

Then:

Area of wall (inc. windows)	= (2 x 200 x 60) + (2 x 120 x 60)= 38,400 ft^2	
	= 38,400 x $(0.3048)^2$	= 3,567 m^2
Heat loss from windows	= 0.4 x 3,567 x 0.11	= 156.9 kWh/degree day
Heat loss from walls	= 0.6 x 3,567 x 0.024	= 51.4 kWh/degree day
Heat loss from roof	= 0.3048^2 x (200 x 120) x 0.03	= 66.9 kWh/degree day
So: $\sum$ U A	= 156.9 + 51.4 + 66.9	= 275.2

Volume, V = 0.3048^3 x (200 x 120 x 60) = 40,776 m^3

From the straight-line equation:

$$\text{slope} = \frac{275.2 + (40{,}776 \times 0.00792 \times N)}{0.75} = 1{,}807$$

Therefore:

$$N = \frac{(1{,}807 \times 0.75) - 275.2}{40{,}776 \times 0.00792} = 3.34 \text{ air changes per hour}$$

From this it can be seen what proportion of the total observed weather-related energy use is lost by different components of the building fabric and operation:

Boiler			= 25%
Walls	=	(51.4 / 1,807) x 100	= 3%
Windows	=	(156.9 / 1,807) x 100	= 9%
Roof	=	(66.9 / 1,807) x 100	= 4%
Ventilation	=	(40,776 x 0.00792 x 3.34/1,807) x 100	= 59%
			100%

Clearly, ventilation in this building is overwhelmingly the largest energy user; any measures applied to the building fabric would have minimal impact. This is not unusual in industrial buildings and a great deal of wasted energy is due to overzealous and poorly balanced mechanical ventilation. This technique provides a means to assess the impact.

4 USING INFORMATION ON ENERGY USE FOR MANAGEMENT CONTROL

The normal way of using information as a basis for on-going management control is to:

- establish a performance standard, based on what has been achieved historically, sometimes modified to give some 'incentive' and expressed in simple terms;
- calculate the difference between actual performance and this standard;
- respond to instances of unusually large differences;
- reduce these differences over time.

In energy M&T historic performance is used for establishing performance standards; however, statistical methods, and an understanding of the physical laws that underlie energy consumption, are applied to make these performance standards robust.

The success of this approach depends on being able to recognise when the difference between actual consumption and the standard in any one period is exceptional. This in turn means being able to accommodate all the factors into the calculation which cause these differences but are not controllable. The smallest difference that identifies a deviation from the standard as a significant exception is called the **resolution** of the management system. The resolution can be improved by being able to select, from the historic information, the data for the particular periods - days, weeks, months - that provide the best standard.

A particularly powerful method for achieving this is a combination of a technique called **CUSUM** and a device taken from quality management called the **control chart.**

These techniques will be illustrated using the data in Fig 17, taken from a factory that produces a fried-food product.

Before applying CUSUM, consider the other information already apparent in the data.

The data for this process appear to split naturally into two groups, following parallel lines a short distance apart. The one of greatest potential interest is the lower one as this appears to represent higher energy efficiency. A best fit line drawn by eye is:

energy ('000 therms) = 0.26 x production (te) + 100

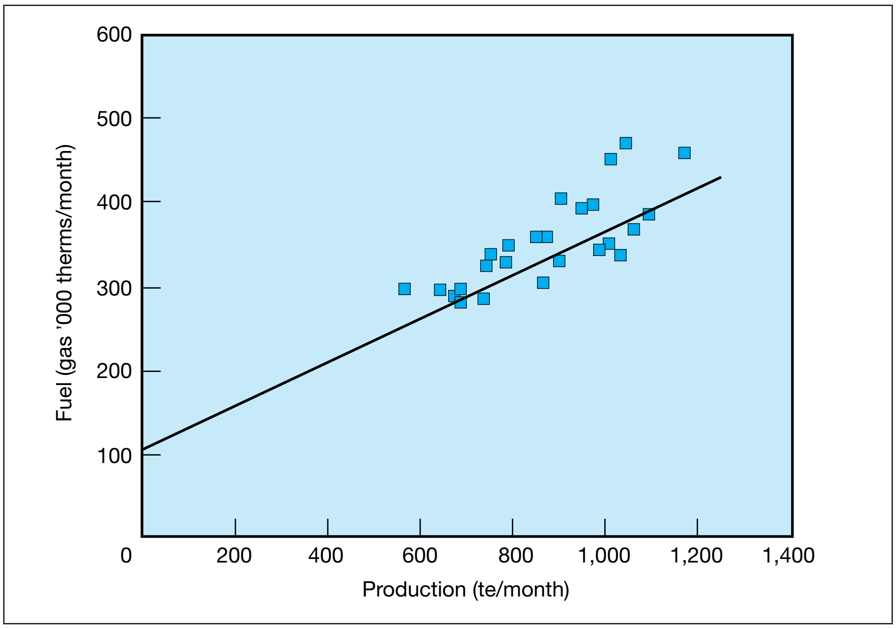


Fig 17 Fuel vs. production for a cooker/fryer in the food industry

Non-productive Consumption

At the commonest output of around 900 te/month, this indicates that production-unrelated energy is:

$$\frac{100}{100 + (0.26 \times 900)} \times 100\% = 30\%$$

Production-related Efficiency

This example is for a fried product in which the process heats the raw material to the frying temperature of 250°C, evaporates the water that makes up 80% of the mass of the raw material and replaces this with cooking oil that makes up 40% of the product. Each te of product therefore contains 0.6 te of raw material, the production of which involves evaporation of four times as much mass of water (80%:20% ratio), i.e. 2.4 te of water and, in an ideal process, the heating of only 0.4 te of oil.

