THE POTENTIAL FOR ENERGY CONSERVING CAPITAL EQUIPMENT IN U.K. INDUSTRY

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ABSTRACT

Energy conservation, the improvement of energy efficiency, is recognised as an important part of energy policy. This thesis examines the potential for conservation investment and possible energy savings, in part of the UK industrial sector. Assessments of the extent and type of energy conservation activity to date, both investments and energy management, within the brewing, malting, distilling and dairy sectors are made. Achievements to date affect future potentials.

In the light of a model of technical change related to energy conservation several potentials are defined. The inter-related problems of estimating or measuring these and measuring performance in energy management are discussed.

Some estimates of potentials, with explicit assumptions, are made for the four sectors studied. As any definition or measurement of potential is arbitrary, processes of change are also examined. A soft systems model of necessary activities in energy management is advanced and used to explore managerial barriers to profitable conservation investments in companies studied. Managerial factors for promoting successful energy management are discussed. Economic barriers to change are explored by profitability modelling for several energy conservation techniques used within the four sectors, including heat pumps and combined heat and power.

The approach used throughout has been systematic and on several levels.

S D FAWKES

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THE STRUCTURE OF THE THESIS

In any wide ranging, systems based study the structure of the final document presents many problems. The written word is linear while the real world is anything but linear, having many kinds of relationships and feedbacks. This thesis has three sections, each dealing primarily with one of the three major objectives. These objectives are:

1. To assess the extent of energy conservation activity in the four industrial sectors studied and to determine which techniques had been used.

2. To assess the potential for further energy conservation.

and

3. To examine barriers to further change.

Each section deals with one objective and is, as far as possible, internally consistent and complete. There are however important interactions between the three sections. For example, achievements to date partially determine potentials for further change, as do the barriers described in Section 3. These interactions are described in the text at appropriate places. Each section is now described.

Section 1: Achievements to Date

This consists of summaries of the achievements to date within the four sectors studied in terms of (a) the reduction in specific energy (energy per unit of output; (b) the techniques used to achieve these reductions, and (c) the characteristics of energy management systems. It is mainly descriptive with little discussion.

Section 2: The potential for further change

In order to assess the potential for further change it is necessary first to define what we mean by potential. This requires modelling the process of change, that is the process of technical change resulting in energy conservation. From this model, really a model of general technical change, it is possible to define potentials for further change. This model also allows us to describe the activities necessary in energy management.

A "soft systems" methodology is used to develop a starting point for structured debate rather than a "final development" of energy management activities.

In this Section it is also necessary to discuss the problems of measuring success in energy management. It is argued that success in energy conservation, i.e. a large reduction in specific energy, does not necessarily correlate with success in energy management. Using a simple specific energy index, without taking into account several factors only discernible by a close inspection of the company's situation, is too simplistic an approach. Only after considering these factors can we estimate the potential for further change in individual companies and the four sectors as entities.

Section 3: Barriers to further change

The model of technical change described in Section 2 allows us to examine barriers to further change. These can be divided into techno-economic and managerial. The absence of energy management in any form is a major barrier to change, as is a lack of "quality" in energy management. What constitutes quality of energy management is discussed and the levels of quality found in the four sectors, described in Section 1, are drawn on in this discussion. Managerial barriers are explored using the soft-systems model described in Section 2. Techno-economic barriers are examined for two major techniques, heat pumps for heat recovery and combined heat and power, and several other less spectacular techniques.

Section 1 is effectively a "snap-shot" of the current position within the four sectors, while Sections 2 and 3 and concerned with "moving pictures" of the processes of change.

Chapter 1

INTRODUCTION

1.1 The international energy problem

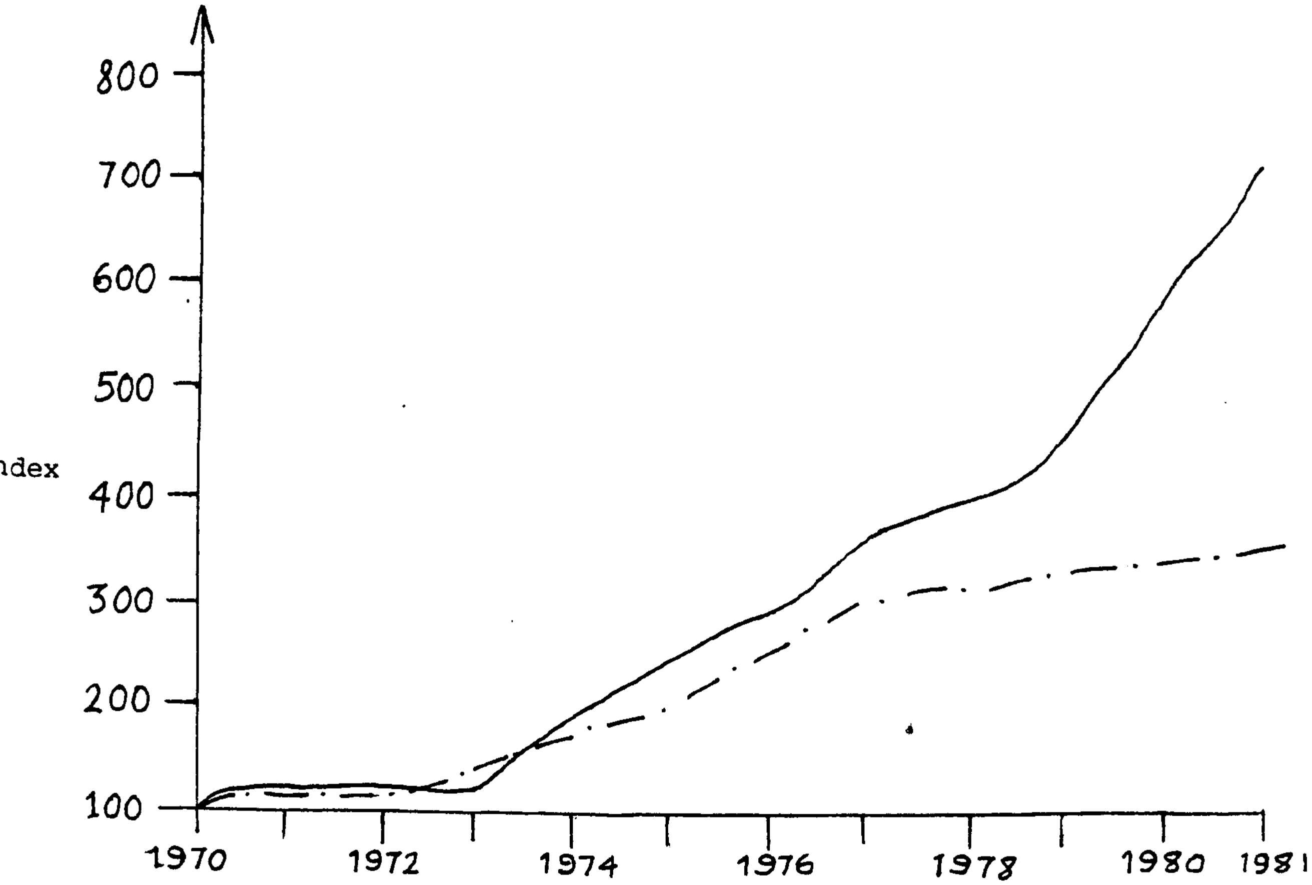
The "oil crises" of 1973 and 1979, combined with increasing environmental awareness, have made energy one of the major world concerns over the last decade. The energy problem is a complex set of inter-related technological, economic and social problems on many levels. Different regions, countries and sectors face very different situations, all of which are aspects of the global energy problem.

It is plain in retrospect that the oil crises were not caused by physical depletion of resources. The events of the early 1970s were a result of a shift of power over resource flows from Western oil companies to the oil producing nations at a time of high demand. The second oil crisis in 1979 was precipitated by the political changes in Iran leading to loss of a major supply of crude oil. For full accounts and various perspectives on both the oil crises and ultimate fossil fuel resource availability see Sampson (1980), Odum (1981), Ion (1980) and Yergin and Hillenbrand (1982).

1.2 The UK consumers' energy problems

At the level of individual consumers, in all sectors of the UK economy, the energy problem has, with a few exceptions, been one of rising real energy prices rather than supply constraints. This thesis is concerned with the UK industrial sector and Figure 1.1 shows industrial energy prices in the UK from 1970 to 1981 compared to general wholesale prices.

Figure 1.1 INDUSTRIAL ENERGY PRICES IN THE UK COMPARED TO WHOLESALE PRICES, BETWEEN 1970 AND 1981



Current prices index 1970 to 1981

1970 = 100

——— Industrial energy prices

—·—·— Wholesale prices, excluding crude oil and carbonised coal.

Source: Energy Efficiency Office, 1983

1.3 What is energy conservation?

Energy conservation is still widely, but incorrectly, associated with sacrifice (for example see H & V News, February 1984). Beijdorff (1979) identifies three ways of conserving energy:

1. By not doing things (e.g. not heating a factory or house).
2. By doing things but reducing the quality, e.g. reduce the heating temperature.
3. By doing things as before (or better), but using less energy, e.g. heating to the same temperature (or higher) but using a system that uses less energy to achieve the same result.

It should be noted that these are methods of conserving energy within the consumer's sub-system which may not reduce total system, e.g. national energy use. For example, a reduction in factory heating temperature may lead to greater absenteeism, which apart from possibly reducing output, could increase domestic energy consumption.

Method 1 in Beijdorff's classification does not usually require capital expenditure, though there could conceivably be decommissioning costs. Method 2 may involve capital expenditure if product or process redesign is necessary. It is more likely to involve a simple control action such as turning down a thermostat. Both methods involve sacrifice and tend to rely on voluntary austerity or compulsory measures such as the legal maximum heating limits of 19°C in public buildings, or the 55 mph speed limit in the USA. As Beijdorff comments, neither voluntary austerity or compulsory measures are likely to be acceptable over long periods, especially when disposable incomes are rising. Method 3 has a lasting effect without sacrificing quality but requires technical change and capital investment. This approach is often called the "technical fix".

This thesis is concerned with the technical fix form of energy conservation within the UK industrial sector. For ease of reading the more familiar term of energy conservation has been used but what is really under discussion is capital investment to improve the productivity of energy use. It should be noted that energy use per unit of economic output has been falling throughout the industrial sector for many years (see Table 1.1), and "energy conservation" means in fact more efficiency improvements.

1.4 Why is conservation important?

Conservation is one part of the Western countries' strategy for dealing with the energy problem which is based on a coal-nuclear-conservation troika. It is seen as an important method of reducing dependence on oil, which remains the most important energy source. As we will see below, crude oil prices are expected to continue rising in real terms despite current slackness in the market. Other energy prices are expected to be tied to oil prices.

1.5 Future energy prices

Consideration of future energy prices requires an international perspective. Even the UK, temporarily self-sufficient in energy, cannot expect to be insulated from world price.

Forecasting energy prices, even in the short-term, is difficult and the only certainty in forecasting is that the forecast will be wrong (Challis, 1982). In recent years there has been a shift towards scenarios and away from econometric forecasts. Scenarios allow the inclusion of qualitative information such as political judgements and help to make assumptions explicit.

The early 1980s have seen a weakening of the oil price which is attributed to two factors: non-OPEC (Organisation of Petroleum Exploiting Countries) reserves coming on-stream and a slackening in oil demand in the industrialised countries due to a combination of

Table 1.1 ENERGY PER UNIT OF INDUSTRIAL OUTPUT IN THE UK from 1960 to 1980

Year	1960	1973	1974	1975	1976	1977	1978	1979	1980
Energy per unit of industrial output 1973 = 100	112	100	83	88	89	85	82	81	75

Source: International Institute for Applied Systems Analysis (1981) recession, conservation and a switch to other fuels, particularly coal. Although physical depletion of world oil reserves now appears further away than judged by early analysts (Odell and Rosing, 1980) several factors suggest that oil prices, and other energy prices, will rise over the long term future.

A major economic factor is that new fossil fuel reserves are likely to be increasingly expensive to find and exploit. Shell (1979) divide oil reserves into low, medium and high costs. Current North Sea developments are medium cost and newer, increasingly marginal, fields will need a high oil price if they are to be developed. Alternatives to conventional fossil fuels such as coal liquefaction, or shale oils, appear to be equally, if not more, expensive.

Added to the economic pressures there are political factors. Despite a reduction in dependence on the Middle East, this unstable region is still vitally important to the industrialised world, especially Europe and Japan. Any restrictions on passage through the Straits of Hormurz, as currently threatened by Iran (February 1984), would have a dramatic effect on oil prices.

Four projections concerning future energy prices are briefly described here to show both the range of opinion and the consensus that real energy prices are expected to continue to rise.

The UK Department of Energy, although refusing to make official forecasts, made price projections in its submission to the Sizewell Enquiry. The estimate was that the real industrial fuel oil price would be between 1.66 and 2.66 times its 1982 level by the year 2000 (Department of Energy, 1982).

A comprehensive private sector forecast (DRI Europe, 1982), covering all fuels in Europe, suggests that European oil prices will be slack until 1987 and then resume an upward trend so that by 2000 they will stand 34% above the 1981 (previous peak) level.

The International Energy Agency warns against complacency in the current oil glut:

> The current outlook for short-term stability in energy markets and the oil market in particular is deceptive because signals in today's surplus markets do not reflect the underlying medium and long-term trends. In fact, trends point to recurrent oil supply stringency later in the 1980s and thus the need for constant attention to energy policy as a means of avoiding severe economic constraint.
>
> International Energy Agency (1982)

Stobaugh (1982) describes two judgemental scenarios for world energy developments to the year 2000, with intermediate stops at 1985 and 1990. The Upper Bound is based primarily on the projections and analyses of the IEA and is optimistic over future energy supplies. The Lower Bound assumes "things do not go very well" but excludes contingencies such as a shutdown of all or a major part of the oil output of the Middle East.

In the Upper Bound the key real oil price is assumed to rise at 2% per year while in the more tightly constrained Lower Bound it rises at 4.5% per year. Starting at $30 a barrel in 1980, the price of oil would thus rise in real terms (1980 dollars) to $45 a barrel in the Upper Bound and $72 in the Lower Bound in 2000. Stobaugh, and other analysts, expect the price trend to follow an unstable pattern of "jagged peaks and sloping plateaus", rather than a smooth upward trend.

The projections for oil prices for the four scenarios are summarised in Table 1.2.

1.6 Summary

This chapter has described the three types of energy conservation, two of which require voluntary austerity or compulsion. The third requires technical change and investment. It is this method of energy conservation that this thesis is concerned with.

We have also seen how the energy problem for consumers in all sectors has been one of rising real prices. The industrial sector, which is the subject of this thesis, has not been and will not be exempt from this trend.

Table 1.2 SUMMARY OF OIL PRICE PROJECTIONS

	FORECAST / SCENARIO			
	UK Dept. of Energy (1)	DRI Europe (2)	Stobaugh Upper Bound (2) & (3)	Stobaugh Lower Bound (2)
Price Index	166 - 266	134	150	240
Base year	1982 = 100	1981 = 100	1980 = 100	1980 = 100

Notes: (1) Industrial fuel oil
(2) Crude oil
(3) Similar to IEA's forecast

Chapter 2

RESEARCH OBJECTIVES AND DATA COLLECTION

2.1 Introduction

The general objective of the research has been to test the feasibility of achieving low energy scenarios, particularly Leach et al (1979). Leach et al, in "A Low Energy Strategy for the United Kingdom", purport to show "how the UK could have 50 years of prosperous material growth and yet use less primary energy than it does today". It claims that the introduction of known conservation techniques, that are "widely judged to be 'economic'", at quite modest rates could counter-balance all increases in energy use that would otherwise come about from growth in material standards.

The approach in Leach et al is "to start wherever possible with the ultimate purpose for which energy is used - the useful energy demand - and work upwards from there to primary energy supplies, fuel by fuel, and sub-sector by sub-sector".

This "bottom-up" approach to energy modelling is based on physical and engineering analyses and is in contrast to the "top-down" methodology of official, econometric models. It is claimed that the bottom-up approach allows the detection of saturation effects and important energy feedback effects. It also identifies where fuel substitution is possible.

Leach's model starts from a detailed breakdown of energy use in the baseline year 1976. Using various studies of energy use in different sectors energy demand in 1976 is broken down into nearly 400 separate categories determined by end uses, fuels and appliances.

In the industry model the central postulate is that the energy intensity of industrial output can be reduced in all sectors at a regular, and quantifiable, rate. "This reduction will be achieved by refurbishing existing equipment and buildings, and by installing more efficient processes when expansion or replacement are required" (Leach et al, 1979).

The model relates the expansion of each industrial sector, which is a function of the assumptions about the growth in GDP, the share of GDP provided by Total Industrial Production (TIP), and the changing proportion of TIP provided by each industrial sector, to the postulated declining energy intensity of output.

A more recent model similar to Leach's is Olivier (1983). This uses the same "bottom-up" methodology and in areas is more detailed than Leach et al. The conclusions of this study are used to advocate a greater use of solar energy in all sectors.

Not surprisingly, given the unconventional conclusions, there have been several criticisms of Leach et al. These include Littlechild and Vaidya (1982); Marshall (1980); Day et al (1980); and ETSU (1982). Day and the ETSU Report conclude that the rate of diffusion of energy saving techniques implicit in Leach are optimistic.

Marshall, from an economic viewpoint, points out that a methodology used, in which a large number of uncertainties are multiplied together, must lead to uncertain answers. Leach however only gives single-figure estimates with no sensitivity testing of the assumptions made. Government intervention is an implicit assumption built into the Leach projections but there is no indication of how much lower demand will be through the interplay of market forecasts. Leach and his colleagues "see their 'forecasts' as something that must be made to happen, assuming that, with encouragement and sanctions, current best practice in terms of energy saving technologies could be universally adopted". (Marshall, 1980). No attempt is made to estimate the costs, private or social, of the required investments or government intervention. Marshall concludes the report is optimistic.

Littlechild and Vaidya (1982) compare the High GDP growth case in Leach with the Birmingham Energy Model (BEM) Base Case which has similar GDP growth assumptions. Comparisons of energy consumption projections between these two show wide divergence. Total energy consumption in the Industrial Sector (excluding Iron and Steel) in Leach rises at almost 1% per annum up to 2000, but then levels off, presumably as conservation takes effect. In the BEM Base Case total energy consumption in this Sector grows at about 1.5% per annum throughout the period 1980 - 2025. There are also large differences in fuel mix.

These differences also occur in the other sectors, leading to large differences in total projected demands for the four major fuels. By the end of the period, coal, oil, gas and electricity consumption in Leach's model are respectively 56%, 72%, 44% and 31% of the consumption in the BEM Base Case.

Littlechild and Vaidya summarise the criticisms of Leach as follows:

> There is no discussion of how far individuals are expected to respond of their own accord and how far they are to be influenced by government policy.
>
> There is no mention of the exact nature of the government measures considered necessary.
>
> The report claims the measures are cost-effective but no details or evidence are given.
>
> There is no discussion of how far market forces alone will yield the envisaged level of conservation.
>
> It is arguable that energy is income-elastic.
>
> It may be more difficult to eradicate energy using habits than the authors envisage.

2.2 A personal criticism of Leach

The reduction in energy per unit of output in the industrial sector hypothesised by Leach is 32% by 2000 (ETSU, 1982). This is similar to figures for technical potential, without regard to commercial constraints, given in Beijdorff (1979) and the Energy Audits Series.

Leach, both in his book and in personal communication, comments on the similarity of these results and implies this is supporting evidence for his hypothesis. A look at Leach's references shows that several of his experts are the authors of the Energy Audit Series. The ETSU (1982) Report also concludes that Leach is equivalent to the Energy Audits. This similarity implies that Leach's scenario involves the measures outlined in the Energy Audits becoming both economic and fully exploited.

A crucial point is Leach's use of the phrase "existing technology". He appears to assume that because a technology exists in one application it can easily be used in others. As Rosenberg (1976) points out, technology is very specific and there are considerable difficulties in transferring technologies between applications. For most types of energy conservation equipment, economic viability is determined by site-specific factors, therefore economic viability in one site does not guarantee viability in another, even within the same application.

From a "macro" point of view, such as that of Littlechild and Vaidya, Leach contains "a great deal of detail". From a "micro" point of view, however, there is insufficient detail and the report contains several generalities that are misleading.

For example, much is made of the potential for waste process heat recovery, particularly for space heating. This is undoubtedly possible and has been carried out in several applications, but there are many site specific constraints. Firsty, there are problems of geography, sources of process heat are often a long way from the potential demand and the transmission of heat, usually as warm air, requires expensive ducting and involves high losses (see Dryden, 1982, for costs). Another constraint, of which there are two dimensions, is time. Often the heat is not produced when it is needed or it has variations in quantity and/or quality that make its use for regular, reliable, space heating unacceptable. Capital costs are also increased by the need to retain a standby heating system in case of a production stoppage. Space heating demand is seasonal which means in summer heat has to be dumped, involving extra ducting, dampers and a control mechanism. Leach's assertion that "with such an installation the need for other space heating can often be eliminated completely" looks distinctly optimistic.

Leach also states in a tautology that "heat recovery systems can be used wherever there is usable waste heat and somewhere to use it". The implication being this is nearly everywhere. Technically this may be true and several studies have shown the immense size of the waste heat resources (e.g. Laws, 1981). Costs however are such that few schemes are viable. Addy (1983) reports that his company examined and assessed 247 possible heat recovery applications, all cases where either the user or his consultants had considered that there was real potential for heat recovery. In only 43 cases was a realistic solution possible, and of these 43, only 11 would truly have a payback better than the two years commonly demanded for retro-fit measures. Missions (1981) and Brookes and Reay (1982) stress that industrial heat recovery systems are very site specific, making Leach's generalisation misleading.

Leach also mentions flat plate solar collectors and is obviously in favour of increasing the use of solar energy. In his model however he has made no quantification of the potential for solar "because it is recognised that it is unlikely to be economic until the turn of the century". He does claim that "the large roof areas of factory buildings would provide suitable locations for solar collectors". Here again several vital constraints are ignored, namely space, direction and angle of roofs, existence of large areas of skylights, and inability of roofs to take wind loads on solar collectors. The impression given by Leach is that every factory roof can be fitted with a solar collector. Devonold (1982) in investigating the potential for solar energy in the textile industry (considered by a Metra study for ETSU in 1977 to have most potential), concludes that conservation measures are currently likely to be ten times more cost effective than solar water heating (SWH). Devonold also comments that SWH may only be feasible, if at all, in new single storey buildings on new industrial sites in which all aspects of energy supply, heat recovery, storage and recycling could be integrated.

Leach correctly states that "investment in energy saving tends to be low on the list of industrialists' priorities". He continues, "the payback period for many measures such as fixing steam leaks by maintenance staff, who are being paid in any case, or fixing broken skylights, is virtually instantaneous". This ignores the opportunity costs represented by what else the maintenance staff could be doing. It also ignores the tight constraints often acting on maintenance staff. It also fails to recognise the very real physical difficulties of apparently minor repairs, such as fixing steam leaks or skylights. Often these occur in hard-to-get-at places and repairs involve more time and effort, i.e. cost, than the savings are worth (Jacques, 1981). Often minor repairs cannot be carried out while production is in operation which means they have to wait for planned shutdowns or opportunistic maintenance. A tour of most factories will reveal several minor faults that Leach no doubt would say should be repaired immediately to save energy. For many of these however, it is rational for management to leave them indefinitely or at least until an opportunity for repair presents itself.

2.3 Research Objectives and Methodology

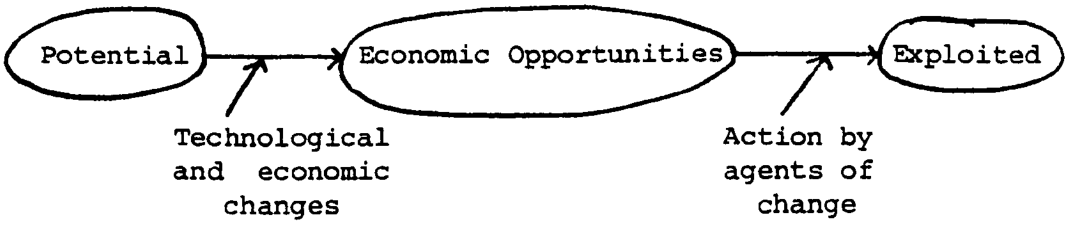
The approach used in this research has been at the micro-level. Few if any other studies have been made of the potential for energy conservation at this level. It is also distinctive in that it looks at both the potential for change and the processes through which change comes about.

Early consideration of the title, "The potential for energy conserving capital equipment in UK industries", suggested a hard estimate of the potential was required. As the work progressed it became obvious that potential, when used in anything other than its physical science meaning, is a "soft" concept. This problem over defining what is meant by potential, is crucial in determining the feasibility of low energy scenarios yet is not addressed in the literature. Leach et al make no attempt to differentiate the different types of potential that will be explored in a later section.

Consideration of any potential raises the question "how can that potential be achieved?" This appears to be more important than some arbitrarily defined potential which is continually being altered by technical and economic developments. Understanding the mechanisms by which potential is realised would seem to be more useful to decision makers at both corporate and national levels than arbitrary estimates of potential.

This thesis is concerned with both the potential and the mechanisms of change by which that potential might be exploited. As such it deals with technology, economics and management. The generalised process of change, to be described in more detail in a later section, involves technological possibilities becoming economic opportunities as prices and technology change. These opportunities then have to be exploited. This process is shown in Figure 2.1

Figure 2.1 THE GENERALISED PROCESS OF CHANGE



This process is directly analogous to the situation with mineral resources whereby technological and economic changes turn resources into reserves. Action by economic agents can exploit these reserves. As Eden (198) comments, estimates of the resource and reserve base of energy conservation vary as greatly as those for fossil fuels.

Leach's whole thesis stresses "existing" technologies, most of which he claims are already "economic" at today's energy prices. This thesis is concerned with testing this assertion. Technological and economic disciplines have been used to assess the extent of economic opportunities while management disciplines have been used to examine the actions of agents of change. (This has included consideration of those factors conducive to energy saving technological change).

2.4 Selecting the Sectors for Study

It soon became clear that only a few industrial sectors could be studied within the constraints of a PhD timetable. The criteria for choosing sectors were:

- that a potential for energy conservation should be documented.
- a variety of company size should exist so that any differences in approach to the energy problem due to size differences could be investigated
- that there should have been reported energy conservation activity in the sectors, promising a range of investment levels.
- similarity of technology to allow the possibility of inter-sector diffusion of energy saving techniques.

An analysis of energy conservation investments reported in the Department of Energy's newspaper "Energy Management" over the year October 1981 to October 1982 (see Appendix 1) showed that the Food, Drink and Tobacco industry accounted for 20 out of 100 investments. This was the most commonly occurring industry, suggesting considerable energy conservation activity relative to other industries. Five of the reported investments were in the brewing sector.

Initial contacts in the brewing sector were productive and it was decided to concentrate on this sector. The industry is known for its openness and technical cooperation and in this respect the industry, with a few exceptions, has lived up to its reputation in its assistance with this project. Some closed doors, however, were encountered. On further analysis it often turned out that the most open companies were the most progressive, a conclusion similar to that of Carter and Williams (1959) and Baker (1983) in their innovation adoption research.

As the brewing sector appeared to have been particularly active in energy conservation it was decided to investigate other sectors, these were malting, dairies and distilling. Together the four sectors form a major part of Standard Industrial Classification

Order III, Food, Drink and Tobacco. Three of the four, brewing, distilling and dairies have similar underlying technologies. They all involve low temperature (i.e. less than 150°C), heating, cooling and batch operations. This offered the possibility of observing inter-sector transfer of energy saving techniques.

All four sectors contain a variety of company size as well as independent and group companies.

The technical possibilities for energy conservation in three of the four sectors, brewing, malting and dairies, are well documented in the Energy Audit Series (Harris, 1978, 1979 and 1981). The brewing industry is also well documented through the Brewers' Society energy surveys (see Gordon, 1981).

The malting industry is recognised as having made considerable energy savings through heat recovery (Harris, 1981). Study of the technical, economic and managerial reasons behind this rapid diffusion of an energy saving technique could be expected to be useful.

The four sectors studied are relatively small in terms of their total primary fuel equivalent energy consumptions, which are shown in Table 2.1.

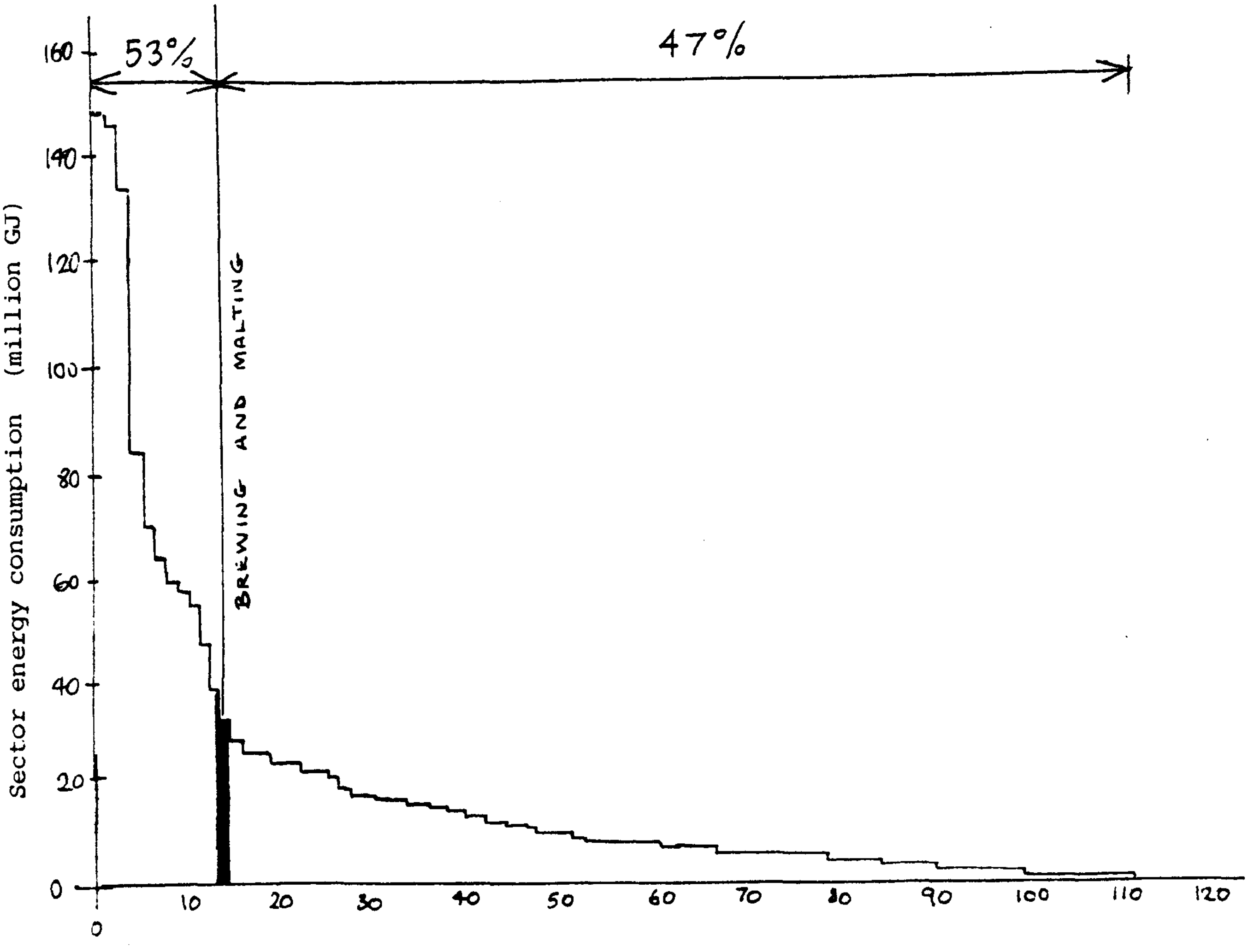
Table 2.1 TOTAL PRIMARY FUEL EQUIVALENT ENERGY CONSUMPTION OF THE FOUR SECTORS IN 1976

	SECTOR			
	Brewing	Malting	Distilling	Dairies
Total primary fuel equivalent energy consumptions				
MGJ	26.5	9.8	30	28
m.t.c.e.*	1	0.323	1.1	1.06

* million tonnes coal equivalent.

Sources: Harris, 1978, 1979, 1981; Malkin, 1982.

Figure 2.2 PARETO DIAGRAM SHOWING THE FUEL PURCHASES (IN PRIMARY ENERGY TERMS) OF THE BREWING INDUSTRY RELATIVE TO OTHER SECTORS (OUTSIDE IRON AND STEEL AND HEAVY CHEMICALS)



Sectors arranged in decreasing order of energy consumption.

Source: Harris (1979)

Together the four sectors account for approximately one-third of the total primary fuel equivalent energy used in the Food, Drink and Tobacco industry in 1976. Although only about 1% of total UK primary energy demand, the real importance of these small sectors in energy terms is highlighted by Figure 1.2 47% of industrial energy uses outside iron and steel and heavy chemicals is in industries similar in size to or smaller than brewing. If a high level of savings is to be achieved overall in industry, then a reasonable number of these sectors must achieve savings of a high proportion of current use.

Two interesting footnotes illustrate that the study of the brewing industry in connection with energy conservation has a long history. Firstly, Joule's discovery of the fundamental law that energy is always conserved was made after early experiments in his father's brewery. For a description see Crowther, 1935. Secondly, Sir Oliver Lyle's classic work "Efficient Use of Steam" (1946) chose a brewery to demonstrate the calculation of heat balances. Opening with the statement "The input of a brewery is cold water. The output is cold beer", he then proceeded to examine why it is that a product which is as cold when it comes out of the brewery, as the water of which it is largely composed was when it went in, needs more energy than just the "necessary push to start things off".

In 1976 66% of all energy used in industry was used for process heat, a total of 1493 Petajoules. Therefore a major area for conservation could be recovery and reuse of process heat, an assumption backed up by an examination of the Energy Audits series. In these, heat recovery is reported as technically feasible in 11 out of the 16 industries surveyed. Heat recovery has a particularly large technical potential in the four sectors, brewing, malting, distilling, and dairies. Consequently it was decided to concentrate on heat recovery technologies in the modelling of profitability. This was extended to include combined heat and power or co-generation.

In the firm approach, each firm's total effort was of interest and any technology they had used, or considered, was of interest, not only heat recovery or combined heat and power. Despite this general restriction on the techniques under consideration, it was decided in the section on energy saving within the individual firms that such a restriction was inappropriate. Hence each firm's total effort was examined.

2.5 Refined Objectives

The refined objectives of the research have been to:

1. Study the potential for energy conservation equipment within the brewing, malting, distilling and dairy sectors.
2. Investigate the extent of adoption of energy saving technologies since 1976 and the results in energy saving achieved in these sectors.
3. Investigate barriers, both managerial and techno-economic, to adoption of energy saving technologies within the four sectors; and
4. To use the information to comment on the viability of low energy scenarios within these sectors.

2.6 Data Collection

Within the general strategy described above two approaches have been used; modelling the profitability of possible investments open to firms in the four sectors, and examining the extent of adoption of technologies and the processes of change within individual firms. The former is primarily technology focused while the latter is focused on managerial issues.

The modelling of profitability for heat pumps and combined heat and power is described fully in Section 3 (and in the case of heat pumps in Fawkes and Jacques, 1984). Such modelling is necessarily somewhat general but wherever possible real examples and real prices have been used. Sensitivity analysis has been carried out to identify the important factors in each case. Data has been obtained from potential and actual investors, suppliers of equipment and the energy conservation trade press.

Data for the firm approach has been obtained by a combination of techniques. Interviews were chosen as the primary technique as they offered a suitable depth of information. A postal survey was carried out within the brewing sector so as to increase the sample size. Also in the brewing sector, two companies were visited over an extended period, eighteen months in one case, to monitor a changing situation and to construct case studies. In one case the researcher was able to assist the company in project selection. Thus data collection within the four sectors was at three levels.

In all, data was collected from 100 sites run by 66 companies within the four sectors. Additional to this, 44 suppliers of equipment and services were contacted to find their perspective and obtain details on existing equipment and services as well as new developments. Three government bodies and five trade associations were also contacted. Table 2.2 shows the numbers contacted in each of the four sectors. A list of organisations contacted is shown in Appendix 27.

Table 2.2 NUMBER OF SITES DATA COLLECTED FOR IN EACH SECTOR

	SECTOR				
Technique	Brewing	Malting	Dairy	Distilling	Totals
Interview	14	7	12	32	65
Survey	35	-	-	-	35
TOTAL	49	7	12	32	100

Initial interviews were conducted in several sectors as well as the four finally chosen to explore the issues involved in the problem and to gauge the likely reaction to this type of data collection.

After five initial interviews in the brewing sector, it was decided to increase the sample size in this particular sector through a postal survey. A pilot questionnaire was constructed and sent to ten brewing sites. Three replies were received from this source. A copy of the pilot was also sent to the Brewers Society for comment and possible endorsement. The Society took it upon itself to distribute copies of the pilot to 56 members of its Energy Working Party which would have been a good sample, covering as it does all types of sites. Only two replies however were received from this source despite a written follow-up from the Society. Several members of the Energy Working Party subsequentlv completed a final version. After modification the final questionnaire (see Appendix 28) was administered to 90 sites.

While the questionnaire was being administered, and after, the programme of interviews was continued. In the light of earlier interviews and returned questionnaires later interviews often explored additional issues.

Data from the interviews and the more detailed cases fed directly back into the profitability modelling of selected technologies.

2.7 Summary

The general objective of the research has been to test the feasibility of low energy scenarios, particularly Leach et al (1979). The latter has been briefly reviewed and several criticisms of it presented.

Consideration of the thesis title led to the conclusion that a hard estimate of potentials for energy conservation was not possible and that an understanding of mechanisms of change was at least as important as any arbitrary estimate of potentials. Therefore the thesis will discuss both estimates of potential for change and the processes by which potentials can be exploited. The two are inter-linked.

Two strategies were used in the research, one examining the energy conservation activities of individual firms and one examining the profitability of various energy conservation techniques. On practical grounds it was decided to confine the study to a few industrial sectors and four were chosen: brewing, malting, distilling and dairies. Most attention has been paid to brewing. Originally it was decided to concentrate on heat recovery techniques only but within the firm approach it was essential to study the companies' total energy management programme. Any restriction on the techniques would have been arbitrary and ignored an important aspect of the problem, the varying and sometimes non-existent response of companies to rising energy costs.

Data collection within firms was on three levels, postal surveys, interviews and multiple visits over extended periods. Data from interviews often fed back into the more general profitability modelling of specific techniques. A wide ranging approach to data collection was necessary to illuminate different areas of the problem and the relationships between them.

The refined objectives of the research have been to:

1. Study the potential for energy conservation equipment within the brewing, malting, distilling and dairy sectors.
2. Investigate the extent of adoption of energy saving technologies since 1976 and the results in energy saving achieved in these sectors.
3. Investigate barriers, both managerial and techno-economic, to adoption of energy saving technologies within the four sectors; and
4. To use the information to comment on the viability of low energy scenarios within these sectors.

Section One

ACHIEVEMENTS TO DATE

SECTION ONE

ACHIEVEMENTS TO DATE IN THE FOUR SECTORS

Introduction

The following section examines the extent and type of energy saving investments within the sampled companies in the four sectors. It addresses the question "what energy conservation activity has already occurred?" The results and discussions are in three sections. Firstly, the reductions in specific energy, i.e. energy per unit of output achieved over the last two to five years, are reviewed. Reduction in specific energy is the end result of energy conservation of most interest to the low energy strategists. Leach's (1979) model is based on a systematic, regular reduction in specific energy in all sectors.

Leach's model is based on 1976 data but most companies sampled did not have data on specific energy from that year, indeed many companies did not even have it for the last five years. In most cases only data referring to the last two years was available. This difficulty reflects the problems in collecting specific energy data (to be discussed further in Chapter 7), and that many companies have only developed energy management activities within the last five years.

Secondly, the energy saving techniques used are examined to answer the question "what techniques have been used?" The techniques are divided into retro-fit and new plant investment, and innovations or adaptations of existing equipment. The latter division is necessary to test Leach's assertion that the energy savings he assumes can be brought about by the use of existing techniques, presumably meaning already innovated techniques.

Thirdly, the observed characteristics of energy management systems are reviewed. In the case of the brewing sector these results are used to test hypotheses about the utility of energy management techniques such as monitoring and targetting. Such techniques are often advanced as being effective, but have rarely if ever, been tested systematically.

Results for each sector are given in turn, followed by a discussion of that sector. At the end comparisons between the four sectors are made to highlight differences and similarities.

Throughout the section, unadjusted reductions in specific energy figures are used as an indicator of performance. Chapter 7 discusses the shortcomings of this measure, both for on-site and inter-site comparisons. Even in the light of these shortcomings, the absence of adjusted data in most companies has made the use of unadjusted data necessary. In the three sectors, brewing, malting and distilling, occupacity, a major cause of variance in specific energy figures, has been low. This suggests that the unadjusted reductions in specific energy recorded may well be understating the true figure.

Chapter Three

ENERGY SAVING IN BREWERIES

3.1 Introduction

The recorded reductions in specific energy achieved, the techniques used and the observed characteristics of energy management systems in the brewing sector are now described. The results are used to test hypotheses about the utility of energy management techniques in bringing about a reduction in specific energy.

These results are derived both from interviews and a postal survey. The latter had several shortcomings as a means of data collection. Firstly it did not refer to energy saving investments which were investigated for other purposes, i.e. investment in new plant that produced energy savings but was not justified on these savings alone. Secondly, replies were not always complete. Thirdly, it ignored site specific factors. It was impossible to tell whether a company was achieving its full potential.

Breweries are split into three size ranges, 0 - 299,000 hl/a capacity; 300,000 - 1,000,000 hl/a capacity; and 1,000,000 + hl/a capacity. This was to allow the testing of hypotheses concerning company size and to illustrate any differences in approach between companies in different capacity ranges.

3.2 Small Sites (0 - 299,000 hl/a)

3.2.1 Reported reductions in specific energy:

In a sample of 29 sites, six reported no investments in energy conserving or cost reduction equipment and no reduction in specific energy over the last five years. Of these, one was evaluating Copper Vapour Heat Recovery at the time of the survey. A further three sites had only invested in cost saving measures, i.e. fuel switching or power factor correction.

Seven sites reported investments in energy conservation equipment but did not report a figure for reduction in specific energy, reporting "unknown" or nothing. Twelve sites reported investments that had resulted in a reduction in specific energy of between 2% and 25% over the last two years. Five sites reported a reduction in specific energy of between 5% and 50% over the last five years. The distribution of reported reductions in specific energy is shown in Figure 2.I. Table 3.1 shows the number of sites reporting savings for three size ranges within the small brewery sub-sector.

3.2.2 Retro-fit versus investment in new plant:

Of the nineteen sites making some investments, sixteen had made retro-fit investments with no major investment in new plant reported. Three sites, excluding the one with the new brewery, had evaluated retro-fit possibilities and found them to be largely uneconomic. The savings they had achieved, ranging from 10 - 25% over two years, and up to 50% over five years, had come about through incorporating energy saving features in new plant purchased for non-energy reasons. Managerial aspects of this issue will be explored fully in a later section.

Figure 3.1 DISTRIBUTION OF REPORTED REDUCTIONS IN SPECIFIC ENERGY - SMALL BREWERIES (0 - 299,000 hl/a)

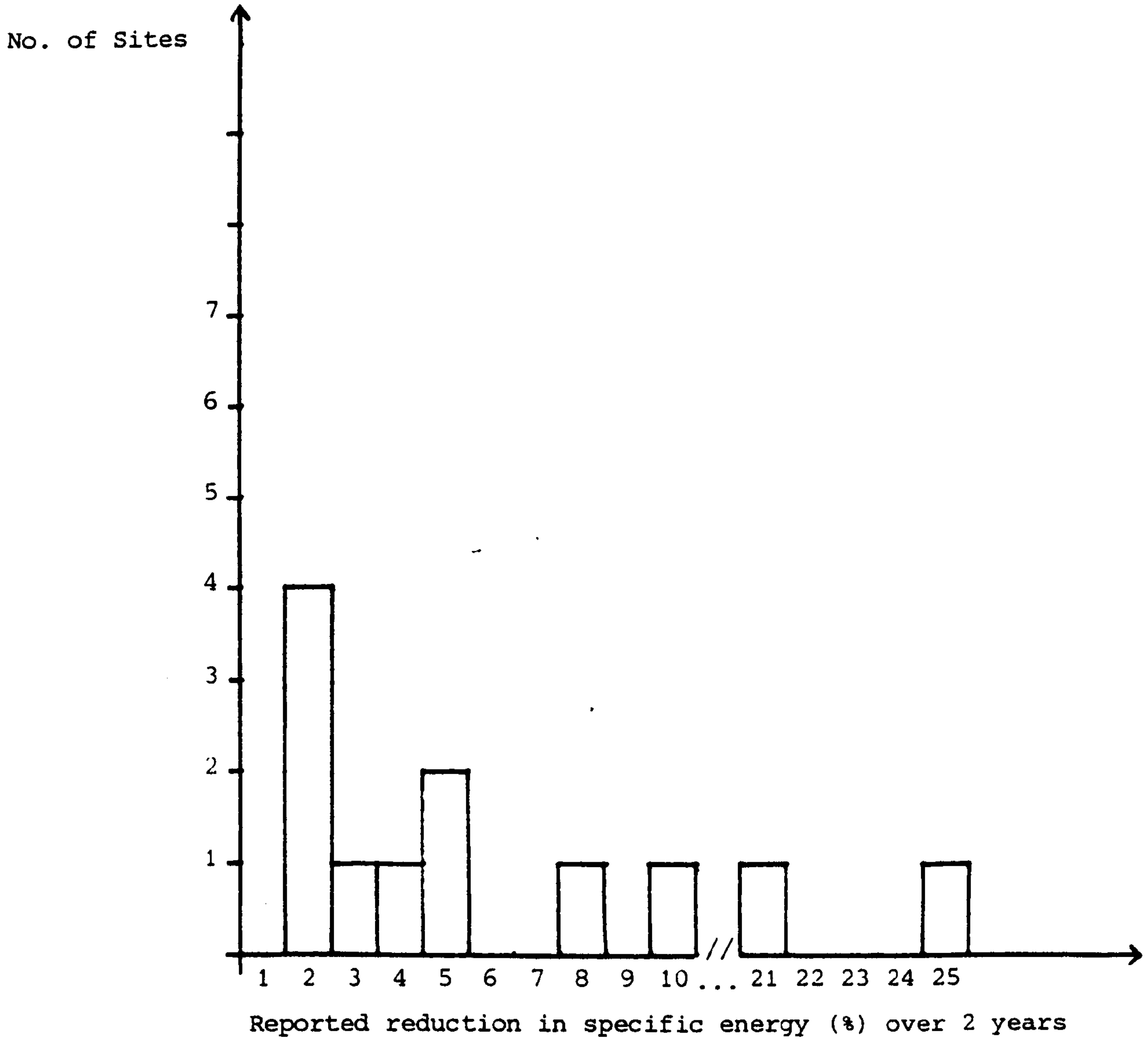


Table 3.1 NUMBER OF SITES REPORTING SAVINGS IN THE SMALL BREWERY SUB-SECTOR ACCORDING TO SIZE

Size (000s hl/a)	No. with known savings over the last 2 years	No. with unknown savings	No. with cost saving measures only	No. with no savings, no investments	Totals
0 - 99	8	6	2	4	20
100 - 199 (1)	3	1	1	2 (2)	7
200 - 299	1	-	-	-	1
Totals	12	7	3	6	28

NOTES: (1) This size range included a new brewery, not included here as savings figures are not relevant.

(2) Includes one site currently evaluating CVHR.

3.2.3 Innovation versus Adoption of existing equipment:

Only one site made an investment that could be regarded as an innovation. It had worked in conjunction with an equipment supplier to adapt a novel, indirect copper heating system. This system had originally been developed for a pre-packaged mine-brewery for use outsize the UK and had to be adapted to fit the new application. All the other investments could be regarded as straight-forward adaptations of existing, well-tried methods; straight-forward that is except for the necessary site-specific modifications.

3.2.4 The energy conservation techniques used:

Table 3.2 summarises the techniques used in this sub-sector. Additional heat recovery from cooled wort, power factor correction and high efficiency lighting were the most common investments.

3.3 Medium Breweries (300,000 to 1,000,000 hl/a)

3.3.1 Reported reductions in specific energy:

In a sample of eleven sites, ten reported a reduction in specific energy over two years. All sites had invested in energy conservation techniques and the reported reductions in specific energy ranged from 2 - 40% over two years and from 10 - 60% over five years. The distribution of reductions in specific energy over the last two years is shown in Figure 3.2.

3.3.2 Retro-fit versus investment in new plant:

Most of the investments were in retro-fit measures rather than in new process plant.

Table 3.2 RANKING OF FREQUENCY OF USE OF ENERGY SAVING TECHNIQUES IN THE BREWING SECTOR

(Superscripts indicate equal rankings)

Rank	Small sub-sector	Medium sub-sector	Large sub-sector	Overall
1.	Wort cooling heat recovery	High efficiency lighting	High efficiency lighting	High efficiency lighting
2.	Power factor correction	Keg line heat recovery	Power factor correction	Wort cooling heat recovery
3.	High efficiency lighting	Boiler blow down heat recovery^{3}	Wort cooling heat recovery	Power factor correction
4.	Fuel switching	Power factor correction^{3}	Building insulation^{4}	Keg line heat recovery
5.	Keg line heat recovery	Space heating controls^{5}	CVHR^{4}	Fuel switching
6.	Boiler blow down heat recovery^{6}	Fuel switching^{5}	Economiser^{4}	Boiler blow down heat recovery^{6}
7.	Pipe lagging^{6}	CVHR^{5}	Fuel switching	CVHR^{6}
8.	Wort heat recovery tanks^{8}	Wort cooling heat recovery^{5}	Keg line heat recovery	Building insulation
9.	CVHR^{8}	Motor replacement^{9}	Flash steam heat recovery^{9}	Pipe lagging^{9}
10.	New boiler^{8}	Maximum demand control^{9}	Back end dampers^{9}	Economiser
11.	Meters^{8}	Building insulation^{9}	Oxygen trim^{9}	Space heating controls
12.	Building insulation^{8}	Oxygen trim^{9}	Meters^{9}	Motor replacement^{12}
13.	Motor replacement^{8}	Economiser^{9}	Space heating controls^{9}	Condensate recovery^{12}
14.	Variable speed drives^{8}	Condensate recovery^{9}	Maximum demand control^{9}	Oxygen trim^{14}
15.	Process control^{8}	Regeneration on pasteuriser^{15}	Motor replacement^{9}	Maximum demand control^{14}
16.	Air mains isolation^{8}	New boiler^{15}	New compressor^{9}	New compressor^{16}
17.		Pipe lagging^{15}	Use of well water^{9}	Air mains isolation^{16}
18.		Motor speed controls^{15}		Meters^{16}
19.		New keg line^{15}		New boiler^{16}
20.				Flash steam heat recovery^{16}
21.				Use of well water^{16}
22.				Tanks for wort heat recovery^{22}
23.				Variable speed drives^{22}
24.				Motor controls^{22}
25.				Regeneration on pasteuriser^{22}
26.				Process control^{22}
27.				New keg line^{22}

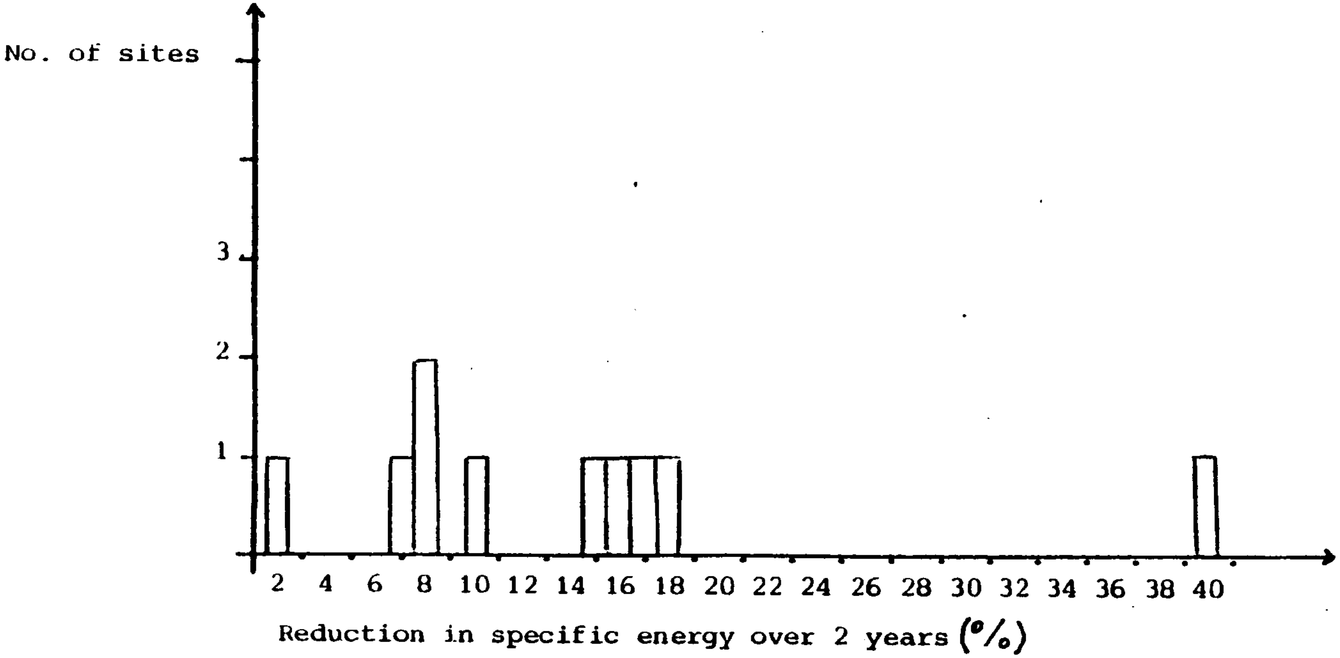
Table 3.3a TECHNIQUES USED IN THE SMALL BREWERY SUB-SECTOR

	Company Number																					
Technique	045	155	104	156	105	109	022	111	044	133	077	199	008	142	143	150	039	126	043	061	009	Totals
HEAT RECOVERY TECHNIQUES																						
Additional heat recovery from wort cooling	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	16
Cask/keg line heat recovery	✓											✓		✓						✓		4
Additional tanks for wort heat recovery					✓																	1
Copper Vapour Heat Recovery (CVHR)																			✓			1
Extra regeneration on pasteuriser																						0
Effluent heat recovery																						0
Boiler blow down heat recovery	✓												✓									2
Flash steam heat recovery																						0
Condensate recovery																						0
Economiser																						0
BOILER RELATED TECHNIQUES																						
New boiler													✓									1
Back end dampers																						0
Oxygen trim																						0
Fuel switching			✓		✓							✓			✓			✓		✓		6
Pipe lagging								✓													✓	2
Additional steam metering																					✓	1

Table 3.3b TECHNIQUES USED IN THE SMALL BREWERY SUB-SECTOR

	Company Number																				
Technique	045	155	104	156	105	109	022	111	044	133	077	199	008	142	143	150	039	126	043	061	009	Totals
BUILDING and SPACE HEATING TECHNIQUES																						
Building insulation												✓										1
Controls for space heating																						0
ELECTRICAL TECHNIQUES																						
Power factor correction	✓		✓	✓		✓	✓		✓		✓	✓		✓	✓					✓	✓	12
Maximum demand/load shedding																						0
Over-sized motor replacement													✓									1
Variable speed pumps/motors																	✓					1
Motor speed controls																						0
Low energy lighting						✓	✓		✓		✓	✓	✓	✓	✓	✓	✓		✓			11
MISCELLANEOUS																						
Process control system																				✓		1
Air mains isolation															✓							1
Compressor controls																						0
New compressor(s)																						0
New keg line																						0
Use of well water																						0

Figure 3.2 DISTRIBUTION OF REDUCTIONS IN SPECIFIC ENERGY ACHIEVED OVER 2 YEARS - MEDIUM SUB-SECTOR



3.3.3 Innovation versus adaption of existing techniques:

None of the investments could truly be labelled innovations in the sense of first commercial application. One site, however, was experimenting with a bio-gas producing effluent digestor. To date this is producing gas successfully and after an evaluation process the site is likely to invest in a full sized plant. The bio-gas produced will either be used in boilers or gas engines driving refrigeration compressors, currently driven by electric motors. If the plant goes ahead this will be the first application of this technique in the UK brewing industry. An application in a dairy does exist (Plant and Works Engineering, August 1984) and a similar system is being evaluated in a distilling company (see Section 3). One site was evaluating a relatively new technique, turbulators in boilers. This site had multiple boilers and so experimentation in a single boiler was possible. Another site was experimenting with a reduction in boiling time, a process change rather than an investment. As the product characteristics are dependent on many factors, including possibly boiling time, this is a radical change that many breweries have been reluctant to make. Many sites would rule it out on quality grounds, whether or not scientific proof of the effects of a change were available. For meaningful comparison full scale production tests are necessary, and the threat of possible lost production due to experimentation with the process ia a major disincentive. Brewing "recipes" have some of the characteristics of paradigms.

One site invested in an integrated copper vapour heat recovery, dearator, condensate return and economiser project. This required the development of a sophisticated microprocessor-based control system. The integration of disparate heat flows, all with different qualities, quantities and timings, required considerable development work. Even after commissioning, the system required considerable tuning to make it run in the most efficient manner.

3.3.4 The energy conservation techniques used:

Table 3.4 summarises the major techniques requiring capital investment used by the sample of medium breweries. Low, or zero cost operational changes are not shown.

3.4 Large Breweries (greater than 1,000,000 hl/a)

3.4.1 Reported reductions in specific energy:

In a sample of nine sites the reported reductions in specific energy ranged from 2 - 20% over the last two years, and from 6 - 30% over the last five years (reported for six sites). The distribution of reported reductions over two years is shown in Figure 3.3.

3.4.2 Retro-fit versus investment in new plant:

The reported investments were predominantly from retro-fit investments rather than investments in new plant. One site had invested in a new brew-house which was fully integrated to maximise heat recovery. This was not however justified on energy grounds. The opportunity to include energy saving features afforded by the decision to build a new brew-house was not lost. Unfortunately such opportunities are not always taken (see Section 3).

3.4.3 Innovation versus adaption of existing equipment:

All the investments reported were adaptations of existing techniques. One site seriously evaluated copper vapour heat recovery (CVHR) using mechanical vapour recompression (MVR) but rejected it on absolute capital cost grounds (see Section 3). If this project had gone ahead it would have been a true innovation.

Table 3.4a TECHNIQUES USED IN THE MEDIUM BREWERY SUB-SECTOR

Technique	030	164	016	019	100	093	064	059	003	072	050	Totals
	Company Number											
HEAT RECOVERY TECHNIQUES												
Additional heat recovery from wort cooling		✓		✓			✓			✓		4
Cask/keg line heat recovery		✓	✓		✓			✓		✓	✓	6
Additional tanks for wort heat recovery												0
Copper Vapour Heat Recovery (CVHR)		✓	✓					✓		✓		4
Extra regeneration on pasteuriser							✓					1
Effluent heat recovery												0
Boiler blow down heat recovery					✓	✓	✓	✓		✓		5
Flash steam heat recovery		✓					✓					2
Condensate recovery				✓				✓				2
Economiser							✓			✓		2
BOILER RELATED TECHNIQUES												
New boiler								✓				1
Back end dampers												0
Oxygen trim			✓						✓			2
Fuel switching			✓		✓	✓	✓					4
Pipe lagging								✓				1
Additional steam metering												0

Table 3.4b TECHNIQUES USED IN THE MEDIUM BREWERY SUB-SECTOR

Technique	Company Number											
	030	164	016	019	100	093	064	059	003	072	052	Totals
BUILDING AND SPACE HEATING TECHNIQUES												
Building insulation								✓		✓		2
Controls for space heating							✓	✓		✓	✓	4
ELECTRICAL TECHNIQUES												
Power factor correction		✓		✓			✓		✓	✓		5
Maximum demand/load shedding								✓		✓		2
Over-sized motor replacement						✓		✓				2
Variable speed pumps/motors												0
Motor speed controls										✓		1
Low energy lighting	✓	✓	✓		✓	✓		✓	✓	✓		8
MISCELLANEOUS												
Process control system												0
Air mains isolation										✓		1
Compressor controls												0
New compressor(s)										✓		1
New keg line				✓								1
Use of well water										✓		1

Table 3.5a TECHNIQUES USED IN THE LARGE BREWERY SUB-SECTOR

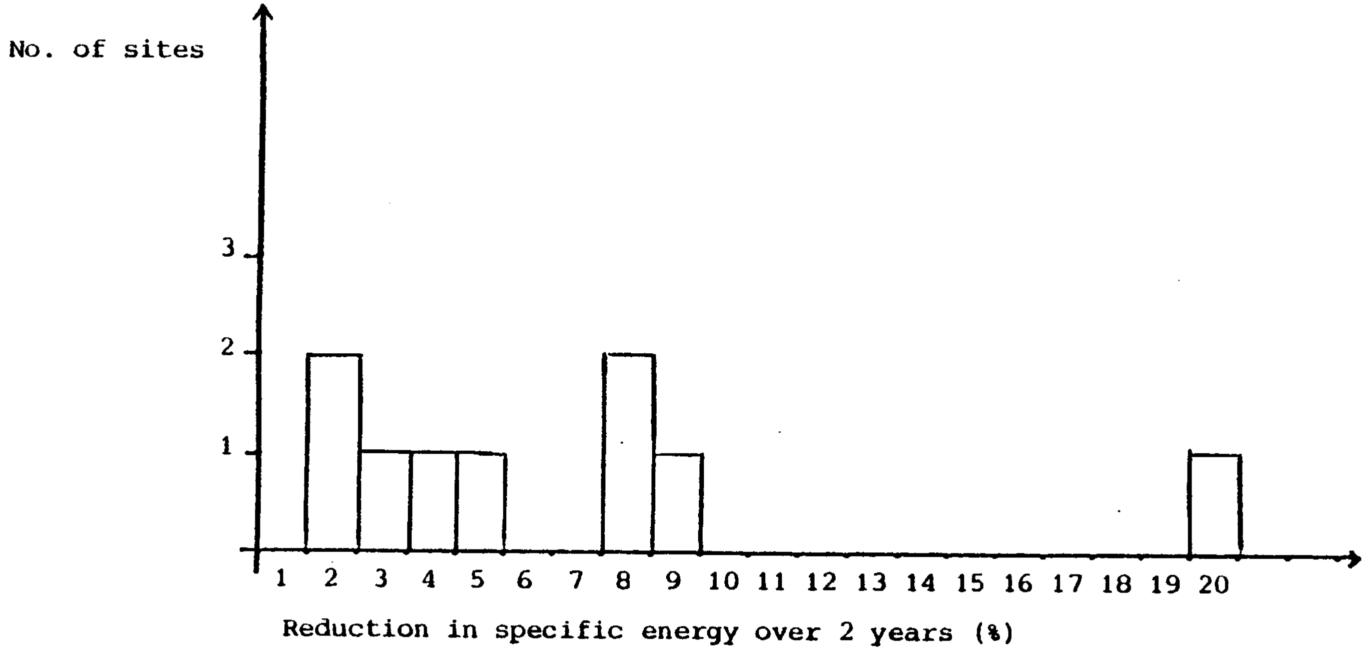
Technique	Company Number									
	066	136	031	151	135	166	005	007	062	Totals
HEAT RECOVERY TECHNIQUES										
Additional heat recovery from wort cooling	✓		✓		✓	✓	✓		✓	6
Cask/keg line heat recovery	(1)		✓	✓						2
Additional tanks for wort heat recovery										0
Copper Vapour Heat Recovery (CVHR)	✓		2			3			✓	4
Extra regeneration on pasteuriser										0
Effluent heat recovery										0
Boiler blow down heat recovery						✓				1
Flash steam heat recovery										0
Condensate recovery										0
Economiser	✓					✓	✓	✓		4
BOILER RELATED TECHNIQUES										
New boiler										0
Back end dampers									✓	1
Oxygen trim									✓	1
Fuel switching					✓	✓		4		3
Pipe lagging										0
Additional steam metering									✓	1

Table 3.5b TECHNIQUES USED IN THE LARGE BREWERY SUB-SECTOR

	Company Number									
Technique	066	136	031	151	135	166	005	007	062	Totals
BUILDING AND SPACE HEATING TECHNIQUES										
Building insulation	✓					✓		✓	✓	4
Controls for space heating						✓				1
ELECTRICAL TECHNIQUES										
Power factor correction	✓	✓		✓	✓	✓	✓	✓		7
Maximum demand/load shedding				✓						1
Over-sized motor replacement							✓			1
Variable speed pumps/motors										0
Motor speed controllers										0
Low energy lighting	✓	✓	✓	✓	✓	✓	✓	✓	✓	9
MISCELLANEOUS										
Process control system										0
Air mains isolation										0
Compressor controls										0
New compressor(s)	✓									1
New keg line										0
Use of well water						✓				1

Notes:
1. Study under progress
2. Installed 1954, improvements under consideration
3. Control improvements added later
4. Dual fuel operations.

Figure 3.3 DISTRIBUTION OF REDUCTION IN SPECIFIC ENERGY OVER 2 YEARS - LARGE BREWERIES



3.4.4 The energy conservation techniques used:

The major techniques used are shown in Table 3.5. Low, or zero cost operational changes are not shown.

3.5 Discussion and Summary

3.5.1 Reduction in specific energy achieved:

In each size category there was a wide range of reported reductions in specific energy over both two and five years. In the small brewery sub-sector 19 sites had made some energy saving investments but only 12 reported a reduction in specific energy over the last two years. This probably reflects the absence of an energy management information system. The small sites that were interviewed, 4 in all, did not produce specific energy figures. In the larger brewery sub-sectors 19 out of 20 sites reported a reduction in specific energy, indicating the existence of information systems incorporating specific energy figures.

The wide range of reductions in specific energy achieved could, as we will discuss in Section 2, be due to differences in opportunities as well as differences in management effectiveness. The ranges reported in the three sectors are broadly similar, 2 - 25% in the small sub-sector; 2 - 40% in the medium sub-sector (2 - 28% excluding the 40% figure) and 2 - 20% in the large sub-sector (all over the last two years). The corresponding figures for the reported reductions over the last five years are 5 - 50%, 10 - 60% and 6 - 30%. No one sector achieved noticeably higher results although as has already been noted, more firms in the small sub-sector did not report a figure or reported zero reduction.

Only 16 sites reported a reduction in specific energy over the last five years. This probably reflects the absence of information and the development of energy management over the period.

Most sites interviewed had made some energy saving investments prior to 1979 but did not have energy management information systems. Two large brewery groups had started their energy "campaigns" in 1979, <u>after</u> the second oil crisis.

3.5.2 Investment criteria:

Of the 15 sites interviewed, 12 had broadly similar investment criteria. In 11 cases the criteria for cost saving projects was a two-year simple pre-tax payback. In one case a three-year simple pre-tax payback was acceptable. One small site had no explicit criteria and projects with very short paybacks had been rejected while some projects with longer paybacks had been accepted with no apparent reason. Two other small sites did not have set criteria because they felt they could not afford retro-fitted, cost saving measures. Any energy saving in these cases would have to come about through investment in new plant as part of the normal capital replacement cycle.

3.5.3 Retro-fitting versus Investment in new equipment:

As described above, most of the energy saving investments encountered were retro-fitted to existing plant. Where investment in new plant, justified on non-energy grounds, was made and energy saving features incorporated, the resulting reductions in specific energy were significant. Incorporation of energy saving features into new plant were observed in all three size categories, as was failure to do so.

The design of the questionnaire will have missed investments in new plant as it concentrated on techniques designed solely for energy conservation rather than investments resulting in energy savings. Differentiation of the savings resulting from retrofit and new equipment would require an in-depth study of individual plants and has not been attempted here.

The purchasing of major capital equipment such as new keg washing lines is a slow, group decision making process. Such decisions are relatively infrequent and have a lasting effect on energy efficiency. The problems of integrating energy saving features caused by organisational design and other factors will be discussed in Chapter 13 using examples from interviewed companies. A single shot interview can only capture one moment in the decision process and the history of that process from one viewpoint. Further research into this area may profitably use the "snowballing"[1] technique in which different actors in the process are interviewed to form a composite view

The energy savings achieved by investment in new plant suggest that in the long run, larger savings will result from new plant investments than through retro-fitting. This is particularly true in the small brewery sub-sector where plant is often very old and finances are not available for retro-fit measures. Three small breweries reduced their specific energy by between 25 - 50% over the last 5 years by incorporating energy saving features into new plant. The fact that this potential exists does not necessarily mean it will be exploited, as shown by the examples in Section 3.

3.5.4 Innovation versus Adaption of existing equipment:

The majority of investments in all sub-sectors were adaptations of existing equipment rather than true innovations. This supports the views of Johnson (1976) and Fores (1977) that most technical change is incremental in nature. As will be discussed in Chapter , most of the literature has been concerned with large scale, technically spectacular innovations whereas there is substantial evidence to suggest that incremental technical change is economically more important.

Innovations have occurred, or been seriously considered but rejected on economic grounds, in all three sub-sectors. No conclusions about differing propensities to innovate between the sub-sectors can be made. It can only be said that innovation in the small brewery sub-sector shows that the capacity to innovate is not confined to large firms.

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[1] See Moriaty and Bateson, 1982.

Several examples of firms experimenting by applying techniques to a proportion of their capacity have been found. Examples include keg washing line heat recovery, an O_2 trim system installed on one of three boilers, bio-gas effluent digestor, and insulation spheres for one of four hot liquor tanks. Rogers (1962) and Baker (1983) state that the extent to which a new product can be tried out before making a full commitment is a major factor influencing attitudes towards it. The evidence of this survey supports these views. The examples found, with the exception of the bio-gas effluent digestor, and the keg washing line heat recovery had been applied in other applications, but were both relatively new to the market (introduced within the last five years) and novel to the company making the investment.

Experimentation reduces uncertainties over the actual savings that can be achieved and hence contributes to the ultimate adoption/rejection decision. It should be noted that in many cases, experimentation is not possible as energy saving techniques have to be applied to the whole of the production capacity.

3.5.5 The energy conservation techniques used:

Overall, the three most frequently used techniques were in order, high efficiency lighting, wort cooling heat recovery, and power factor correction (a cost saving rather than an energy saving measure). These occurred 28, 26 and 24 times respectively in the sample of 49 sites, while the next most frequent technique, keg line heat recovery, was only reported 12 times.

The overall three most frequently used techniques were also the three most frequently used (in different orders) in both the small and large brewery sub-sectors. High efficiency lighting and power factor correction were in the top three in the medium sub-sector while wort cooling heat recovery was equal fifth. These similarities suggest these techniques may have characteristics that make them more likely to be adopted than some other techniques.

High efficiency lighting comes in many forms, each with different applications. Most of the lighting investments found in this research were replacements of fluorescent tubes in high-bay factory areas by high pressure mercury or sodium lamps. Such investments often give payback periods of two years or less, and the financial justification for one example is shown in Chapter 12.

Conversion to high efficiency lighting can be phased, an area at a time, thus reducing absolute capital outlay. The actual work can be carried out quickly with little or no disruption to production and the site specific adaptation costs are low compared to the overall cost. Another point in its favour is that savings can easily and reliably be calculated. This is in contrast to heat recovery projects where savings figures often have a high degree of uncertainty, both before and after the investment.

Additional wort cooling heat recovery consists in most cases of simply adding additional plates to an already existing plate heat exchanger. As the frames of these exchangers are designed to take additional plates down time and adaptation costs are minimal. The technique is simply an extension (literally) of existing hardware. In one case discovered, it was not viable because of insufficient space for extra tankage, needed to take the extra volume of pre-heated liquor.

Power factor correction is a well proven technique that is easily applied to existing hardware. The savings available are easily proven and the overall capital cost is low, usually of the order of £1,000 - £5,000. As electrical loads change, the power factor varies and it should be checked after any addition or removal of electricity consuming plant. Thus, power factor correction could be a regular investment.

Less techniques were used in the small sub-sector than the larger sub-sectors. This may reflect fewer opportunities or less ability or willingness to use different techniques. No oxygen trim systems had been used in the small sub-sector. This is despite the fact that oxygen trim systems are applicable to most sizes of industrial boiler. As these are a relatively new technique it may reflect that small sites are slower to adopt innovations. Space heating controls are also absent in the smaller sub-sector. Small sites spend less on space heating and controls may not be viable. On the other hand, there is probably less knowledge about controls, a technology that is rapidly advancing as microelectronics are replacing electromechanical devices.

The absence of economisers in the small sub-sector can be explained because they can only be viably applied to boilers above a certain size. Furthermore, specific site constraints, notably physical space, are often tighter in smaller sites.

Maximum demand controls may be less viable in smaller sites because there are less loads than can be shed without affecting production.

Eight sites had invested in some form of copper vapour heat recovery (CVHR) since 1974, while two had installed systems prior to 1974. One site had evaluated a novel CVHR system using mechanical vapour recompression (MVR) that would have been a true innovation. It was however, rejected because of capital shortage. One of the most recent (1983) CVHR installations was part of a Demonstration Project.

Although CVHR has been widely used in the industry it still suffers from a number of technical problems, notably fouling of heat exchangers by hop oils. Another factor inhibiting the further use of CVHR is that, without the use of MVR, the product is hot water and not steam. In sites with an established energy conservation programme, demand for additional hot water is likely to be limited. The site with the Demonstration Project CVHR invested without knowing what the water would be used for.

The approach advocated by all heat recovery system designers (Addy, 1983; Brookes and Reay, 1982; Missions, 1981) is to find a use for the recovered heat first. If no use can be found the investment will have been wasted.

Keg or cask washing line heat recovery, the subject of a Demonstration Project, had been used by eleven sites since 1974. One site reported using the technique before 1974, one site was evaluating it and three had evaluated but rejected it. The reason for rejection in all three cases was insufficient effluent to make heat recovery economically viable.

The Demonstration Project started in 1978, casting doubts on the Scheme's claim to promote novel projects.[1] This particular project achieved a five year payback, insufficient to attract investment capital for retro-fit projects in most companies.

An investment appraisal for this scheme is shown in Chapter 12. The company claimed to be able to reduce the capital cost from £50,000 to £15,000 on subsequent projects and at this cost, ceteris paribus, the investment is both attractive and robust.

Seven sites reviewed and rejected conversion to coal firing, one site was currently evaluating it and one investing. Several sites interviewed reported that although the basic equipment such as new boilers or burners could be made to show an acceptable return, the total system including feeder equipment and silos could not under reasonable assumptions

Another barrier to coal conversion was lack of space. This factor was made worse by the so-called "Scargill factor" which deems storage volume should be two to three times the otherwise optimal size. Obviously the current (summer 1984) miners' strike has further reduced confidence in the security of supply. Another frequently heard objection was the "dirtiness" of coal, even though suppliers of equipment and recent installations convincingly show this objection is no longer valid.

Cheshire and Robson (1983) report that the majority of users in their general industrial survey had not yet given serious attention to assessments of fuel substitution, especially to coal if they were not already using it. This finding is supported by others, e.g. G F Ray and J Morel, and a recent (confidential) survey undertaken by the Chemical Industries Association.

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[1] See Fawkes (1984), R & D Management, July 1984.

The sample in this research supports these findings within the brewing sector. Failure to seriously evaluate fuel substitution probably reflects general failures of energy management.

Three sites had invested in oxygen trim control systems for boilers. This relatively new technique (at least for ordinary industrial boilers) has wide application. The technique is discussed in Section 3. The investment is both attractive and robust. In time this technique can be expected to diffuse widely.

One site was planning to invest in a combined heat and power (CHP) plant. At two other sites where the possibility was raised, the opinion was that CHP was too complex to consider. A full financial analysis and discussion concerning CHP is to be found in Chapter 11.

Three sites reported evaluating some form of effluent heat recovery project. A major barrier at one site interviewed was the lack of demand for additional hot water.

The techniques used are summarised in Table 3.6.

Table 3.6a TECHNIQUES USED IN THE BREWING INDUSTRY - SUMMARY

	Company Number																				
Technique	045	155	104	156	105	109	022	111	044	133	077	199	008	142	143	150	039	126	043	061	009
HEAT RECOVERY TECHNIQUES																					
Additional heat recovery from wort cooling	✓	✓	✓	✓		✓	✓			✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
Cask/keg line heat recovery	✓											✓		✓						✓	
Additional tanks for wort recovery					✓																
Copper Vapour Heat Recovery (CVHR)																			✓		
Extra regeneration on pasteuriser																					
Effluent heat recovery																					
Boiler blow down heat recovery	✓												✓								
Flash steam heat recovery																					
Condensate recovery																			✓		✓
Economiser																					
BOILER RELATED TECHNIQUES																					
New Boiler													✓								
Back end dampers																					
Oxygen trim																					
Fuel switching			✓		✓							✓			✓			✓		✓	
Pipe lagging								✓													✓
Additional steam metering																					✓

Table 3.6b TECHNIQUES USED IN THE BREWING INDUSTRY - SUMMARY

Technique	Company Number																				
	030	164	016	019	100	093	064	059	003	072	052	066	136	031	151	135	166	005	007	062	Totals
HEAT RECOVERY TECHNIQUES																					
Additional heat recovery from wort cooling		✓		✓			✓			✓		✓		✓		✓	✓	✓		✓	26
Cask/keg line heat recovery		✓	✓		✓			✓		✓	✓			✓	✓						12
Additional tanks for wort heat recovery																					1
Copper Vapour Heat Recovery (CVHR)		✓	✓					✓		✓		✓		2			3			✓	8
Extra regeneration on pasteuriser							✓														1
Effluent heat recovery																					0
Boiler blow down heat recovery					✓	✓	✓	✓		✓							✓				8
Flash steam heat recovery		✓					✓														2
Condensate recovery				✓				✓													4
Economiser							✓			✓		✓					✓	✓	✓		6
BOILER RELATED TECHNIQUES																					
New boiler									✓												2
Back end dampers																					0
Oxygen trim			✓							✓										✓	3
Fuel switching			✓		✓	✓	✓													✓	11
Pipe lagging								✓								✓	✓		4		6
Additional steam metering																					2

Table 3.6c TECHNIQUES USED IN THE BREWING INDUSTRY - SUMMARY

Technique	Company Number																				
	045	155	104	156	105	109	022	111	044	133	077	199	008	142	143	150	039	126	043	061	009
BUILDING AND SPACE HEATING TECHNIQUES																					
Building insulation												✓									
Controls for space heating																					
ELECTRICAL TECHNIQUES																					
Power factor correction	✓		✓	✓		✓	✓		✓		✓	✓		✓	✓					✓	✓
Maximum demand/load shedding																					
Over-sized motor replacement													✓								
Variable speed pumps/motors																	✓				
Motor speed controls																					
Low energy lighting						✓	✓		✓		✓	✓	✓	✓	✓	✓	✓		✓		
MISCELLANEOUS																					
Process control system																				✓	
Air mains isolation														✓							
Compressor controls																					
New compressor(s)																					
New keg line																					
Use of well water																					

Table 3.6d TECHNIQUES USED IN THE BREWING INDUSTRY - SUMMARY

Technique	Company Number 030	164	016	019	100	093	064	059	003	072	052	066	136	031	151	135	166	005	007	062	Totals
BUILDING AND SPACE HEATING TECHNIQUES																					
Building insulation								✓		✓		✓					✓		✓	✓	7
Controls for space heating							✓	✓		✓	✓						✓				5
ELECTRICAL TECHNIQUES																					
Power factor correction		✓		✓			✓		✓	✓			✓	✓		✓	✓	✓	✓	✓	24
Maximum demand/load shedding								✓		✓						✓					3
Over-sized motor replacement						✓		✓											✓		4
Variable speed pumps/motors																					1
Motor speed controls										✓											1
Low energy lighting	✓	✓	✓		✓	✓		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	28
MISCELLANEOUS																					
Process control system																					1
Air mains isolation										✓											2
Compressor controls																					0
New compressor(s)										✓			✓								2
New keg line				✓																	1
Use of well water										✓							✓				2

3.6 Observed characteristics of energy management in breweries

The observed characteristics of energy management information and control systems in the brewery sector are summarised in Table 3.7. The breweries sampled can be divided into the following six classifications according to their observed characteristics:

Type	Characteristics
I	Monitoring at greater than monthly intervals; no targetting.
II	Monitoring at greater than monthly intervals; targetting.
III	Monitoring at monthly or more frequent intervals; no targetting.
IV	Monitoring at monthly or more frequent intervals; targetting.
V	Monitoring at monthly or more frequent intervals; use of cost centres; no targetting.
VI	Monitoring at monthly or more frequent intervals; use of cost centres; targetting.

The numbers in each group are shown in Table 4.1.

Type I consists entirely of small sites (i.e. ⩽ 299,000 hl/a capacity), as do Type II and Type III. Type IV consists of two small sites, five medium (300,000 to 1,000,000 hl/a) and four large sites (> 1,000,000 hl/a). Site 003 is medium in size while Type VI consists of one small site, four medium sites and six large sites.

Table 3.7a OBSERVED CHARACTERISTICS OF ENERGY MANAGEMENT SYSTEMS IN THE BREWING SECTOR

Size (000s hl/a)	Company Number	Full-time energy manager	Monitoring: daily	Monitoring: weekly	Monitoring: monthly	Monitoring: longer	Area metering	Cost centres	Overall targets	Area/cost centre targets	Separate budget	% reduction in energy over 2 years	% reduction in energy over 5 years	Classification
0 - 99	109											5		III
0 - 99	022					✓			✓			2	3	II
1000 - 1499	066				✓		✓	✓	✓	✓		3.2	30.1	VI
1000 - 1499	136				✓		✓		✓	✓		2		VI
500 - 999	164		✓				✓	✓	✓	✓		16		VI
0 - 99	067											0		I
0 - 99	111					✓						0		I
100 - 199	044											0		I
0 - 99	103				✓							0		III
1500+	151			✓			✓					2	4	IV

Table 3.7b

Size (000s hl/a)	Company Number	Full time energy manager	Monitoring: daily	Monitoring: weekly	Monitoring: monthly	Monitoring: longer	Area metering	Cost centres	Overall targets	Area/cost centre targets	Separate budgets	% reduction in energy over 2 years	% reduction in energy over 5 years	Classification
0 - 99	133				✓							0		I
100 - 199	077				✓							3		I[1]
1000 - 1499	135				✓		✓	✓	✓			5	20	VI
100 - 199	143				✓							2		III
0 - 99	132				✓							0	0	III
1500+	166	✓			✓		✓	✓	✓	✓		4.1	6.6	VI
1500+	005	✓		✓					✓			20	30	IV
0 - 9	150			✓								0	0	III
500 - 999	100			✓			✓	✓	✓	✓		40	60	VI
0 - 99	126					✓			✓			8		II

Notes: (1) Not yet

Table 3.7c

Size (000s hl/a)	Company Number	Full time energy manager	Monitoring: daily	Monitoring: weekly	Monitoring: monthly	Monitoring: longer	Area metering	Cost centres	Overall targets	Area/cost centre targets	Separate budget	Reduction in energy over the last 2 years	Reduction in energy over the last 5 years	Classification
100 - 199	038											0		I
100 - 199	104				✓							0		III
0 - 99	156											0		I
0 - 99	105					✓						0		I
0 - 99	134			✓					✓			0		IV
100 - 199	033				✓							5		III[1]
0 - 99	008				✓							4	7	III
100 - 199	142		✓				✓	✓	✓	✓				VI
100 - 199	061				✓		✓		✓			5	5	IV
500 - 999	019			✓			✓	✓	✓			7		IV

Notes: (1) Estimated e/o - difficult to assess due to product changes

Table 3.7d

Size (000s hl/a)	Company Number	Full time energy manager	Monitoring: daily	Monitoring: weekly	Monitoring: monthly	Monitoring: longer	Area metering	Cost centres	Overall targets	Area/cost centre targets	Separate budgets	Reduction in energy over the last 2 years	Reduction in energy over the last 5 years	Classification
300 - 399	093			✓					✓			18		IV
0 - 99	079				✓							25		III
0 - 99	009				✓							10		III
500 - 999	059				✓		✓	✓	✓		✓	10		VI
100 - 199	039					✓			✓			2		II
300 - 399	003				✓		✓	✓			✓	2	10	V
1500+	007				✓		✓					8	30	IV
0 - 99	043				✓							20	50	III
1500+	031		✓				✓	✓	✓	✓		8		VI

Table 3.8 CLASSIFICATION OF BREWERY SITES ACCORDING TO OBSERVED ENERGY MANAGEMENT CHARACTERISTICS

Classification	Sites	No. of Sites
I	045, 155, 023, 133, 077, 067, 111, 044, 038, 156, 105	11
II	022, 126, 039	3
III	071, 143, 132, 043, 150, 109, 103, 104, 033, 008, 079, 009	12
IV	052, 072, 064, 016, 005, 151, 134, 019, 093, 007, 061	11
V	003	1
VI	030, 062, 135, 166, 100, 066, 136, 164, 142, 054, 031	11
	TOTAL	49

Of the fourteen companies that were interviewed, all but two had an energy management system in which explicit responsibility for energy management lies with the engineering staff. This was also common in the other sectors (see Chapter 5). Some of the problems with this organisational form are described in Section 3. Four of the sites, classified as Type IV, were at various stages of moving towards a system in which energy would be metered in cost centres and responsibility for energy conservation handed over to cost centre line managers. These sites all had well developed energy management systems and felt that without such a shift they had encountered the limit to cost effective investment. It was felt that additional savings would result from improved housekeeping and from ideas motivated by making line managers explicitly responsible for meeting targets in that area. It was also felt that this move would make the line managers more motivated to assist engineering staff in conservation efforts, to date problems had been encountered in getting co-operation. For examples see Section 3.