The energy required to evaporate water from liquid at 30°C to steam not under pressure at 250°C can be looked up in standard engineering steam tables for superheated steam - the value is 2,870 kJ/kg (it is important to use the right steam table). The specific heat of the cooking oil was obtainable from the supplier as 2 kJ/kg/°C. The specific heat of the other solid material is not known but it is a carbohydrate with a rigid structure and so cannot be far from that of wood or polystyrene, i.e. about 1 kJ/kg/°C. The accuracy of specific heats of solid materials in this case (and most cases involving evaporation of water) is not found to be critical and the effect of temperature on specific heat, in this case, is negligible. One therm is 105.5 MJ.

From Fig 17 we know that the slope of the line is 260 therms/te. The production-related efficiency of the process is the theoretical energy required to process 1 te of product, divided by the actual energy used per te:

$$\text{efficiency} = \frac{\{(2{,}870 \times 2{,}400) + (2 \times 400 + 1 \times 600) \times (250 - 30)\}}{260 \times 105.5 \times 1{,}000} \times 100\% = 26\%$$

This is poor efficiency performance for this kind of process.

CUSUM

CUSUM stands for the **CU**mulative **SUM** of differences and is a technique for measuring bias in **equal interval time series data**, i.e. information of the same kind gathered at the same time each day, week, month etc., and organised in the same time order as it was measured (which is the way most of industry collects information anyway). The differences added are those between the actual energy used and the energy predicted by the best fit line on the chart of energy vs. production.

In the example of the cooker/fryer, for any given production rate there is a wide range of energy consumption in the data. At around 900 te/month, energy consumption seems to vary between about 290,000 and 400,000 therms/month - a variation of +/- 16%. If this is the normal variation in these data, then this is about the limit of resolution of any system based on it. In fact, it is not representative of the true week-to-week variation - at least some of this apparent scatter is due to the way the process has changed over time. CUSUM is a technique that can take account of this.

The prediction formula calculated previously was:

energy ('000 therms) = (0.26 x production in te) + 100

Calculating CUSUM from this involves four steps:

1. Use this formula to obtain a predicted energy use for each week from the production for that week.

2. Subtract the predicted consumption from the actual to obtain a difference for each week.

3. Add up the differences from the first week to each week in turn to obtain CUSUM.

4. Plot a graph of CUSUM against time.

The first three of these steps are usually carried out in adjacent columns of a spreadsheet (or database if proprietary software is used). This result is shown calculated in the table below.

CUSUM data for a cooker/fryer

	Production (tonnes)	**Actual gas ('000 therms)**	**Predicted gas ('000 therms)**	**Difference**	**CUSUM**
Feb 1992	896	334	332.96	+ 1.04	+ 1.04
March	1,054	371	374.04	- 3.04	- 2.00
April	678	288	276.28	+11.72	+ 9.72
May	781	332	303.06	+28.94	+38.66
June	.	.	.	.	.
July	.	.	.	.	.
Aug	.	.	.	.	.

The resulting chart is shown in Fig 18.

If all the scatter on the CUSUM chart was only random about the best fit line, the computed differences would also be randomly positive and negative. The resultant cumulation of these differences, CUSUM, would also be random and not far from zero. CUSUM would then track horizontally on this chart.

If something happens which changes the pattern of consumption - moves to a pattern for which the constants in the best fit relation are different from those in the prediction - then the differences will not be random; they will be biased positive or negative and CUSUM will track up or down from the time of that event. The CUSUM chart therefore consists of a series of straight sections separated by kinks, each kink representing a change in pattern. Lengths of the CUSUM chart which run parallel to one another indicate the same process behaviour pattern being followed.

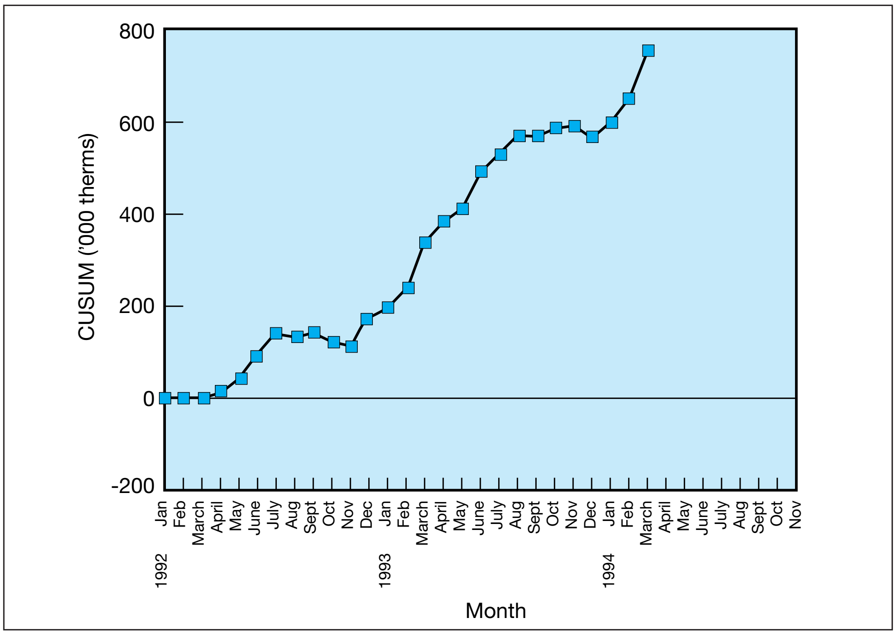


Fig 18 The CUSUM graph for the cooker/fryer

The CUSUM graph, Fig 18, identifies two clear patterns:

1. When the line runs horizontal which is:
   - up to April 1992;
   - from August to November 1992;
   - from September to December 1993.
2. When the line runs upward which is:
   - from May to July 1992;
   - from December 1992 to August 1993;
   - from January 1994 onwards.

Discussing the CUSUM chart with various managers in the factory brings out an explanation for the two patterns. A few years previously the cooker had been fitted with a heat recovery system, partly on economic grounds and partly to reduce the visible plume of steam over the factory from the evaporated water. The rising trend in the CUSUM chart could be attributed to a reduction in the performance of the heat recovery equipment.

This poor performance of the heat recovery equipment had, in fact, been picked up by an energy consultant during an energy survey in early 1993 when the system was cleaned on his recommendation.

The upward trend in early 1994 occurred because management did not realise that the deterioration in the performance of the heat recovery system was not a one-off problem - repeated cleaning at intervals would be necessary to maintain the higher performance.

The Control Chart

The control chart is already a familiar concept in organisations that use any form of statistically-based quality control.

To calculate a control chart:

- recalculate the best fit formula for all the data identified from the CUSUM chart as belonging to a workable standard and, if possible, over a recent period;
- calculate a new control prediction from this pattern for the actual production in each month;

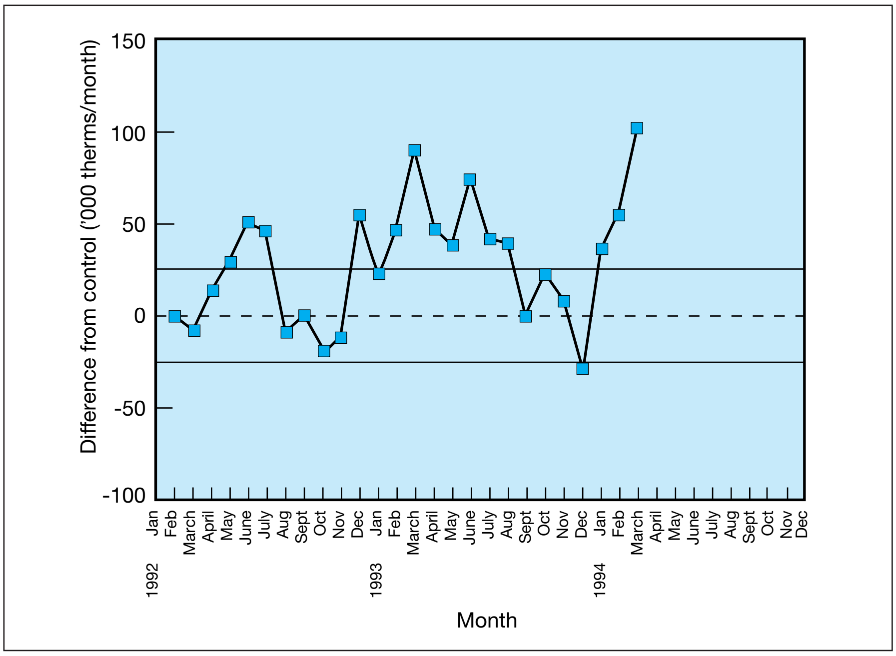


Fig 19 The control chart for the cooker/fryer

- calculate the difference between the actual consumption and the control prediction;
- plot these differences against time as shown in Fig 19;
- decide on a control band such that, if the energy use goes outside this level, someone is required to account for it.

The horizontal periods on the CUSUM graph represent the periods with the heat recovery system working properly. Regression produces a best fit line to these data of:

energy ('000 therms/month) = (0.28 x production (te)) + 84

and a correlation coefficient of 0.96. The correlation coefficient for all of the data was 0.8. The correlation coefficient, easily calculable on a computer spreadsheet, is a good indicator of the improvement in data used to predict energy use on the control chart.

The control band needs to be sufficiently narrow to indicate to the process operators that there is supervision of the process, but wide enough not to alert too many exceptions and thereby produce no response. Band width can be decided by simple reasoned judgement, although there are also formal statistical methods available for deciding this. In this case there are, as yet, too few data to decide this statistically. By eye, 25,000 therms/month is enough to detect deterioration in the heat recovery system. At the 336,000 therms that correspond to the average production of 900 te/month, the resolution is 7%. Weekly data and more sophisticated analysis can improve this. Nonetheless, it is a good start - it picks up the most immediate threat to performance.

There are various styles of application for this simple principle:

- The control band can be based on absolute differences (in energy units) or as a percentage; in either case the differences are calculated on the same basis (if percentage control levels are being used, calculate the differences as percentages too).
- Data can be provided to the responsible departments in the factory in several ways:
  - as charts which display the immediate last period and previous periods;
  - as reports which indicate only the data for the immediate previous week or shift;
  - as look-up tables which enable the user of the information to deduce that energy consumption is outside acceptable levels.

- At factory level, the calculation of the forecast consumption, difference and control limit for the immediate past interval can be added to a spreadsheet and used as the basis for discussion at production control and planning meetings.

The control chart can be used practically to raise awareness in various ways. One way is to circulate a paper copy of the chart to relevant staff, but this means circulating an entire sheet of paper to highlight only the last point on the chart. Control charts are often useful when displayed on company noticeboards or circulated through an electronic noticeboard or computer system.