3.7 The Relationships between observed energy management characteristics and reduction in specific energy in the brewing sector

Non-parametric statistical tests have been used to explore the relationships between observed energy management characteristics and reduction in specific energy in the brewing sector. The results of the tests are shown in Appendices 2 to 16 and discussed below.

3.7.1 Size and energy management grouping

It is not possible to test whether site size is significant in explaining energy management grouping because of the low numbers in each group. It is, however, possible to test whether size is significant in explaining the use of targetting and the use of monitoring at monthly, or less, intervals. The tests in Appendices 2 and 3 show that size is significant in explaining the use of both targetting and monthly monitoring. It should not be inferred from these results that monitoring and targetting are not possible in small sites, the presence of one small site in Type VI shows what can be done; only that to date these techniques have not been widely used in this sub-sector.

3.7.2 Use of monitoring and reduction in specific energy

The tests shown in Appendices 4 and 5 show that the use of monitoring at monthly or more frequent intervals is significant in explaining both whether a site achieves any reduction in specific energy and whether it achieves a larger than median reduction. Appendix 6 shows that the use of monitoring at monthly or more frequent intervals is significant in explaining a difference in means between the two samples.

3.7.3 Use of targetting and reduction in specific energy

The tests shown in Appendices 7 and 8 show that the use of targetting is significant in explaining both whether a site achieves any reduction in specific energy and whether it achieves a greater than median reduction in specific energy. Appendix 9 shows that there is a significant difference between the mean reductions in specific energy achieved by sites with targetting and those without.

As there is considerable overlap between those sites with monitoring and those with targetting it is useful to test the effect of targetting alone. Appendix 10 shows that targetting alone is not significant in explaining a reduction in specific energy. Appendix 11 shows that the use of targetting alone is not significant in explaining a higher than median reduction in specific energy. Appendix 12 shows that the use of targetting alone is not significant in explaining the difference in means between the two samples.

Thus the evidence for the use of targetting alone is contradictory. It is significant in explaining a higher than median reduction in specific energy but not in achieving any reduction or in explaining the difference of means of the two samples. Targetting alone may not be a significant activity compared to monitoring. Success, as measured here, may be due to other, untested variables, or a combination of those tested.

3.7.4 Use of cost centres and reduction in specific energy

The tests shown in Appendices 13 and 14 show that the use of cost centres is significant in explaining whether a site achieves any reduction in specific energy but not significant in explaining a higher than median reduction in specific energy. Appendix 15 shows that there is a significant difference between the mean reductions in specific energy achieved by sites with cost centres and those without.

3.7.5 Energy management grouping and achieving a higher than median reduction in specific energy

Appendix 16 shows that the energy management grouping is significant in explaining a higher than median reduction in specific energy.

3.7.6 Full-time Energy Manager

Only two sites had a full-time energy manager. One achieved a reduction in specific energy over two years of 20% and the other 4%. A full-time energy manager is not significant in explaining achieving a reduction in specific energy or achieving a higher than median reduction.

3.8 Summary

This Chapter has examined the reductions in specific energy achieved in the brewing sector, the techniques used and the observed characteristics of energy management systems. We have seen that a wide range of reductions in specific energy were recorded over both the last two years and the last five years. In this Chapter reduction in specific energy has been used as an indicator of success but it will be shown in Section 3 that it should not in a simple form be used as a measure of management effectiveness. Thirteen out of 49 sites reported no investments in energy conservation or no reduction in specific energy.

A range of energy conservation techniques were used in this sector. The overall three most common techniques were frequently used in all three sub-sectors. They have characteristics that make them easy to adapt to different sites. This question of adaptability will be explored in Chapter 7. The majority of the techniques reported were retro-fit measures and adaptations of existing equipment rather than innovations. Innovators, or potential innovators, were found in all three sub-sectors.

Sites were categorised into groups according to observed characteristics of their energy management systems, namely frequency of monitoring, the use of targets and the use of cost centres. Monitoring at monthly or more frequent intervals was found to be significant in explaining both achieving any reduction in specific energy over the last two years and achieving a larger than median reduction. There is considerable overlap between those sites that monitor and those that target. Targetting alone is not significant in explaining a reduction in specific energy but is in explaining a larger than median reduction. Cost centres were found to be significant in explaining a reduction in specific energy but not a higher than median reduction. There is, however, a significant difference between the mean reductions of sites with and without cost centres.

Because of the inter-relatedness of the characteristics it is difficult to disentangle the effects of any single factor. The reductions in specific energy may be due to groups of factors, or other unmeasured factors.

Chapter Four

ENERGY SAVING ACHIEVEMENTS IN THE DAIRY SECTOR

4.1 Introduction

This Chapter examines the reductions in specific energy, the techniques used and the observed characteristics of energy management systems in the dairy sector. The sample of eight companies, covering twelve sites, were all interviewed.

4.2 Reduction in specific energy

In this sector it was difficult to obtain figures for the reduction in specific energy over any consistent period. The reported figures varied widely. One site reported a reduction in electricity usage of 35% and a reduction in oil usage of 25% over one year for broadly similar output and product mix. Another, similar sized site, reported savings of "only" 10% over five years. The reported reductions in specific energy are shown in Table 4.1 for each site.

Table 4.1 REDUCTIONS IN SPECIFIC ENERGY ACHIEVED BY SAMPLED DAIRY SITES

Site	Reduction in Specific energy	Time period Reduction achieved over	Notes
D001A	)		
D001B	) 10%	5 years	Estimated
D001C	)		
D002A	5%)		
D002B	15%)	2 years	Estimated
D002C	20%)		
D003	0%	5 years	No investments
D004	15%	5 years	-
D005	20%	5 years	-
D006	0%	5 years	No investments
D007	5%	5 years	Estimated
D008	35% electricity 25% fuel	1 year	-

NOTES: "Estimated" means estimated by company employees in the absence of detailed information.

4.3 Investment Criteria

The investment criteria of the sites that had made investments in energy conservation were broadly similar with a two or three year simple payback being required. One company (D001) required an eighteen month payback period. The two sites that had made no investments said they could not afford cost saving retro-fit measures and so had not set criteria.

4.4 The energy conservation techniques used or considered

Table 4.2 lists the techniques used or considered in the twelve sites interviewed. Condensate recovery, pipe insulation, oxygen trim control, back end dampers, low energy lighting and power factor correction were all used in two sites. All other techniques had only been used in one site to date. If current plans in the three sites of D002 go ahead, additional oxygen trim systems, metering and boiler instrumentation will soon be installed.

Economisers had been considered or were under consideration in four sites. In one of these, economisers had not been economically viable because of a shortage of space in the boiler houses. Obviously it would have been technically possible to rebuild the boiler house but the cost would have been prohibitive. In the other site an economiser was not viable because of a lack of demand for additional hot water.

Improving condensate recovery and pipe insulation are undramatic but useful technical changes that could probably be more widely practiced. The same applies to back end dampers for boilers.

The only investment in fuel switching was from oil to gas. This was made after a switch to coal was considered but rejected as being uneconomic. Another site evaluated a switch to coal firing and found it to offer an acceptable rate of return. If, however, the cost of lost production during the conversion was included, the project was not viable. This company thought they would opt for coal firing in a greenfield site but a retro-fit installation would not be possible.

Table 4.2 INVESTMENTS MADE IN THE DAIRY SECTOR

	SITES												
Techniques	DOO1A	DOO1B	DOO1C	DOO2A	DOO2B	DOO2C	DOO3	DOO4	DOO5	DOO6	DOO7	DOO8	Totals
Condensate recovery		✓										✓	2
Economiser				x	x	x		x					
Pipe insulation	✓		✓										2
Shutting down evaporator		✓											1
Oxygen trim control			x	x	x		✓					✓	2
Metering			x	x	x			✓					1
Boiler instrumentation			x	x	x								
Absorption refrigeration					x								
Evaporator modifications					x								
Mechanical vapour recomp.					x								
Back end dampers							✓					✓	2
Low energy lighting							✓				x	✓	2
Heat recovery in new office							✓						1
Load shedding								x					
Motor speed controllers								x				✓	1
Boiler blow down with h.r.	x	x							✓				1
Insulation of oil tanks									✓				1
Power factor correction									✓			✓	2
Reuse of effluent from evap.									✓				1
Fuel switching		x							x	✓			1
Heat recovery from pasteuriser										x			
Heat pump for process h.r.								x			✓		1
Controls for c.i.p. system												✓	1
Smaller compressors												✓	1
Ambient air cooling												✓	1
New effluent plant												x	
Refrigeration controls												x	
Feed tank insulation	x	x											
Recuperation on spray driers		x						x					

NOTES: ✓ = invested in

x = considered/under consideration

h.r. = heat recovery

c.i.p. = cleaning in places

Most of the other investments were small improvements with the exception of two, heat recovery from a spray drier, and use of a heat pump for heat and water recovery. The latter represents a true innovation, one that has only been copied once to date (trade sources). One other site had reviewed several low temperature process heat recovery options including a heat pump but found the paybacks unacceptably long, eight years for the heat pump system. The installed heat pump system has had numerous technical problems and had to be modified after installation. On current performance it will have a payback period of five to six years including water savings (D Boss, personal communication). Heat pump economics are explored further in Section .

The heat recovery from a spray drier project is an integrated system which uses recovered heat from both the spray drier and the air heater flue, to preheat ambient air prior to passage through the air heater. A four year payback was considered acceptable on this project, as opposed to the two year criterion normally required, because of the very large savings to be gained.

4.5 Innovation versus Adaption of existing equipment

All the investments, except the heat pump heat recovery system, were adaptations of existing equipment and not innovations. The heat pump system was installed under the aegis of the Energy Conservation Demonstration Projects Scheme.

4.6 Observed characteristics of energy management in the dairy sector

The dairies sampled can be divided into three categories, the characteristics of which are as follows:

- I No energy monitoring.
- II Monitoring on a plant-wide basis.
- III Monitoring on a cost-centre basis.

The numbers found in each group are summarised in Table 4.3.

Table 4.3 CLASSIFICATION OF DAIRY SITES ACCORDING TO ENERGY MANAGEMENT GROUPING

Type	Sites	Number
I	D003, D006	2
II	D001A, D001B, D001C, D002A, D002B, D002C, D005(1), D007(2)	8
III	D004, D008	2
	TOTAL	12

NOTES: (1) In transition towards Type III.
(2) No action taken on meter readings.

Group I is made up of smaller sites. Little or no conservation investment has occurred in this sub-sector. The remaining sites cover a range of sizes, with total energy bills between £238,000 and £2,110,000 per annum at current prices. These sites exhibit a range of investments made. One of the two small sites (Group I) expressed an interest in starting an energy management programme. Advice on monitoring and the use of consultants was given in an attempt to influence their action. It is too early, however, to assess the results.

A characteristic of Group II sites, in common with much of the brewing sector, is that engineers are responsible for energy conservation and departmental managers often lack motivation to assist in conservation measures. This phenomenon is related to the lack of sub-metering in these sites. One site, whose fuel bill alone is £800,000 p.a. has minimal sub-metering. This contrasts with one site in Group III which has 20 fully metered cost-centres for a total fuel bill of only £200,000 p.a. In the latter site the departmental managers have full responsibility for energy cost control in their areas.

In one site (D007), monitoring is carried out at four-weekly intervals, but management explicitly stated that no action is taken based on the information gained.

One large store group with three dairies (DOO2) has a well-developed information system with reporting on a four-weekly basis. The group energy manager, who acts as an internal consultant and "product champion", regards monitoring as the single most effective measure. To date, progress in this company has been mainly through small projects initiated at plant level while the group energy manager's attention has been focused on the stores. Over the last five years an over-all reduction in energy per floor area of 40% has been achieved in the stores. Reduction in specific energy in the dairies varies from 5 - 20% over the last two years. Currently the group energy manager is conducting surveys to identify investment opportunities. Once this is done, all viable opportunities are likely to be exploited. Part of the investment programme will include more extensive sub-metering.

One site in Group II (DOO5), part of a large dairy group, is gradually investing in sub-metering and shifting towards a Type III system. The group Board however, refused to sanction expenditure on a complete sub-metering system and so meters are being installed gradually. At the same time, the Board is now moving towards a more complete costing system that will involve extensive metering of utilities and materials. As part of this exercise the group commissioned statisticians to correlate energy and material usages to production and other relevant factors. This recognises the effects of several variables on specific energy (to be discussed in Chapter 7) and is a sensible approach.

Group III sites combine extensive sub-metering with line manager responsibility for energy conservation. One site (DOO8) uses weekly specific energy figures (which are adjusted for production and other variances) as a guide to good housekeeping action. The second site (DOO4) uses a cost based information system.

In Site DOO8, part of a large group, central energy staff act as consultants, reviewing progress and providing engineering expertise on large projects.

The store group with three dairies (D002) was one of the few companies in any sector that had an explicit policy on innovation. The group energy manager decided that the company would not risk being an innovator. Novel projects, such as mechanical vapour recompression (MVR), would not be undertaken until other companies had proved the concept in practice.

4.7 Summary

This Chapter has reported on the energy savings achieved, the techniques used, and the observed characteristics of energy management systems in a sample of companies in the dairy sector. A wide range of reductions in specific energy were reported and most techniques used had only been installed in one site. Observed characteristics of the energy management systems were used to categorise companies into three energy management groups. Two sites with no energy monitoring had achieved no reduction in specific energy. One site in Group III, having monitoring on a cost-centre basis, had achieved a larger reduction in specific energy in one year than any other site had in five years. The other site in Group III achieved the third largest reduction in specific energy over five years while the second largest reduction was achieved by a site in Group II.

Only one example of an innovation was found. All the other investments were adaptations of existing equipment.

Chapter Five

ENERGY SAVINGS IN DISTILLERIES

5.1 Introduction

This Chapter reviews the reductions in specific energy achieved, the techniques used and the observed characteristics of energy management systems in the sample of distilling sites. The information covers seven companies owning a total of 31 sites. With the exception of S004 the energy staff of these companies were interviewed and visits were made to a selection of sites.

5.2 Reductions in specific energy

The industry has been running at a very low occupacity over the last few years, typically 50%, and this, simultaneously increased the need for cost-cutting but reduced the availability of capital. Despite these constraints, the larger distilleries, owned by groups, have invested in energy conservation projects where viable. The resulting reductions in specific energy have been between 10 and 25% over the last five years on an uncorrected basis.

Larger sites have now encountered difficulties in finding viable projects given existing prices, techniques and capital availability. In the face of these limitations two companies are being innovative. One is experimenting with anaerobic digestion of effluent to produce methane for combustion. Successful utilisation of this technique would also reduce effluent disposal costs. The second company is investing in a gas turbine combined heat and power scheme that will be the first in the UK to export power under the provisions in the 1983 Energy Act.

5.3 Investments made or considered in the distilling sector

The investments made in the distilling sector sample are listed and summarised in Table 5.1. Experience in this sector again shows the site specific nature of many energy conservation techniques. One company found waste heat boilers recovering heat from the still combustion gases to be viable on one of its sites but not on another. Viability on the first site was possible because the boilers could be sited close to both the source of waste heat and the demand for steam. In the second site, this proximity was not possible and the cost of ductwork and pipework, coupled with the resultant heat losses, made the project non-viable.

Another company invested in a horticulture project as a way of utilising waste heat and this, along with aquaculture, has been suggested as a possibility with large potential in other sites. There were however several site and company specific factors that made it viable. These are described by the company itself as:

> Private company with history of diversification.
>
> Decision to keep direct heating on quality grounds.
>
> Distillery could only use 60% of recoverable heat.
>
> More cooling capacity was required because of an increase in production capacity.
>
> Disappearance of "Scotch" tomatoes because of escalating fuel costs.
>
> Availability of suitable land nearby.
>
> Large market close to hand.
>
> Heat recovered was at a high enough temperature.
>
> Distillery operates 24 hours per day, four days a week except for mid-summer shutdown.
>
> (Source: Cockburn, 1981)

Table 5.1 SUMMARY OF INVESTMENTS MADE BY DISTILLING COMPANIES

Company	No. of Sites	Measures invested in	Measures considered	Notes
S001	9	2 waste heat boilers using waste combustion gases from stills Insulation on stills Additional screw press Condensate recovery Power factor correction Replaced 280 kW for motors with 220 kW	Coal fired conversion Heat recovery using copper h/e (no use for heat) Load shedding (no suitable loads)	Weekly monitoring Targets Correct for prod. variances 18 month pbp criterion (was 24 months)
S002	1	None		
S003	1	None		
S004	2	Waste heat recovery using thermo-compressors Waste heat recovery - used for horticulture	Aquaculture	
S005	9	Improved condensate recovery Numerous small improvements	Currently looking at anaerobic digestor Currently looking at thermo-compression. Rejected MVR.	Monitoring 4-weekly 35% dcf pre-tax required

S006 /

Table 5.1 (cont'd) SUMMARY OF INVESTMENTS MADE BY DISTILLING COMPANIES

Company	No. of Sites	Measures invested in	Measures considered	Notes
S006	2	Numerous small improvements	Currently trying to justify a new distillery on energy grounds alone. Rejected CHP at warehouse - too low a utilisation	30% IRR pre-tax required
S007	7	Changing steam ejectors to electrical vacuum pumps Operations changes e.g. stop heating c.i.p. water after every batch Heat recovery Operations changes to reduce max. demand Replaced over-sized pumps. Variable speed drives Converted 4 effect evaporator to 6 effect Use of water vapour and exhaust air for drying Gas turbine driven total energy scheme (approval given 1984)		Computerised energy reporting system-corrects for start-up and shut-down. Cost based. 2-3 year pbp on retro-fit projects

Table 5.2 INVESTMENTS IN DISTILLING SECTOR SAMPLE

	Site						
Technique	S001	S002	S003	S004	S005	S006	S007
Waste heat boilers	✓						
Insulation on stills	✓						
Condensate recovery	✓				✓		
Power factor correction	✓						
Replacement of over-sized motors	✓						✓
Coal fired conversion	x						
Load shedding	x						
Heat recovery from stills using h/a	x						✓
Waste heat recovery using thermo-compressor				✓	x		
Waste heat recovery using horticulture				✓			
Waste heat recovery using aquaculture				x			
Anaerobic digestion of effluent					x		
Mechanical Vapour Recompression					x		
CHP at warehouse						x	
CHP at distillery (gas turbine)							✓
Various operations changes					✓	✓	✓
Variable speed drive							
Changed 4 effect evaporator to 6 effect							✓
Use of exhaust air for drying							✓
Numerous small improvements						✓	
Variable speed drives							✓

NOTES: ✓ = invested

x = under consideration/considered

CHP = Combined Heat & Power

In the five large distilleries waste heat recovery had been exploited wherever economically viable. A major barrier to further use of waste heat recovery in these sites is lack of additional demand for hot water, the product of all relevant heat recovery techniques except waste heat boilers.

With the exception of the horticulture scheme, the combined heat and power schemes and the experimental anaerobic digestor, the other investments were unspectacular but largely effective.

One company investigated combined heat and power (CHP) for a warehouse but found it to be uneconomic because of the low utilisation of heat. The distilling site where CHP was viable, and is being installed, offered a high utilisation of heat. Management at this site expressed surprise that CHP was viable, indicating perhaps an untapped potential in other sites. CHP economics are explored in detail in a later chapter, and indicate this technique may be more attractive than is generally recognised.

One company (S001) considered converting from oil firing to coal at one of its sites. The simple payback period would have been approximately four years at full production levels and the capital cost £700,000. The main Board recalculated the payback period on the assumption of current production levels (about 50% occupacity) and rejected the proposal. This illustrates the sensitivity of energy conservation investments to occupacity levels.

Company S001 also rejected further heat recovery from stills because they had no further use for additional hot water. They also rejected load shedding as a means of controlling Maximum Demand charges because there were no large loads that could be shed during production.

Company S005 is experimenting with an anaerobic digestor bio-gas system that if put into practice will both produce methane for combustion, and reduce effluent charges. This is similar to the system being tried in the brewery sector. If a full scale system goes ahead it will be an innovation in the distilling sector.

The same company rejected Mechanical Vapour Recompression (MVR) for being too risky and likely to have high maintenance costs.

Company S006 is currently trying to justify the building of a new distillery on energy grounds alone. This interesting possibility is currently being designed (Summer 1984) in order to produce a financial case.

5.4 Investment criteria

All companies except the two small sites (S002 and S003) reported a simple payback investment criteria between 18 months and three years.

5.5 Observed characteristics of energy management in the distilling sector

The five larger companies, excluding S002 and S003, monitor energy consumption on a weekly basis. All five companies have computerised systems to calculate specific energy and in two cases, costs per litre of spirit. In two companies this information is integrated with the overall management information systems.

Only two companies have explicit targets for reduction in specific energy. Of these, only one currently takes explicit account of production variances and start-up and shut-down effects in comparing actual specific energy usage and the target figure. The computerised system in question is programmed to correct for these effects.

In the second company with explicit targets, the group energy manager recognises the need to correct for these effects and is planning to implement a system that can do this. One constraint to date has been lack of storage space on the company's central computer, but the advent of powerful microcomputers should allow an independent energy management system to be established.

5.6 Summary

In the distilling sector there has been a wide range of reductions in specific energy and a variety of techniques used. Those five companies that have made investments in energy conservation have energy monitoring on a weekly basis. Only two of these companies have explicit targets for reducing specific energy but a third company is moving towards targetting.

In those companies that have invested in energy conservation techniques, further opportunities for viable investments are limited. Heat recovery techniques in particular are limited by the lack of demand for additional hot water. In the face of these constraints two companies are being innovative. One is experimenting with a bio-gas generator and the other is investing in a gas turbine driven combined heat and power (CHP) system.

Chapter Six

ENERGY SAVING IN THE MALTING INDUSTRY

6.1 Introduction

This Chapter reviews the reductions in specific energy achieved, the energy conservation techniques used and the observed characteristics of energy management systems in the malting sector. Most attention is paid to heat recovery from malting kilns because this technique can have a far larger effect on malting energy costs than any other single technique, and because it has diffused throughout the industry extremely quickly. Factors affecting this rapid diffusion are discussed.

6.2 Reductions in specific energy achieved

Measured reductions in specific energy have been hard to obtain in this sector, but available unadjusted figures range from 25 to 40% over the last five years. The sites achieving these figures had invested in heat recovery. One site with a high initial specific energy use reported a reduction of 20% through simple recirculation alone.

6.3 Investments made in the malting sector

The investments made in the malting sector sample are listed in Tables 6.1 to 6.4 and summarised in Table 6.5.

In addition to the companies interviewed, two small companies were contacted. One had made no investments in energy conservation and had no plans to do so. The second had invested in heat recovery on five kilns since 1981.

Table 6.1 DATA SUMMARY - MALTING COMPANY M001

Company:	M001
No. of sites:	1
Annual production:	45,000 tonnes
Annual energy bill:	£400,000
Monitoring:	Monthly
Payback criteria:	3 years simple payback
Investments made:	1960 switched from coal to gas oil 1973 switched from gas oil to gas Looked at heat recovery from 1979, invested 1981 Installed low NO_x burners Capital cost of heat recovery project: £100,000 Payback period: 18 months
Investments under consideration:	Motor speed controls on fans

Notes: Heat recovery reduced energy from 53% of total overheads to 50% despite a 25% rise in fuel prices.

Investment on heat recovery made easier because of (a) large room above kilns; (b) floor with sufficient load bearing capacity; (c) proximity of two stacks.

N.B. NO_x = oxides of nitrogen

Table 6.2 DATA SUMMARY - MALTING COMPANY M002

Company:	M002
No. of sites:	4 (3 box sites, 1 Clova site)
Annual production:	
Annual energy bill:	
Monitoring:	After every batch
Payback criteria:	2 year simple payback
Investments made:	Recycling air post-break on one site Heat recovery on 2 sites - run around coil systems Computer process control Recycling on "Clovas" (1)
Investments under consideration:	Variable speed motor controls Variable pitch fans Conveyor controls Fluidised bed coal combustion (2)

Notes: Heat recovery on 1 site made possible by common ducting. On third site heat recovery is not viable because each box has its own ducting. No heat recovery system is viable on "Clovas" because the whole process from germination to kilning is carried out in one container, hence kilning only occurs 3 days out of 7.

(1) Circular, continuous process, malting kilns contrasting with the traditional rectangular boxes.

(2) Not considered viable without a market led switch to indirectly fired malt.

Table 6.3 DATA SUMMARY - MALTING COMPANY M003

Company:	M003
No. of sites:	1
Production:	40,000 tonnes/annum
Annual energy bill:	£400,000
Monitoring:	Monthly
Payback criteria:	2 year simple payback, 30% dcf hurdle rate
Investments made:	Recirculation 1976/77
	Heat recovery 1981
	Capital cost of heat recovery project: £160,000
	Payback: 20 months
	Microprocessor system for monitoring
Investments under consideration:	Microprocessor system for control
	Conversion from oil firing to gas - rejected as cost of laying main - 2 miles (payable by the company) was prohibitive.

Notes: Recirculation reduced consumption from 50 therms/tonne to 40 therms/tonne. (20%) Heat recovery added further 20%.

Table 6.4 DATA SUMMARY - MALTING COMPANY M004

Company:	M004
No. of sites:	3
Production:	
Annual energy bill:	
Payback criteria:	3 year simple payback, 30% IRR hurdle rate
Monitoring:	
Investments made:	5 run around coil heat recovery systems 3 air to air heat recovery systems 1 gas engine driven heat pump recovery system Microprocessor control systems Fuel switching to coal (1 site)
Investments under consideration:	Combustion of straw - rejected as being impractical and not cost effective.

Notes: Heat pump has reduced consumption from 23% to 17 therms/ tonne. Justification was possible because of market led demand for indirectly fired malt. An indirect system would have cost £100,000 and increased consumption to 24 therms/tonne. Heat pump cost £300,000 and was justified on marginal basis, including Demonstration Project Scheme grant of 25% of capital cost. Heat pump also justified on "experience" grounds as major competitor installed one.

The various heat recirculation and recovery options available for the malting process are explained in Harris (1981), Chapman and Walker (1979), Dangerfield (1978) and Neidermayer (1977).

Company M001 with one site, had switched from coal firing to gas oil firing around 1960. It was decided that despite the higher cost of gas oil per litre compared to heavy fuel oil (HFO), the additional costs of maintenance and electricity for trace line and tank heating made gas oil cheaper overall. This systematic approach to appraising energy costs is to be noted and is in contrast to other examples explored in Section 3.

In 1973 a switch was made to an interruptible natural gas supply (only interruptable contracts were available at that time) and gas oil became a stand-by fuel. Later, negotiations led to a firm supply of gas at advantageous delivered price per therm.

The company's General Manager started investigating heat recovery in 1979, three years after the first installation in the UK industry. At the start of 1979 there was the first "scare" about the level of nitrosamines (believed carginogens) in the product and this led to "sulphuring", the addition of sulphur to the combustion process. The resultant oxides of sulphur inhibit oxides of nitrogen, and hence nitrosamines, forming. Sulphuring also caused corrosion in several of the early heat recovery projects.

The company's General Manager was concerned about corrosion and spent much time visiting installations and investigating alternatives. During this information gathering phase, considerable assistance was received from other companies in the industry, noted for its "friendly competition". Before heat recovery was attempted low NO_x burners became available and these were installed on the company's kilns. (Sulphuring is still required by the USA, a major export market). Now the USA will not accept directly fired malt. Interestingly, indirect firing does not remove the problem entirely as nitrosamine levels are increased by pollution.

After investigating all available systems, the company dropped its "Buy British" policy in order to install a system based on a German stainless steel tube air-to-air heat exchanger. Investment cost was £100,000 for two kilns and an 18 month payback period was envisaged. The system achieved a 15 month payback.

Stainless steel tube heat exchangers are very resistant to corrosion (with a five year anti-corrosion warranty) and self-cleaning, two major advantages. Installation of the system was made easier because of the existence of a large room, with a floor of sufficient load bearing capacity, directly over the two kilns, and the fact that the two exhaust stacks are adjacent. On two other kilns of the company the existing arrangement was not so favourable, making a retro-fit project non-viable. Therefore, the company waited for the opportunity afforded by capacity enlargement and renovation of these two kilns, to incorporate heat recovery.

Company M002 owns four sites, two with 10 conventional boxes one with 5, and one with 2 circular "Clovas". The company first invested in simple recycling of post-break air wherever possible. Subsequently two run around coil heat recovery systems were installed. On two sites heat recovery was "easy" because the boxes utilise common ducts. At the third conventional site each box has individual ducts and in order to install heat recovery the duct system would have had to been rebuilt. The cost of this made heat recovery non-viable.

The two "Clovas" have post-break recycling. All alternative heat recovery systems, including heat pumps integrated with combined heat and power have been considered here but none are economic because each container is used for both germination and kilning. Consequently kilning occurs only three days out of 7 or 8 in each unit, and there is insufficient utilisation to justify heat recovery.

Table 6.5 INVESTMENTS IN THE MALTING SECTOR

	Site							
Technique	M001	M002A	M002B	M002C	M003	M004A	M004B	M005C
Recycling of kiln air post break		✓	✓		✓			
Heat recovery - air to air heat exchangers	✓				✓	←	3	→
Heat recovery - run around coil		✓	✓			← ✓	5	→
Heat recovery - heat pump								
Low NO_x burners								
Fan speed motor controllers	x	x	x	x				
Variable pitch fan blades		x	x	x				
Computer for monitoring process					✓			
Computer control of process		✓	✓	✓	x	✓	✓	✓
Conveyor motor controls		x						
Fuel switching: oil to gas					*			
Fuel switching: oil to coal								
Fuel switching: fluidised bed coal		*				✓		
Straw combustion						*		

NOTES: ✓ = invested

x = considering at time of interview

* = considered and rejected

Nos. represent total number of systems in sites with multiple kilns.

The company has also invested in computer process control and is considering variable speed controls on the fan motors, variable pitch fans and conveyor motor controls. Fluidised bed coal combustion has been rejected on economic and "convenience" grounds. Conversion to coal firing would be considered again if the market demanded a switch to indirect fired malt. (Use of an indirect system would increase energy use).

Company M003 operates one site with three kilns. Simple recirculation systems were added to all kilns in 1976. A heat recovery system, using the same stainless steel tube heat exchanger as in M001, was installed in 1981 on two kilns. The investment cost was £160,000 and the expected payback period two years. As in Company M001, management were concerned about corrosion. Visits were made to German installations 8 to 12 years old, which showed no signs of corrosion despite use of sulphur. The largest barrier to installing the heat recovery system was senior management. It took four years of effort from the operational staff to convince senior management that investment in heat recovery was necessary and viable.

Company M004 has three separate sites, each with multiple kilns. Over the last five years the company has invested in five run-around coil heat recovery systems, three air-to-air heat recovery systems, and one gas engine driven heat pump heat recovery system. In addition to these, it has invested in computer process control systems, being the first to develop them in the UK malting industry; and fuel switching to coal at one site. This company was the first in the UK to invest in run-around coil and glass tube air-to-air heat exchangers. One early heat recovery system failed through corrosion after sulphuring was started to reduce nitrosamine levels in the product. The early heat recovery systems had to be forced onto conservative equipment suppliers who, in the eyes of the company, did not consider them viable.

At the site where a coal fired system was installed an indirect steam heating system had been used from new. For various technical reasons the heat recovery alternatives were not viable at this site and so coal firing was the only option for reducing kilning costs. Conversion was made easier because the site had a lot of empty space.

The heat pump system was justified because of an Energy Conservation Demonstration Project Scheme grant (ECDPS) and because a switch in market demand to zero nitrosamines content necessitated an indirect heating system. An indirect system would have cost £100,000 and increased energy consumption from 22 to 24 therms/tonne. It was estimated a heat pump system would cost £300,000 and reduce consumption to 16 therms/tonne. Using these figures and the 25% ECDPS grant a three year payback was calculated. In practice it is likely to be longer because of equipment failures and failure of the system to operate at the design performance level. The management, however, justified the system on the basis that their major competitor had one and that they should gain early experience in case heat pumps became standard. In effect the financial appraisal was "cooked" to ensure the project went ahead and the project was experimental.

6.4 Observed characteristics of energy management in the malting sector

Two companies read meters monthly and produced specific energy and cost information. The other two read meters and produced specific energy information for every kilning. Their specific energy figures were corrected for ambient conditions, the biggest cause of variance in malting specific energy consumption (batch size being constant).

Metering is usually comprehensive in maltings because of the very large quantities of both fuel and electricity consumed.

6.5 Investment criteria

As shown in Tables 6.1 to 6.4 the investment criteria used were either a two or three year simple payback period.

6.6 Discussion

Harris (1981) reports that one-fifth of productive capacity in 1980 already had heat recovery equipment installed (whereas none had in 1975), and that plans then existed for adding heat recovery to 80% of productive capacity within three years. This sample suggests these plans have been implemented.

The rapid diffusion of heat recovery techniques in the malting industry demands further attention. Several powerful forces, unique to the industry, were at work in causing this rapid take-up of a new technique (new at least in the UK).

Firstly, energy typically represents 50% or more of total costs in a malting operation. The cost of barley and labour, the two inputs, are relatively fixed. This high proportion of total costs has made energy a very relevant problem in the industry. Heat recirculation and recovery in its various forms offered a way of reducing costs that could not be matched by any other single technique. In fact, there are only a small number of energy saving techniques that are relevant to the industry, and these are only worth considering after heat recovery.

Secondly, the industry is competitive. Even maltings associated with breweries are not usually immune from competition. Despite their competitive nature, there is generally a free exchange of technical information.

The use of heat recovery in Europe, in some cases for more than a decade, meant that it was possible for potential investors to see actual installations and reduce their uncertainty over corrosion. The high capital cost of the systems made wide ranging information gathering worthwhile.

The early adopters in the malting industry consisted of the two largest companies in the industry. The nature of the malting process meant it was possible for them to easily install early versions of heat recovery on a proportion of their output. In the early days the pressure to innovate came from the malting companies themselves and UK manufacturers were reticent to supply the requipment. This represents a failure of marketing by the suppliers.

Unlike in the brewing industry, the malting industry's trade association has not been particularly active in energy conservation. Most of the information exchange seems to have been through personal contacts backed up by the trade press and the Energy Technology Support Unit.

6.7 Summary

We have seen the range of reductions of specific energy achieved in the malting company sample. The sector exhibits more uniformity in its investments than the other three sectors. Heat recovery has diffused widely over the last 5 to 6 years. Circumstances peculiar to the industry have been operating to promote this remarkably rapid diffusion.

The early adopters in the industry of both heat recovery and process control systems were the dominant companies in the sector.

Summary of Section One

This section has described the energy conservation achievements to date in the sampled companies within the four sectors. The information forms a background to discussing the process of technical change resulting in energy conservation and the management challenges of that process. It also forms a basis for estimating future potentials for energy conserving capital equipment.

All four sectors show a wide range of reductions in specific energy, a wide range of techniques used and a range of energy management approaches. Malting is exceptional in that one technique has been far more important than all others. Techniques vary from sector to sector with the exception of a few common ones such as oxygen trim systems, improved condensate recovery, power factor correction, and high efficiency lighting. These techniques are not industry-specific as they are at least technically feasible wherever steam systems, electricity or artificial lighting are used. They may not, however, be economically viable.

In all four sectors, there is evidence concerning the site specific nature of energy conservation investments. Economic viability in one site does not automatically mean economic viability in all similar sites, even assuming similar definitions of economic viability.

Investment criteria for cost saving measures, i.e. definitions of economic viability, are broadly similar, both within and between sectors.

Most of the energy saving investments to date have been retro-fitted to existing plant and adaptations of existing equipment rather than innovations. Those sites that have incorporated energy saving features into new plant have achieved significant reductions in specific energy. Sites that have innovated, or are considering innovation, have been found in all size ranges in the brewing sector. Innovators and early adopters in the malting sector have been the dominant companies in the industry. In the distilling sector innovating companies have been both large and small.

The variety of energy management approaches in all four sectors can be classified into three broad categories; those that do not regularly monitor energy use; those that monitor energy use on a plant-wide basis; and those that monitor energy use on a cost-centre basis.

There is evidence from the brewing sector that the use of monitoring at monthly or more frequent intervals is associated with a larger than median reduction in specific energy. The statistical links between the use of either targetting or cost centres and a larger than median reduction in specific energy are less strong.

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Section Two

THE POTENTIAL FOR FURTHER CHANGE

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INTRODUCTION

This Section describes the process of technical change that results in energy conservation. Langrish's (1979) model of technical change is integrated with Baker's (1983) model of buying behaviour in order to (a) define potentials for energy conserving capital equipment; and (b) form a basis for exploring the problems of managing energy conservation activity. Only by understanding the process of change itself can we adequately define the potentials and understand the barriers to exploitation of these potentials.

Having defined the potentials for energy conserving capital equipment the problems of measuring these potentials are discussed. These problems are related to the important area of defining success in energy management, which is also discussed. Estimates for industry wide potentials are shown to be arbitrary and the number of companies achieving their potential is advanced as a more useful value.

From the model of technical change a soft systems model of the activities necessary in energy management is developed. This is used in Section 3 to explore some of the barriers to effective energy management.

Chapter Seven

THE PROCESS OF TECHNICAL CHANGE

7.1 Introduction

Most of the technical change literature has been concerned with the economic causes and effects of such changes rather than the process itself. Here we are more concerned with the process itself, with the workings "inside the black box" of Rosenberg (1982a).

Fores (1977) states that most analysts of general economic performance, and of industrial performance in particular, have stressed the importance of general technical change. Yet most of the specialist literature has been concerned with innovation, which is only a special case of technical change, being a discrete step in the development of product or process. As we have seen in Section One, most of the investments in energy conserving capital equipment have been in modest, incremental technical changes using previously innovated techniques.

7.2 The process of technical change

Langrish (1979) in one of the few works to consider the process of technical change itself, advances a new conceptualisation in order to clarify what he sees as paradoxes in the literature, paradoxes similar to those identified by Fores. Langrish suggests that there are three necessary conditions that have to be met before a technical change will occur. These are:

(1) a TECHNICAL CONCEPT must exist, capable of being developed to the stage of achieving
(2) an ADVANTAGE over alternative technical concepts; and
(3) the CAPABILITY of developing (1) to the stage of (2) must exist.

All three conditions have to occur simultaneously and in the same place. An important modification would be that it is more the perception of advantage and capability rather than any absolute values that motivate a coupling agent to bring all three together and force a technical change. The coupling agent fulfills an entrepreneurial role even though in most cases of technical change he is unlikely to be the classic independent entrepreneur, but rather an employee of an established organisation.

The technical concept may be a brand new idea, a new combination of ideas (old and/or new) or an old idea not previously developed because of lack of advantage or capability.

The ease with which the concept can be turned into a commercially viable installation depends on the extent to which components of the concept are already embodied in available hardware. If the central concept is already embodied in commercially available hardware only adaptation to fit the specific site will be necessary. (The difficulties of adaptation as we will see are frequently overlooked in the literature). If hardware has to be developed, as in the case of an entirely new concept, or invention, more research and development work is necessary. Thus, there are different levels of research, design and development. Depending on the state of the concept it may involve R & D in the traditional sense, "experimental design" or more mundane "routine engineering design", as defined by Freeman (1983).

The advantage is usually, in the case of industry, an economic advantage. It may be an advantage over alternative concepts or over the status quo. Other non-economic advantages, or at least non-quantifiable advantages such as improved quality control or working environment may be associated with the technical change but economic advantages will be the usual driving force for change in industry. An exception would be technical changes that are required by law.

Capability to develop the technical concept to the stage of achieving the required advantage over alternative concepts or the status quo may exist in either the potential host or a supplying organisation. In many energy conservation investments the basic hardware will already exist and the necessary capability will be the capability of adapting the basic hardware to meet the potential host's technical and financial needs. The greater the level of research, design and development necessary to bring the concept to the hardware stage, the more important, and more difficult, it is to assess the capability of vendor companies. Several examples of vendors promising the capability to develop innovative techniques, and then failing to deliver, were encountered in the sampled companies. This adds an extra uncertainty to the investment decision. Interestingly this "new conceptualisation" of Langrish's is similar to Asimow's (1962) description of the engineering design process in which the starting point is an abstract archtype or concept. This is refined through an iterative process into a less abstract, detailed design and finally embodied in hardware.

7.3 Adoption and Adaptation

In diffusion studies (for example Mansfield, 1968) and Davies (1979), and in texts on buying behaviour (for example Bellizzi, 1981, and Wind, Robertson and Fraser, 1982) the purchase of technology is often presented as a simple adoption process. In many of the examples discussed by these authors, and the energy conservation investments made in the sampled companies in the four sectors, the process is more one of adaptation.

Even when the concept is well proven and the basic hardware exists some adaptation work is necessary for all but the simplest techniques, to make a viable system in the particular site in question. This requires original, though not dramatic, engineering design work.

The basic hardware may well be standard and simple but the system must be engineered to meet the technical conditions and the required economic return at each specific site. The difficulties this can present, and the effect of site specific technical factors on economic viability, have been neglected in the adoption literature.

There is a great variety of energy conservation hardware available, ranging from low energy lamps to sophisticated process heat recovery and electronic energy management systems. Each technique has a degree of adaptability, the inverse of which can be labelled specificity. At one end of the scale, with a high adaptability, would be low energy minature fluorescent lamps which can plug straight into existing fittings. In more complex relighting situations, such as a warehouse where high pressure sodium lamps are to replace fluorescent tubes, considerable adaptation of the esisting lighting circuits may be necessary. For descriptions of the various techniques available see Payne (1984).

A technique with a lower adaptability than low energy lighting would be heat recovery from boiler stacks using economisers.

Ostensibly this mature technology (first patented in 1845) looks very adaptable as it can, in principle, i.e. technically, be applied to any gas fired boiler, or dual fuel boiler if a bypass is used during oil firing. For descriptions of the technique see Gray et al (1981) and Payne (1984).

Numerous site specific factors affect the financial viability of proposals for boiler economisers, including:

- physical space for the hardware
- load bearing supports
- quantity and quality of demand for hot water
- flue gas temperature and composition
- boiler utilisation
- boiler load pattern
- time spent burning gas on dual fuel boilers.