Non-parametric Forms of CUSUM and Control Chart

The form of CUSUM described is called the **parametric** form because it examines specifically how the relationship between variables or **parameters** changes over time. Although it has been a familiar feature of energy management for some years and is a common feature of dedicated M&T computer software, it is not well known in other management disciplines. The form of CUSUM which is familiar to quality managers is the **univariant** which applies to parameters that are not expected to vary over time.

Parameters which follow recurring patterns over time require a different variant of CUSUM - the **recurrent** form. In this, all the steps are the same except in making the prediction. In recurrent CUSUM the prediction is based on calculating the average values of each time interval in the cycle, e.g. for daily intervals in a weekly cycle, the average for all the Mondays, all the Tuesdays, etc. The remaining steps, along with the interpretation of the CUSUM chart and setting up of the control chart, remain the same. This form of CUSUM is a recent innovation (1990) and is also not necessarily familiar to energy managers.

Application of CUSUM

CUSUM analysis and control charts can be applied to a wide range of process and production parameters, including:

- ovens, kilns and furnaces - fuel consumption, mass of material processed, running hours, temperature in and temperature out;
- melting furnaces - material melted, energy input, coke additions, oxygen supplied, electrode wear, recycled material, new materials added, alloying and other additives;
- ovens and cookers - fuel consumption, product weight, mass of water evaporated, process running hours;
- electrolytic and electroplating processes - electricity consumption, voltage, material deposited;
- rolling machinery, mixers, pulverisers - electricity consumption, mass of material worked, work done;
- cutting machinery - electricity consumption;
- pumps - electricity consumption, volume delivered;
- fans - electricity consumption, volume delivered (often as some other variable such as furnace throughput), fuel consumption;
- air compressors - electricity consumption, air delivered, leak rate;
- refrigeration - electricity consumption, evaporator load, heating and cooling, degree days;
- inert gases - gas usage, production, boilers - fuel consumption and steam generated;
- building space heating - fuel consumption, degree days;
- vehicle fuel - tonne miles, kilometres per litre, journey times.

Such is the ease of calculation of control charts that it should be feasible to maintain them on all of these parameters, even if all the information is not routinely circulated.

5

IMPROVING THE CAPABILITIES OF M&T

The successful application of M&T leads to lower energy consumption and a diminishing difference between actual consumption and the control standard. Once the most obvious areas of energy waste have been identified, making further progress depends on building further sophistication into the system.

Possible achievements have been greatly influenced by the availability of computers, and of information technology in the wider sense. Computers substantially reduce the management time involved in analysis. Digital output metering increases the frequency at which meter readings can be taken. The increasing use of computers in monitoring and control of production also increases the availability of production data.

There are six ways to improve the performance of a basic-level M&T system:

- remove errors in the data;
- improve the time correspondence of data;
- increase the frequency of meter readings;
- increase the number of variables taken into account;
- choose the right form of analysis;
- increase the sophistication of the analysis.

These are roughly in the right order of priority to optimise benefit and cost. The first three apply to quite basic systems; the last three apply particularly to the use of computers.

The Impact of Data Errors

Removing data errors and choosing the right form of analysis are very closely linked. This is because of two features of M&T:

1. Energy tends to be measured on accumulating meters where the meter often indicates the cumulative energy that has passed through it, and the consumption in an interval is determined as the difference between two readings. A wrong meter reading, in effect, transfers a block of units from one period to another, thereby creating two errors in successive intervals. Data errors therefore occur in pairs.

2. The general way in which computers translate data into best fit line formulae is by a method called **least squares**.

Least squares

Most users of software tend not to worry too much about how the software carries out its functions. How a computer translates data into a formula for use as a performance standard, as it does for the prediction formula in an M&T control chart, can produce surprising effects and it is important for energy managers to be aware of them.

Least squares is a mathematical tool for calculating the constants m and c in a relationship of the form:

$$y = m x + c$$

This is the best fit to a set of data comprising a list of values of x (production, say) and y (energy, say) for corresponding time periods, and where the criterion of best fit is that the sum of the squares of the differences between the actual y values and the values predicted by the formula is a minimum. In mathematical terms it is a remarkable tool - extracting an equation that summarises a whole collection of data and optimises at the same time is no mean feat, but it has its limitations. To have used the least sum of just the straight differences or square roots would have been better, but least squares is the only procedure that can be made to work mathematically, and straight lines are the only form of relation for which it works (although some non-linear relationships can be converted to straight lines by changing the variables).

In least squares, a point which is 3 kWh from a line is 3^2 = 9-times more influential than a point 1 kWh from the line (points actually on the line have no influence at all!). The most likely cause of data being very far from a line is an error in the data, which is why data errors must be eliminated from data *before* computation of the performance standard.

Example

Fig 20 shows data for a furnace in which there is a meter reading error which affects weeks with very different production rates. Least squares attaches more importance to these two points than to the rest. The result was to reduce the resolution of the system from +/-9% to +/-18%, a factor of 2. It also led to an apparent 90% increase in production-related energy consumption and an entirely false impression of the furnace heat balance.