Total system cost, as in other heat recovery projects, is often three times the cost of the economiser or heat exchanger (Missions, 1982; Cooper, 1983; personal communication).

At two brewery and one dairy sites visited during the research, economisers were not financially viable because of lack of space in the boilerhouse. Obviously it would have been technically feasible to extend the boiler house but the cost would have been prohibitive. Consequently, the technical potential for energy saving through the use of economisers at these sites is unlikely to be exploited at current prices until a new boiler installation is necessary for other reasons. Applications of commercially available hardware are rarely prevented by purely technical problems but by failure to meet economic criteria.

At the top end of the specifity scale, i.e. the least adaptable, would be a process heat recovery system such as malting kiln heat recovery or a brewery effluent heat recovery system. The number of technical factors affecting financial viability will be substantially higher than a boiler economiser. For discussion of these factors for process heat recovery systems see Missions, 1981; Brookes and Reay, 1982; Turner, 1982; and Addy, 1983.

The determinants of the adaptability are the sensitivities of capital costs and savings to variations in specific technical factors inherent in the technique and the site.

The technique of heat recovery from malting kilns using air-to-air heat exchangers has a high adaptability because the technical factors that affect capital cost and savings, notably physical dimensions, air flow rates, temperatures, tend to be similar. There are only a few basic designs of malting kilns.

On the other hand brewery effluent heat recovery systems have a low adaptability into other brewery sites because their viability is very sensitive to site specific factors such as plant layout and quantities and qualities of effluent (determined by the type and operating conditions of existing plant).

The importance of specificity is supported by several writers on innovation.

Rosenberg (1982a) stresses the importance of adaptation and the role of "unspectacular design and engineering activities". He also notes that in the literature there is frequent preoccupation with what is technically spectacular rather than what is economically significant. Rosenberg also emphasises the importance of studies at the level of the individual firm.

Rogers (1962) in discussing the adoption of innovations divides the "antecedents" to the innovation decision into two categories:

(1) perceived attributes of the innovation, and
(2) characteristics of the adopters.

Five attributes can be summarised for the first category:

1. Relative advantage
2. Compatability
3. Complexity
4. Trialability
5. Observability

Compatability, "the degree of fit of the innovation with existing norms and needs of potential users", (Rogers, 1962), subsumes adaptability as well as other factors.

The importance of adaptability, or its inverse specificity (in connection with innovations) is also supported by Boylan (1977), who states:

> "The number of firms in an industry which are potential adopters of an innovation, and the proportion of their output to which it might be applied, depends on the functional specificity of the innovation at successive stages of development as well as the range of relevant processes and products in individual plants. Hence, adoption rates cannot properly be compared with the total number of firms in, or the total output of, their common "industry" classification. Rather the progressively changing characteristics of the innovation in its various forms must be accompanied by changing measures of the array of economically feasible applications."

Gold (1977) notes that it cannot be assumed that the expected benefits of an innovation are so clear that all potential adopters would assess them similarly or even that all potential adopters give serious consideration to the same innovations in any given period. In addition, it has been shown in Section One that economic viability in one site does not automatically confer economic viability in a similar site because the costs of adopting the basic hardware into a system can make it not viable. This is true even assuming similar definitions of economic viability. Gold continues to suggest that "the criteria applied to the evaluation of available innovations may differ widely among firms, reflecting differences in their internal urgencies, resource availabilities and specialised expertise rather than deriving solely from the demonstrable benefits of the innovation itself." Gold also states "Instead of assuming ignorance, sloth, bias or stupidity as the causes of (such) restrained rates of diffusion, it would be more helpful to make field studies of the actual considerations and evaluations responsible for the decisions made."

Bradbury (1978) observed that technology "is not something that can be bought off the shelf or stored in a bank vault". Components of systems may be bought off the shelf but an input or knowledge is necessary to design financially viable systems, even where the concept has been used elsewhere.

Baker (1983) in discussing the adoption of innovations states that "adoption decisions are very much situation related".

7.4 Intermediate Summary

Langrish's model of technical change has been advanced as useful for understanding the actual process of technical change, rather than the economic causes and effects. This understanding is necessary to understand the process of investment in energy conservation and to define potentials for energy conservation. Three conditions must occur simultaneously and in the same place before a technical change can occur, a technical concept must exist, it must offer an advantage and the capability of developing the concept into reality must exist. It is perceptions of advantage and capability, rather than any absolute values, that motivate a coupling agent to bring all three conditions together and force a technical change. This conceptualisation of technical change, which is similar to earlier writers' views of the design process, shows innovation as being a special case of general technical change.

Depending on the extent to which the concept is already embodied in available hardware, different levels of research, design and development will be necessary to bring the concept into reality. Much of the research, design and development activity is at the routine engineering design level not usually thought of as "R & D".

The advantage in industry is an economic advantage. In order to begin the development process the concept must be perceived as promising to meet the required investment criteria at the particular site.

Capability to undertake the development work must be perceived to exist in either the host organisation or in the vending company.

Even where the concept only entails the use of existing commercially available hardware the difficulties of adapting the concept to fit the specific site have been overlooked in the technical change literature. Straightforward replication, with no site specific adaptation, is very rare for all but the simplest techniques. Different techniques have different adaptabilities, a characteristic determined by the sensitivities of capital costs and benefits to specific technical variables. This means that a technique that is financially viable in one site is not necessarily viable in another similar site, even assuming the same definition of viability.

The importance of adaptability, or its inverse specificity, is supported by other authors on technical change. This view of technical change as a very site specific activity has important consequences for the general innovation diffusion literature, the definition of potentials for energy conserving capital equipment and agents of change promoting energy conservation. Further research into the role of adaptability, or site specificity in the adoption decision is advocated.

7.5 The situation facing a firm

Let us examine the situation facing a firm considering investment in energy conservation equipment. It faces an array of technical concepts, the application of any of which would result in reduction of energy use. These concepts are, to varying degrees, embodied in available hardware.[1] Some, for example boiler economisers, involve mature hardware and are well proven, others for example microprocessor controlled oxygen trim control systems, are "state of the art". Others, for example microprocessor control of malting kilns, would (prior to 1982) involve a higher level of research, design and development to implement as they are beyond the current state of the art. New concepts may also be invented in response to specific needs.

Most concepts are technically suitable for both retrofit and new installations. Not all of the array of technical concepts are likely to be known by one person, even in a limited field or industrial sector.

From the array of perceived concepts some will be adopted to be considered in more detail. The objective at this stage is to work up the concept into a feasible project. As mentioned before, this process is essentially one of research, design and development (R, D & D), but much of the activity is not on the level reported as "R & D" in the literature. Depending on the state of the concept it may involve R & D in the traditional sense, "experimental design" or more mundane "routine engineering design" as defined by Freeman (1983).

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[1] Some concepts embodied as hardware border on the fraudulent which adds another dimension of uncertainty.

Most of the investments made by the sampled companies used well proven concepts utilising commercially available hardware. The R D & D necessary was at the adaptation level involving routine engineering design. Most companies take a passive role, accepting concepts and hardware already developed. One company in the malting sector had taken an active role in pushing vendors into developing heat exchangers suitable for malting kiln heat recovery. One large brewery company used its central engineering staff to develop a new, low cost, space heating control unit. Other large companies could take an active role in developing new techniques and hardware in collaboration with vendors.

Most potential investor companies do not have the resources or the expertise to develop novel concepts not yet embodied in commercially available hardware.

The differences between a decision to adopt or develop a new technique, i.e. to innovate or to be an early adopter, and a decision to adapt a proven existing technique, have perhaps been overstressed in the literature. Both involve change and uncertainty for the host company. Investing in an already innovated technique still involves the uncertainty over whether the technique will work, and work profitably (as defined by the company) in the particular site. The decision to adopt a technique first involves the extra uncertainty over whether the technique can be made to work at all, or perhaps more realistically, can be made to work within acceptable performance i.e. cost and benefit, limits.

The process of working up a concept has several iterative stages. Technical evaluation, or the "technology design" described by Schmidt-Tiedmanns (1983) in discussing innovation, is concerned with assessing whether the technique(s) will operate in the designed manner in the particular application in question. For most energy conservation techniques, for which commercially available hardware already exists, this is routine engineering design or engineering judgement, and will be done by the potential investor, often in conjunction with one or more vendors. It is partly a process of establishing confidence in the equipment and the supplier, and partly a process of overall system design. The larger the potential investment, the greater the time and money likely to be spent on this stage. For example, when considering malting heat recovery systems costing about £100,000 potential investors spent much time evaluating alternatives and visiting existing installations in Europe.

The (array of) technically feasible project(s) is then subject to commercial evaluation using the potential investors criteria. This is usually done by soliciting quotations, or where systems are to be installed by internal staff, preparing estimates of costs and savings. Some techniques require considerable specific design work to prepare quotations and judgement is often exercised over which concepts should be pursued.

Investment is only likely to occur if the potential investor's criteria are met and so it will be argued that use of any other criteria in defining potentials is irrelevant. Investment criteria are more complex than simple payback period or discounted cash flow rate of return. Absolute capital constraints are also important as shown by the brewery site which rejected copper vapour heat recovery using mechanical vapour recompression. The payback period was within the company's normal criteria but the project was rejected on absolute capital cost grounds. Failure to meet financial criteria may lead to outright rejection and abandonment of the project, or redesign of the concept or system.

A third aspect of evaluation is often ignored, both in diffusion studies and by management. It can be labelled contextual evaluation. The viability of proposed projects must be examined in the context of other energy conservation investments, new plant investments, corporate strategy, market changes and personnel skills. Failures to consider the interactions between projects and these factors at the design stage can lead to expensive failures. Some examples of such failures are described in a later section.

Having evaluated the array of concepts there remains an array of technically feasible, financially viable, appropriate projects. It will be argued in the next section that these form the true potential for energy conserving capital equipment.

Any static description of such a dynamic process cannot do justice to its complexity. Firstly, as noted, different concepts are at different levels of development. Then energy conservation projects interact with each other, with other capital projects and with strategy. Prices of energy and capital change and future prices must always remain uncertain. New concepts, both as ideas and hardware, are entering the market. Improvements are being made to existing hardware, particularly in such fields as microelectronics. The manager of technical change must cope with this complexity and uncertainty.

7.6 Technical change and buying behaviour: a synthesis

Two similarities are apparent here, and a synthesis is useful. Firstly the process above is essentially the design process described by Asimow (1962) and Simon (1975). The second similarity is between this process and the composite model of buying behaviour advanced by Baker (1983).

This may be expressed notionally as follows

$$P = f[SP,(PC,EC,T_A-T_D),(E_A-E_D),BR)]$$

where

P = probability of purchase

f = a function (unspecified) of

SP = selective perception

PC = precipitating circumstances

EC = enabling conditions

T_A = technological advantages

T_D = technological disadvantages

E_A = Economic advantages

E_D = Economic disadvantages

BR = Behavioural response

Baker points out that this is a sequential process model: PC is equivalent to interest, $(T_A - T_D)$ and $(E_A - E_D)$ represents evaluation, and BR dictates the action taken.

The precise nature of the function is not specific because it is not known and it is unlikely that any single functional form could capture the interactions between the other variables in the model.

Placing SP or selective perception at the beginning as a factor mediating the other variables it is possible to show this is a process model. Selective perception will determine whether or not one will become aware of a purchase opportunity besides conditioning the information selected for evaluation and the interpretation placed upon it.

This model, which Baker uses in relation to identifying early adopters of new product developments, is equally applicable to general technical change. Selective perception partly determines which concepts are worked up into feasible projects, affects evaluations of technical and economic advantages, as as well as capability.

As Baker states, "The adoption decision is based on perceived advantage rather than absolute economic advantage". To this it could be added that the decision is also based on perceived technical advantages and perceived capability of implementing the concept.

7.7 Defining potentials for energy conserving capital equipment

The model of technical change allows us to define conceptually two potentials for energy conserving capital equipment, each with three sub-sets representing different levels of change.

Firstly, in any one site there is a potential for reducing specific energy using known concepts, not necessarily existing as hardware. This is potential achievable through the use of esisting inventions, i.e. the savings that would result if all relevant existing inventions were developed and built as hardware.

The available concepts can be divided into concepts designed solely for energy conservation and retrofitting onto existing plant, concepts for new production techniques using the same basic processes, and concepts for new processes; the application of any of which would result in energy conservation.

The potential using retrofit concepts can be defined as those savings that would result if all relevant retrofit energy conservation concepts were developed and installed on the existing plant. It takes no account of whether the technique is already embodied into hardware or of economics.

The potential using new techniques but the same basic processes can be defined as those savings that would result if all relevant new concepts were developed and installed, replacing the existing plant, without regard to economics or hardware availability.

The potential using new production processes can be defined as those savings that would result if any new process concepts were developed and installed, replacing existing plant, without regard to economics or hardware availability.

All savings are relative to the existing plant.

The second potential is a sub-set of the first, it is that achievable through the use of existing innovations i.e. hardware that is available commercially and has been utilised elsewhere. This again can be sub-divided into potentials using techniques designed purely for retrofitting, new production techniques using the same basic process, and new processes. These potentials are easier to visualise than those using concepts.

The potential using innovated retrofit hardware can be defined as those savings that would result if all available retrofit techniques were installed onto the existing plant, with no regard to economics.

The potential using innovated production techniques using the same basic process can be defined as those savings that would result if all available production techniques were installed in the existing plant, with no regard to economics.

The potential using innovated new processes can be defined as those savings that would result if all available new process techniques were installed in the existing plant, with no regard to economics.

Using the technical change model it is at least possible to imagine that economic opportunities, i.e. those meeting the potential investor's criteria, exist prior to them being discovered. Thus we can divide the potentials further, into economic and non-economic at any one time.

This schema of potentials is shown in **Figure 7.2**. The different categories that a technique may fall into are shown in Figure 7.3.

Now, which of these potentials should we define as being real? It can be argued that the most realistic potential in any one site, i.e. most actionable, is made up of those investment possibilities that meet the following criteria:

(a) are capable of being developed by the host company or vendor.
(b) meet the investors financial criteria for investment.
(c) are appropriate in context.

Obviously this definition of potential depends on judgements and decisions outside the usually accepted boundaries of energy management.

Any other definition of potential would encourage a non-systematic approach, resulting in sub-optimisation. Failure of consultants and outside agencies to appreciate the wider context of energy conservation investments is reported in Jacques and Wood (1982a) and have been observed in this research. Jacques (1981) and Rosenberg (1982) warn against the dangers of sub-optimisation in considering energy conservation investments. As we have already seen, Gold (1977), in discussing innovation, argues that a wider view of the adoption decision is necessary. Although applied to innovations rather than the less dramatic technical changes usual in most energy conservation activity, these comments support the need for the systematic assessment of relevant factors used here.

It can be seen that a site by site approach to defining potentials is necessary. A certain technique may fall into different categories of potential at different sites and hence the realistic potential as defined above may differ between sites for one or more of the following reasons:

1. There may be differences in the existing technical conditions between sites that limit the scope for profitable (as defined by the investor) use of the technique in question. Existing technical conditions arise from historical decisions over plant design. For example, site specific constraints at one site may make a boiler economiser not financially viable whereas at a similar site with the same investment criteria an economiser may be viable.

2. Differences in financial criteria may exist, i.e. sites may have different acceptable payback criteria. These will arise from differences in capital availability and differences in allocation of funds between offensive and defensive spending. The latter is one aspect of the <u>context</u> of the investment.

3. There may be differences in other aspects of context. Differences in production technology strategy, e.g. a decision to switch to nitrogen pushing in brewing (see example in Section Three) affects the viability of certain other energy (and other resource) saving techniques. Differences in market demand for the final product also affect the array of viable investment opportunities. For example the reduction in acceptable nitrosamine levels in malt (see Section One) forced some companies to switch to indirect heating methods. The increased kilning costs associated with this switch made heat recovery more attractive economically.

   Differences in corporate strategy, e.g. a decision to close a site within two years would greatly reduce the incentive to invest in energy conservation at that site.

4. Differences in historical performance in exploiting energy conservation opportunities will exist. A site where profitable conservation opportunities have always been recognised and exploited is less likely to have potential for further profitable change than a site where no energy conservation investments have ever been made. Although past decisions may affect the viability of specific techniques (as in 1), failure to invest in energy conservation in the past will have left more opportunities open when energy conservation is examined.

5. Differences in the level of innovation that will be attempted, both within the framework of existing process technology and beyond it. A site that is willing to risk innovating a new technique opens up the range of achievable potentials.

Given these reasons why real potentials may differ between sites, it would hardly be surprising if there is a difference in performance between ostensibly similar sites as measured by reduction in specific energy. Added to these factors that can account for differences in potentials there are of course differences in managerial performance in identifying or creating, and exploiting opportunities.

The factors that influence the realistic potential in any one site at any one time are shown in Figure 7.1.

Differences in perceptions may come from two sources, differences in the quality of internal and external information flows, and differences in the selective perception of information by actors in the process. For example, in one site the possibility of condensate recovery may not be perceived at all because of a lack of knowledge about the efficient use of steam. At another site it is recognised but not considered realistic because the Chief Engineer once worked in a site where severe problems had been experienced with this technique. Such "Biases", or in some cases, paradigms, are important in determining what is considered achievable and appropriate by management. They reflect a failure to recognise the system and available techniques as they exist now, an undue discounting of newer techniques, and lack of "scientific inquisitiveness" about the system. Paradigms are discussed further in Section Three.

7.8 Measuring potentials

In order to measure the potentials as defined above at any one site it would be necessary to conduct a full technical survey to identify possible techniques, and then conduct cost benefit studies on each. Then the company's economic and other criteria would have to be applied to the resulting array of possible projects to determine which potential each technique fell into at that particular time. The resulting energy saving from each technique could be summed to give a total energy saving for each type of potential.

This is the sort of exercise that companies conduct before investing except the high cost and time extensiveness of gathering information at the required level of detail means that only projects that are judged likely to be viable are worked up into proposals.

Several other problems obscure the measurement of potentials. Firstly, managerial decisions outside the usually accepted boundaries of energy management are a necessary part of measuring potentials as defined here. Although it is conceptually possible to imagine an objective observer making notional rather than actual, i.e. actionable, decisions in order to measure potentials, there would seem to be little point if different decisions were taken to those that the company's management would take. Asking management to make these decisions is obviously possible. This would be a useful exercise from the point of view of the analyst and, if it forced management to consider important but previously ignored issues, from the point of view of the company. Other suitable agents of change or mechanisms such as short courses may stimulate this action.

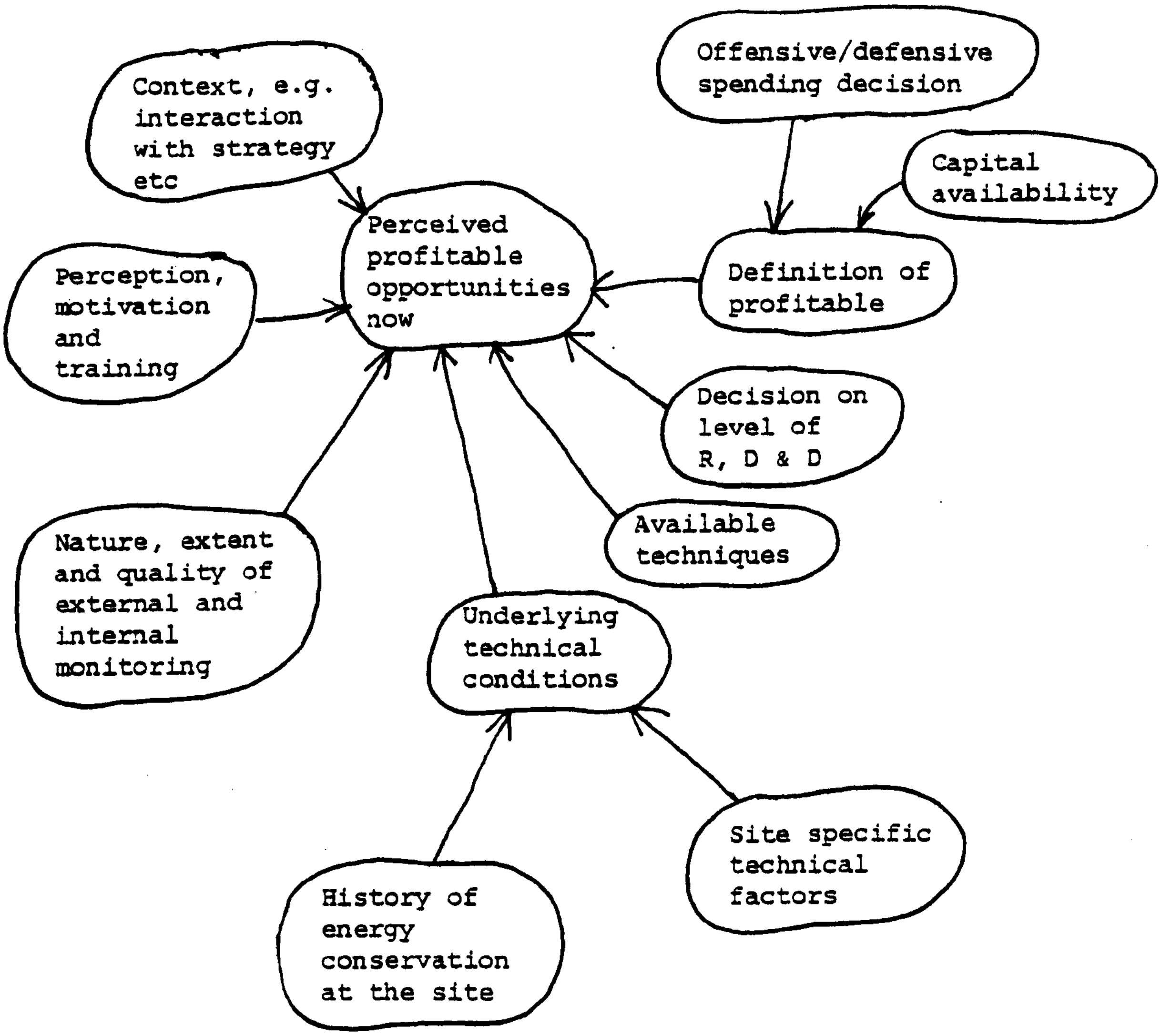
Secondly, it is hard to reliably estimate costs and benefits of techniques that have not yet been innovated.

Thirdly, there are two kinds of mutual exclusivity between both possible energy conserving techniques and other possible investments.

There is "true" mutual exclusivity, e.g. investing in a new, more efficient keg line that does not produce hot effluent removes the option of retrofitting a keg washing line heat recovery system on to the existing line. Then there is "designed in" mutual exclusivity, e.g. building a boiler house without sufficient space for the addition of an economiser increases the capital cost of retrofitting an economiser in future, thus making it uneconomic.

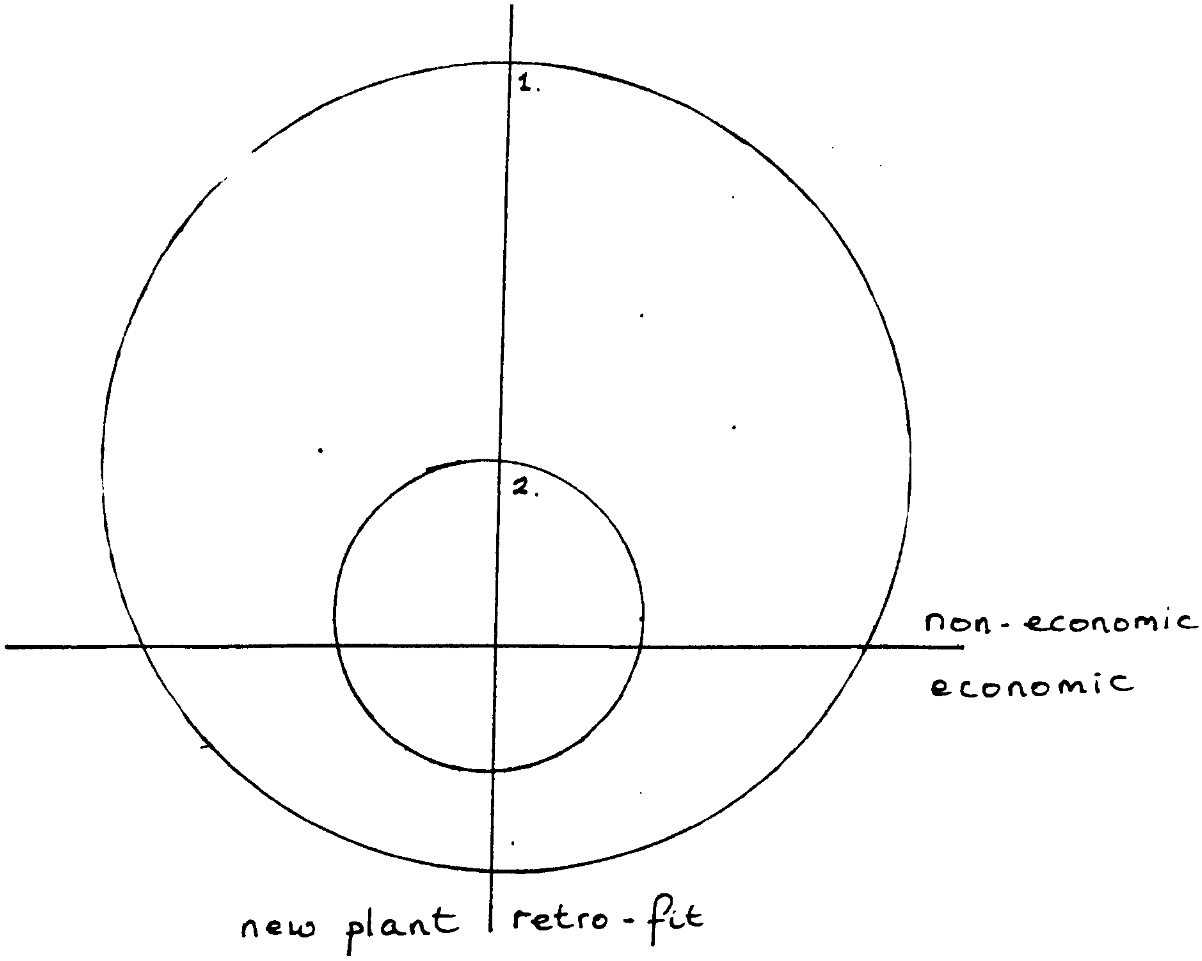
Finally, as prices and available techniques change, the potentials change. Thus any measurement of potential is likely to remain fuzzy. Attempting to objectively measure the potentials is probably not a worthwhile exercise for a company because of the high cost of information at the necessary level, and the ephemeral nature of the information gained, but viewing techniques as falling into different potentials is useful in planning investment portfolios. (See section on soft systems model).

Figure 7.1 FACTORS THAT INFLUENCE THE REALISTIC POTENTIAL IN ANY ONE SITE AT ANY ONE TIME



———▶ = Influences

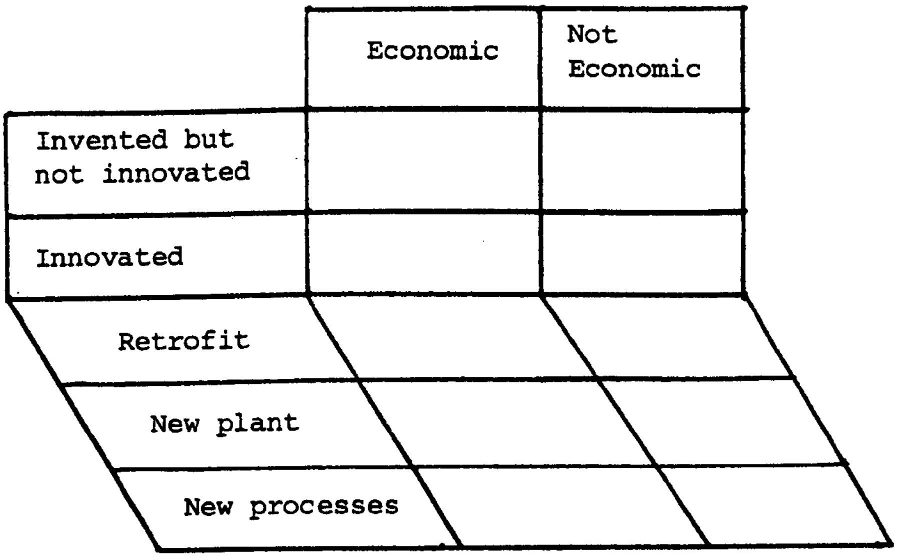
Figure 7.2 SCHEME OF POTENTIALS



1. Potential achievable through invented techniques.
2. Potential achievable through innovated techniques.

Invention of new concepts increases 1.
Innovation of a technique increases 2.

Figure 7.3 CATEGORIES FOR CLASSIFYING ENERGY CONSERVING TECHNIQUES



7.9 Measuring success or performance in energy management

We have seen the problems in objectively measuring potentials for energy conserving capital equipment. These problems are directly related to those in another important area, defining and measuring success in energy management. This topic has not been discussed in the literature and simplistic measures are frequently accepted without comment. The question of what consistutes successful energy management is an important offshoot of understanding the process of technical change resulting in energy conservation.

7.10 Specific energy for inter-site comparisons

As energy management, or conservation activity, results in a reduction of specific energy, i.e. energy per unit of output (ceteris paribus), specific energy or its reduction over time may be thought of as suitable measures of success or performance. Remarks such as those recently made by Ministers[1] suggest this may be accepted as a Government guideline.

As a measure for inter-site comparison single specific energy figures can only show a technical efficiency. No conclusions about managerial effectiveness can be drawn from simple comparisons of single specific energy because of the widely differing circumstances between sites and companies, even within the same industry. For example an old site with old plant in a bad lay-out (from an energy conservation point of view) will have a higher specific energy than an up-to-date plant with more

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[1] See for example statement by Lord Avon reported in Energy Management, 1984

efficient plant. An example of this is given by two liquid milk processing plants within the same group. One is five years old and has a specific fuel consumption only one-fifth that of a site, similar in output and product mix, which is twenty years old. Smaller breweries have a higher average specific energy consumption than larger breweries (Gordon, 1981). Thus no conclusions about managerial effectiveness can be drawn from single specific energy figures.

7.11 Reduction in specific energy for inter-site comparisons

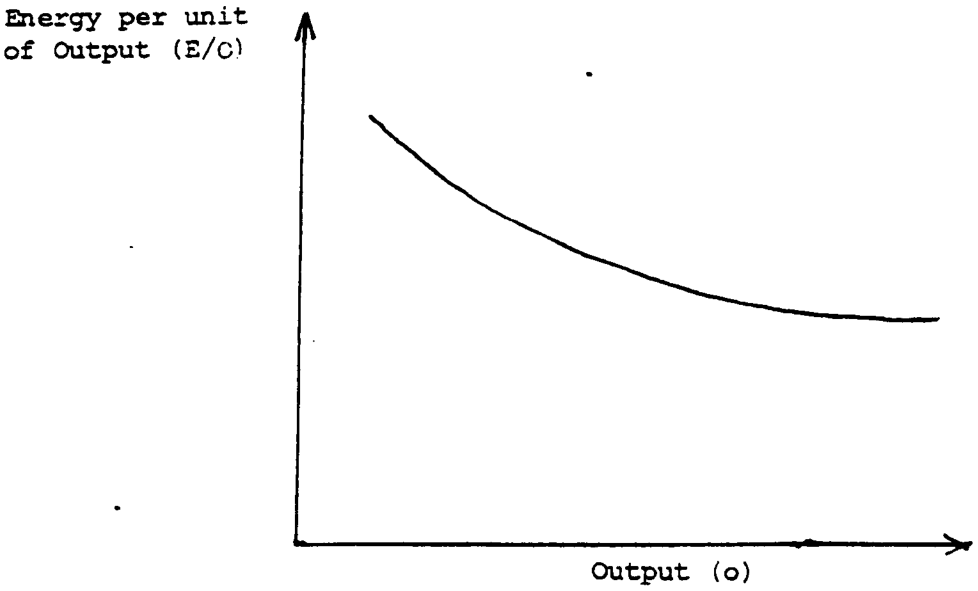
The reduction in specific energy achieved over time is often used as an indicator of success in energy management. "Savings" figures quoted in the press usually relate to unadjusted reductions in specific energy. (The adjustments necessary to make these figures valid are discussed later).

We have, however, seen that there are several valid reasons why the realistic potential for energy conserving equipment and hence conservation may vary from site to site. Thus the realistically achievable reduction in specific energy will also vary from site to site and using reduction in specific energy for making inter-site comparisons is invalid.

7.12 Reduction in specific energy for in-site comparisons

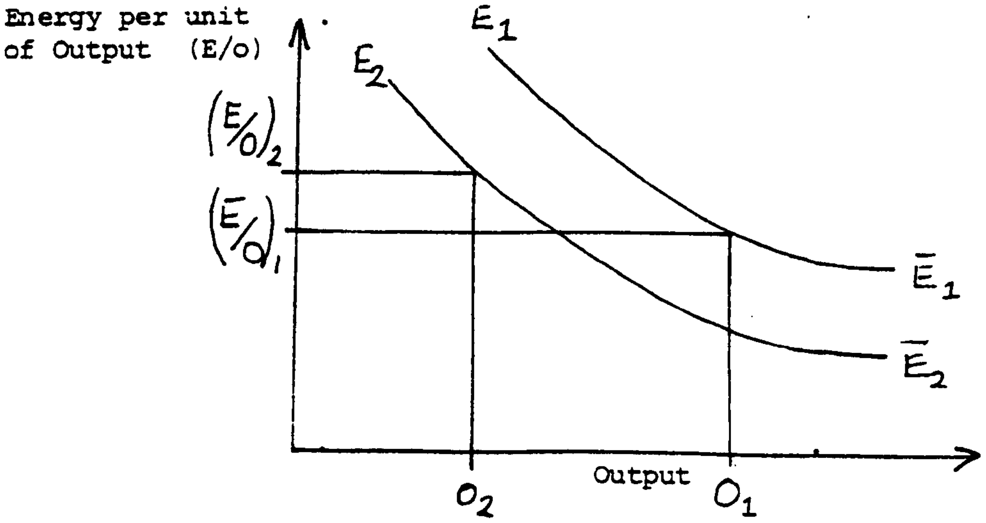
Even as in-site measures of conservation activity specific energy or its reduction over time suffer from several problems. Firstly due to the existence of a base load (a fixed energy use representing a fixed cost specific energy varies with production level or occupacity. A typical energy per output versus output curve is shown in Figure 7.4. As Boland (1982) points out, this may result in an increase in specific energy despite the implementation of effective conservation measures.

Figure 7.4 TYPICAL ENERGY PER OUTPUT VERSUS OUTPUT CURVE



This situation is shown in Figure 7.5, in which conservation activities displace the energy per output curve from $E_1\bar{E}_1$ to $E_2\bar{E}_2$. A reduction in output, however, from 0_1 to 0_2, increases the recorded specific energy in the period being monitored from $(E/o)_1$ to $(E/o)_2$.

Figure 7.5 EFFECT OF CONSERVATION ACTIVITY AT TIMES OF REDUCED OUTPUT



Secondly, in a multi-product situation, specific energy varies with product mix. Thirdly, where energy is used for space heating, or as in malting where ambient air is used in combustion, specific energy varies with season and climate due to variations in ambient air temperature. Fourthly, there are start-up and shut-down effects caused for example by the need to bring process equipment up to a certain temperature before production can begin. Finally, there can, in some processes, be yield effects. In the distilling process, for example, an increase in the quantity of water in the incoming-grain increases the minimum energy necessary to produce a litre of spirit. An effective energy management system needs to correct for all these variances if management efforts, and attempts at national reporting such as the Brewers' Society surveys, are not to be misleading.

In the brewing sector only two sites out of fourteen corrected specific energy for any of the variances mentioned above. Of the other twelve sites, nine used an uncorrected specific energy index and three did not monitor specific energy. In the nine sites it was acknowledged that these variances occurred and factors such as cold weather were considered before taking action when high specific energy values occurred.

In the dairy sector two companies corrected for major variances while four companies, covering nine sites, did not. Two other companies did not use specific energy as an index.

In the distilling sector two companies, covering ten sites, corrected for the variances using a computer based system. Two other companies, covering sixteen sites, did not although one was considering a computer based system. A major barrier was seen as being the difficulty of deriving data from historical records of energy use and production.

In the malting sector two companies, covering sites took account of variances caused by ambient conditions in comparing specific energy with targets.

A problem with specific energy for external analysts is that not all sites calculate values for this parameter. The basic data exists in the company records but the two sets of figures, energy use and production, are not used to produce a ratio in all companies. In one dairy this is because specific energy is not regarded as a useful index, a cost based system is used instead, In the brewery sites that did not report specific energy figures, however, this reflects the poor quality of management information systems. These sites were all small in production capacity.

Reduction in specific energy over time, usually in an uncorrected form, is frequently used as a basis for reported "savings" and by implication, performance. For comparisons in one site over time it is a valid measure, subject to the corrections described above, but as a means of comparing sites it is of limited use. As we have seen there are several reasons why the achievable potential for energy conservation equipment, and hence the achievable reduction in specific energy, may vary between sites. Simple comparisons of reduction in specific energy cannot take these into account.

7.13 The Brewers' Society Index

In devising a targetting system for its industry, the Brewers' Society recognised that specific energy is an inadequate measure of individual brewery performance due to differing circumstances between breweries. A means of taking account of some of these differences was devised and is shown in Appendix 17.

An allowance, expressed in MJ/hl, is allocated to the particular process used as shown and this sets a target figure for each process. The total target figure for all brewing and packaging is divided by the actual consumption to give the "usage efficiency". The efficiency of fuel and electricity usage can be determined separately. (A usage efficiency greater than 100% indicates a performance better than the established target).

Although the Brewers' Society does take into account the use of different processes, it cannot consider the effects of different vintages, different types of plants for the same basic process, different plant layouts, different profitability criteria or other factors that affect the limits of viable conservation activity. It also does not correct for variances caused by occupacity, product mix, season or climate.

Gordon (1981) reports that the main variables affecting consumption in a given plant are space heating and occupacity. Other factors, such as the type of beer brewed or the range of beer brewed, are "unlikely to be significant until the specific energy fall below 2.0 MJ/hl or the usage efficiency exceeds 100%". (Gordon, 1981).

Gordon also shows how a simple linear regression exercise can be used to correct for space heating and occupacity variances. As we have seen however, such corrections are rarely made in practice.

7.14 Summary

The factors that affect the realistically achievable energy conservation potentia, and hence the achievable reduction in specific energy, mean that the use of reduction in specific energy over time as a measure of inter-site comparison is invalid. The fact that one site has achieved a reduction in specific energy of 20% over the last five years does not necessarily mean that it has better energy management than a site that has achieved a reduction in specific energy of 10% over the last five years. The realistically achievable potentials may have been different in the two cases and, in fact, the second site may have exploited a greater proportion of its achievable reduction than the first site. Thus, it could be said to have better energy management. In order to make valid judgements about the effectiveness of energy management it is necessary to go beyond figures and examine the company in-depth in a systematic way.

A company that is successful at energy management can be defined as one that has identified and exploited, or is in the process of exploiting, its achievable energy conservation potential.

Indicators of successful companies include: knowledge of available energy saving techniques; evidence that these have been evaluated in a "scientific" manner; well defined and known investment criteria; evidence of systematic thinking; a stock of evaluated but not viable projects; well developed information and control systems; evidence of staff training and a positive attitude towards energy conservation.

Chapter Eight

ESTIMATING INDUSTRY WIDE POTENTIALS

8.1 Introduction

After defining potentials for energy conserving capital equipment on a site basis and describing the problems in measuring them, it is necessary to raise the question of estimating industry wide potentials. It has been argued above that potentials have to be defined on a site by site basis to allow for site and company specific factors. This thesis, however, set out to examine the potential for energy conserving capital equipment in UK industries, implying industry wide estimates are required. By defining potentials on a site basis any estimate of industry wide potential becomes arbitrary. This section examines some estimates of industry wide potentials, compares them to the framework of potentials developed earlier, and advances some estimates based on the surveys of the four sectors.

8.2 Estimates of potential in the literature

The Energy Audit Series estimated technical potentials, with no regard to commercial constraints, for total primary energy conservation in inter-alia, the brewing, malting and dairy sectors. The potentials reported are summarised in Table 8.1. No similar estimate for the distilling sector is available.

The Energy Audit Series reports, according to their common introduction, are "based on a detailed examination of the processes involved and of manufacturing practice." As no regard is paid to commercial constraints, and the Series includes in some cases techniques that at the time of writing had been invented but not innovated, this potential is most akin to that available though invented but not innovated techniques. It does not, however, include all possible energy saving concepts but concentrates on those that are under development.

Table 8.1 ESTIMATES OF THE TECHICAL POTENTIALS FOR ENERGY CONSERVATION IN THE BREWING, MALTING AND DAIRY SECTORS MADE IN THE ENERGY AUDIT SERIES

Sector	Total primary energy used in base year (MGJ)	Base Year	Primary energy Saving Potential (MGJ)	Saving potential as a %
Brewing	26.5	1976	8.76	33
Malting	9.8	1980	7.84	80
Dairy	28	1974/75	6.4	23

Sources: Harris, 1978, 1979, 1981.

Roberts (1983b) reports: "experience suggests that, starting from a 1983 base, the scope for saving probably stands at around the 30% mark, divided almost equally between the three categories - measures involving no capital cost, low cost and high costs". Despite basing this claim on experience, the twenty cases cited by Roberts, covering a range of industrial and commercial activities, saved "only" between 5 and 22%, averaging 14%. No indication of the time scales over which these savings were achieved is reported. From these cases it appears that only some of the medium cost and none of the high cost measures are being exploited, possibly because they fail to meet economic criteria. The figure of 30% is arbitrary.

8.3 Estimates of potentials in the four sectors

Using the data reported in Section One it is possible to make informed estimates of the realistic potential for each sector. The method is to examine the savings achieved by sites which have had a well developed energy management programme for the last five years. The average saving achieved over the period is assumed to have been generally achievable over the period, i.e. form a realistic potential for the industry. In each sector some sites are moving towards exploiting that potential while others have yet to begin.

The potentials form a short term (say five years) potential achievable using technically feasible and economically viable techniques, mainly retrofits to existng plant. Each site of course will have a different array of viable techniques because of the site and company specific factors. A longer term potential is derived from those sites that have invested in new plant or greenfield sites.

The estimates for each potential, as well as the actual industry achievement over the last five years where known, are summarised in Table 8.2. The difference between the short term potential and the industry achievement over the last five years gives some indication of the slackness in the sector, or the take-up of viable opportunities. The averages derived from the sampled companies in dairy, distilling and malting sectors, are probably higher than the actual industry averages because the sample of interviewed companies was biased towards companies known to have active energy management programmes.

These estimates are made ceteris paribus whereas in the time scales envisaged both prices and the available techniques will change, thus changing the potentials. These estimates may be useful in providing targets for sites with no previous energy management activities although they should not be lifted wholesale. Target setting requires knowledge of the individual plant and company characteristics as well as industry "norms".

8.4 Discussion

It has been argued that estimates of industry wide potential are arbitrary. The estimates made here are also arbitrary but have explicit assumptions. Concentrating on the realistic short term potential, i.e. that achievable using existing hardware that is at least economic in some sites, reduces the uncertainties inherent in such estimates.

Table 8.2 ESTIMATES OF THE POTENTIALS IN THE FOUR SECTORS

Sector	Short term potential (%)	Long term potential (%)	Industry achievement over the last 5 years
Brewing	20	25 - 50	16.5 (1)
Dairy	20	25 - 50	14 (2)
Distilling	20	25 - 50	17 (2)
Malting	40	40 - 80	32 (2)

Notes:

All potentials are relative to 1978/79.

(1) An industry wide figure derived from the Brewers' Society surveys.
Source: Energy Management, February 1984.

(2) Average figure for sampled companies.

Earlier it has also been argued that examining the processes of technical change leading to energy conservation is at least as important as making arbitrary estimates of potential. It is relevant to ask what proportion of sites have exploited, or are in the process of exploiting, their potential for energy conservation as constrained by existing technology and current prices. The brewing sector sample is discussed in these terms below.

8.5 Small breweries (<299,000 hl/a): potentials

The nine sites that have invested in retrofit measures reported savings of between 2 and 8% over the last two years with eight sites saving between 2 and 5%. Three sites had incorporated energy saving features into new plant and saved between 10 and 25% over the last two years, and up to 50% over the last five years.

It could be assumed that savings of 5% were generally achievable in this sub-sector over the last five years. About one-quarter of sites had not achieved any reduction at all. The long term potential is between 25 and 50%, but because of financial constraints in this sector, this is only likely to be economically viable through investment in new plant, not retrofitting. (Of course there is no guarantee that energy saving features will be incorporated in new investments and several examples of failure to do so have been found - see Section Three). The challenge in this sub-sector is to ensure management are aware of the possible improvements and their cost-effectiveness when considering new plant investment[1].

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[1] Given the long life of capital plant in this sector it can be expected that the small brewery sector, which has a higher average specific energy than larger breweries, will lag behind in improvements as larger breweries invest in retrofitting. There is some evidence to show this is already happening. (Long, pers. comm.).

8.6 Medium and Large Breweries (<300,000 hl/a): potentials

About one-third of sites in these sub-sectors have had energy management programmes over the last five years. Most of these sites are at or near the limit of energy efficiency set by available techniques, current prices and investment criteria. They report difficulties finding projects that meet their investment criteria. (This does not imply that they are at an absolute limit. Creative thinking, willingness to innovate, or simply questioning old assumptions can usually yield new savings even in these sites). These sites have achieved reductions in specific energy of between 10 and 60% over the last five years with most saving 20 to 30%.

The remaining two-thirds of companies in these sub-sectors have some form of energy management programme, which often has not been established for five years. Many of these sites could, in time, be expected to achieve their potential for energy conservation, ceteris paribus.

Overall in the brewing sector sample, about one-quarter of firms could be said to have exploited their potential for energy conservation over the last five years. About half of the firms have some form of energy management and are likely to exploit it in time. The remaining quarter, mainly small firms, are making little or no progress towards achieving their potential. The constraints in the small sub-sector may mean that the potential can only be exploited through incorporating energy saving features in new plant.

8.7 Summary

From the definitions of potentials it follows that any estimate of industry wide potential will be arbitrary. The estimates of potential presented for the four sectors are arbitrary but based on the data reported in Section One. Estimtes of the proportion of sites in the brewing sector that have exploited, or are exploiting their potential, were also given. Objective measurement of industry wide potentials is not possible; this is an important result of this research. Any industry wide estimates of potential must be viewed with caution.

Chapter Nine

A SOFT SYSTEMS MODEL OF ENERGY MANAGEMENT

9.1 Introduction

This section describes a soft systems model of management activities necessary for exploiting profitable energy conservation opportunities in industrial firms. A soft systems methodology, developed by Checkland (1976, 1981), has been used. This approach forces a structured debate rather than producing a "hard" solution. The general model outlined here is not to be taken as a "final development", nor as a description of the real world, only as a starting point for debate in specific companies. In describing the model real world examples have only been used where necessary to illustrate the need for certain activities.

Following the Checkland approach the model was developed after extended observation of the real problem situation in several companies, examination of the literature, and participation in the energy management process in two companies. As stressed in Checkland (1981), the model is a purely conceptual, logical device and not meant to be a model of the real world. Insights come from comparing the model with the outside world. The model is shown in Figure 9.1 and deeper levels are shown in Figures 9.2 to 9.6.

In the thesis the model has two roles. Firstly it is an attempt at presenting a logical, systematic model of the activities necessary in an energy management programme. Secondly it is used in Section Three to give a finer resolution in examining real problems in energy management that reduce both energy savings achieved and return on capital employed.

In industry energy management has become a recognised activity but the nature and quality of this activity differs widely. Much that has been written on "energy management" is concerned with energy engineering rather than management. The model described here represents an attempt to define the activities of energy management. It is believed that the basic model is applicable to the management of other resources, such as water, which are likely to become increasingly expensive.

Three levels within energy management can be distinguished:

1. Good housekeeping which is concerned with running existing plant in the most efficient manner.

2. Retrofitting which is concerned with the addition of hardware designed primarily to save energy onto existing plant; and

3. New equipment purchase which is concerned with ensuring energy conservation is a factor in new plant design and purchase decisions.

All three levels interact and are constrained by external (i.e. external to energy management) factors. These interactions will be described below.

9.2 The hierarchy of systems

It should be noted that the system modelled here fits into a hierarchy of corporate systems and interacts with them at various levels. In this model, for example, it is assumed that the allocation of resources between offensive spending, e.g. new product development, marketing campaigns, and defensive spending, cost cutting on existing products and processes, is a given factor. Success in energy conservation may lead to a change of this allocation in the absence of other, more attractive projects. Alternatively of course, a reduction in available resources will affect the amounts available for defensive spending such as energy conservation.

9.3 System objective

In soft systems the objective is not clearly defined. The soft systems methodology starts from a Root Definition of the problem, based on rich observation of the problem situation.

The following Root Definition was selected:

> to design a management system for an industrial company that encourages staff and other agents of change to create, identify and exploit energy conservation investment opportunities that are profitable to the firm, subject to constraints.

Checkland (1981) uses the mnemonic CATWOE to check for well formed Root Definitions. The five elements in this example are:

Customers; the company

Actors; the staff of the company and other agents of change, for example consultants and government agents.

Transformations; information and other resources are transformed into action that exploits profitable energy conservation investments.

Ownership of the problem; the company

Environmental constraints; although not made explicit in the definition their existence is recognised. Possible constraints include investment finance, expertise and the risk levels the company is willing to accept.

Added to the five elements above, but not explicit in the Root Definition is a Weltanschauung, "an outlook, framework or image which makes a particular Root Definition meaningful" (Checkland, 1981). In this case the outlook is that exploiting profitable energy conservation opportunities is a desirable activity.

9.4 The activities in the model

We now consider the activities in the systems model shown in Figure 9.1. Each level of energy management activities will be considered in turn.

9.4.1 Good housekeeping level

An internal monitoring system is necessary to gather data on energy usage and costs. The data has to be processed into information that is useful to decision makers and delivered to them in time for them to take effective action. To be a guide for action energy usages and costs have to be broken down to answer the question, where is the cost being incurred? As Drucker (1964) says, "it is impossible to manage an aggregate." The breakdown of energy costs into cost centres is advocated by Hewgill et al (1979), Murphy and McKay (1982) and Roberts (1983). This requires more extensive metering than is common at present, a topic discussed in a later section.

In order to be meaningful current energy consumptions must be compared with targets or budget figures. This is stressed in Jacques (1981), Roberts (1983) and Finer (1984). For effective good housekeeping variances must be identified quickly by the decision maker with control over the cost centre. Then, the cause of the variance can be identified and appropriate action taken (which may in fact be no action if the costs of action are judged greater than the benefits).

9.4.2 Investment levels (retro-fit and new plant)

The information system described above is also necessary at the level of retrofit investments. Clear targets are acceptable proxies for economic "optima" that are unknowable and constantly shifting as prices and technology change. Well chosen targets also act as a clear policy guide and a stimulus to action, i.e. tney motivate. The selection of overall and cost-centre targets, given the effects of climatic, seasonal, production and product mix variances faced by most companies is a difficult task rarely addressed as was shown earlier in Section 2.

To identify or create investment possibilities requires information about energy costs coupled with a knowledge of "relevant" technical concepts. Creativity may redefine what is relevant, and the use of creativity techniques may be helpful at this stage. A creative synthesis of internal and external information is necessary.

The process of technical change as already described suggests that an explicit decision on the appropriate level of innovation is necessary. For a firm willing and able to innovate in the energy conservation field the appropriate stage may be pre-prototype. For other, more common companies with less resources, the appropriate level may be simple adaptation of already innovated techniques.

Once potential opportunities are identified they must be appraised technically, economically and contextually. These appraisals interact in an iterative process (see section on technical change) which may itself lead to new ideas. The contextual evaluation is often neglected (see Section Three for example). There is often an excessive concentration on hardware to the detriment of managerial, organisational and training "software".

Both hardware and software must fit on all relevant levels. Engineers who design, specify or install the hardware need to understand it; maintenance staff need to be able to maintain it; and operators need to be able to operate it. Although these points seem obvious they appear to be often forgotten in project appraisal. Any training or use of an outside resource that is necessary is an additional cost that should be considered at the investment appraisal stage. Social costs, either internal or external to the company, may also need to be considered, e.g.

noise, vibration or emissions. Other dimensions of contextual evaluations include deciding whether a project fits with corporate strategyl marketing strategy, and personnel policies. Interactions between technical, contextual and economic evaluations suggest that the overall "adoption" decision is more complex than simple linear models imply. Even Baker (1983), dealing as he does with a single adoption decision, does not do justice to the complexity of the process.

Energy conservation investments can interact with each other and with process plant or operational changes. Such interactions, which can be synergistic or negatively synergistic, need to be anticipated in the evaluation/design stage to ensure investment returns, and energy savings, are maximised. Examples of interactions are discussed in Section Three.

Interactions between projects and the scarcity of capital in most firms suggests that assembling a portfolio of possible projects would be a useful activity. If insufficient resources are available for both of two synergistic projects in one period they could be phased with full benefits coming after the second project. Assembly of a portfolio would also make checking for negative or positive synergy explicit and allow marginal projects to be easily reassessed as conditions change.

Any investment in energy conserving plant will affect energy consumptions and costs and possibly necessitate retargetting for the cost centre involved. Any corporate plan should be assessed for energy implications. Constraints such as fuel use limits (common for industrial gas users in the early 1980s) or boiler capacity may exist. The provision of new boiler capacity, which requires substantial planning time and capital, may affect the viability of a corporate plan.

Alternatively, plans to reduce capacity could lessen the attractiveness of energy conservation investments. There would be little point investing heavily in energy conservation in a plant that was due for closure within a short period. These interactions suggest a need for a corporate energy plan or policy.

Choice of basic process technologies affect the range of viable conservation investment opportunities. There is a need for a technology policy as advocated by Pappas (1984).

The status and relevance of developing technologies, both in production and ancillary activities (e.g. heating and ventilating) and both in retrofit and new equipment, need to be reviewed regularly so that they can be considered as investment opportunities at an appropriate stage of their development.

Figure 9.1 SOFT SYSTEMS MODEL OF ENERGY MANAGEMENT ACTIVITIES

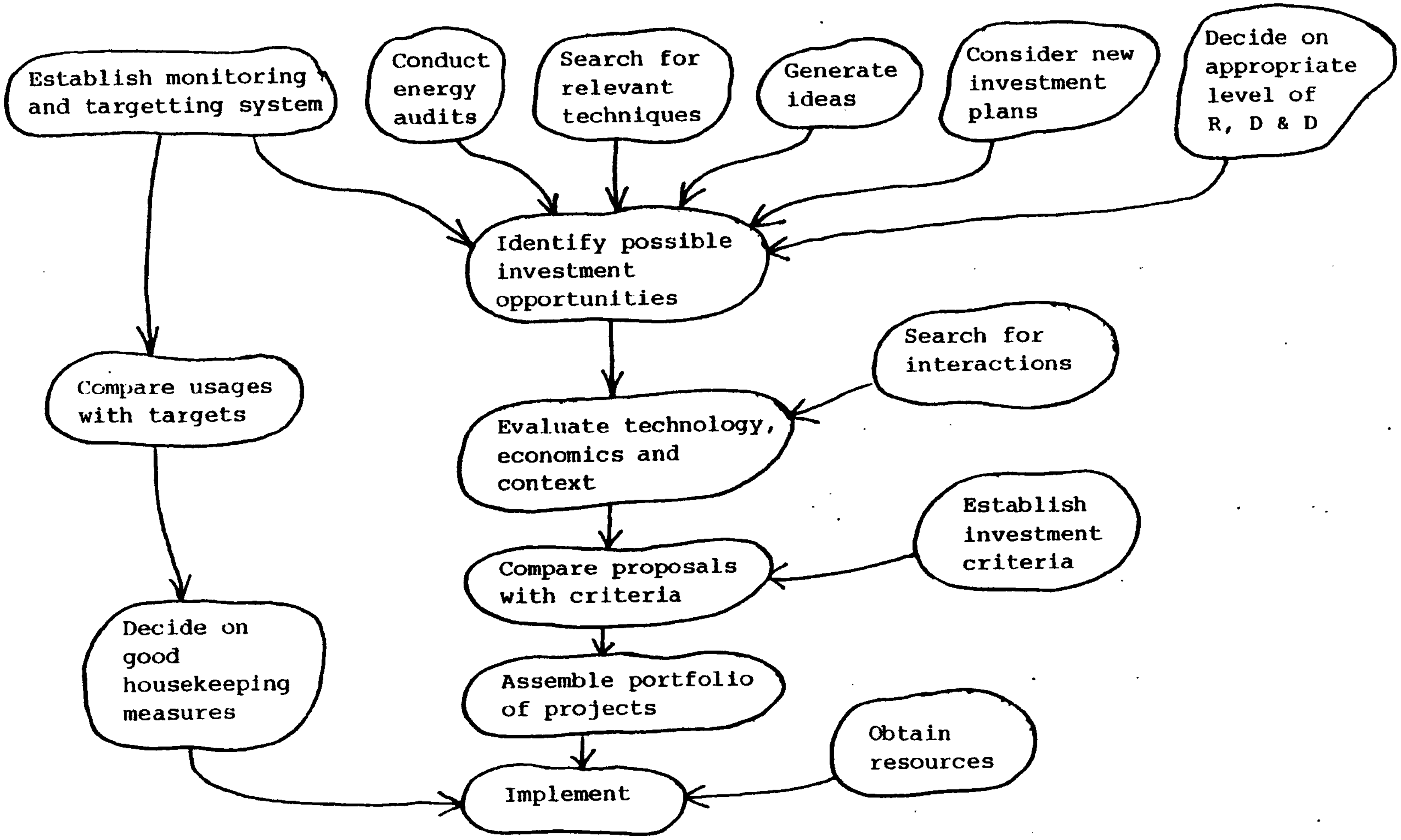


Figure 9.2 SUB-SYSTEM FOR GOOD HOUSEKEEPING LEVEL

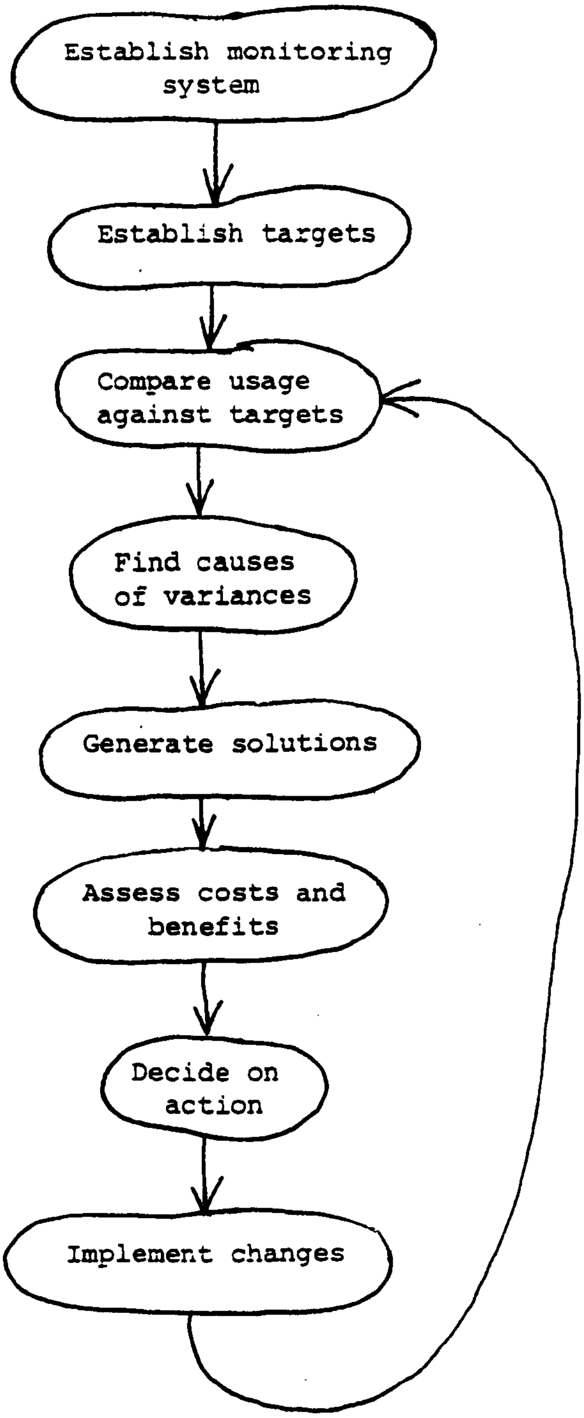


Figure 9.3 SUB-SYSTEM FOR IDENTIFYING RETROFIT INVESTMENT OPPORTUNITIES

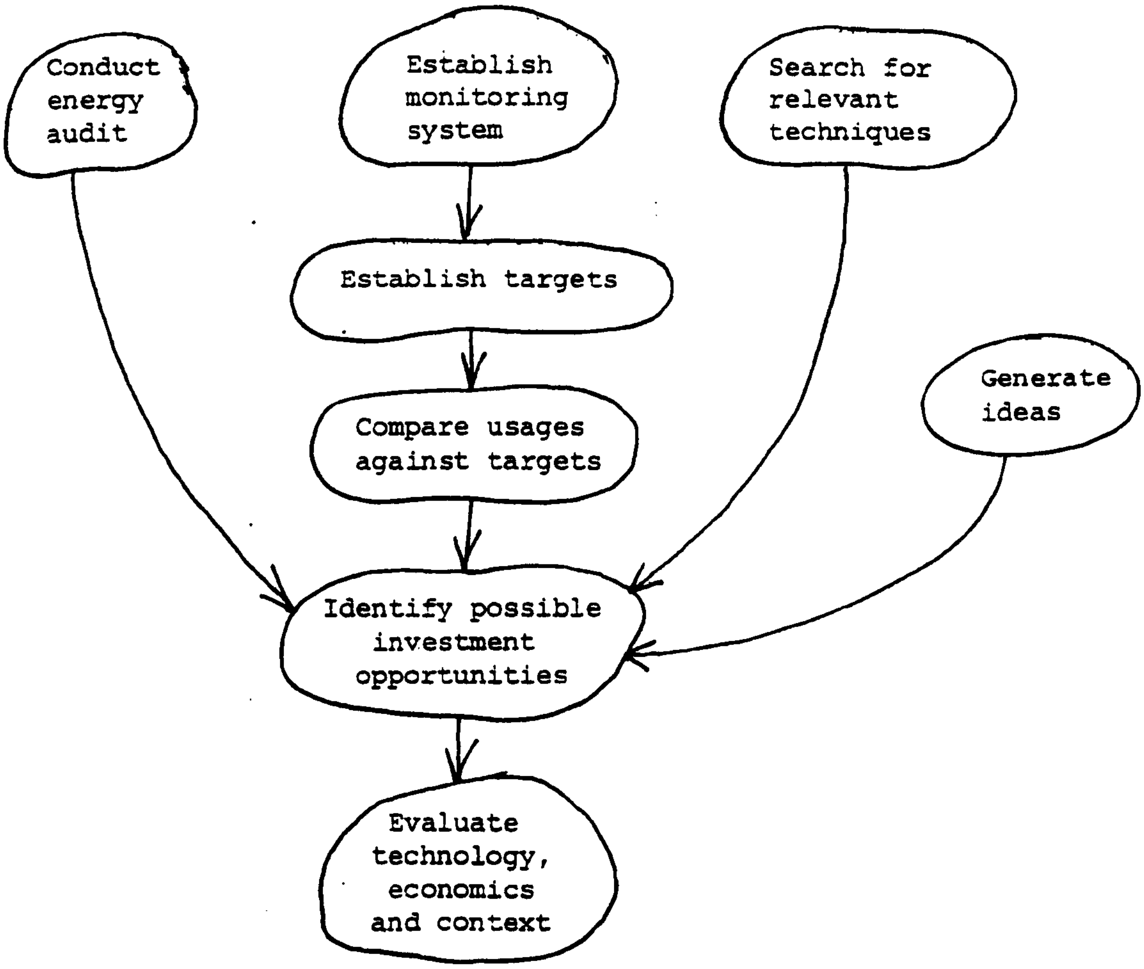


Figure 9.4 SUB-SYSTEM FOR EVALUATION STAGE

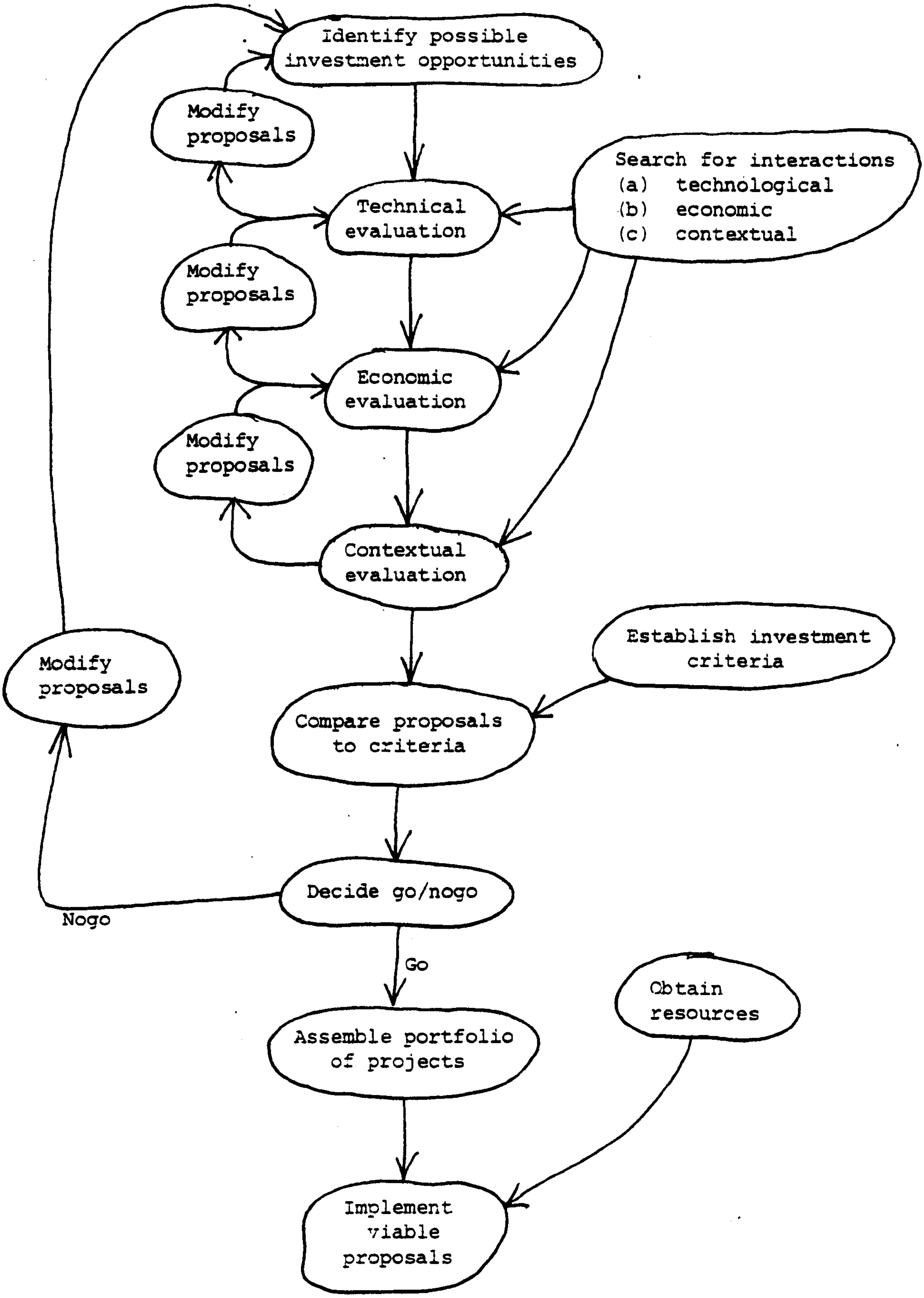


Figure 9.5 SUB-SYSTEM FOR NEW INVESTMENTS

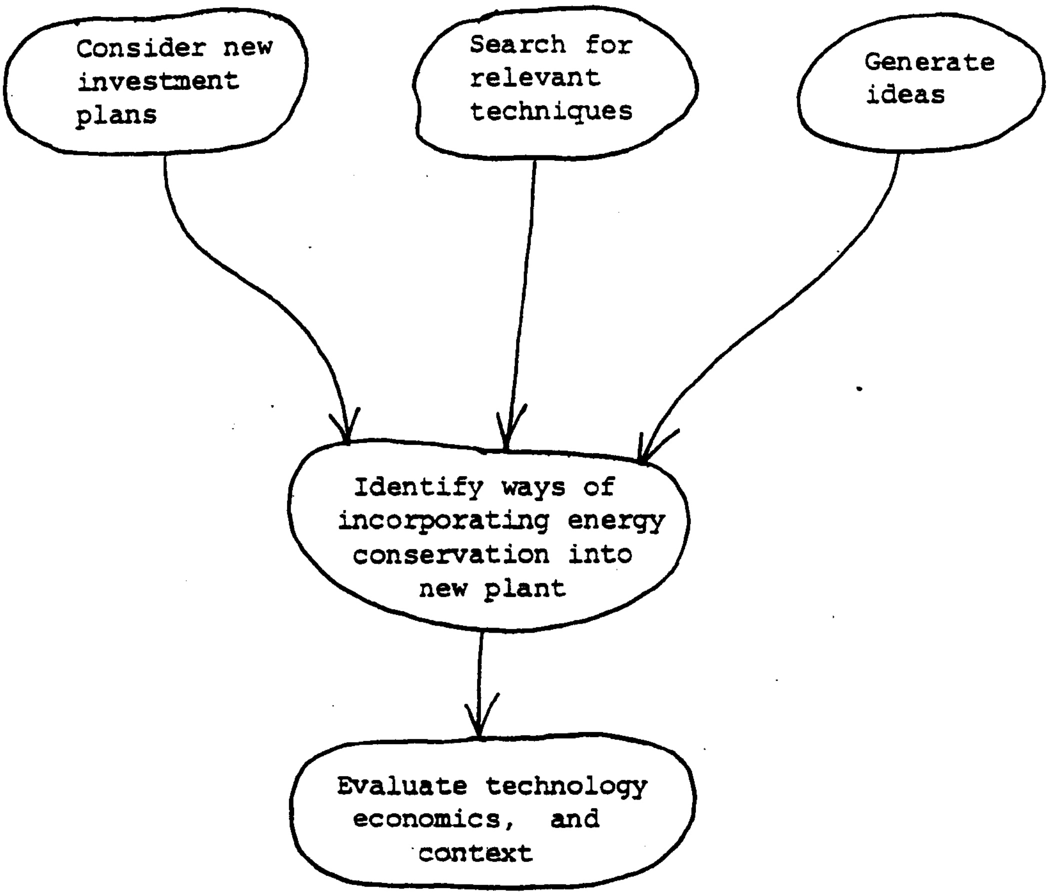
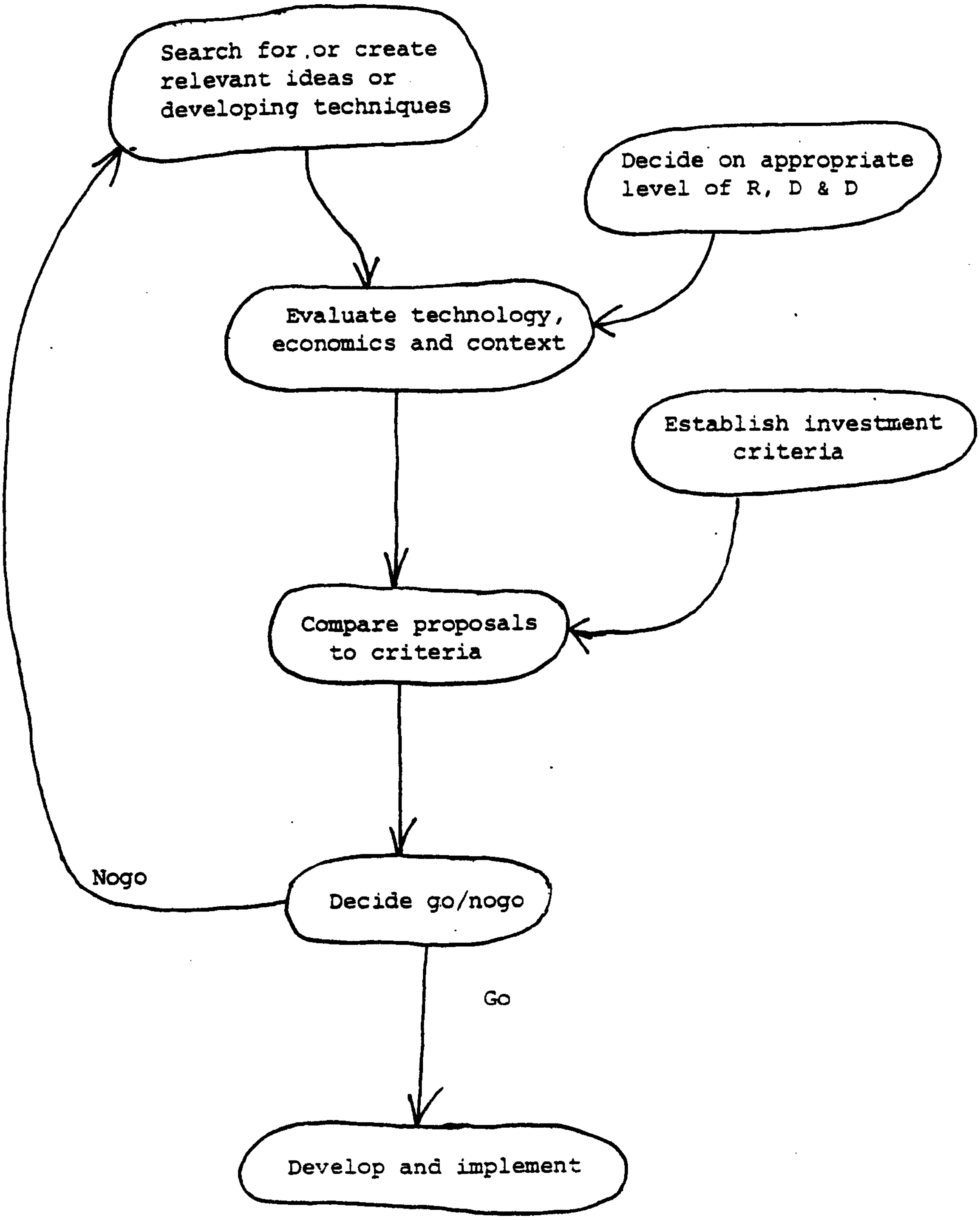


Figure 9.6 SUB-SYSTEM FOR ACTIVELY DEVELOPING NEW TECHNIQUES



9.5 Summary

A soft systems model of the management activities necessary for exploiting a company's energy conservation potential has been presented. It is necessary to examine the nature of energy management as its presence is the major mechanism of change resulting in energy conservation. Without some form of energy management conservation, opportunities will not be exploited however profitable they are.

The soft systems methodology develops models that should be taken as starting points for discussion rather than final solutions. This model is no exception.

The activities within the model are on three levels: good housekeeping, retro-fit projects onto existing plant, and new plant investment. All three interact. Monitoring of energy costs and consumptions is vital to all three levels. The basic process is to monitor, establish targets and identify or create possible conservation measures. These are then subjected to technical, economic and contextual evaluation and developed from concepts through final design to implementation. The process has many feedbacks and interactions.

This soft systems model, although developed for energy management, could profitably be adapted to the management of general technical change.

SUMMARY OF SECTION TWO

Section Two has necessarily been wide ranging. It started with a model of the process of technical change which results in energy conservation. Most works on technical change have concentrated on large scale innovations whereas most energy conservation, and indeed probably most technical change, is in the form of incremental improvements. Similarities between the technical change model and Baker's (1983) model of buying behaviour and Asimow's (1962) model of the design process were highlighted. The process of technical change is essentially a design process.

The importance of adaptability in the adoption of techniques was stressed. Site specific factors ensure that economic viability in one site does not ensure viability in another, ostensibly similar, site. This has important consequences for defining potentials for energy conserving equipment as well as casting doubts on the usefulness of diffusion studies. At each site, even for techniques using standard hardware, site specific factors must be considered in order to engineer a system that will meet the required profitability criteria.

The model of technical change was used in order to define potentials for energy conserving equipment on a site by site basis. One potential involves techniques that have been invented, techniques which can be for retrofitting, new production techniques using the same basic process, or for new processes. A sub-set of this potential is the potential utilising techniques that have been innovated, i.e. commercially installed. This can also be divided into the potentials due to retrofit, new plant and new process techniques. Both these potentials can be conceived as being either economic, or non-economic, as defined by the particular company.

It was argued that only the economic,as defined by the company, potential can be regarded as "real". Any other definition would encourage sub-optimisation.

Reasons why real potentials may differ between sites were advanced. Apart from the site specificness of economic viability the reasons are:

1. Differences in financial criteria
2. Differences in context, e.g. strategy
3. Differences in historical performance in exploiting energy conservation opportunities.
4. Differences in the level of innovation that will be attempted.

Given these reasons why potentials may differ between sites, it is hardly surprising there may be differences in performance as measured by reported reductions in specific energy.

The problems of measuring potentials for energy conserving equipment were discussed. It was argued that to measure them would require an extensive engineering exercise with cost benefit analysis of all possible techniques. This would be an extended version of the energy audits, sometimes undertaken as part of an energy management programme. The cost in money and time of gathering information at the level needed to measure potentials mean that it is unlikely to be undertaken by companies. Considering which potentials different techniques fall into at particular sites, however, could be a useful activity for management and other agents of change.

The issues involved in measuring potentials are related to those involved in measuring success in energy management. Commonly quoted measures used to imply success, including the reduction in specific energy utilisation used in Section One, were shown to be simplistic. Single measures or ratios cannot be used to imply managerial success without consideration of many relevant factors such as

site characteristics
site history
financial investment criteria
context
appropriate level of innovation.

Each site considered in simple comparisons may be at different stages of the development of energy management structures and techniques.

Given the definitions of potentials on a site basis any attempt at estimating industry wide potentials can be seen to be arbitrary. Estimates from the literature were reviewed. Using the data from the sampled companies in the four sectors, estimates of industry wide potentials were made. These are recognised as being arbitrary but are at least based on explicit assumptions. The arbitrary nature of industry wide estimates is an important conclusion of this research.

Finally, a soft systems model of the activities necessary to exploit profitable energy conservation opportunities was presented. This is based on both the model of technical change and extended observation of the real world problem situation. This model was advanced for two reasons; it is a prescriptive guide for management designing energy management systems, and it serves as a diagnostic tool for examining problems within energy management which are discussed in Section Three.

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Section Three

BARRIERS TO FURTHER CHANGE

SECTION THREE

BARRIERS TO ENERGY CONSERVATION INVESTMENT

INTRODUCTION

The barriers to energy conservation investment can be divided into two categories:

(a) techno-economic
(b) managerial

The term techno-economic is used as there are rarely purely technical barriers to applying existing equipment, the problems come when technical factors cause failure to meet the required economic return, hence preventing investment. Managerial barriers include all aspects of management that prevent investment in profitable opportunities.

Profitability modelling is used to explore economic barriers for a number of techniques. Heat pumps and combined heat and power (CHP) are two techniques that have received much attention in the literature and in industry. Although CHP has long been established recent changes in technology and legislation concerning private generation of electricity merit renewed interest. Heat pumps are an old concept but are a fairly recent innovation. As far as the four sectors studied are concerned they have not yet been widely adopted. The other techniques for which profitability modelling is conducted have all been applied in the sampled companies in the four sectors.

It was stressed in both the previous sections that the profitability of energy conservation techniques is sensitive to site specific factors. The profitability modelling of heat pumps and CHP is based on specific sites while for the other techniques it is more general, although still based on practical examples.

The majority of this section is concerned with managerial barriers because of the site specificness of profitability. Without some form of energy management activity the profitability of techniques will not even be evaluated and so it is considered that managerial barriers are more important than economic barriers. The soft systems model of management activities necessary in energy management advanced in Section Two is used to explore examples of different categories of management problems discovered in the sampled companies and in the literature.

TECHNO-ECONOMIC BARRIERS

The profitability of two major techniques, heat pumps and combined heat and power are modelled for specific applications in the next two chapters. The purpose of this modelling is to explore which potential the techniques fall into. As yet these techniques have not been widely adopted in the four sectors studied. Although concentrating on the profitability issue, these chapters also address other problems likely to impede the adoption of these particular techniques. Brief technical descriptions of the techniques are contained in two technical appendices. A third chapter examines the profitability of other, more widely adopted techniques.

Chapter Ten

HEAT PUMPS FOR HEAT RECOVERY IN THE BREWING AND DAIRY SECTOR

10.1 Introduction

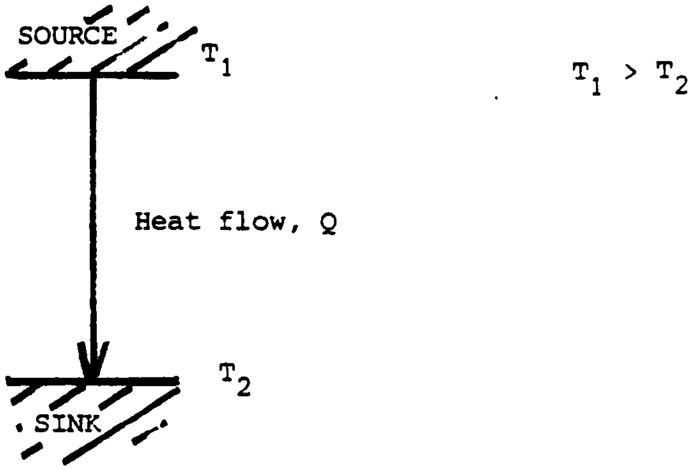
The heat pump, the invention of one form of which is generally attributed to Lord Kelvin, is thermodynamically identical to the household refrigerator. The principle difference between the heat pump and the refrigerator is in the role they play as far as the user is concerned. On the one hand refrigerators (and air conditioners which work on the same principle), provide useful cooling, whereas the heat pump provides useful heat.

Heat pumps should be contrasted with conventional heat exhange or recovery. The second Law of Thermodynamics requires that heat flows down a temperature gradient. It can only be made to flow up a temperature gradient by the input of work and it is this principle that the heat pump is based on.

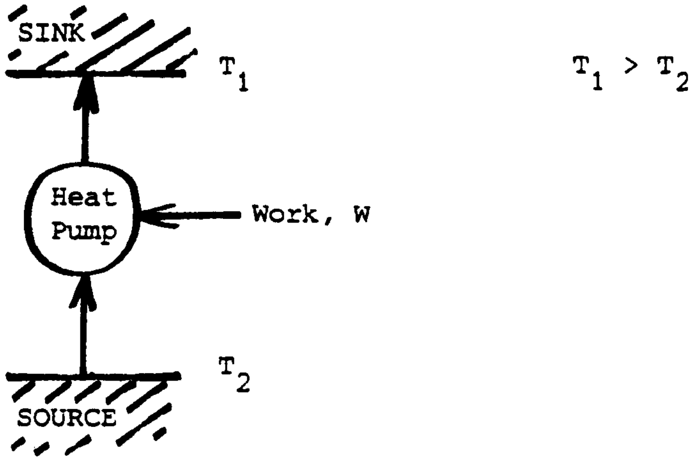
Figure 10.1 shows the two cases. In 1.a, normal heat exchange, heat (Q) flows down the temperature gradient from a hot source at temperature T_1, to a cool sink (temperature T_2). In 1.b heat, Q, is pumped from a cool source (at temperature T_2) to a hot sink at temperature T_1, through the input of work (W). Conventional heat recovery utilises normal heat exchange while heat pumps reverse the normal flow of heat.

Figure 10.1 HEAT EXCHANGE AND HEAT PUMPING

1.a Heat Exchange



1.b Heat pumping



Early practical machines were built in the 1930s but widespread interest in heat pumps had to await the oil price rises of the 1970s. Technical descriptions are given in Technical Appendix 1 and a full history of the development of heat pumps, as well as expositions on the technical principles can be found in the literature, particularly Reay and Macmichael (1979) and von Cube and Stienle (1981).

This Chapter explores the profitability of using heat pumps for industrial heat recovery, particularly in the brewing and dairy sectors. Market forcasts for industrial heat pumps are reviewed and compared to the current state of the market. The profitability of eighteen proposed installations in the brewing and dairy sectors is modelled. Sensitivity analysis is used to explore the conditions under which these installations would become viable investments under criteria commonly used in the two sectors.

Heat pumps are mentioned in several contexts in Leach (1979) and appear to be a favoured technology of the low energy strategists because of the savings in primary energy they can, in the right circumstances, produce. Heat pumps for commercial building space conditioning are rapidly spreading and for new buildings where both heating and cooling are required, they are now a very attractive option (Electricity Council). Their use is also viable in renovations of existing buildings (Energy Manager, Feb. 1984). This particular market segment need concern us no further as it is not an industrial market. The same applies to domestic heat pumps, a market which is static at present (H & V News, 7 Jan. 1984).