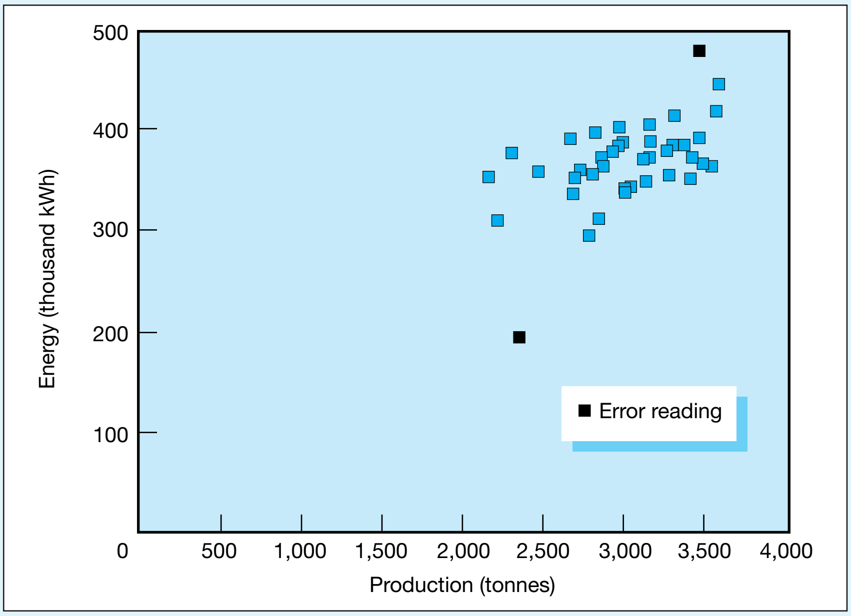


Fig 20 Energy vs. production for a furnace in which there is a meter reading error

Time Correspondence

Time correspondence of data means that the energy and production data refer to identical time periods. A common problem when data are first analysed is that production and energy in the historic record are recorded at different times, e.g. production records from Monday to Sunday, where data collection starts at a quiet time, but energy meter readings are taken during production part-way through a shift, perhaps to avoid overtime. One of the key operational aspects which has to be established to achieve a good resolution is when meters are to be read; specific provision must be made for this.

Example

In a review of management practices at a paper mill, it was decided to change the way data was collected for the Monday morning production planning meeting. Instead of using the previous week's production and quality data (Saturday to Friday) consolidated by hand calculation over the weekend, the meeting would have the data from Monday to Sunday consolidated using a computer spreadsheet early on Monday morning.

The spreadsheet print-out was discussed at the production planning meeting. It carried information on the boiler fuel, steam usage, electricity generated and electricity bought in. When energy M&T was introduced, the input data were taken from the past copies of the report printed from this spreadsheet (which was normally overwritten so the archive was just these paper copies) as the raw data. When some events in the data were found difficult to interpret, the mill staff were asked about the data collection. It then became clear that energy data were still collected on Friday and, within any one pair of production and energy data, the weekends were different.

More Frequent Meter Readings

More frequent meter readings do not add to the capability of a system where energy is governed by some variable, such as production, unless the increased frequency of data collection extends to the other variables as well.

The technical capability of being able to page a meter every half-hour offers a benefit only if production can be measured not merely at the same frequency, but also at the same interval. In practice, these conditions of matching the energy to production are met only in near continuous processes working on homogeneous materials with short residence times.

Example

Fig 21 shows the same combustion air fan as Fig 15. The original data were measured half-hourly - Fig 21 uses daily data. In this case the half-hourly data are so frequent that they have begun to obscure the true relationship in the data. This is a potential hazard in any case where data are gathered at very short intervals. The solution is always available - test the relationships with longer intervals.

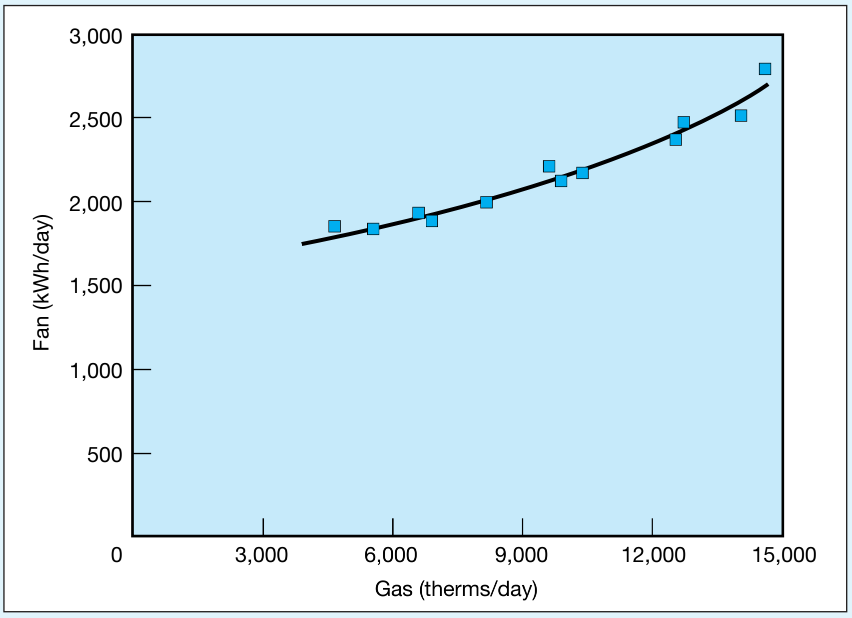


Fig 21 Fan power compared to gas consumption for the steel reheat furnace, showing better definition of the process by longer rather than shorter interval data

More frequent manual meter readings add to costs in proportion, but not necessarily to knowledge or control in the same way. At some point it has to be decided whether manual data collection can be substituted by automatic data acquisition.

With automatic data collection the frequency of collection is not a problem for energy, but production data may not be available. If this is the case, techniques of analysis may need to change from energy/production to time-based profiles. Electricity profiles are a good example. The only analysis which can then be applied is internal comparisons within the data - to monitor the changing shape of the profile.