Market forecasts for industrial heat pumps show large potential markets. Masters, Pearson and Read (1980) estimate that heat pumps could supply 20% of total industrial heat demand. Currie (1982) estimates that industrial heat pumps could save 600,000 tonnes of coal equivalent per annum. Making an assumption that these machines had an average Performance Effectiveness Ratio (PER, see Technical Appendix 1 for definition) of 2.0, Currie's estimate is one-fifth of that made by Masters et al, or about 4% of total industrial heat demand.

To date (August 1984) there have been three installations in the malting sector, two in the dairy sector, none in brewing, one in textiles (Linnell, 1983), a grand total of six installations for heat recovery excluding drying. The market forecasts lack segmentation and are suspect for that reason alone. A supplier of heat pump systems indicated that the brewery and dairy sectors were considered major markets and have been the focus of unsuccessful heavy selling attention. As these were two of the four sectors under investigation it was decided to research this apparent mismatch between market expectations and current market realities. The objects have been threefold: to investigate the profitability of heat pumps in these sectors in order to explain this gap between expectations and realities; to give advice to potential adopters in this sector; amd to see if there is a real market for heat pumps in these sectors.

10.2 Method

As the market forecasts had not considered the profitability of heat pumps from the investor's viewpoint and profitability is a major factor in adoption decisions, it was decided to model the economics of a range of individual proposed installations. Technical data concerning eighteen proposed installations in the brewing and dairy sectors was obtained from a supplier of heat pump systems. This data was gained from actual site measurements and the descriptions and characteristics are summarised in Appendix 18. Figures for the technical performance ratios (discussed in Technical Appendix 1) at various temperature differentials were obtained from the literature and are shown in Appendix 19. The temperature differentials between load source in Appendix 18 were used with the data in Appendix 19 to derive a Performance Effectiveness Ratio (PER). This, when combined with capital cost data (given by the supplier) and energy prices, can be used to calculate the profitability of an installation.

It can be shown that the annual financial savings due to energy saving alone resulting from a heat pump installation by the equation:

$$\underset{\text{(p/yr)}}{\text{Savings}} = \underset{\text{(hrs/yr)}}{\text{Utilisation}} \times \underset{\text{(kW)}}{\text{Output}} \times \left[\text{Cost of heat replaced} - \frac{\text{Cost of energy used}}{\text{PER}} \; \text{(p/kWh)} \right]$$

Source: Masters et al, 1980

This, it should be noted, is simply the savings due to energy savings. Any water savings, which are possible in some installations which are discussed below, will be additional savings. Any other running costs, notably maintenance, are also not included in the above equation.

From the annual savings and capital cost the profitability, either in terms of simple payback or Internal Rate of Return (IRR), can easily be calculated. This was done for all eighteen proposed installations using a computer program which allowed rapid sensitivity analysis.

For each installation both gas-engine and electrically driven heat pumps were analysed. A full factor sensitivity analysis for one proposed installation, for both gas engine and electrically driven machines, was carried out.

The computer program was validated against the two actual dairy installations and three quotations for heat pump systems received by breweries in the sample of companies in this sector. A good agreement between the program results and the actual cases was reached.

10.3 Computer program assumptions

The following assumptions were made in the computer program:

1. Financial savings are due to energy savings alone.

2. Cost of maintenance for a gas engine heat pump = 0.2p/kWh shaft energy generated.

3. Cost of maintenance for electric heat pump = 0.004 x heat pump cost per annum.

4. Efficiency of boiler and existing heat distribution = 80%.

5. Efficiency of electrical use in an electric heat pump motor = 100%.

6. Total system cost = 1.5 times heat pump cost.

The figures in assumptions 2 and 3 are taken from Masters et al (1980). They are projections from experience with experimental systems. Boiler systems typically run at 80 to 85% efficiency at full load (Payne, 1984) and a figure of 80% allows for distribution losses. Any reduction in this figure would increase the cost of the heat to be replaced and hence increase the attractiveness of a heat pump system. The efficiency of electric motors approaches 100% at full load but diminishes at part-load. Any reduction in this figure to allow for part-load running will increase the cost of heat delivered by the heat pump system.

Kew (1982) states that system cost is typically 1.5 times the heat pump cost. Other estimates are up to three times the heat pump cost, a figure in line with that for conventional heat recovery where system cost is typically three times the heat exchanger cost (Cooper, personal communication 1983; Addy, 1983).

10.4. The use of the payback criterion and Internal Rate of Return

The payback periods given in the general results are simple pre-tax paybacks. Although payback is less than ideal as a means of project appraisal, it is still widely used in practice. It is adequate as a rough filter prior to the use of discounted cash flow (DCF) techniques such as Internal Rate of Return (IRR) and Net Present Value (NPV). Most UK companies visited during research and consultancy (about 200 in all between 1981 and 1984) use a simple payback criterion of two years for cost saving measures (relating to retrofitted equipment). This finding is in line with those of the Advisory Committee on Energy Conservation (Department of Energy, 1976) and Jacques and Wood (1982). (See Section One discussing investment criteria in the four sectors).

For cases where the payback period is less than ten years and in the sensitivity analysis on one installation, the Internal Rate of Return has been calculated using the following standard assumptions: ten-year lifetime; 75% first year capital allowance; 50% tax rate; one year tax lag; no balancing charges; and a company with sufficient profit to benefit from allowances. The capital allowances are those outlined in the 1984 Budget for financial year 1984/85.

A ten year life has been used as a standard throughout the thesis but it should be noted that when retrofitting to existing plant, five years may be more appropriate. Use of a five year life severely reduces Internal Rate of Return when compared to a ten year lifetime.

10.5 Base Case Assumptions

Payback periods for all eighteen proposed installations were calculated using the following base case assumptions:

Gas price (p/therm)	30
Electricity price (p/kWh)	3.5
Fuel replaced price (p/therm)	30 to 48
Utilisation (hours/year)	2,500
Capital cost (£/kW):	
Gas engine machines	120
electrically driven machines	60

The gas and electricity prices given were the average gross prices in the UK in July 1983 (Energy Manager). A fuel replaced price of 30p/therm is equivalent to gas and 48p/therm is equivalent to the average UK price of 3,500 second oil, a common industrial fuel.

A utilisation base case of 4,500 hours was originally used but discussions with potential adopters suggested this was too high. It corresponds to 12 hours continuous operation 365 days a year while 2,500 hours corresponds to 6.8 hours of continuous operation 365 days a year. Most of the processes involved are batch operations and will not be operating continuously.

The capital costs used, £120/kW for gas engine machines, and £60/kW for electrically driven machines, are the mid-points of the ranges given by the supplier, £80 to £200/kW for gas engine machines and £40 to £80/kW for electrically driven machines. Capital costs for heat pump systems are very dependent on a number of site specific features and thus the profitability modelling is somewhat general. Actual capital costs can only be determined after quotations, based on extensive engineering analyses, are obtained for specific applications. The modelling does, however, show the conditions that need to be achieved for viability and indicates the questions potential adopters should ask in their investment appraisals.

10.6 General results

The payback periods of the eighteen proposed installations, under the base case prices and at both 2,500 and 4,500 hours utilisation are shown in Figures 10.2 and 10.3.

For a fuel replaced price of 30p/therm, neither a gas engine machine using gas at 30p/therm nor an electric machine using electricity at 3.5p/kWh can produce better than a ten year payback period in any site, at either utilisation. Thus the proposed installations are not viable if the replaced fuel is gas at 30p/therm.

At a replaced fuel price of 48p/therm, a gas price of 30p/therm and a utilisation of 2,500 hours, the paybacks of the gas engine options fall between 6 and 8 years, giving IRRs of between 3 and 13%. For the same price conditions at a utilisation of 4,500 hours the payback periods fall between 3 and 5 years, giving IRRs of between 14 and 21%. Under these conditions, which correspond to replacing heavy fuel oil, and as we have seen a utilisation considered high, the proposed installations begin to look marginal. If water saving can be obtained at little or no extra capital cost, they may become viable under the two year payback rule.

For the electrically powered options, an electricity price of 3.5p/kWh, a fuel replaced price of 48p/therm and a utilisation of 2,500 hours, the paybacks fall between four and ten + years. Corresponding IRRs are <1% to 16%. Under the same price conditions at a utilisation of 4,500 hours the paybacks are 2 to 10+ years, giving IRRs between <1% and 34%. Twelve of the proposals have a payback period under five years with these conditions, while at the lower utilisation only three met this criteria.

From these results it can be seen that the proposed installations only become, at best marginal, for replacing fuel at 48p/therm. At the fuel prices current at the time of the analysis (July 1983) this corresponds to the price of heavy fuel oil (HFO, 3,500 second viscosity). At fuel replaced prices above this, more of the proposed installations will become viable. For the gas engine options the question of fuel switching must be raised. If gas is available for use in a heat pump why can't it be used to supply heat to the process in question, either directly or indirectly. There may be constraints or gas availability but if there are not, then fuel switching is likely to be an easier, less risky investment than a heat pump with a higher return.

The electrically driven options that look marginal suggest that they would become viable for replacing oil at more than 48p/therm. Again, the question of fuel switching must be raised. If gas is not available, or only available at a high capital cost (as in the case when the Gas Board requires a contribution to laying a new main), then an electric heat pump may be viable for replacing oil fired heat if a high utilisation can be achieved.

10.7 Sensitivity analysis

One of the eighteen proposed installations was subjected to sensitivity analysis. The installation chosen had a payback of 6.2 years in the base case. Its characteristics are as follows:

Output	160 kW
Δ_T/load-source	30°C
PERs:	
Electric machine	3.1
Gas engine driven machine	1.5

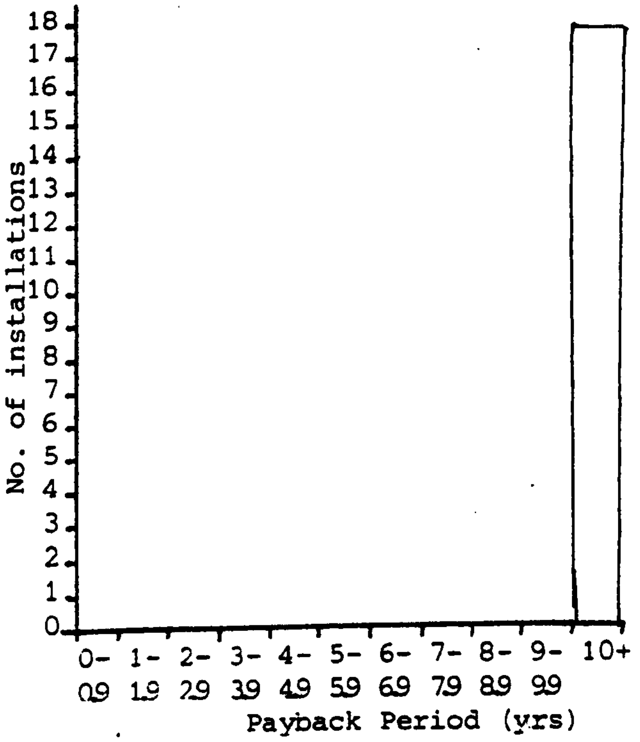
10.7.1 Capital cost factor:

For the gas engine driven option the specific capital cost per kW was varied from £80 to £200, the range of costs given by the supplier. As shown in Table 10.1, at a gas price and a fuel replaced price of 30p/therm, the payback period throughout the range of specific capital costs was greater than twelve years. At a gas price of 30p/therm and a fuel replaced price of 48p/therm, the payback periods varied from 4.2 to 10.4 years, equivalent to IRRs between <1 and 16%. This result confirms the general result that investments using gas engine driven machines are only likely to be viable at a gas price of 30p/therm if the fuel replaced price is 48p/therm. At these prices and a capital cost of £80/kW, the lowest end of the range given by the supplier, the installation has a payback of 4.2 years which is marginal but not viable. If water recovery were possible it may make the installation viable.

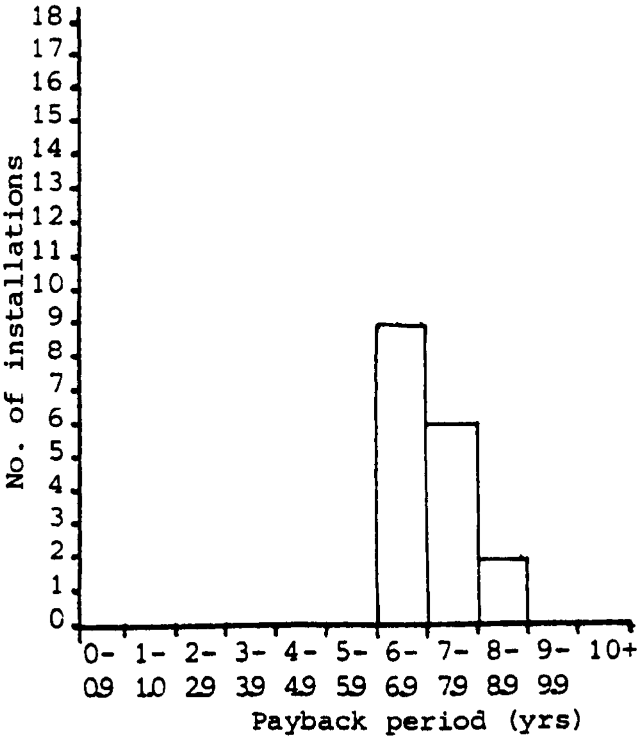
For the electrically driven option the specific capital cost was varied between £40 and £80/kW, again the range given by the supplier. Table 10.2 shows that at an electricity price of 3.5p/kWh and a fuel replaced price of 30p/therm the paybacks are all greater than 30 years. At an electricity price of 48p/therm the paybacks vary from 2.9 to 5.8 years, equivalent to IRRs between 9 and 27%. Thus, the base case cost assumption of £60/kW and below make the investment marginal under these prices.

Figure 10.2 PROPOSED GAS ENGINE HEAT PUMP INSTALLATIONS - PAYBACK PERIODS

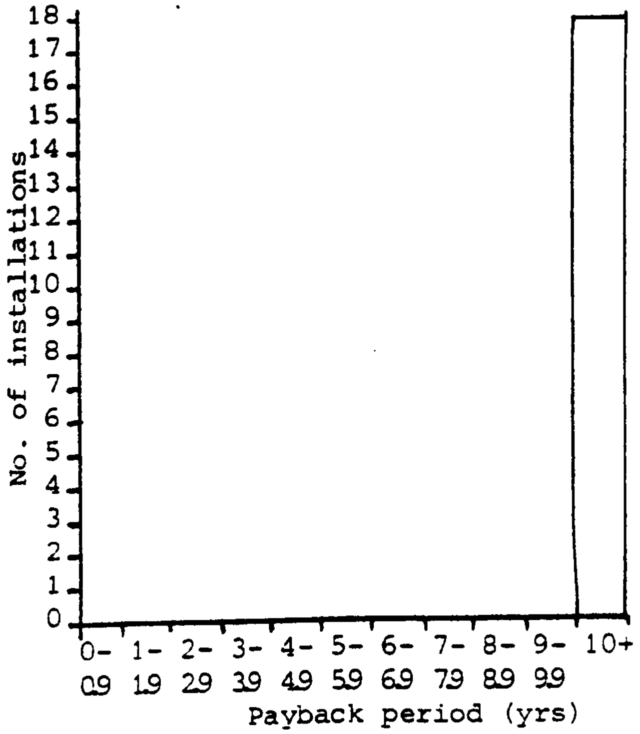
Gas price = 30p/therm
Fuel Replaced price = 30p/therm
Utilisation = 2,500 hours



Gas price = 30p/therm
Fuel replaced price = 48p/therm
Utilisation = 2,500 hours



Gas price = 30p/therm
Fuel replaced price = 30p/ther,
Utilisation = 4,500 hours



Gas price = 30p/therm
Fuel replaced price = 48p/therm
Utilisation = 4,500 hours

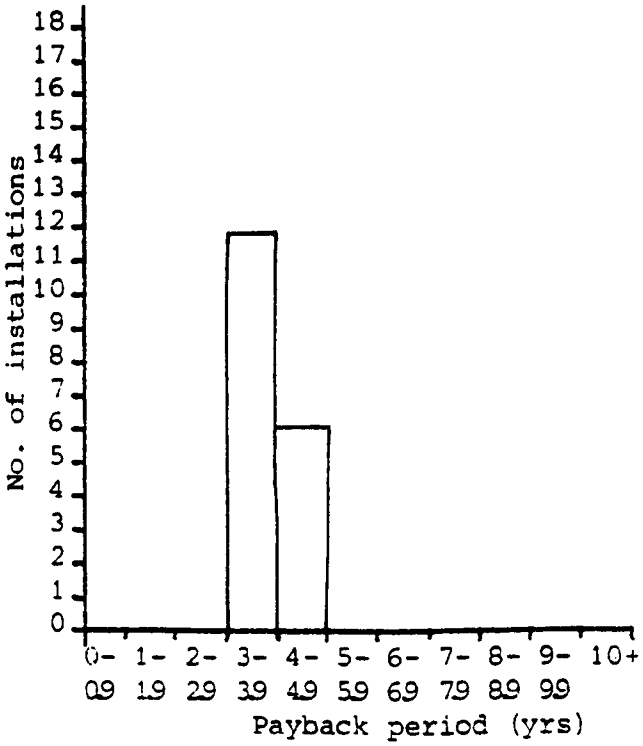
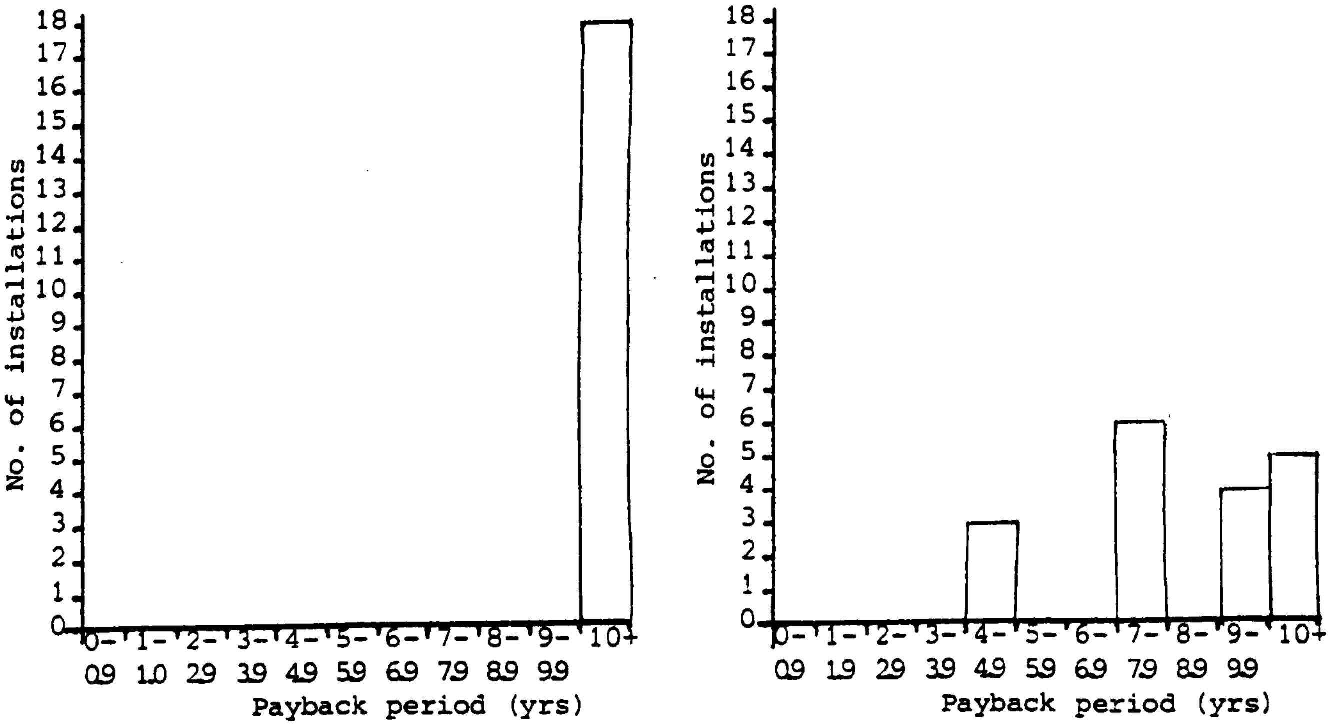


Figure 10.3 PROPOSED ELECTRICALLY DRIVEN HEAT PUMP INSTALLATION - PAYBACK PERIODS

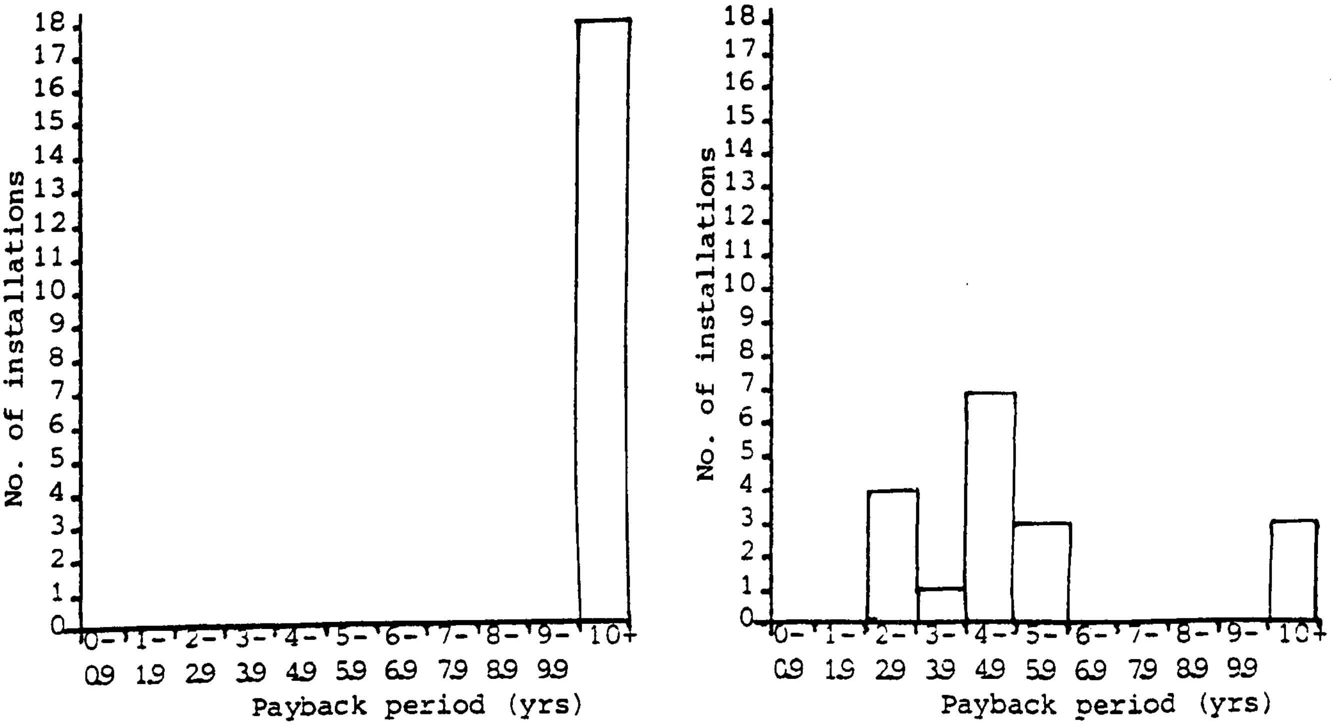
Electricity Price = 3.5p/kWh
Fuel replaced price = 30p/therm
Utilisation = 2,500 hours

Electricity Price = 3.5p/kWh
Fuel replaced price = 48p/therm
Utilisation = 2,500 hours



Electricity Price = 3.5p/kWh
Fuel replaced price = 30p/therm
Utilisation = 4,500 hours

Electricity Price = 3.5p/kWh
Fuel replaced price = 48p/therm
Utilisation = 4,500 hours



Heat pump installation sensitivity analysis

Variable factor: capital cost per kW of output (£/kW)

Table 10.1 GAS ENGINE MACHINE

Gas price (p/therm) Fuel replaced price (p/therm)		30 30		30 48	
Cost (£/kW)	System Cost (£)	Payback (yrs)	IRR (%)	Payback (yrs)	IRR (%)
80	19,200	12.4	-	4.2	16
120	28,800	18.6	-	6.2	8
160	38,400	24.8	-	8.3	3
200	48,000	31.0	-	10.4	<1

Table 10.2 ELECTRICALLY DRIVEN MACHINE

Electricity price (p/kWh) Fuel replaced price (p/therm)		3.5 30		3.5 48	
Cost (£/kW)	System Cost (£)	Payback (yrs)	IRR (%)	Payback (yrs)	IRR (%)
40	9,600	37.4	-	2.9	27
60	14,400	59.1	-	4.3	16
80	19,200	83.1	-	5.8	9

10.7.2 Utilisation factor

The utilisation was varied from 1,000 to 8,000 hours per year for both gas engine and electrically driven options. Table 10.3 shows the payback periods and IRRs for the gas engine option at two different prices of replaced fuel. For a gas and fuel replaced price of 30p/therm, and utilisation at 1,000 hours, the payback is 46.5 years. With the same prices and a utilisation of 8,000 hours a payback of 5.8 years is achieved.

With gas at 30p/therm, a fuel replaced price of 48p/therm and a utilisation of 1,000 hours, the payback is 15.6 years (an IRR of <1%). Under these prices and a utilisation of 8,000 hours the payback is reduced to 1.9 years (an IRR of 43%).

Table 10.4 shows the payback periods and IRRs for the electrically driven option at a range of utilisations and two prices of replaced fuel. For a utilisation of 1,000 hours, a replaced fuel price of 30p/therm and an electricity price of 3.5p/kWh, the payback period is 193 years. At a utilisation of 8,000 hours under these prices the payback is reduced to 16.7 years.

For a fuel replaced price of 48p/therm, an electricity price of 3.5p/kWh and a utilisation of 1,000 hours, the payback period is 11.1 years, corresponding to an IRR of <1%. Under these prices the payback at a utilisation of 8,000 hours is 1.3 years, corresponding to an IRR of 64%.

Thus, for the gas engine option, at a gas and price of fuel replaced price of 30p/therm, no increase in utilisation is sufficient to make the investment marginal. At a fuel replaced price of 48p/therm the investment looks interesting at 4,000 hours per year and becomes viable at 7,000 hours per year. As was mentioned above (see section 10.5), a utilisation of 4,000 hours would be considered high in most of the processes considered here.

Heat pump installation sensitivity analysis

Variable factor: utilisation in hours per year (h/y)

Table 10.3 GAS ENGINE MACHINE

Gas price (p/therm Fuel replaced price (p/therm	30 30		30 48	
Utilisation (h/y)	Payback (yrs)	IRR (%)	Payback (yrs)	IRR (%)
1000	46.5	-	15.6	-
2000	23.2	-	7.8	3
3000	15.5	-	5.2	11
4000	11.6	-	3.9	18
5000	9.3	1	3.1	25
6000	7.7	4	2.6	31
7000	6.6	7	2.2	37
8000	5.8	9	1.9	43

Table 10.4 ELECTRICALLY DRIVEN MACHINE

Electricity price (p/kWh) Fuel replaced price (p/therm)	3.5 30		3.5 48	
Utilisation (h/y)	Payback (yrs)	IRR (%)	Payback (yrs)	IRR (%)
1000	193.4	0	11.1	-
2000	76.9	-	5.5	10
3000	48.0	-	3.6	21
4000	34.9	-	2.7	29
5000	27.4	-	2.2	36
6000	22.5	-	1.8	45
7000	19.2	-	1.5	55
8000	16.7	-	1.3	64

For electrically driven machines, an electricity price of 3.5p/kWh, a fuel replaced price of 48p/therm and a utilisation of more than 2,000 hours is needed to make the project interesting, and 5,000 hours to make it viable. Thus, if additional savings such as from water recovery could be effected for no additional capital cost, the project may be viable at reasonable utilisations. Note again, however, this is at a fuel replaced cost of 48p/therm.

10.7.3 Price factors

Tables 10.5 and 10.6 show the effect of varying the gas price and the fuel replaced price on the payback periods and IRRs of the gas engine driven option. At a gas and fuel replaced price of 30p/therm the payback period is 18.2 years (IRR <1%), while at a gas price of 30p/therm and a fuel replaced price of 66p/therm the payback is reduced to 3.7 years (IRR = 20%). Table 10.6 shows that a gas price and a fuel replaced price of 48p/therm the payback period is 9.7 years, corresponding to an IRR of <1%. At a gas price of 48p/therm and a fuel replaced price of 66p/therm the payback is 4.8 years, an IRR of 13%.

Tables 10.7 and 10.8 show equivalent information for the electrically driven option. At an electricity price of 3.5p/kWh and a fuel replaced price of 30p/therm the payback is 59.1 years while at a fuel replaced price of 66p/therm it is 2.3 years, an IRR of 35%. With an electricity price of 7p/kWh, only a fuel replaced price of 66p/therm produces a positive payback, in this case 9.3 years (IRR < 1%).

Thus, for a gas engine driven machine a gas price of 30p/therm and a fuel replaced price of 66p/therm is necessary to make the project marginal. This raises the question that if a gas supply is available to run the heat pump why can't it be used in the boiler instead of the fuel at 66p/therm? Any firm with fuel available at 30p/therm whole using fuel at 66p/therm would almost certainly find fuel switching an attractive option with a much lower capital outlay than a heat pump.

Heat pump installation sensitivity analysis

Variable factor: price of gas (p/therm) or price of electricity (p/kWh)
price of fuel replaced (p/therm)

Table 10.5a GAS ENGINE MACHINE

Gas price (p/therm)	30	30	30
Fuel replaced price (p/therm)	30	48	66
Payback period (years)	18.6	6.2	3.7
IRR (%) savings	-	8	20

Table 10.5b

Gas price (p/therm)	48	48	48
Fuel replaced price (p/therm)	30	48	60
Payback period (years)	>> 10	9.7	4.8
IRR (%) savings	-	<1	13

Table 10.6a ELECTRICALLY DRIVEN MACHINE

Electricity price (p/kWh)	3.5	3.5	3.5
Fuel replaced price (p/therm)	30	48	66
Payback period (years)	> 10	4.5	2.3
IRR (%) savings	-	16	35

Table 10.6b

Electricity price (p/kWh)	7	7	7
Fuel replaced price (p/therm)	30	48	66
Payback period (years)	> 10	> 10	9.3
IRR (%) savings	-	-	<1

Possible conditions where fuel switching may not be possible include gas supply restrictions. These could be due either to the Gas Board applying restrictions on industrial customers, as it did in 1980/81 (now relaxed), or due to limited availability of gas from another source e.g. mines gas, or bio-gas.

As the absolute prices of fuels (both gas and replaced fuel) rises, the payback for any given differential between gas and replaced fuel prices falls. At 30p/therm for gas and 48p/therm for replaced fuel, a differential of 18p/therm, the payback is 6.2 years while at a gas price of 48p/therm and a fuel replaced price of 66p/therm, the payback is 4.8 years. Thus, if a constant price differential is maintained as absolute fuel prices fall, gas engine machines will become more attractive. The point about the availability of a cheaper fuel, however, still holds true.

For an electrically driven machine, an electricity price of 3.5p/kWh and a price of replaced fuel of 48p/therm is necessary before the project becomes marginal. At a price of replaced fuel of 66p/therm the project becomes viable. Once again the option of fuel switching should be examined if the replaced fuel price is 66p/therm. Heavier grades of oil are almost certainly available with a lower price per therm. It appears that the electrically driven option may be attractive in a situation where gas is not available as a fuel, and oil is currently used.

10.8 Conclusions

Even under an optimistic assumption about utilisation, the proposed installations in the brewing and dairy sectors look at best marginal when replacing oil derived heat. Considering that the majority of sites interviewed in these sectors used gas as the prime fuel, the number of sites in which heat pumps are likely to be even marginal, must be small.

The result of the modelling exercise were supported by three quotations for heat pump systems obtained by two breweries. None of the systems could produce a payback period better than eight years. One of the actual dairy installations, on current performance, will produce a payback period of over five years even after including water savings.

Opinions of heat pumps in the sampled companies in the brewing and dairy industry are generally negative. Even the most technically progressive companies regard them as complex and hard to maintain.

Another factor inhibiting the adoption of heat pumps is the degree of innovation necessary. Any application in a brewery would be a major innovation. Even within the brewery or dairy sectors, however, each application is very different and has to be designed for the specific site - a high degree of innovative activity is necessary. Any company contemplating adoption of a heat pump system must recognise that they are taking the risks inherent in innovation. The low returns available in all but the most favourable situations mean that this particular innovation is unattractive.

Given the poor rates of return from these applications, the poor opinion of heat pumps within the industries, and the high risk and difficulties of adaption, it is hardly surprising that there has been hardly any adoption of heat pump systems.

Why should the market forecasts and market expectations of the suppliers be so much at variance with reality, at least in these two sectors? Firstly, as mentioned above, the general forecasts make no attempt at market segmentation. They do not recognise the very real differences in needs between sectors and even applications. Masters et al (1980) appear to simply have taken the percentage of total industrial heat at temperatures that could be supplied by heat pumps and ignored economic factors. Currie (1982) does not indicate a methodology.

Leach (1979) does not appear to recognise the differences between different applications. He apparently assumes that because a heat pump is viable in a simple space conditioning application it will be viable in process applications.

Suppliers of heat pump systems seem to have been product oriented rather than market oriented. One supplier indicated that no market research had been undertaken before deciding on entering the heat pump market. If heat pumps are to be viable it is as part of a heat recovery system. As Addy, Missions, and Reay & Brookes stress, it is important in heat recovery system design not to prejudge the means of heat transfer, be it simple heat exchangers of any type or heat pumps. What is necessary is a heat recovery systems company that will use heat pumps if appropriate, not a company supplying heat pumps.

The following guidelines for heat pump viability are given by Currie (1982):

1. Very high utilisation.
2. Small temperature difference between load and source.
3. Heat requirements must be at relatively low temperature.
4. There must be no high grade heat available in the plant. If a high grade source is available then conventional heat recovery will always be cheaper than heat pumps.
5. Combined heating and cooling of adjacent process streams is required.

Added to these could be:

6. A different energy price regime than is currently operating in the UK.

The restrictions imposed by these conditions appear to be more severe in the brewing and dairy sectors than currently believed by suppliers of heat pumps. This, plus fears over the reliability of the technology, would seem to limit the market severely in these sectors.

Chapter Eleven

COMBINED HEAT AND POWER IN THE FOUR SECTORS

11.1 Introduction

The title Combined Heat and Power (CHP) refers to the simultaneous generation of electrical or mechanical power and useful heat. This chapter examines the profitability of this technique for a particular brewery and reviews evidence about its viability in the other three sectors. It addresses the questions:

(a) is CHP economically viable in these sectors?
(b) which is the favoured technique?
(c) what conditions would affect the answers to (a) and (b)?

11.2 What is industrial CHP?

Most attention on CHP has been focussed on large scale centralised schemes for providing District Heating (DH). These schemes are not under consideration here because they are not credible investments for private companies whose main business is not power generation. Industrial CHP is on a smaller scale and is concerned with the provision of process heat, usually used on-site, and the generation of electrical power, some of which may be sold to the national grid.

The CHP techniques that are commercially available today are: back pressure steam turbine (Rankine cycle) systems; gas turbine (Brayton cycle) systems; internal combustion engine (Diesel cycle) systems; and reciprocating steam engine systems. The principles of these techniques are explained in Technical Appendix 2 as are fuel cells systems. Fuel cell CHP systems have been included as they are to be commercially available in the UK by the end of the 1980s (Ryan and Cameron, 1984).

These systems are known as topping cycles because the energy for electrical power generation is extracted at the higher temperatures associated with fuel combustion, and process heat requirements are met with the lower temperature exhaust flow from the prime mover.

Bottoming cycles, which are becoming available for power generation, produce electricity in connection with a flow of heat at between 100 and 250°C. They are primarily a heat recovery technique and compete with conventional heat recovery systems.

Organic Rankine Cycle (ORC) bottoming cycles have been limited to chemical industry processes in Japan and the USA (Boland, Hill and Townsend, 1981). In the four sectors studied no applications for bottoming cycles have been proposed. Currently available ORCs on the UK market are designed to order and only available in sizes from 10MW up (trade sources) far too large for the typical site in the four sectors. For these reasons bottoming cycles have not been discussed further.

Micro-CHP systems, based on automotive engines converted to run on gas have recently become available in the UK. These are finding rapidly growing markets in swimming pools, hotels and sheltered housing applications (Linnell, personal communication). As they are designed primarily for space heating uses, and produce low pressure hot water rather than steam, they have not been considered in the analysis. Brewery companies owning large hotels however should certainly consider micro-CHP as a way of reducing energy costs in these premises.

11.3 Why examine industrial CHP?

An investment in industrial CHP does not significantly alter the energy consumption, either heat or power, of the investors site. Why then is it included in a thesis concerned with energy conservation investments? Firstly, it can in the right conditions reduce energy costs and therefore is an investment capable of producing an economic return. Secondly it does save energy at the national level.

National energy savings result because the power generated in a CHP scheme, which typically has an overall efficiency of 80%, replaces power generated in centralised power stations with an overall efficiency of about 35%, and an overall generation and transmission efficiency of about 30%.

These potential savings have made CHP, both centralised and decentralised, attractive to writers of low-energy scenarios.

Industrial CHP is a technique with a long history. Before the advent of the national grid it was widely used. The convenience of the grid, and falling real electricity prices and difficulties in selling surplus power have made private generation less attractive. From 1957/58 to 1981/82 the proportion of power privately generated in the UK fell from 15.6% to 7.5% (excluding internal power generated in nuclear power stations). The actual energy privately generated rose over this period from 12,657 GWh to a 1973/74 peak of 18,656 GWh and fell to 15,799 GWh by 1981/82 (Source Energy Statistics, 1983).

Rising real energy prices, and recent changes in critical factors affecting the viability of industrial CHP systems, mean that the technique merits reappraisal. The first factor that has recently changed is that the 1983 Energy Act mandated area electricity boards to purchase privately generated power, publish tariffs for the purchase of privately generated power and generally assist potential or existing private generators. It also allowed companies to generate power as their main business.

The second factor that has changed is the British Gas Corporation's (BGC) policy towards using gas in power generating systems. Supply restrictions and a policy of reserving this "premium fuel" for other uses had meant that gas used for power generation was priced above the normal industrial tariff. Now supplies are more plentiful the BGC has dropped the power generation premium and is actively assisting potential private generators. This change opened up the possibility of using gas engines and gas turbines for economical private generation.

Table 11.1 CHARACTERISTICS OF CHP SYSTEMS

	Steam turbine	Gas turbine	Gas turbine with after-burner	Diesel
Heat to power ratio R	< 15	2.3	2 - 18 (1)	0.4 - 1
Power conversion efficiency μp	0.13 - 0.16	0.15 (3)	0.15	0.37
Size range kW(e)	50-30000 (2)	500 - 3500	500 - 3500	30-1000
System cost estimates £/kW	100 - 300	200-300 (4) 400-700 (5)	300 - 700	300-500 (6)

Notes:

1. Variable after-burner
2. Most industrial units are 1000-5000 kW(e)
3. Larger units have $\mu p < 0.2$
4. For 3 to 6 MW units
5. For 0.5 to 3 MW units
6. Large sites less expensive

Sources: Bleay and Fells, 1979; Murphy and McKay, 198 ; Williams, 1978; Dryden, 1975; Trade sources.

fixed throughout the year. Many industrial sites, particularly those in the four sectors studied, have more complex heat to power ratio patterns.

11.5 CHP in the brewing sector

CHP has long been used in some large breweries. None of the sampled sites had invested in CHP recently and only one was known to operate a scheme. Perceptions of CHP in other sampled sites were generally that it would not be viable. In the light of these opinions it was decided to examine the viability of a CHP scheme in one particular medium-sized brewery and select and size the most viable system.

Sizing CHP systems, as pointed out above, has been a problem. A linear programming (LP) approach has been used here to select and size a system as LP can combine all the basic variables such as electricity and heat demands, conversion efficiencies and economic parameters such as fuel and electricity prices, capital costs and non-fuel running costs. The principle is similar to that used for plant operations planning in the chemical industry and sign conventions follow those used by Allen (1971).

The approach used here follows the original use of LP for CHP system design by Bleay and Fells (1979) with some important modifications. The basic model used for formulating the LP algorithm is shown in Appendix 20. It was decided to optimise the model on the basis of running costs alone to allow use of payback and discounted cash flow (DCF) analysis rather than to optimise total costs as in Bleay and Fells (1979). Maintenance and other costs were excluded for simplicity but could easily be included in a more extensive analysis. An LP computer package, MPOS, was used to run the model. Five CHP techniques were considered: diesel engines; gas turbines (fixed ratio); gas turbines with variable after-burners; steam turbines; and fuel cells. The characteristics of each CHP technique are shown in Table 11.1. Base case analyses were carried out for each technique and sensitivity analysis was conducted on the diesel driven system.

Electricity prices, both sale and purchase, were obtained from the local area board. Fuel prices used were those currently (mid-1984) operating.

Data on the heat and power demands on a "typical" day for the brewery were obtained from recent past records. The pattern is shown in Figure 11.1. These heat and power demands were used to optimise the running cost for each technique over a range of sites on an hourly basis. Summing the hourly running costs produces a running cost curve for the day, from which the optimum size of system can be derived. Multiplying the daily running cost by a figure for days per year operation results in an annual running cost.

As the heat to power demand pattern varies even from day to day questions can be raised about the typicality of the days used. This can however be corrected for approximately by reducing the days run per year figure.

The annual running cost was compared to that without a CHP system to give annual savings due to energy savings. These, when combined with the capital cost data in Table 11.2 give payback periods and IRRs.

11.6 General results

The results are summarised in Table 11.2. The Internal Rate of Return quoted were calculated on the assumption of a ten year lifetime and using current (1984/85) capital allowances and tax rates (75% first year allowance and 50% tax rate).

All options except the fuel cell offer payback periods under 2.5 years under the highest capital cost assumption. Although this analysis has only considered energy running costs it suggests that industrial CHP with sale of surplus power may be an attractive option for this particular brewery, and by implication, other similar sites.

The third factor to change has been available technology. Diesel systems with waste heat boilers are a recent entry to the market along with smaller, packaged gas turbine systems. The available techniques are described in Technical Appendix 2.

11.4 Heat to power ratios and system sizing

Critical characteristics in a CHP installation are the heat to power ratios of the various systems and the heat to power ratios demanded at the site. Heat to power ratios for each system are relatively fixed and are shown in Table 11.1.

The high heat to power ratio of a simple steam turbine system limits its application. Savings result from replacing grid electricity and sizing the system to meet a reasonable proportion of electrical load. This will, in most sites, lead to more heat than can be used on-site. Sizing the system to meet heat demand results in such small electricity output that the scheme becomes uneconomic in many sites.