Increasing the Number of Variables

Whether or not the performance standard needs to take more variables into account is governed primarily by the system being managed and its **energy drivers**. An energy driver is analogous to the management accounting concept of a **cost driver,** and refers to the variable, or combination of variables, which determine the energy requirements in production.

How many and which variables, and how they should be combined, is determined by the process or production system being managed and the degree of control that management decides it wants to exercise. If management wants to achieve a particular degree of control, or there is a particular level of resolution that needs to be achieved to make M&T yield a benefit, this determines the minimum number of variables that need to be input into the system and which data need to be collected.

In some industries, what is recorded as output for ordinary production management purposes may not be appropriate for monitoring energy. Food cookers like the earlier example are a case in point. The main energy requirement in this process is to evaporate water. A more suitable measure of production for monitoring energy would be water evaporated. The weight of water evaporated is rarely, if ever, directly measured in a factory, but in industries where it is the key indicator of energy requirements - paper, food products, textile finishing, malting, sugar, chemicals - all the data necessary to calculate it are often being collected, not as production information but as information on quality.

Example

In the case of the food cooker, because the raw material is a natural product, its water content tends to be variable. This affects the process settings required to achieve a consistent appearance in the product, so the fractional water content in the raw material, w, is routinely monitored by the quality department. The rest of the weight of raw material (1 - w) are solids that go through the cooker and combine with cooking oil in the ratio 1 kg of solids to 'R' kg of oil. The oil content in the product is also a parameter monitored by the quality department. In this case, it is appropriate to monitor energy not against weight of production alone, but against the parameter $\frac{w}{R(1-w)}$ x production.

Comparing energy with production output alone produces a scatter that limits resolution to not much better than about 10%. Identifying this parameter as the driver achieves a resolution of better than 1%. At this level, energy monitoring detects faults leading to inefficient energy use, and the fuel meter becomes a means to monitor even the performance of the quality management system.

Collecting more information on production is only one way of increasing the number of variables; the other is to collect more information on energy use by sub-metering. In practice there is a balance to be struck between sub-metering and sophistication in analysis. If the production and quality information is sufficiently comprehensive, there are occasions when the need to sub-meter energy use can be reduced.

The Right Form of Analysis

Least squares assumes that the best fit line being sought is a straight line. Presented with data, the least squares routine in computer software has no way of knowing if data are related in any other way but as a straight line.

In many industries there is a long-standing tradition of relating costs on a per unit weight basis. It is largely a hangover from cost accounting practices in times before the widespread use of calculators, computers and more recent developments in management accounting practices. As a general rule, it is more likely (rarely is it otherwise) that energy vs. production is a straight line than specific energy vs. consumption is a straight line. If a chart of energy vs. production produces a straight line with a non-zero intercept, specific energy consumption *cannot* be a straight line - application of least squares is misleading if applied to energy per unit of output.

With easy access to computer routines that can compute multiple linear regression (least squares with more than one independent variable), there is a temptation to apply this to whatever data are available. There are two hazards associated with this:

1. Multiple regression can only handle relations of the form:

$$\text{energy} = m_1P_1 + m_2P_2 + m_3P_3 + c$$

2. There are many instances where the variables simply are not related to one another in this fashion - the food cooker is one example among many. There is the possibility that two variables may be related to one another and so are not independent - the most serious of which, for the time series information that is the main focus of M&T, is the so-called **serial correlation.**

The particular combination of variables:

$$\text{energy} = m_1P_1 + m_2P_2 + m_3P_3 + c$$

is called **linear** because of the mathematical behaviour of relationships of this form.

There are many instances where linear patterns do occur, although they tend to be of interest mainly in situations where sub-metering is being avoided, e.g. two processes being monitored from the same meter where the x-variables would be production for the individual processes, or production and space heating on the same meter.

There are variables that do not combine in this way and which need to be treated appropriately, e.g. temperature in furnaces designed to produce a hot output, as in billet reheat in the metals industries. The appropriate relationship is not:

$$\text{energy} = a + b \times \text{production} + c \times \text{temperature} \quad \text{(wrong)}$$

but

$$\text{energy} = a + b \times \text{production} \times (T_{output} - T_{input}) \quad \text{(correct)}$$

In general, the way variables should be combined needs to be thought through before applying least squares. Applying multi-variate least squares indiscriminately to lists of variables is dubious practice. Using software to test variables indiscriminately and select its own variables for monitoring - using statistical measures such as correlation coefficients - is more dubious still.

A wise precaution after applying multi-variate regression is to decompose the final expression by substituting typical and realistic extreme values for the variables to see what impact each term has on the total energy consumption. Multi-variate regression has a tendency to compute a coefficient for any variable offered to it, and may end up with a coefficient for a variable which really has little genuine influence but which then requires continued collection and processing of data.

Serial correlation refers to when changes in one variable over time are followed by changes in another, giving an impression of a relationship between them. If the true relationship between them is itself changing, the result from least squares or multi-variate regression can be totally misleading. Inadvertent undetected serial correlation is among the worst fears of professional statisticians. Professional statisticians work with problems where they often have no idea what kind of statistical relationship they are looking for. Energy M&T does not have to face this problem and, if there is the possibility of it, it should be specifically tested for.

Example

An engineer trying to establish a standard for various departments of a brewery examined the quality of correlation between brewhouse steam and a range of variables - production, degree days, production time and number of copper boilings - using the correlation coefficient as the measure of goodness of fit. A good fit was obtained between steam consumption and degree days and this was set as the standard. It turned out that this was incorrect; the data he had used covered the run-up to Christmas and the correlation was dominated by the seasonal production schedule for beer.