The heat to power ratio of a fixed gas turbine system is more in line with many industrial sites. Their use however has been restricted by the need to use gas or distillate oil. Until recently gas used for CHP schemes was priced at a premium as this was not considered a suitable use for a high quality fuel, and gas was in short supply. The British Gas Corporation has recently changed this policy and is now actively supporting potential investors in CHP schemes.

Gas turbines with after-burners in the waste heat boilers offer useful flexibility. Another approach would be to use a variable recuperated gas turbine. This system is reported by Lowder (1979) as being under development for CHP schemes but no commercial applications have been built to date.

Choice and sizing of CHP systems has to date been a simple affair with little attempt at optimising. This lack of sizing techniques, and lack of flexibility in the heat to power ratios has been an impediment to further use of CHP. To date its use has mainly been in process industries where heat and power loads are relatively

Figure 11.1 DAILY PATTERN OF HEAT AND POWER *DEMANDS IN A BREWERY*

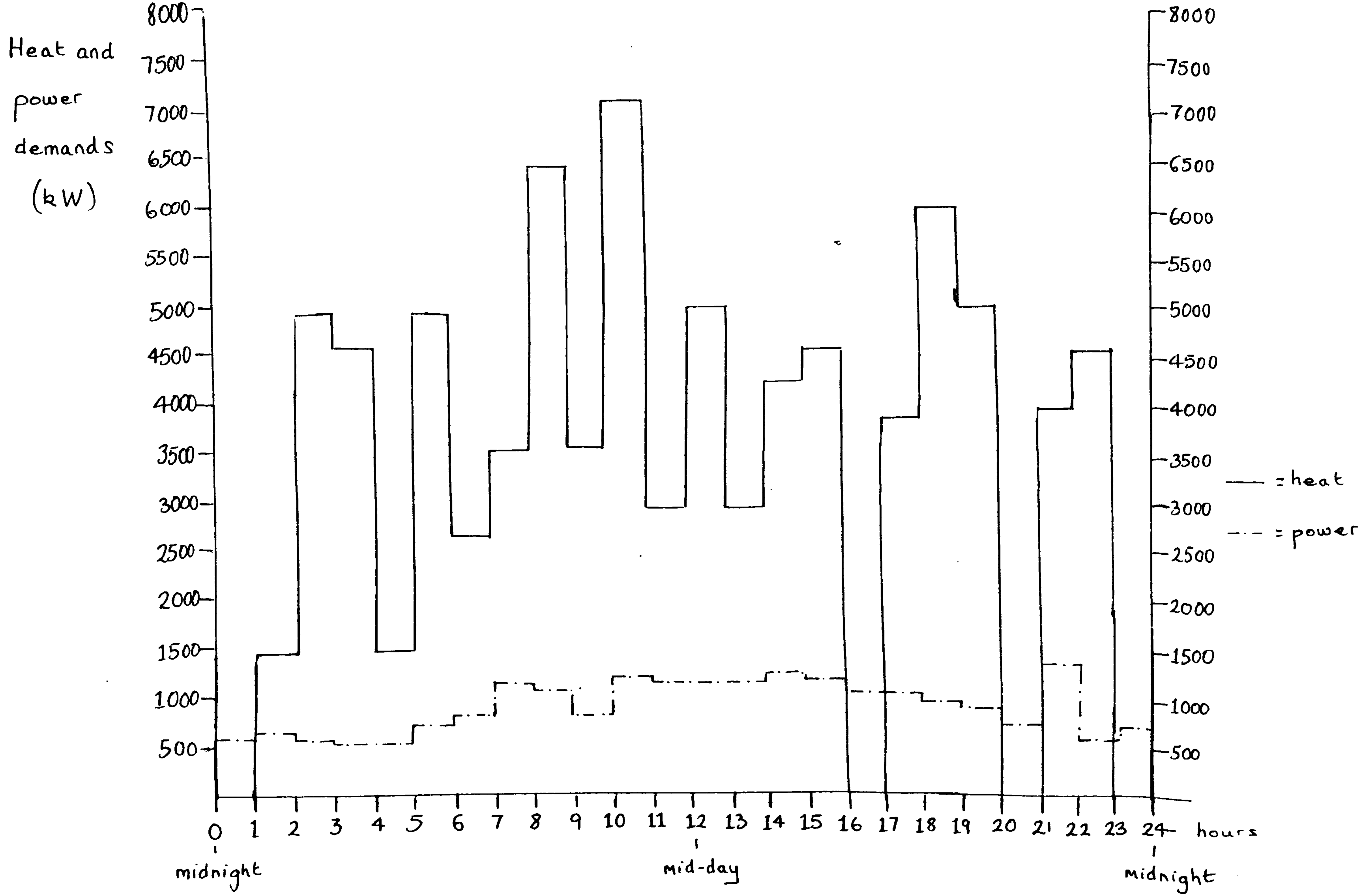


Table 11.2 RESULTS SUMMARY

	Diesel	Gas turbine	Gas turbine with after-burner	Steam turbine	Fuel cell
Optimum size (kW)^1	500^2	500^2	500^2	500^2	1000
Capital cost range (£/kW)	300-500	200-700	300-700	100-300	750-1500
Payback period given standard assumptions	1.1-1.5	0.7-2.5	1.1-2.5	0.5-1.5	3.1-6.2
IRR (%)	76-57	118-32	78-32	174-55	25-8

Notes: (1) Optimum in terms of running costs using this model i.e. excluding maintenance costs.

(2) The fact that the model shows an optimal size of 500 kW(e) for all CHP techniques except fuel cells reflects two factors. Firstly the electrical load in this site is constantly 500 kW or more. Secondly for most of the time the heat to power ratio is high so that even the use of a steam turbine generator to meet most of the electrical demand is feasible without generating excess heat. Other industrial sectors, as have already been noted, do not have such favourable conditions.

Nash (1984) reports payback periods of less than four years for standard matched diesel engine and boost fired systems. If part of the capital cost is offset by the need to replace conventional boilers or if dealing with a greenfield site, the payback period on the incremental cost can be reduced to about two years. This suggests that either the analysis here is optimistic in its assumptions or that the case in question is particularly suitable for CHP.

A major distilling company is currently investing in a gas turbine CHP scheme with export of power to the grid. It reported some surprise that a two year payback period was achievable under reasonable assumptions, but this is in keeping with our own findings in the brewery example.

11.7 Sensitivity analysis

A full sensitivity analysis was conducted on the diesel engine example and the results are presented in Tables 11.3 to 11.7. The base case has the following characteristics:

Capital cost (£/kW)	400
Utilisation (% of year)	82
(days/year)	300
Fuel price (p/kWh)	1.05
Imported electricity price (p/kWh)	4
Exported electricity price (p/kWh)	2

Savings are energy costs alone.
Heat and power loads as given are typical.

Even at the highest capital cost, £600/kW, which is above the range given by trade sources, the payback period of the installation is 2.2 years, giving an IRR of 37%. As the price of fuel rises relative to that of electricity the payback period of the investment is increased; at a price of fuel of 2.1p/kWh, twice the current level, the payback period is increased to 7.3 years and the IRR falls to 5%.

If the price of imported electricity falls relative to all other prices the payback period increases. If the price gained for exported electricity falls to half its current average value the payback period increases from 1.5 to 1.9 years (IRR falls from 57 to 44%), still an attractive investment. The investment is sensitive to changes in utilisation but even at 27% utilisation (equivalent to 100 days a year operation), the payback period is only 4.4 years (IRR = 15%).

Thus, the investment is most sensitive to a rise in fuel prices relative to all other prices or a fall in the price of imported electricity relative to all other prices. If electricity prices become decoupled from fuel prices, for example through the increasing use of nuclear energy private generation of power in industrial CHP systems will be less attractive.

11.8 Other barriers to CHP

A major barrier to increased investment in industrial CHP may be capital availability. Although acceptable paybacks may be attainable CHP systems do cost more than conventional boilers and power supplies. In times of constrained capital this may be the deciding factor. Other barriers may be lack of management expertise in running CHP systems and fears over their complexity. Both these constraints could be eased by the emergence of third party financing and management companies. This phenomena, more advanced in the USA than the UK, is beginning to occur for non-CHP boiler plant and other energy conservation investments. If, as seems likely, it spreads, this will pave the way for third party financing and management of CHP systems.

Third party companies with expertise will also be able to assist in negotiations with the electricity supply industry. Although the industry is mandated to assist potential private generators by the 1983 Energy Act industrial contacts suggest that the response to enquiries has been mixed. Improvements are undoubtedly needed in some areas if CHP is to be encouraged.

Table 11.3 DIESEL INSTALLATION SENSITIVITY ANALYSIS

Variable factor: capital cost

Capital cost (£/kW)	300	400	500	600
Payback period (yrs)	1.1	1.5	1.8	2.2
IRR (%)	76	57	45	37

Table 11.4 DIESEL INSTALLATION SENSITIVITY ANALYSIS

Variable factor: fuel price

Fuel price (p/kWh)	0.5	1.05	2.1
Payback period (yrs)	1.4	1.5	7.3
IRR (%)	60	57	5

Table 11.5 DIESEL INSTALLATION SENSITIVITY ANALYSIS

Variable factor: imported electricity price

Imported electricity price (p/kWh)	3	4	8
Payback period (yrs)	4.4	1.5	1.0
IRR (%)	15	57	85

Table 11.6 DIESEL INSTALLATION SENSITIVITY ANALYSIS

Variable factor: exported electricity price

Exported electricity price (p/kWh)	1	2
Payback period (yrs)	1.9	1.5
IRR (%)	44	57

Note: It is not conceivable that the average price of exported electricity, i.e. the price the grid pays for electricity, would exceed the average price of imported electricity, i.e. the price the grid sells electricity for. Therefore this case has not been explored.

Table 11.7 DIESEL INSTALLATION SENSITIVITY ANALYSIS

Variable factor: utilisation

Utilisation (% of year)	27	55	82	96
(days/year)	100	200	300	350
Payback period (yrs)	4.4	2.2	1.5	1.3
IRR (%)	15	36	57	66

To date industrial gas turbines have mainly been derivatives of aero engines. The minimum size currently available of 500 kW is a limiting factor. Despite an increase in cost per kW and a decrease in thermal efficiency with decreasing size there may well be an untapped market for small, packaged gas turbine CHP systems designed to sell excess power to the grid.

Another possibility with potential may be smaller closed cycle systems or fluidised bed gasifiers connected to gas turbines as reported in Williams (1978). The viability of these systems would depend on the prices of coal and other fuels. From a national point of view they have the advantage of encouraging use of solid fuels rather than premium gas and distillate oils, if this is seen as an advantage.

11.9 Conclusions

Industrial CHP appears to be an attractive investment for the particular brewery used in the example. To the extent that it is typical of medium sized breweries there could be a large, as yet untapped, profitable opportunity for CHP in the brewery sector.

The size of the investment required means that CHP systems are only likely to be purchased as an alternative to replacing conventional boilers, rather than as a retrofit investment. Given the changed circumstances, the evidence from the example and from the distilling company investing in CHP, medium to large breweries and distilleries should certainly examine CHP as an option when considering replacing boilers, if not as a retrofit measure.

Further research into the viability of industrial CHP, using simulation techniques and concentrating on the sensitivity of financial returns to factors such as peak loads, tariff structures and changing demand patterns is advocated. Due to the importance of site specific factors this work should model a range of real sites. The size of investment necessary for CHP, coupled with the advent of cheap microcomputer based investment analysis packages suggest that a full risk analysis would be appropriate.

Chapter Twelve

PROFITABILITY MODELLING OF OTHER TECHNIQUES

12.1 Introduction

Having examined the profitability of two major techniques in-depth this chapter looks briefly at the profitability of seven other techniques. The term "major techniques" is used in the sense that much of the energy conservation literature, and indeed activity in some organisations, is concerned with fashionable techniques such as heat pumps or combined heat and power. In reality many neglected, technically unspectacular techniques are probably more important both in terms of energy conservation and economic returns. These techniques are too numerous, and often too site-specific, to usefully model their profitability here other than in a general sense. Each technique is briefly described and an example cost-benefit analysis, taken either from the literature or the sampled companies, is presented with basic sensitivity analyses. Non-economic factors found to have affected the adoption decision in sampled companies are also discussed.

The techniques chosen, with the exceptions of keg washing line heat recovery and pasteuriser improvements, have applications in all four of the sampled sectors.

12.2 Sub-metering

We have stressed the importance of monitoring for effective energy management. Monitoring is dependent on the measurement of energy flows through metering and as we have seen, in the four sectors, sub-metering of energy flows is not widely practiced and this is a barrier to improved energy management.

In the companies sampled a recurring complaint was that meters, especially steam meters, are expensive, unreliable, inaccurate and hard to maintain. In several companies these were held to be valid reasons for not investing in more extensive sub-metering. Another reason often advanced for not investing is that meters are hard to justify financially because there are no directly attributable savings.

Savings from metering come about in two ways. Direct savings result from tighter controls over energy use, and indirect savings result from improvements in the quality of information used in future investment decisions. It should be remembered that meters on their own do not save energy. It is only the management actions based on the information gained from metering and monitoring that can save energy.

Evidence from consultants (e.g. Roberts, 1983), suppliers and the companies that have invested in sub-metering shows that the investment does have a direct return through improved good housekeeping. Typical savings are 5% of total energy usage. Consequently there is no need to regard meters solely as a form of "R & D" for improving the quality of future investment decisions.

There will be a cut-off point in site size below which sub-metering is uneconomic (given normal investment criteria for retrofit projects). The use of extensive sub-metering in one small brewery (see Section One) suggests that the cut-off point is well below the size of most breweries. One dairy in the sample utilises twenty fully metered cost-centres for a total energy bill of £200,000 p.a. while a site with an energy bill of £800,000 p.a. has no cost centres and only 50% of steam use is metered. There must be cost-effective potential for additional metering in the second site.

A rough calculation, assuming 5% reduction in energy use and a two-year payback period suggests it would be worth the second site spending £80,000 on metering. This would probably be sufficient to extensively sub-meter the site.

Criticisms of the failings of steam and other fluid flow meters are not entirely without foundation. Metering techniques and some of the problems are discussed in Brian and Scott (1982) and Gervase-Williams (1984). Despite the problems a properly designed and installed metering system can be very cost-effective. Much of the bad opinion against meters appears to be based on experiences with older metering techniques and does not recognise recent improvements in this important field.

The cost and benefits of a metering installation will be dependent on a number of site specific factors, such as pipe diameter, flow-rate, turn-down ratio, pipe lay-out, and cost of steam. Cost benefit analysis for three meter installations are shown in Appendix 21. Sensitivity analysis suggests that the investments, based on actual cases, are robust. In one case cited a 22% saving in steam was recorded, solely due to improved good housekeeping.

12.3 Low Energy Lighting

The term low-energy lighting covers many different techniques and types of hardware including "slim" fluorescent tubes, miniature fluorescents, mercury halide lamps and low and high pressure sodium lamps. Savings result from replacing old and often inappropriate lighting systems, often installed on minimum capital cost grounds, with modern and more appropriate systems. In many installations lighting quality is increased dramatically at the same time as energy costs are reduced.

As energy costs typically account for 70% of total costs in industrial high bay lighting schemes (Philips Lighting Advisory Group: Energy Effective Lighting Manual), a reduction in energy costs has a major effect on total costs. The various lighting techniques are described in Payne (1984) and elsewhere.

In Section One it was shown that 28 out of the 49 breweries sampled had invested in low energy lighting of some form. Many of these installations were partial schemes which illustrates one factor that makes low energy lighting easy to adopt (increases its adaptability), the investment can be phased. Its wide use in the brewery sector suggests that it is economic in most sites where it is evaluated.

In the dairy sector low energy lighting was only installed in two out of eight sites. Given the similarities between many of the buildings in the brewing and dairy sectors it would appear that low energy lighting is under-utilised in the dairy sector.

Maltings and distilleries had not invested in low energy lighting to any great extent. As lighting represents a much smaller proportion of costs in these sectors investment in relighting will rationally be low on the priority list.

The most common type of relighting scheme encountered in the brewing sector was the replacement of fluorescent tubes with high pressure sodium lamps in high bay areas such as bottling halls or keg stores. Appendix 22 shows a cost-benefit analysis for a relighting scheme in a brewery keg store.

The cost-benefit analysis and the large number of installations in the brewing sector show that low energy lighting schemes are attractive, robust investments. They should be evaluated in all breweries and dairies. Further use is also probably cost effective in many dairies and also in bottling halls and stores of distilleries.

12.4 Energy Management system for a building with an annual energy cost of £25,000 p.a. for heating and lighting

Electronic energy management systems have rapidly developed in the last five years. The technology is still evolving and the price of systems falling as computing power falls in price. Descriptions of systems are found in Fielden and Ede (1982) and Johnson (1982) and recent editions of Energy Manager (1983/84).

No applications of energy management systems for the control of heating, ventilating and lighting, have been found in the four sectors. It was decided however to investigate the costs and benefits of a system designed for a building with a heating and lighting bill of £25,000 p.a. The data is taken from a real application in another industry. Large brewery companies own many buildings other than the actual brewery sites, notably for storage. Many of these will have heating and lighting bills of about £25,000 p.a.

A simple cost-benefit calculation and sensitivity analysis are shown in Appendix 23. The Appendix shows the cash flows when the system is leased. Leasing is offered as an option by several energy management bureaux which use their central computers to control clients' out-stations.

Even under a pessimistic savings assumption of 10% the project offers a 2.8 year payback. The figure of 20% is based on performance in similar installations.

12.5 Condensate recovery

Condensate recovery is an essential element in the efficient use of steam. In many applications where steam is used directly, condensate recovery is not possible because the returned liquid becomes too contaminated for utilisation in boilers. From the survey it appears that many breweries and dairies, however, could improve their recovery of condensate. In addition to the energy savings resulting, there will be water cost and water treatment cost savings.

Four brewing sites, two dairies and two distilleries have invested in improving their condensate recovery systems. The cost benefit analysis suggests that cost effective improvements could be made in other sites. Payback periods quoted are for energy saving alone, ignoring water and water treatment cost savings which can be significant. A cost-benefit analysis for an improvement scheme for a condensate recovery system is shown in Appendix 24.

12.6 Oxygen trim control systems

The use of oxygen trim control systems, both to ensure maximum combustion efficiency and to provide continuous efficiency monitoring, has long been practiced on very large boilers such as those in power stations. Recent advances in the technology, especially the use of microprocessors, have allowed its economic use in smaller, industrial boilers. The principle is described in Payne (1984).

Over the last five years the technique has had a chequered history with many organisations experiencing very poor returns on significant capital investments. Recent technical advances, notably the use of self-adaptive microprocessor control systems, have improved the reliability and attractiveness of this technique.

The savings gained depend mainly on the efficiency currently being achieved in the boiler. Paybacks of under two years however have been demonstrated in a wide range of situations, on package boilers as small as 7,000 lb/h steam or 7m Btu/h hot water. It is not worthwhile providing a cost benefit analysis for this technique as such an analysis would be very general. The evidence in the literature and from the sample suggests that oxygen trim systems are worth evaluating and in most cases will be found to be cost effective.

As well as offering high returns, oxygen trim systems are easily installed onto boilers and other combustion equipment. In sites with multiple boilers they can easily be installed on one boiler for experimentation (typical installed cost is £3,500). These factors suggest they have a high adaptability and will find wide application in the four sectors.

12.7 Economics of a keg washing line heat recovery system

The system is described in ETSU (1981). The first system, built under an Energy Conservation Demonstration Project Scheme, cost £51,000 and resulted in a 5.5 year payback period. Subsequent systems were installed for a capital cost of £15,000. At this cost the projects offer a two year payback even at low occupacity.

Keg washing and sterilising lines are frequently one of the largest users of steam in a brewery after wort boiling (Harris, 1979). The keg cleaning cycle involves multiple rinses, steam purges, detergent washes and steam and air pressurisations. The precise details of the cycles vary widely and are usually controlled on time intervals rather than temperature or volume. Thus the hot water effluent varies greatly in quantity, quality and timing. This affects the economic viability of heat recovery schemes as well as the design of systems. Essentially there are two types of keg washing lines; old ones with no heat recovery, and newer ones with first stage heat recovery. The installation described here was applied to the latter type, suggesting that large savings could be achieved by retrofitting heat recovery systems onto the older lines. In one case found in the research this was not possible because of space constraints. It also raises the question whether the older lines should not be replaced. Modern lines incorporate full heat recovery and thus produce similar savings to retrofit systems. They are, however, only likely to be purchased as part of the normal capital replacement cycle and not on energy cost saving grounds.

As many older lines are in small breweries with limited resources exploitation of this potential is likely to be through new lines rather than retrofitting.

Design of retrofitted keg washing line heat recovery systems poses many engineering problems because of the intermitten flow of effluent. One site in the survey had installed a system prior to the Demonstration Project. During the research the author discovered that for most of the cycle the heat exchanger was transferring heat from the hot liquor (water) tank to the effluent, the reverse of the design conditions. Removal of the system saved about £20,000 for an expenditure of about £2,000. This example also illustrates the need to always question assumptions about how plant operates. It does not always operate in the way it was designed to do. The design problems are a major impediment to further use of this technique as are low effluent flow rates in many cases. A cost-benefit analysis for this technique is shown in Appendix 25.

12.8 Improvements to Pasteuriser

Manufacturers of pasteurisers offer an upgrading option in which additional heat and water recovery systems are retrofitted onto existing pasteurisers. The example used in the cost-benefit analysis in Appendix 26 was a can pasteuriser in a brewery.

Even at the lowest utilisation figure of 2,000 h/y the improvements package offers a payback period of about 1.5 years (IRR = 67%).

Although offering an acceptable return the capital cost of this technique is high (about £125,000 in the example used). An important question that must be raised in considering this investment concerns the projected life of the pasteuriser. If replacement is thought likely in the near future the value of the retrofit improvements will be reduced. None of the breweries in the sample had invested in this technique. In some cases it is likely to be viable.

12.9 Other techniques

The techniques that have been cost-effectively used in at least one site must be worth examining in others even though viability is not assured. A major task of energy management must be to maximise the evaluation of possible investments. Given that techniques already used in at least one site have been found to be viable, often under similar investment criteria, they must be worth considering.

A technique which is currently experimental in one brewery and one distillery in the sampled sites is biological digestion of effluent to produce bio-gas. This appears to have great promise and has already been installed in conjunction with a CHP scheme in a dairy (Plant and Works Engineering, September 1984). It would be worth larger breweries, dairies and distilleries considering this technique.

12.10 Summary

The profitability of adoption of several energy conservation techniques has been discussed along with non-economic factors. In Section Two the site-specificness of all energy conservation investments was stressed and because of this any profitability modelling must be rather general. It can only really serve to show what might be possible in a particular site and to indicate the sensitivity of any adoption decision to variables such as utilisation.

Numerous unspectacular techniques are likely to be more cost-effective than some of the more fashionable concepts such as heat pumps. They have in most cases been proven over a long period. In any energy management programme it is important that these techniques are not neglected in the pursuit of more glamorous projects.

Chapter Thirteen

MANAGERIAL BARRIERS TO CHANGE

13.1 Introduction

The following sections explore managerial barriers to energy conservation. Many reports on the barriers to energy conservation cite management problems but do not explore them in detail. Here the soft systems model of the activities necessary in energy management developed in Section Two is used to examine barriers to energy conservation. The examples used are drawn mainly from the interviewed companies with some from the literature. Three types of managerial barriers can be distinguished: informational, strategic, and organisational and human. Each is now discussed in turn and the interactions between the three types described.

13.2 Informational Problems

Probably the biggest barrier to energy conservation is lack of information, or poor information management of one kind or another. As shown in Section One, 26 companies out of 49 sampled in the brewing sector monitor energy consumption at greater than monthly intervals or not at all. Without regular management information, effective action is unlikely to occur as shown by the evidence of these companies, eleven of which reported no reduction in specific energy use over the last two or five years.

In the dairy sector sample, two out of twelve sites did not monitor energy use at all while in the malting and distilling sectors samples monitoring is nearly universal.

The incidence of monitoring in the four sectors was higher than that reported by Hoare (1983) in a geographically localised but general in industry sector, survey in which only 50% of respondent companies practiced some form of energy monitoring.

We have seen that most sites in the brewery and dairy sectors do not adjust their monitoring figures for variances such as production, production mix, season and climate. Corrections are more often made in the distilling and malting sectors. Only twelve out of 49 sites in the brewing sector divide energy use into cost centres and allocate responsibility for energy to line managers, while only two out of eight dairy sites do. In the other sites engineers are responsible for energy conservation. In two distilling companies production managers are responsible for energy and all other resource uses, energy specialists provide a service to the production managers. In the other distilling companies and in malting sites, the energy manager, usually an engineer, is responsible for energy conservation.

This allocation of responsibility is necessitated by a lack of information on energy use within the plant. Provision of this information requires sub-metering which generally does not exist. Giving responsibility for energy conservation to engineers can create organisational barriers to change which are discussed in more detail below.

Another informational problem, possibly caused by organisational and human problems, occurs when information is either not passed on to the relevant people or when people do not understand the significance of information. In one of the large breweries interviewed it was admitted that prior to a recent management "shake-up" information concerning energy use was collected but not distributed to any managers. Roberts (1983b) cites a similar case in a brewery in which after the information was circulated it quickly led to action that saved one-third of the energy used in bottling.

In one distillery interviewed the chemistry laboratories were responsible for carrying out boiler blow-down water and stack gas analyses. When the readings were outside set limits (indicating low efficiency that can easily be corrected), the chemist often did not communicate the message to the chief engineer as he had neither been trained to understand their significance, nor to realise his own role in the communication chain of management.

Another major problem which is information related, is the existence and prevalence of paradigms. All too often decisions appear to be based on paradigms and views that may have been relevant in the past but have become out of date. One of the quickest and cheapest ways to save energy is simply to question all practices and assumptions. Roberts (1983b) cites the case of a brewery where the same product was being stored in three separate vessels at three different temperatures, 30°F, 38°F, and 44°F respectively. In each case, the product was bottled and delivered under the same name and tested against a common quality standard. A detailed investigation led to a more rational and lower overall consumption of energy, and revealed spare refrigeration capacity in each case.

In one brewery the author discovered that a heat exchanger was working in reverse most of the time, heating up effluent instead of recovering heat from it before dumping it to drain. Similar examples abound in companies with extensive energy management programmes.

An interesting example of a paradigm concerns pumps, again in a brewery. The type of pump used was inefficient because of its impellor design but preferred by the brewers as it was "easier to clean" than the alternative, more efficient pump. Only after extensive tests and persuasive efforts did the brewers admit that it was just as easy to clean the more efficient impellor. Admittedly the threat of biological contamination in a brewery is serious but the brewers exhibited an almost fanatical unwillingness to even consider change. Belief in paradigms, and failure to question assumptions represents a failure to see the problem and available techniques as they exist now. Several viable techniques are prevented in some cases because engineers distrust a technique they experienced ten or twenty years before, ignoring any advances in knowledge and ability made in the intervening period.

13.3 Strategic Problems

These can be divided into two types: lack of strategic thinking in integrating energy conservation investments and other investments; and lack of strategy within the energy conservation investment sub-set of company activities. The need to integrate energy conservation investment plans both with non-energy investments and with other energy investments was stressed in the soft systems model.

Examples of failures of the first type are now illustrated:

a. A small brewery invested over £2,000 on replacing a burner system for heating a copper. Savings were estimated before the investment at £1,000 p.a. and these were being achieved. Within a year however, the copper was replaced as part of the normal capital investment cycle. This illustrates a failure to think strategically about the effect of planned or anticipated changes to process equipment (or possibly process itself in some cases) on energy conservation investments. The company did learn from its mistake and ensured that energy saving features, including a novel heating system, were incorporated into the new copper. These reduced the gas bill by 20% relative to the performance with the improved burner system.

b. A medium sized brewery installed a CO_2 recovery unit on the understanding that the alternative method of beer pushing, using nitrogen, would not be installed. The engineering department had previously lobbied for a nitrogen system because of the energy saving potential. This occurs because with a nitrogen system, nitrogen blanketing can be used to de-aerate the water used for diluting high strength brews rather than using steam heating followed by refrigeration (de-aerated water is used as the presence of air in the water imparts an undesirable metallic flavour to the product). The brewers, however, had flatly refused to consider nitrogen pushing. Less than a year after the CO_2 recovery system was installed the brewers changed their mind and announced a switch to nitrogen pushing. The capital and time invested in the CO_2 recovery was largely wasted by this change in policy.

Although some CO_2 recovery will still be practiced after nitrogen pushing is installed, the system is now unlikely to achieve a satisfactory rate of return.

c. A brewery decided to open a "brew pub", a public house which brews beer on the premises. Under marketing pressure the engineering department was instructed to convert the existing building by a certain date. The engineers estimated that a reasonable time to design, build and install the brewing system and building modifications would be twice as long as the time allowed. It was completed on time but without "luxuries" such as energy conservation features. The time constraint left insufficient time to design in several possible energy saving features. The sole objective was to build a working brew-pub by the date set. Constraints in the building, notably space, meant that advance planning for later addition of energy conservation features was also not possible.

d. A brewery that was investing £1.2 million in a new brew-house had the option of including copper vapour heat recovery (CVHR) using mechanical vapour recompression (MVR). This novel scheme would have added £0.5 million to the capital cost (before a government grant of 25%) and had a 2.5 year payback period which was within the company's normal criteria for retrofit investments. The MVR system would have reduced brew-house running costs by 80%. The option was rejected by senior management on grounds of shortage of capital. Leasing the MVR system, a possible way round the capital constraint, was not considered by the company. A secondary reason, which if it goes ahead within a medium time-scale would make this an example of systematic thinking, was a Board decision to reduce boil-off from 10% to 5% within ten years. This would reduce the cost-effectiveness of the MVR system.

In this example the engineer was being systematic in trying to incorporate a major energy saving technique into a new brew-house necessitated by the normal capital investment cycle. If the reduced boil-off decision is implemented it may well show strategic decision making by the Board. It appears however that the interactions between the projects, for example the effects of reduced boil-off on MVR system size and return, were not considered.

e. A large dairy was built for a group and reputed to be the most modern in Europe in terms of automation at that time, but had a very low energy efficiency. Even at 1979/80 energy prices, numerous viable energy saving projects were feasible. These would have been relatively easy to include during the design stage but "no attention" was paid to energy. The dairy was over-rapidly designed and built with no attention paid to reducing running costs.

Staff at the dairy are now attempting to rectify some of the failures to incorporate energy conservation projects. Some retrofit opportunities have been made difficult or non-viable because of constraints built into the dairy. Consequently the dairy is locked into a higher energy consumption and higher running costs than could have been achieved even with techniques economic at 1979 prices.

Examples of proper strategic total system thinking in which the synergy between general investment decisions and energy conservation investments was considered include the following:

1. A medium sized brewery, when building a cask-conditioned beer line, included drainage sumps that would enable an effluent heat recovery scheme to be added later, even though this project was not past the idea stage. Without the drainage sumps, easily incorporated at the construction stage, the costs of adapting the plant for effluent heat recovery at a later stage would have been prohibitive.

2. Two small breweries, neither of which could allocate capital to retrofit measures, ensured that all new plant was designed to be energy efficient. In one company the Head Brewer even included meters in new capital plant expenditure, "hiding" them from the cost-conscious Board.

This latter example could represent one of two possible cases. Either top management were being systematic and conserving capital for other, higher return projects, e.g. marketing, and the production manager (Head Brewer) was wasting capital on meters; or he was being systematic in using the opportunity afforded by new plant purchase and doing what he could against higher opposition. The important point is that this issue was not made explicit.

Discussions with management suggested that sufficient capital was available for metering and that top management had failed to appreciate the importance of metering in reducing energy costs. This lack of appreciation indicates an important communication failure between energy managers, meter suppliers, government agencies and senior management.

Examples of the more narrowly drawn sub-system approach within energy conservation investment are now given:

A company operating high temperature kilns (not in the food, drink and tobacco sector) decided to install a secondary recuperator on one kiln. During the system design it was also decided to install a microprocessor temperature control system which would save energy by keeping the kiln temperature within tighter limits. The secondary recuperator was installed followed by the control system. The tighter temperature control reduced the exhaust temperature such that the temperature in the secondary recuperator fell below the dew point, consequently acid condensed out of the exhaust and rapidly corroded the recuperator. Better strategic design would have delayed the recuperator until the control system was in place and working. Then the design of the recuperator could have taken the lower temperature into account.

A company installed insulation behind a false ceiling without realising that uninsulated heating ducts passed through the void space. Consequently the heating bills increased because of greater heat losses from the ducts and they had to be insulated. Total capital costs would have been much lower if both the ceiling and ducts had been insulated at the same time.

An example of the problem of deciding when to invest in new techniques is the case of a large brewery which invested £50,000 in a computerised data logging system for energy monitoring in 1981. When the system was installed the company had an energy management system in which the engineering department was totally responsible for energy conservation. Within two years the data logging system was found to be inflexible and have insufficient monitoring points even for the existing organisational form. It was decided to switch to a system in which line managers were responsible for energy conservation. The data logging system had to be replaced by a more flexible and extended system.

This example shows the relationship between informational systems and organisational form (to be explored below) as well as the problem of when to buy new technology.

Although it failed to recoup the investment the original system did help to sell the value of metering and monitoring to senior management. As Rosenberg (1982) and Jacques (1981) have shown, there can be rational reasons for not investing in new technology now and waiting for a more advanced, possibly more proven, and possibly cheaper form of the technology. This decision, however, must be made explicit. Costs and capabilities of electronic energy management systems in particular, in common with other electronic equipment, have rapidly changed during recent years.

13.4 Discussion

We have seen that examples of non-strategic thinking leading to wasteful investment occurred in a variety of companies, of all sizes. Some of the companies were noted for successes in energy conservation. Examples of both good and bad strategic thinking sometimes occurred in the same company. In all cases returns from investments were reduced, if not obviated.

Several problems appear to be due to a lack of appreciation of technological problems by top management. Although working under pressure does have advantages the example of the brew-pub is extreme. Essentially the project had to be "crashed". If the extra costs, capital, running and human costs, were considered explicitly and judged to be less than the benefits the decision would be defensible. If, as seems likely, they were not, it was a poor decision. In either case the impression gained is a lack of appreciation of technical problems. The example of the new dairy is similar and possibly reflects poor production facility planning at a higher level.

The example of nitrogen pushing and the CO_2 recovery unit suggests a lack of any consistent, explicit technology policy. The Head Brewer's initial rejection of nitrogen pushing was reversed within a year, suggesting that either the original decision was ill-considered, or the degree of uncertainty in this "decision" was not correctly communicated to engineering staff and others. The policy was understood to be "no N_2 pushing" whereas it seemed in retrospect to be "wait and see". If this had been explicitly recognised by all parties the CO_2 recovery system could have been delayed.

Several brewery engineers complain that top management, which is often dominated by marketing and accounting specialists, do not understand technology. It would be easy to dismiss this view but some of the examples do support it. Top management decisions with technological implications often appear to be made without recognition of these implications and without strategic technological planning. The need for such planning and general acknowledgement that senior management lack technological know-how is found in Pappas (1984) and Steele (1983).

Other examples also suggest that top management do not understand technology. One brewery engineer was asked whether he could use mild steel trunking instead of stainless steel on a boiler economiser to reduce capital costs. This would have been possible but the estimated lifetime of the ducting would be less than two years. The project had a payback period, with stainless steel trunking, of about two years. The engineer resisted and won the case.

The need for systematic planning at all levels is again illustrated by this case. If senior management had alternative higher return projects in which to invest they were correct to try to reduce capital costs. Their lack of technological know-how led them, however, to do this in the wrong way. Delaying the economiser rather than trying to impose false economies would have been a better strategy. This attempt implicitly shows a lack of faith in the engineer's ability to design or specify an appropriate system. If senior management did not have alternative projects they did not have a valid reason to reduce capital costs. The important point again is failure to make this issue explicit.

Many brewery managements have problems understanding technology. In the words of one brewery engineer, "this place has gone through a technological revolution and no one has adjusted yet". The revolution appears to have been more accidental than managed. The brewing industry in particular remains saddled with an unwarranted craft romanticism whereas the reality is a high technology, chemical engineering operation.

The nature of energy conservation activities, and technology in general, suggests that an explicit technology policy, if not an energy policy, is necessary. Only one example of an explicit energy policy was found within the four sectors examined. This contrasts with experience in the chemical industry (S R Graham, D Boland, personal communications).

Some examples of non-strategic thinking are a result of day-to-day pressures taking precedence. One brewery engineer said that the only time he had to work on projects was in the evenings and at weekends. Although such application is laudable it is a comment on the organisation in which such "moonlighting" is necessary. The day-to-day pressures seem to have three possible causes: poor management; pressure caused by projects being given priority by top management; and organisational designs and climates in which engineering staff are interrupted throughout the day on minor administrative matters (a case of confusing the urgent with the important). These causes reflect hierarchical structure problems of the firms' management which have effects other than in energy management activities. These are specific examples of the general disease of bad management.

13.5 Organisational and Human problems

In most of the sites in the four sectors large enough to merit separate engineering departments responsibility for energy conservation was primarily with the engineering function. Engineers have technical expertise in energy related matters, (though not usually energy conservation per se) but only energy generation in boiler houses, and possibly energy distribution is under their direct control. Energy use, or mis-use, is under the control of the users and not the producers. This important principle is often ignored.

Any attempt to make energy management at the good housekeeping level the responsibility of engineering staff is likely to lead to several problems. Firstly the engineer-energy manager is unlikely to have time to keep a close check on all energy users in all departments. Secondly, any attempt to change working habits in another manager's department is likely to compromise that manager's authority. Thirdly, without explicit responsibility the department manager is unlikely to have sufficient motivation to ensure good housekeeping is practiced.

One remedial approach encountered is to appoint energy wardens who are made responsible for ensuring good housekeeping in their particular areas. This may be good for spotting problems such as steam leaks but is unlikely to result in operational changes where appropriate because the energy wardens lack authority.

In some brewing sites where the engineers are responsible for energy conservation a common attitude amongst line managers is that "energy is something the engineers look after". These managers have no explicit responsibility for controlling energy costs and express their objectives as producing beer, not producing beer at a profit. In two sites where this occurs there are suggestion schemes and energy committees but 80% of the input comes from the engineering departments.

It may be that line managers have insufficient expertise in energy conservation. Most managers, however, do have an in-depth knowledge of their own production equipment and operations that should be a good basis for energy conservation activity. It seems more likely that the lack of action is caused by a lack of motivation. Unless departments or areas are sub-metered and line managers given full explicit responsibility for reducing energy costs, in co-operation with engineers, there is no motivation.

The effect that this problem can have is illustrated by the example of a production manager who had always scheduled steam cleaning of plant at weekends. This resulted in the boiler having to be fired up at weekends at an estimated cost of £600 per occasion. On one weekend when essential maintenance work necessitated a complete electrical and therefore steam shut-down, (the boilers cannot be run without electrical power), the cleaning operations were rescheduled to occur during the week.

When the plant energy manager suggested that this could be done every week, saving about £30,000 per annum, the production manager refused. The energy manager subsequently arranged several notional electrical shut-downs at weekends to illustrate that rearranging the cleaning was possible and resulted in little, if any, extra cost. After several "shut-downs" and persistent persuasion by the energy manager, the practice was made permanent.

The production managers stated reason for refusing to reschedule cleaning operations, extra cost was not justified. If the costs had been real the energy manager would have been wrong to persist and this would have reflected unsystematic thinking on his part. In this case however, he did consider all other costs and decided upon action which was subsequently proved correct. The production manager did not regard energy conservation as part of his role. Presumably, he felt no motivation to do so because energy use in his area was not metered and he was not explicitly made responsible for energy use within the area.

The importance of allocating responsibility to line managers is supported by Roberts (1983b) and Boatfield (1982). The latter stresses that line managers must be totally responsible for all functions including engineering. In order to be responsible for a technical function, the non-specialist must make the engineering management accountable to him for the engineering function. The same applies to other specialist functions such as Health and Safety. This approach has had spectacular results, both in energy conservation and environmental pollution control (Boatfield, 1982; see also Financial Times, 29 August 1980).

One distillery company illustrates the difficulties in switching to a system in which line managers are given full responsibility. The group energy manager realised the problems inherent in having chief engineers responsible for controlling energy consumption. Despite having one supporter on the main board it took two years to change the system. Eventually, in 1981, the Assistant Manager at each site was appointed as an Energy Co-ordinator. Each had complete responsibility for energy conservation and engineering staff as a resource. Energy savings since 1981 have been about 25%. The central energy manager, a chemical engineer by training, believes that technical people are needed for energy work but they do not need to be energy engineers: "there is no problem in a technically aware person acquiring the principles of energy conservation".

Organisational problems can also occur at the level of new equipment purchase. In a large brewery where the manager responsible for energy use in public houses, an engineer, was establishing specifications for new buildings and renovations, encompassing lighting, heating and ventilating, cooking and dishwashing equipment. The purchasing department had traditionally been responsible for purchasing new equipment and its objective had often been to minimise capital outlay. The energy manager was trying to minimise running costs within a definition of profitable investment (i.e. the payback period criterion). There are, however, no formal links between purchasing and the energy management function. The energy manager is having to forge these links but is encountering resistance from the purchasing department, who see a takeover of some of their functions.

Another "human" problem, possibly exacerbated by organisational designs in which engineers are given responsibility for energy conservation, is excessive concentration on hardware and high cost solutions. Roberts (1983b) cites a case where high cost measures were instigated first and saved £250,000 a year on a site having an annual fuel bill of £4 million. The capital cost of the projects amounted to £250,000 and management were pleased with achieving a one year payback. Later, when the site was examined for no-cost and low-cost improvements, a further £250,000 per annum of energy was saved for a capital cost of only £25,000. All too often engineers concentrate on hardware instead of information and organisational software.

An organisation in which functions are rigidly separated can present barriers to effective energy management. In many companies interviewed, engineers produced proposals on a payback basis which were then handed to accountants for DCF analysis. If any sensitivity analysis is conducted it is done without access to engineering information necessary to assess technical risks. This rigid separation of functions lowers the usefulness of sensitivity analysis. In one case found the project had been rejected because of a low IRR but a check by an engineer trained in DCF techniques proved the analysis was incorrect. In one of the larger breweries engineers had recently acquired microcomputers and started to do their own DCF calculations and spreadsheet modelling.

Only one company in the brewing sector sample had a separate energy conservation capital budget, expenditure being requested from a general capital budget. This means that projects can be accepted and rejected on a piecemeal basis, making integrated planning of projects more difficult. It also has two important consequences for companies supplying energy saving equipment. Firstly, as in all marketing, it is important to find out at an early stage in the contact who actually makes the decision. In most cases the engineer or energy manager decides what equipment or service he requires, but the finance department has the final say over what is bought through control over the capital budget as well as financial appraisal.