There is a particular combination of circumstances where serial correlation can give rise to a very misleading picture. In some processes the rate of energy supply to the process affects the rate of production. Improvements to energy efficiency in such processes then lead to an increase in the average rate of production. Lack of awareness of this when it occurs can give rise to bizarre interpretations.

Example

Fig 22 shows energy vs. production for an electric arc furnace using the foaming slag process. In the final stages of the arc melting process, the efficiency of transfer of heat from the arc to the steel falls off and the rate of melting slows down. Injecting oxygen under the slag layer and adding carbon generates gases which can cause the slag to foam. This prevents loss of energy from the arc to the sidewalls of the furnace and directs it into the melt. The result is improved energy efficiency and increased production rate. The improvement in production rate and energy consumption are likely to be serially correlated. In Fig 22 both the slope and intercept on the graph are artificial because the data at different points on this apparent line refer to different times.

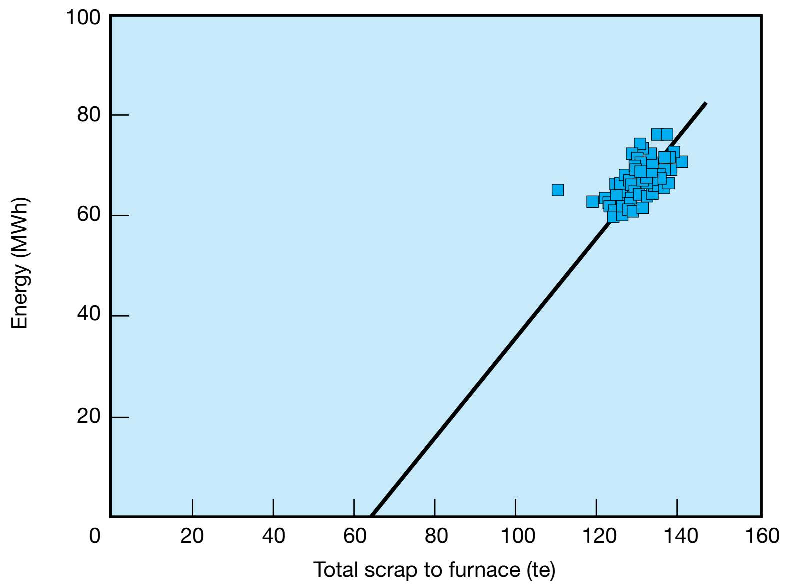


Fig 22 Energy vs. production for an electric arc furnace, showing the impact of serial correlation between energy and production

More Sophisticated Analysis

With the exception of CUSUM, this Guide covers only the most basic techniques of analysis, most of which are covered by standard textbooks on applied industrial statistics, and defines resolution only in terms of exceptions brought out by the analysis having a high probability of being attributable to faults.

There is a range of techniques of analysis which lie beyond the scope of this Guide. There are specific statistical tests for serial correlation and tests for other conditions on which confidence in the analysis depends. These are available in commercial statistics software packages designed for professional statisticians, and are now available at very favourable cost.

It is worth noting in this context, however, that the widespread use of CUSUM in energy management is unusual. Not many professional statisticians are aware of it and none of the dedicated statistical software packages as yet (in 1996) offer the parametric or recurrent forms of it (few general statistical textbooks mention them either); however, almost all energy M&T packages include the parametric form. The simplicity of CUSUM belies its importance in the broader context of applied statistics. Most statistical techniques assume that time-related effects are not present in data. CUSUM is the simplest method for detecting their presence and, in general, should be applied before any other forms of analysis.

6

CASE HISTORIES

Six case histories are presented that illustrate the savings potential from M&T in different industrial environments.

	Project	Monitoring system	Management system	Saving measures
1	**Paint additive manufacture** Annual utility cost £900,000 M&T investment costs £20,000 Annual savings £40,000 (4.5%)	Electricity - 60 meters originally, 5 more added. Steam - 15 steam meters covered the main users. Water - Additional water meters were added. Gas - 8 gas meters already covered all the main users.	25 different products were monitored weekly and multi-regression analysis was used, requiring a longer pilot period. After six months, the M&T software was able to predict the site's energy usage. Reporting was passed to departmental managers. Energy saving initiatives were discussed with management/ supervisors and then implemented.	• Rationalisation of steam distribution mains; • leakage checks on water distribution system; • improved insulation on process plant; • better scheduling of process plant; • improvements in compressed air system.
2	**Food manufacture and canning** Annual utility cost £4.5 million M&T investment costs £100,000 Annual savings £100,000 (2.2%)	Electricity - 30 meters added to existing 60 to improve departmental accountability. 8 compressed air flow meters were installed. Water/effluent - 20 extra water meters installed to cover the large users. Meters installed to monitor effluent from the main process departments. Steam - 20 additional steam meters installed. Total steam usage targeted (multi-regression analysis) against main production streams and weather (degree days).	M&T was operated along the same lines as Total Quality Management initiatives. Departmental 'energiser' teams were formed and met fortnightly to discuss potential projects and action members of the team to implement them. The teams were self-running without senior management presence. A percentage share of the savings was allocated to a charity of the teams' choice. This helped to motivate the teams to make improvements.	• Improved insulation of steam lines; • ensuring equipment was switched off at weekends; • ensuring production lines were isolated between production runs; • reducing space heating temperatures in main process departments; • reducing compressed air leaks; • intensive programmes to switch off lighting.
3	**Rubber processing** Annual utility cost £600,000 M&T investment costs £10,000 Annual savings £11,000 (1.8%)	Electricity - 8 new meters installed to complete department accountability. 5 EACs were formed and each charged for electricity used. (New meters are read electronically, older meters are read weekly and data are entered manually.)	The procedure was complex due to the many products manufactured at the site. Data analysis is carried out weekly but is only seen by the engineering department. Performance tables are prepared fortnightly and issued to the appropriate managers. At the end of each four-week accounting period, these tables are augmented with charts showing annual performance to date. Energy saving initiatives were discussed between the different departments and the engineering department; many of the measures implemented were highlighted in the initial site survey conducted by an external consultant.	• Reduction of compressed air leaks and better compressor control; • orders rescheduled to permit efficient use of presses and reduce maximum demand charges; • insulation of electric presses; • minimising mould changes; • minimising cure times; • fitting of occupancy sensors to lighting in appropriate areas.

	Project	Monitoring system	Management system	Saving measures
4	**Crystal glass manufacture** Annual utility cost £2 million M&T investment costs £28,000 Annual savings £100,000 (5%)	Electricity - 20 extra electricity meters installed at the manufacturing sites to complement the extensive network of existing meters. Gas - 5 additional gas meters installed for subsidiary gas users. Space heating consumption estimated by 'virtual' metering (utility meters less process consumption).	Sub-metering allowed fairly accurate departmental accountability. Standard spreadsheet software was used to show the consumption of each main EAC within each department via both charts and tables; energy consumption trends can therefore be assessed quickly. An overall summary sheet is produced for the site manager. Regular meetings are held to discuss energy projects, and results are fed back to the management teams to stimulate further improvements.	• Higher operator awareness leading to switching off lights etc.; • improved furnace combustion conditions; • reduced compressor air usage; • re-wiring lighting into smaller areas to increase versatility; • switching off extraction fans outside production hours; • reduced gas usage on glass 'run-out' burners; • re-setting of space heating time switches.
5	**Creamery** Annual utility cost £1.2 million M&T investment costs £35,000 Annual savings £170,000 (14%)	Electricity - broken down into 28 cost centres based on main services, main process plant and ancillaries. Water/effluent - 20 cost centres established to monitor process usage, cleaning and general use in individual departments. Steam - broken down into five cost centres, mainly using existing metering. Gas - Cost centres were set up for the steam boilers and the two thermal fluid heaters.	Weekly reports were produced for each process department and service. Reports were produced for the evaporators and dryers after each process run, as these were the main energy users. (A process run normally lasts 20 hours.) Targets were established and performance discussed at weekly production meetings.	• Re-introduction of economisers and improved efficiency of steam boilers; • improved efficiency of chilled water system; • reduction of over 50% in mains water usage; • improved performance and management of the evaporators and dryers; • better combustion air control on thermal fluid heaters; • reduction in effluent volume by 10%; • improved water management.
6	**Brewery** Annual utility cost £650,000 M&T investment costs £48,000 Annual savings £42,000 (6%)	Electricity - sub-metered into 20 units based on departments and main services. Steam - 4 steam meters were installed to monitor each main department. Water/effluent - 16 water meters were installed, including five hot liquor meters to monitor heat recovery around the hot liquor system.	Departmental accountability was introduced and utility report sheets were discussed at weekly production meetings. Targets were based on actual performance and comparisons were made with the Brewers' Society energy targets.	• Better control of the hot liquor system; • reduced can pasteuriser water consumption; • refrigeration improvements; • compressed air improvements; • improved process heat recovery; • boiler efficiency improvements.

A

APPENDIX FURTHER INFORMATION

This section contains a list of relevant publications for readers wishing to learn more about the detailed techniques and technical aspects of M&T.

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 large 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.

Good Practice Guides (GPGs)

The following Guides give additional information on Monitoring and Targeting:

GPG 111, *Monitoring and Targeting in foundries*

GPG 113, *Monitoring and Targeting in the semi-manufacture of non-ferrous metals*

GPG 125, *Monitoring and Targeting in small and medium-sized companies*

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 119, *Organising energy management - a corporate approach*

GPG 169, *Putting energy into total quality*

GPG 186, *Developing an effective energy policy*

GPG 200, *A strategic approach to energy and environmental management*

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 information systems for energy management*

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 industrial M&T and energy management principles are:

GPCS 138, *Energy monitoring and target setting at a dairy*

GPCS 142, *Monitoring and Targeting at a general rubber goods site*

GPCS 207, *Monitoring and Targeting in a multi-site company*

GPCS 221, *Monitoring and Targeting in a hospital laundry*

GPCS 247, *Energy management in the pharmaceutical industry*

GPCS 273, *Monitoring and Targeting at a brewery*

GPCS 328, *Effective energy efficiency through Total Quality Management*

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 of 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.

Activity-based Costing and Management. E Glad and H Becker, Juta & Co. Pub. 1994.

Advanced Management Accounting. R S Kaplan and A A Atkinson, Prentice Hall Pub., 2nd Edition, 1989. (Provides a very good guide to the use of regression - written for accountants but equally suitable for other professionals.)

Materials Thermochemistry. O Kubaschewski, C B Alcock and P J Spencer, Pergamon Press, 6th Ed. 1993. (Provides information on specific heats, latent heats and heats of chemical reactions.)

The Department of the Environment, Transport and the Regions' 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 topics 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 topics please contact:
Energy Efficiency Enquiries Bureau
ETSU
Harwell, Didcot, Oxfordshire,
OX11 0RA
Tel 01235 436747
Fax 01235 433066
E-mail etsuenq@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.