In such cases it is important that the potential supplier finds out (a) what the capital expenditure criteria are; and (b) what the preferred methods of proposal presentation (i.e. IRR, NPV, with/without tax etc) are, so that it can either help the engineer prepare, or itself prepare, a proposal with a high probability of acceptance. These basic actions seem to be overlooked by many supplying companies.

The second and possibly more serious consequence is that engineers prepare proposals on the basis of quotes. Proposals are then passed on to finance departments. If they are accepted they are then put into the following year's capital budget. This can result in long delays between acceptance and implementation with obvious consequences for suppliers' cash flows.

The establishment of a separate energy conservation capital budget aids the integration of projects through formation of a portfolio and can reduce the time lag between project acceptance and implementation.

13.6 Summary

Managerial barriers to energy conservation investment have been categorised into three related types: informational, strategic and organisational and human.

The most important informational barrier, and probably the most important barrier of all, is failure to monitor energy use and costs. Monitoring is linked to organisational barriers. Organisations in which energy managers are responsible for controlling energy costs often encounter problems of lack of coordination and lack of motivation for line managers. Giving full responsibility to line managers, and a coordinating and support role to energy "managers", induces this motivation. To do this, however, requires a well developed monitoring system which breaks down energy costs and usages into cost centres and delivers relevant and timely information in a usable form to line managers.

Another informational problem is the existence and prevalence of paradigms both about existing production equipment and energy conservation techniques. These reflect a failure to understand available techniques as they exist now and unwillingness to experiment in a scientific manner.

These managerial barriers conspire to prevent investment in energy conservation techniques, even where such investment would if properly evaluated, meet the company's investment criteria.

Chapter Fourteen

MANAGERIAL FACTORS FOR PROMOTING ENERGY MANAGEMENT

14.1 Introduction

Investment in energy conservation embodies technical change. Wide differences in energy conservation performance, as measured by reduction in specific energy, have been reported in all four sectors. It has been argued however, that success in energy management is not necessarily associated with the magnitude of the reduction in specific energy. Indeed, in some circumstances not investing in energy conserving techniques may constitute successful energy management. Success in energy management is associated with making the issues and decisions explicit and viewing energy conservation as a means of reaching overall corporate objectives. Many companies that have done this have achieved significant reductions in specific energy and hence costs. Soft systems modelling has been used to explore the activities necessary for successful energy management. Here we are concerned with the managerial, in the broadest sense, factors that promote these activities.

It was originally intended to use data gathered from the postal survey of the brewing sector to test hypotheses about the characteristics of successful firms and this was done in Section One. As described in Section Two however the measure of success used in designing the survey, namely reduction in specific energy, is no longer considered wholly appropriate. Indeed, it is now thought that the level and depth of information required to identify successful companies precludes the use of a simple questionnaire. A method akin to the snowballing technique in buying behaviour (see for example Moriaty and Bateson, 1982) may be more appropriate.

Consequently the factors for success described below are derived from both the statistical evidence resulting from the survey, and examination of companies that appear successful by the criteria described in Section Two. This has been combined with a wide ranging review of the literatures on innovation, buying behaviour, organisational design, management information systems, energy management and general management. The factors largely concern intangible and often objectively immeasurable matters.

14.2 The important factors

The factors likely to promote successful energy management that are discussed below are as follows:

Existence of an energy management information and control system

Establishment of targets for energy consumption

An appropriate organisational design

Organisational climate

Support by senior management

Existence of a technological entrepreneur or product champion character

Existence of a technological gatekeeper or hunter-gatherer character

Motivation at all levels

Training and development at all levels

These factors could exist in many companies in many forms but it is their quality and synergism that promote successful energy management. Absence of one or more factor inhibits the effectiveness of energy management and hence inhibits energy conservation.

14.3 Existence of an energy management information and control system, targetting and appropriate organisational design

Information systems, targetting and organisational design are inextricably linked and will be discussed together.

The need for an energy management information system, incorporating frequent monitoring and comparison with targets, is recognised in the energy management literature. Jacques (1981), Roberts (1983a, 1983b), Murphy and McKay (1982), Payne (1984) and Finer (1984) all stress the importance of monitoring. Despite reservations about the validity of reduction in specific energy as a measure of success, the statistical tests on the brewing sector data reported in Section One strongly support a correlation between monitoring at monthly or more frequent intervals and achieving any reduction in specific energy and a larger than median reduction. Several companies interviewed in the sample reported monitoring was the single most effective measure.

It is recognised that adjustment of specific energy figures and the setting of suitable targets are not easy tasks. Targets, for energy use reduction as for other activities, are hard to set and easy to manipulate. The evidence however appears to strongly support the view that the rewards are worth the effort.

Information systems should be designed to adjust for variances caused by production level, product mix, climate and season where appropriate. It is recognised however that this can be difficult, especially in multi-product plants such as breweries and dairies. In the early stages of an energy management programme the adjustments may not be necessary but as easy options are exploited more complete information on energy use patterns is required as a guide to action.

Organisational design is not usually discussed in connection with energy management and we have seen how total responsibility for energy conservation is often given to an engineer or engineering manager. Some of the problems this simplistic approach can cause have already been described.

Organisational designs in which line managers are responsible for all resource use in their departments, and engineers are a service function, can create motivation in line managers often lacking in a system where engineers are responsible for energy conservation.

Such an organisational design carries with it the need for information on a cost centre basis, information that can only be supplied by sub-metering. A method of creating motivation is also needed, namely targetting for each cost centre. Boatfield (1982) and Roberts (1983b) both support the view of allocating responsibility to line managers as well as the need for targetting.

Much emphasis has been put on information systems, especially computerised systems, both in general and in energy management, without paying attention to organisational issues. As Tricker (1976) notes:

> "There is as much need for new organisation structures as computer assisted systems, to meet contemporary issues and opportunities."

This comment certainly applies to energy management.

Allocation of responsibility to line managers is essential for effective good housekeeping on all but the smallest sites but could conceivably lead to sub-optimisation at the investment level because of interactions between projects as described in Section Two. Thus there is a need for a coordinating activity (shown on the soft systems model as assembling a portfolio). This would be one role for an energy manager or energy specialist. It is essentially a systems-managing, coordinating role.

Successful organisations appear to create dual motivation whereby line managers and energy specialists (engineers) are both motivated to actively search out conservation opportunities and implement them. Some companies in the survey and in the literature (BMDF Conference, London, 1983) use a project team approach at the energy conservation investment level. Such an approach overcomes the artificial separation of departments that often occurs, for example between the engineer setting design standards and the purchasing department, an example of which was described earlier.

In conclusion, an information system that provides frequent suitably processed information on a cost centre basis is required. This should be coupled with an organisational design in which line managers are responsible for energy use in their department and assessed on whether or not they achieve targets (probably set in conjunction with energy specialists). At the investment level a team approach, calling on the various functional departments such as production, engineering, purchasing, and finance, is useful with a coordinating role played by an energy specialist or in some cases possibly a consultant.

14.4 Organisational climate

Organisational climate is hard to define but its importance cannot be overlooked. Several examples of the value of questionning assumptions and practices were described earlier and successful companies create a questionning climate. No recipes for achieving it can ever be given but it is an important factor. Its achievement is likely to be helped by the proper design of information and assessment systems.

14.5 Senior management support

Top management support is often quoted as a condition for successful energy management as it is for successful innovation. Few specific guidelines for either top management, or for lower management seeking support, exist.

The important roles for senior management must be in establishing information systems, redesigning organisations where necessary, setting overall targets and allocating resources. Motivation is again relevant. Communicating the importance of energy conservation to all staff, backing up the efforts of operational staff, is an important role senior management can play. For examples of this see Edwardes (1980) and the Allied-Lyons Annual Report, 1983, Chairman's Statements.

Cases of senior management appointing an energy manager but not allocating any resources have been found. Without resources the effectiveness of an energy manager is severely limited. One strategy for the energy manager in this situation, advocated by Boatfield (1982) and Roberts (1983b) is to concentrate on no-cost or low-cost measures first. Evidence about the savings from these can be used in bidding for resources.

14.6 Existence of a technological entrepreneur or product champion character

In the model of technical change presented in Section Two the role of the coupling agent was stressed. The role of this actor in the energy conservation field parallels a similar role described in the innovation literature, the linking of technological possibility and market opportunity. The importance of this coupling role is also stressed in the description of the design process by Freeman (1983).

Two streams of literature stress the importance of the individual in the coupling role. Schon (1963) describes one man emerging as "a man willing to put himself on the line for success". He continues:

> "No ordinary involvement with a new idea provides the energy required to cope with the indifference and resistance that major technological change provokes. It is characteristic of champions of new developments that they identify with the idea as their own, and with its promotion as a cause, to a degree that goes far beyond the requirements of their job. In fact, many display persistence and courage of heroic quality."

In new product development the concept of a product champion is described by Chakrabati (1974).

Energy managers from those companies which have had very successful energy management programmes often exhibit the characteristics of a product champion described by Schon (1963). They drive their organisations towards greater efficiency, often against considerable opposition, through strength of personality.

Admirable though such people are, the need for them implies an organisation in which technical change has not been institutionalised. As people with the characteristics of product champions are, almost by definition, a short resource, relying on their presence is a risky strategy. One possible consequence of relying on extraordinary people of the product champion type can be that when they leave the organisation enthusiasm for energy conservation leaves with them. An example of this is a major dairy company in which all interest in energy conservation died after the departure of one man from the central engineering department.

The need for extraordinary people is reduced by the establishment of an energy management and information control system which blends information, organisational design and recources to produce effective action. In successful companies the energy information and control system is often part of the general information and control system as energy is just one of many resources. The establishment of an appropriate energy information and control system may in itself require a product champion character, as shown by the example of a distillery group energy manager fighting for two years to establish a system with line manager responsibility.

14.7 Existence of a technological gatekeeper or a hunter-gatherer

The innovation literature stresses the importance of information flows in the innovation process. The concept of a technological gatekeeper has been advanced to describe an important role in the innovation process, that of admitting new ideas to the organisation. The word gatekeeper implies a rather passive role which seems inappropriate. A technological hunter-gatherer would seem to be a more appropriate description, implying as it does an active, sorting role.

In the energy conservation context the individual must be plugged into an internal energy management information system as well as other relevant internal information e.g. about financial conditions and general investment plans. The hunter-gatherer must also be plugged into external information about the availability, applicability, performance and costs of a range of techniques. This information must be sought out. Having said that many engineering and energy managers complain about receiving too much information about products and services in the form of unsolicited advertising material. Managing this flow of information in order that it can be exploited at an appropriate time is an important part of the technological hunter-gatherer's role. Often the collection and storage of external information is not formalised but left to the individual.

In many cases the technological entrepreneur and the hunter-gatherer roles will be played by the same person. If they are not, close communication between the two actors would be necessary. In one large company in the engineering sector a consultant is retained partly in order to act as a technological hunter-gatherer, bringing in new ideas. In smaller companies lacking expertise, the use of a good consultant in this role could be vital but in the sampled companies in the four sectors the use of consultants has not been widespread.

14.8 Motivation, training and development at all levels

Motivation has been stressed throughout this section. It cannot be separated from the other factors, some of which are designed to motivate people into taking effective action. Training and development of staff at all levels is another neglected area. Few of the companies in the four sectors had any formal training programmes for energy management or other staff. Training forms another important aspect of software that has been neglected.

As mentioned above, an important method for motivating line managers and others is setting targets and assessing whether these are achieved. Explicit responsibility and clear targets are good motivators.

The existence of a separate energy conservation budget also has a motivating effect on management. It shows that senior management take energy conservation seriously.

The importance of motivation and training at all levels is supported by a Grafton Consultants report, "Employee participation in energy programmes"[1], and various reports in the literature, including one concerning Lyons Bakery at Wakefield.[2]

14.9 Summary

Nine factors for promoting successful energy management have been presented and discussed. They are:

Existence of an energy management information and control system

Establishment of targets for energy consumption

An appropriate organisational design

Organisational climate

Support by senior management

Existence of a technological entrepreneur or product champion leader

Motivation at all levels

Training and development at all levels.

These factors have been derived from both the statistical evidence described in Section One and from observations of companies deemed to be successful by the criteria described in Section Two. The factors can exist in many forms but it is their quality and synergism that promote successful energy management.

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[1] Published by Grafton Consultants Ltd, 1982, reported in Energy Management, April 1982.

[2] Reported in Energy Management, January 1982.

SUMMARY OF SECTION THREE

Section Three examined barriers to energy conservation investment. These can be classified into techno-economic, i.e. failure to meet economic criteria, and managerial. The former were explored using profitability modelling while the latter were analysed in the light of the soft systems model developed in Section Two. Examples from sampled companies in the four sectors were used to illustrate managerial barriers.

Two techniques in particular were selected for in-depth profitability modelling, heat pumps and combined heat and power. These are both reported in the literature as having large potential. Heat pumps for industrial heat recovery in the brewing and dairy sectors do not appear to be attractive investments under reasonable assumptions. This particular "potential" has been over-stated. Industrial combined heat and power (CHP) on the other hand appears to be a viable investment that has not yet been evaluated by many companies. The 1983 Energy Act has improved the viability of this technique. Its potential is only likely to be exploited as and when conventional steam plant have to be replaced because of the high capital cost involved. Other barriers, notably the complexity of running a CHP station, may also be significant.

Example economic evaluations for other techniques were also presented. As stressed in Section Two it is difficult to draw general conclusions about the viability of a technique. It can only be said that if it is viable in one site it is probably worth evaluating everywhere but only in a fraction of sites will it be profitable (assuming the same definition of profitable). Other techniques, not used elsewhere, may also be viable. Low energy lighting, additional metering and oxygen trim control systems seem to be viable in a wide range of sites.

Managerial barriers were divided into informational, strategic and organisational and human. All three categories interact. A major informational barrier is lack of any monitoring of energy use. Even where monitoring is practiced it is often infrequent, on a site wide basis only and unadjusted for unavoidable variances. All three failures reduce its effectiveness as a management tool.

Failure to anticipate the interactions of energy conservation projects and other investments, both energy and non-energy, is another problem within energy management. This failure often reflects the lack of a conservation strategy. Another major barrier to effective energy conservation investment is the prevalence of paradigms and misperceptions about different techniques. This is a direct result of lack of training in energy matters.

Organisational and informational problems conspire to prevent motivation reaching all staff at all levels. All too often the only people motivated to reduce energy use are the engineers who can only really control energy generation and distribution, not its use or abuse. The training and expertise of the engineers often leads to an over-emphasis on energy saving hardware rather than informational and organisational software.

The factors that promote effective energy management were discussed. These are related to the factors that promote general technical change and innovation. They are:

Existence of an energy management information and control system

Establishment of targets for energy consumption

An appropriate organisational design

Organisational climate

Support by senior management

Existence of a technological entrepreneur or product champion character

Existence of a technological gatekeeper or hunter-gatherer character

Motivation at all levels

Training and development at all levels.

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Chapter Fifteen

OVERALL SUMMARY AND CONCLUSIONS

15.1 Summary

Section One reported a great variety in the reductions in specific energy, techniques used and energy management approaches in companies in the four sectors. The malting sector was an exception in that most of the investment was in one technique.

The brewing sector sample was used to show a strong relation between a large reduction in specific energy and monitoring at monthly or more frequent intervals. A weaker relation existed between a large reduction in specific energy and the use of targets and cost centres.

Most investments in all four sectors utilised previously used techniques rather than innovations. Most of the investments were retro-fitted onto existing plant. Investment criteria for retrofit measures were broadly similar in all four sectors. In all four sectors the financial viability of conservation techniques was shown to be very dependent on site and company specific factors. Energy management in the four sectors can be broadly divided into three categories; firstly there are sites with no monitoring, secondly sites with plant wide monitoring, and thirdly sites with monitoring on a cost centre basis.

In Section Two a model of technical change relevant to energy conservation was presented and used to define potentials for energy conservation equipment. A distinction was made between a potential that is achievable through invented techniques or concepts and a potential achievable through already innovated techniques. The site-specificness of the viability of energy conservation techniques means that potentials can only be defined on a site by site basis. To measure these potentials at any site would require extensive engineering and cost-benefit analyses. The high cost of acquiring information at the required level of detail makes actual measurement of these potentials unlikely. Consideration of these potentials may however be a useful activity for example in planning an investment portfolio. Given these definitions of potentials it is clear that any estimate of industry wide potentials must be arbitrary. Estimates for each of the four sectors were given and assumptions behind the estimates were made explicit.

A soft systems based model of activities necessary in energy management was presented. This serves as a descriptive model for management and also as a prescriptive tool for identifying problems within energy management.

Section Three described barriers to investment in energy conservation equipment, dividing them into techno-economic and managerial. The economics of two techniques, often presented as being important in the literature, heat pumps and combined heat and power, were explored. Heat pumps for industrial heat recovery were shown to be uneconomic for retrofitting under reasonable assumptions. Combined heat and power was shown to be viable in many circumstances. Economic analyses for seven other techniques were also presented.

Managerial barriers were divided into informational, strategic and oragnisational. Each type was illustrated by examples from sampled companies within the four sectors.

15.2 Conclusions

In the introduction the refined objectives of the thesis were listed as:

1. To study the potential for energy conservation equipment within the brewing, malting, distilling and dairy sectors.
2. To investigate the extent of adoption of energy saving technologies since 1976 and the results in energy saving achieved in these sectors.
3. To investigate the barriers, both managerial and techno-economic, to adoption of energy saving technologies within the four sectors; and
4. To use the information to comment on the viability of low energy scenarios within these sectors.

The realistic potential for energy conserving capital equipment was defined as those investment opportunities that are technically feasible for the organisation, viable according to the investor's investment criteria and appropriate. Thus the size of the potential is subject to decisions and judgements, some of which are outside the commonly agreed boundaries of energy management. A systematic approach to energy management, and its position within the firm, is necessary to avoid sub-optimising the use of resources. It follows from this definition of potential that an objective measurement of site potentials, or industry wide potentials, is not possible. Any estimates of industry wide potentials are arbitrary.

Many companies within the four sectors have identified and exploited, or are exploiting, much of their realistic potential for energy conservation. Improvements however are undoubtedly possible even in the most successful companies. Small companies in all four sectors have not been as effective in general as larger companies in evaluating and exploiting their energy conservation potential.

The energy saving techniques used vary greatly between individual companies even within the same sector. Malting is exceptional in that most of the energy conservation investment has been in one technique. There is evidence to suggest that the most adaptable techniques are the most frequently adopted. Investments to date have largely been in retrofitted equipment and in commercially available hardware. Companies that have adopted new techniques range from small independent companies to large companies dominant in their market.

A lack of data prevented assessing the reductions in specific energy achieved since 1976. In many cases data was only available over the last two years. This data problem is compounded by the fact that most companies in the four sectors do not correct their specific energy figures for variances caused by changes in occupacity, product mix and climate. Thus specific energy figures can be misleading.

A wide range of reductions in specific energy were reported in all four sectors. The largest savings, up to 60%, are remarkable and should serve as an indicator to what can be achieved. They should not however be assumed to be generally achievable because of the many site and company specific factors that affect the realistic potential.

The barriers to investment in energy conservation equipment can be broadly divided into techno-economic and managerial. If a technique does not at least appear to meet the required investment criteria it will not be adopted, whatever other merits it might have (assuming it is not legally required). Therefore the economics, or relative advantage of techniques, are important in explaining adoption or non-adoption.

Profitability modelling for a number of proposed heat pump heat recovery installations in the brewing and dairy sectors suggest this particular technique has been oversold. Its economics are poor and this explains the lack of adoption of this technique. Industrial combined heat and power looks an attractive investment but the high absolute capital costs may hinder its wider adoption. The attractiveness of this technique has been changed by the 1983 Energy Act and many companies have yet to realise this and evaluate the technique.

The viability of energy saving techniques is very dependent on site and company specific factors and it is difficult to draw general conclusions. Techniques that are viable in many sites include low energy lighting, oxygen trim control systems and additional steam metering. More research into the site specific factors affecting viability is advocated. A rich source of data would be quotations, both those accepted and those rejected.

As the economics of energy conservation techniques vary from site to site one object of energy management must be to evaluate all possible techniques. One managerial barrier to investment in energy conservation is unwarranted rejection of a technique before proper evaluation of its costs and benefits.

Managerial barriers to investment in energy conservation can be divided into informational, strategic and organisational and human. All three types interact. In many companies energy management information and control systems are poorly developed, in smaller companies they often do not exist at all. Lack of adequate monitoring may be the biggest single barrier to energy conservation investments.

Even in some companies noted for success in energy conservation there is a failure to think strategically about energy conservation investments. Planning to anticipate the interactions between energy conservation investments, both with other energy investments and with non-energy investments, is often neglected. The interaction between information systems and organisational designs is also not often considered. Too much emphasis is placed on energy saving hardware and not enough on the information, organisation and motivation software.

Scenarios such as that of Leach et al (1979) and Olivier (1983) are arbitrary in their estimation of potentials. Leach stresses the use of existing technology, much of which he claims is economic at today's prices. He does not define what he means by economic other than by references to the short paybacks that suppliers of conservation equipment can demonstrate. We have noted that authors on general technical change often fail to distinguish between different levels of technology. between concepts and hardware. Leach is no exception. Several of the techniques he mentions exist only at the development stage and their viability will remain very uncertain until they are commercially adopted. There are more barriers to implementation for a concept or a developmental prototype than there are for well proven, commercially available hardware.

Leach also takes generic technologies and assumes they are viable anywhere. For example, because heat pumps are viable for some space heating applications (usually commercial buildings with a demand for air conditioning in summer), he assumes they are viable in other space heating applications (e.g. factories with no need for air conditioning) and in process heat recovery. We have seen that viability in one application does not guarantee viability in similar sites with the same application, let alone viability in other applications. Leach underestimates the specific nature of technology and the problems of adapting even well proven techniques.

Leach also assumes that companies can be expected to optimise processes on an energy basis. It has been argued here and by Jacques (1981) and Rosenberg (1982b) that this is unreasonable as it will lead to sub-optimisation of the company's resource allocation. Companies operating in a market economy should optimise on financial grounds in a planned systematic manner.

Despite these criticisms of Leach, the range of reductions in specific energy already achieved in the four sectors suggests that, given the time scale involved and that further energy price rises are expected, savings equivalent to these postulated by Leach may be achieved in these sectors. To the extent that these sectors are representative of industry a low energy scenario may be achievable through the operation of the market place, including Government incentives. This important conclusion is supported by Cheshire and Robson (1983) and the econometric work of Common (1983).

The largest potential for savings appears to be through the incorporation of energy saving features into new plant design. This potential, however, is only likely to be exploited through the normal capital investment cycle. A large cost-effective potential, equivalent to the savings postulated in Leach, also exists for retro-fit equipment. At present only some of this potential is being exploited, the largest barriers to further exploitation being managerial in nature. The challenge for management, and other agents of change, is to maximise the creation, identification and exploitation of profitable energy conservation investment opportunities, both at the retrofit and new plant levels. As yet this challenge has only partially been taken up.

Some avenues for further research have been referred to in the text. These include further work on the importance of site specificness in the process of technical change which has important implications for the study and management of this activity, beyond simply energy conservation. Further work investigating the role of managerial factors in promoting energy conservation is also advocated. Further modelling of industrial CHP investments, using simulation and including full risk analyses, would also be appropriate.

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APPENDICES

Appendix 1 ANALYSIS OF INVESTMENTS REPORTED IN "ENERGY MANAGEMENT" - OCTOBER 1981 to OCTOBER 1982

Sectors	Various	Dust extraction	Waste incineration	Fuel additives	Roof insulation	Integration of services	High efficiency lighting	Lighting controls	Replacement heating	Controls inc. ems*	Oil to coal firing	Heat pump	Combined Heat & Power	Water treatment	Lining chimney	Air handling	Insulating oil tanks	Solar preheating	Heat recovery	New burners	Max. demand controllers	Use of mines gas	Furnace insulation	Total
	Investments																							
Laboratories/offices	2							1		2														5
Vehicle manufacture				1						3														4
Wood working		1	2									2												4
Ceramics																			1	2				3
General manufacture	1				1				1	2	2			1					3	3				13
Dye manufacture						1							1											2
Chemicals	1					1											1		5			1		9
Pharmaceuticals										1				1										2
Breweries	1						1		1	1											1			5
Food processing	1		1					2		2	2	1			1	1	1		3					15
British Rail Depot									1															1
Electricity Supply Industry													1											1
Hotels										1		2												3
NCB Colliery																		1						1
Local Authorities	6							2		2		2						1	3					16
Electronics	1					1	1			1		1												5
Cable manufacture					2					1														3
Retailing	1											1							1					3
Hospitals										1														1
Paper manufacture												1	1											2
Iron and Steel																							1	1

Appendix 2 SIGNIFICANCE TEST FOR SIZE AND THE USE OF MONTHLY OR MORE FREQUENT MONITORING

	I & II	III, IV V & VI	
Small	14 (8.3)	15 (20.7)	29
Medium & Large	0 (5.7)	20 (14.3)	20
TOTALS	14	35	49

Expected values are in brackets.

H_o: that size makes no difference whether a company has monthly monitoring.

Test: chi^2 test, 4 cell contingency table.

$$\frac{(O-E)^2}{E}$$

3.914
1.569
5.700
2.272

13.455 = $X^2_{(calc)}$

$X^2_{(0.001,1)}$ = 10.828

∴ We can reject H_o at 99.9% confidence level

Appendix 3 SIGNIFICANCE TEST FOR SIZE AND THE USE OF TARGETTING

	Without Targets I, III & V	With Targets II, IV & VI	
Small	23 (14.2)	6 (14.8)	29
Medium	1 (4.9)	9 (5.1)	10
Large	0 (4.9)	10 (5.1)	10
TOTALS	24	25	49

Expected values are in brackets.

H_o: size makes no difference to whether a company has targets.

Test: chi^2 test, 6 cell contingency table

$$\frac{(O-E)^2}{E}$$

5.453
5.232
3.104
2.982
4.900
4.707

26.378

$X^2_{(C.001,2)} = 13.815$

∴ we can reject H_o at 99.9% confidence level

Note: Strictly this test should not be used when the expected value in any cell is less than 5. However, in practice, it is often used when the expected values are close to 5. Combining the "Medium" and "Large" cells would be possible but would defeat the object of the test. As with all the statistical tests the results should be viewed with caution.

Appendix 4 SIGNIFICANCE TEST FOR USE OF MONITORING AT MONTHLY OR MORE FREQUENT INTERVALS AND ACHIEVING A REDUCTION IN SPECIFIC ENERGY

	Monitoring at monthly intervals	Monitoring at < monthly intervals	
Reduction in specific energy	30 (25)	5 (10)	35
No reduction in specific energy	5 (10)	9 (4)	14
TOTALS	35	14	49

Expected values are in brackets.

H_O: Monitoring at monthly or more frequent intervals makes no difference in achieving a reduction in specific energy.

Test: chi^2 test, 4 cell contingency table.

$$\frac{(O-E)^2}{E}$$

1.000
2.500
2.500
6.250

12.25

$X^2_{(0.005,2)} = 10.597$

$\therefore$ we can reject H_O at 99.5% confidence level.

Note: NB expected value less than 5, see note in Appendix 3.

Appendix 5 SIGNIFICANCE TEST FOR MONITORING AT MONTHLY OR MORE FREQUENT INTERVALS AND ACHIEVING A HIGHER THAN MEDIAN REDUCTION IN SPECIFIC ENERGY

	With monthly monitoring	Without monthly monitoring	
Above median	21 (16.4)	2 (6.6)	23
Below or equal to median	14 (18.6)	12 (7.4)	26
TOTALS	35	14	49

Expected values are in brackets.

H_o: that monitoring at monthly or more frequent intervals makes no difference to achieving a higher than median reduction in specific energy.

Test: chi^2, 4 cell contingency table.

$\frac{(0-E)^2}{E}$
1.290
3.206
1.137
2.859
8.492

$X^2_{(0.01,1)} = 6.635$

∴ we can reject H_o at 99% confidence level.

Note: NB expected value less than 5, see note in Appendix 3.

Appendix 6 SIGNIFICANCE TEST FOR MONITORING AT MONTHLY OR MORE FREQUENT INTERVALS AND DIFFERENCE OF MEANS

With monitoring at monthly or more intervals		Without monitoring at monthly or more intervals	
x	$(x - \bar{x})^2$	x	$(x - \bar{x})^2$
2	32.49	5	12.74
2	32.49	0	2.05
0	59.29	0	2.05
20	151.21	0	2.05
0	59.29	3	2.46
5	7.29	0	2.05
0	59.29	0	2.05
0	59.29	0	2.05
5	7.29	0	2.05
4	13.69	0	2.05
25	299.29	0	2.05
10	5.29	8	43.16
2	32.49	2	0.32
8	0.09	2	0.32
15	53.29		
2	32.49		
20	151.21		
2	32.49		
0	59.29		
7	0.49		
18	106.09		
8	0.09		
5	7.29		
2	32.49		
8	0.09		
9	1.69		

(continued)

Appendix 6 (continued)

With monitoring at monthly or more intervals		Without monitoring at monthly or more intervals	
x	$(x - \bar{x})^2$	x	$(x - \bar{x})^2$
5	7.29		
4	13.69		
40	1043.29		
3	22.09		
2	32.49		
16	68.89		
10	7.29		
8	0.09		
5	7.29		
272	2498.88	20	75.4

H_o: No difference between the means of the two samples

Test: t-test for difference of means

Mean: = $\bar{x}$

Subscript 1 refers to "with monitoring"

Subscript 2 refers to "without monitoring"

$n_1 = 35$ $n_2 = 14$

$\bar{x}^{1}_{1} = \frac{272}{35} = 7.77$ $\bar{x}_2 = \frac{20}{14} = 1.43$

$$s^2 = \sum \frac{(x-\bar{x})}{n-1}^2$$

$s_1{}^2 = \frac{(2498.88)}{34}$ $s_2{}^2 = \frac{(75.4)}{19}$

$s_1{}^2 = 73.49$ $s_2{}^2 = 3.97$

$$\text{variance of differences} = \frac{s_1^{\;2}}{n_1} + \frac{s_2^{\;2}}{n_2}$$

$$= \frac{73.49}{35} + \frac{3.97}{20}$$

$$= 2.30$$

$$\text{test statistic, } t = \frac{\text{observed difference of means}}{\text{standard deviation of differences}}$$

$$t = \frac{7.77 - 1.43}{\sqrt{2.30}}$$

$$t = 4.179$$

degrees of freedom = $n_1 + n_2 - 2 = 47$

$t_{(0.0005,45)} = 3.5203$

$\therefore$ we can reject H_o at greater than 99.9% confidence level.

Appendix 7 SIGNIFICANCE TEST FOR USE OF TARGETTING AND ACHIEVING A REDUCTION IN SPECIFIC ENERGY

	Use of Targets	No use of Targets	
Reduction in specific energy	23 (17.1)	12 (17.9)	35
No reduction in specific energy	1 (6.9)	13 (7.1)	14
TOTALS	24	25	49

Expected values are in brackets.

H_o: Targets make no difference in achieving a reduction in specific energy.

Test: chi^2 test, 4 cell contingency table.

$\frac{(O-E)^2}{E}$
2.036
1.945
5.045
4.903
13.929

$$X^2_{(0.001,1)} = 10.828$$

$\therefore$ we can reject H_o at 99.9% confidence level.

Appendix 8 SIGNIFICANCE TEST FOR USE OF TARGETTING AND ACHIEVING A LARGER THAN MEDIAN REDUCTION IN SPECIFIC ENERGY

	With targets	Without targets	
Above median	16 (11.7)	7 (11.3)	23
Below or equal to median	9 (13.3)	17 (12.7)	26
TOTALS	25	24	49

Expected values are in brackets.

H_o: Targetting makes no difference in achieving a higher than median reduction in specific energy.

Test: chi^2, 4 cell contingency table.

$$\begin{array}{c} \frac{(O-E)^2}{E} \\ \hline 2.78 \\ 1.64 \\ 1.39 \\ 1.46 \\ \hline 7.27 \end{array}$$

$$X^2_{(0.02,1)} = 5.412$$

∴ we can reject H_o at 98% confidence level.

Appendix 9 SIGNIFICANCE TEST FOR TARGETTING AND DIFFERENCES OF MEANS

With targetting		Without targetting	
x	$(x - \bar{x})^2$	x	$(x - \bar{x})^2$
8	0.13	5	2.37
2	40.45	0	11.97
2	40.45	0	11.97
2	40.45	0	11.97
8	0.13	3	0.21
15	44.09	0	11.97
2	40.45	0	11.97
20	135.49	0	11.97
2	40.49	0	11.97
0	69.89	0	11.97
7	1.85	0	11.97
18	92.93	2	2.13
8	0.13	2	2.13
5	11.29	0	11.97
8	0.13	20	273.57
9	0.41	0	11.97
5	11.29	5	2.37
4	19.01	0	11.97
40	1001.09	0	11.97
3	28.73	5	2.37
2	40.45	4	0.29
16	58.37	25	463.97
10	2.89	10	42.77
8	0.13	2	2.13
5	11.29		
209	1732.01	83	949.92

H_o = no difference between the means.

Test: t-test for difference of means.

$n_1 = 25$ $n_2 = 24$

$\bar{x}_1 = \frac{209}{25} = 8.36$ $\bar{x}_2 = \frac{83}{24} = 3.46$

t-test for difference of means

$$s^2 = \sum \frac{(x-\bar{x})^2}{n-1}$$

$s_1^2 = 72.17$ $s_2^2 = 41.30$

$$\text{variance of differences} = \frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}$$

$$= \frac{72.17}{25} + \frac{41.30}{24} = 4.61$$

$$t = \frac{\text{observed difference of means}}{\text{standard deviation of differences}}$$

$$= \frac{8.36 - 3.46}{\sqrt{4.61}}$$

$$= 2.28$$

degrees of freedom = $n_1 + n_2 - 2 = 47$

$t_{(0.025,45)} = 2.0141$

$\therefore$ we can reject H_o at 97.5% confidence level.

Appendix 10 SIGNIFICANCE TEST FOR TARGETTING ONLY AND ACHIEVING A REDUCTION IN SPECIFIC ENERGY

	III	IV	
Saving	8 (9.4)	10 (8.6)	18
No saving	4 (2.6)	1 (2.4)	5
TOTALS	12	11	23

Expected values are in brackets.

H_o: that targetting only makes no difference in achieving a reduction in specific energy.

Test: chi^2 test, 4 cell contingency table.

$$\frac{(0-E)^2}{E}$$

$$\begin{array}{c} \hline 0.208 \\ 0.228 \\ 0.754 \\ 0.817 \\ \hline 2.007 \end{array}$$

$X^2_{(0.25,1)} = 1.323$

$X^2_{(0.1,1)} = 2.706$

$\therefore$ we can only reject H_o at 75% confidence level.

Note: NB expected values less than 5, see note in Appendix 3.

Appendix 11 SIGNIFICANCE TEST FOR TARGETTING ONLY AND ACHIEVING A HIGHER THAN MEDIAN REDUCTION IN SPECIFIC ENERGY

	With targets	Without targets	
Above median	3 (4.6)	5 (3.4)	8
Below or equal to median	9 (7.4)	4 (5.6)	13
TOTALS	12	9	21

Expected values are in brackets.

H_o: That targetting only makes no difference in achieving a higher than median reduction in specific energy.

Test: chi^2 test, 4 cell contingency table.

Median value: 5

$\frac{(O-E)^2}{E}$
0.556
0.753
0.346
0.457
2.112

$X^2_{(0.25,1)} = 1.323$

$\therefore$ we can only reject H_o at 75% confidence level.

Note: NB expected values less than 5, see note in Appendix 3.

Appendix 12 SIGNIFICANCE TEST FOR TARGETTING ONLY AND DIFFERENCE OF MEANS

With targets		Without targets	
x	$(x - \bar{x})^2$	x	$(x - \bar{x})^2$
2	16.81	15	42.25
2	16.81	2	42.25
0	37.21	20	132.25
0	37.21	2	42.25
5	1.21	0	72.25
0	37.21	5	12.25
0	37.21	7	2.25
5	1.21	18	90.25
4	4.41	8	0.25
25	357.21		
10	15.21		
20	193.21		
73	754.92	77	436.25

H_o: no differences between the means

Test: t-test for difference of means

$\bar{x}_1 = \frac{73}{12} = 6.1$ $\bar{x}_2 = \frac{77}{9} = 8.5$

t-test for difference of means

$$s^2 = \sum \frac{(x-\bar{x})^2}{n-1}$$

$$s_1^2 = \frac{754.92}{11} = 68.63 \qquad s_2^2 = \frac{436.25}{8} = 54.56$$

variance of differences $= \frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}$

$$= \frac{68.63}{12} + \frac{54.56}{9}$$

$$= 5.72 + 6.06 = 11.78$$

$$t = \frac{\text{observed difference of means}}{\text{standard deviation of differences}}$$

$$= \frac{8.05 - 6.1}{\sqrt{11.78}}$$

$$= 0.7$$

degrees of freedom $= n_1 + n_2 - 2 = 12 + 9 - 2 = 19$

$t_{(0.25,19)} = 0.6876$

∴ we can only reject H_o at 75% confidence level.

Appendix 13 SIGNIFICANCE TEST FOR COST CENTRES AND ACHIEVING A REDUCTION IN SPECIFIC ENERGY

	With cost centres	Without cost centres	
Reduction in specific energy	13 (9.5)	23 (26.5)	36
No reduction in specific energy	0 (3.5)	13 (9.5)	13
TOTALS	13	36	49

Expected values are in brackets.

H_o: cost centres make no difference in achieving a reduction in specific energy.

Test: chi^2 test, 4 cell contingency table.

$$\frac{(0-E)^2}{E}$$

1.289
0.462
3.500
1.289

6.540

$X^2_{(0.025,1)} = 5.024$

∴ we can reject H_o at 97.5% confidence level.

Appendix 14 SIGNIFICANCE TEST FOR COST CENTRES AND ACHIEVING A GREATER THAN MEDIAN REDUCTION IN SPECIFIC ENERGY

	With cost centres	Without cost centres	
Greater than median	8 (6.1)	15 (16.9)	23
Less than or equal to median	5 (6.9)	21 (19.1)	26
TOTALS	13	36	49

Expected values are in brackets

H_o: Cost centres make no difference in achieving a greater than median reduction in specific energy

Test: chi^2 test, 4 cell contingency table.

$\frac{(O-E)^2}{E}$
0.59
0.52
0.52
0.19
1.82

$$X^2_{(0.25,1)} = 1.323$$

∴ we can only reject H_o at 75% confidence level.

Appendix 15 SIGNIFICANCE TEST FOR USE OF COST CENTRES AND DIFFERENCE OF MEANS

With cost centres		Without cost centres	
x	$(x - x)^2$	x	$(x - \bar{x})^2$
2	53.73	5	0.02
8	1.69	0	23.14
9	0.11	0	23.14
5	18.75	0	23.14
4	28.41	0	23.14
40	940.65	0	23.14
3	40.07	0	23.14
2	53.73	0	23.14
16	44.49	0	23.14
10	0.45	0	23.14
8	1.69	0	23.14
5	18.75	0	23.14
		0	23.14
		0	23.14
		3	3.28
		8	10.18
		2	7.89
		2	7.89
		2	7.89
		20	230.74
		5	0.036
		5	0.036
		4	0.66
		25	407.64
		10	26.94
		2	7.89
		8	10.18
		15	103.84

Appendix 15 (continued)

With cost centres		Without cost centres	
x	$(x - \bar{x})^2$	x	$(x - \bar{x})^2$
		2	7.89
		20	230.74
		2	7.89
		7	6.35
		18	173.98
		8	10.17
		5	0.02
112	1202.52	178	1562.96

H_o: No difference between means

Test: t-test for difference of means

$n_1 = 12$ $n_2 = 37$

$\bar{x} = \frac{112}{12} = 9.33$ $\bar{x}_2 = \frac{178}{37} = 4.81$

t-test for difference of means

$$s^2 = \frac{(x - \bar{x})^2}{n-1}$$

$s_1^2 = 108.98 \qquad s_2^2 = 45.97$

$$\text{variance of differences} = \frac{108.98}{12} + \frac{45.97}{37} = 10.33$$

$$t = \frac{\text{observed difference of means}}{\text{standard deviation of difference}}$$

$$t = \frac{9.33 - 4.81}{10.33}$$

$t = 1.41$

$\text{degrees of freedom} = n_1 + n_2 - 2 = 47$

$t_{(0.1,45)} = 1.3006$

$\therefore$ we can reject H_o at 90% confidence level.

Appendix 16 SIGNIFICANCE TEST FOR ENERGY MANAGEMENT GROUPING AND ACHIEVING A HIGHER THAN MEDIAN REDUCTION IN SPECIFIC ENERGY

	Greater than monthly monitoring I & II	Monthly or more frequent monitoring III & IV	Monthly, targets and cost centres V & VI	
Greater than median	2 (6)	12 (4.4)	7 (5.6)	21
Less than or equal to median	12 (8)	10 (12.6)	6 (7.4)	28
TOTALS	14	22	13	49

Expected values are in brackets

H_o: Energy management grouping makes no difference in achieving a higher than median reduction in specific energy.

Test: chi^2 test, 6 cell contingency table.

$\frac{(O-E)^2}{E}$
2.66
13.13
0.35
2.00
0.54
0.26
18.94

$$X^2_{(2,0.01)} = 9.210$$

$\therefore$ we can reject H_o at 99% confidence level.

Appendix 17 CALCULATION OF BREWERS' SOCIETY INDEX

Target Figures:

PROCESS	VOLUME (V) (hl)	ELECTRICITY (MJ/hl)	ELECTRICITY Total (MJ x 10^6)	FUEL (MJ/hl)	FUEL Total (MJ x 10^6)
Brewed and Fermented	228,561	5	1.14	100	22.86
Chilled and Conditioned	361,494	16	5.18	0	-
Bottled	60,309	44	2.65	258	15.56
Canned	-	22	-	97	-
Kegged	301,185	11	3.31	59	17.77
Casked	76,069	2	0.15	48	3.65

	ELECTRICITY	FUEL
TOTALS (MJ x 10^6)	A 13.03	B 59.84

TARGET TOTAL (A + B)	(MJ x 10^6)	C 72.87
ACTUAL USAGE	(MJ x 10^6)	D 90.57
USAGE EFFICIENCY (C ÷ D x 100)		80.5%

Source: Gordon (1981)

Appendix 18 SUMMARY OF CHARACTERISTICS OF PROPOSED HEAT PUMP INSTALLATIONS

Type of Site	Process Demand	Waste Heat Source	Output (kW)	ΔT_{L-s} (^{o}C)
Cheese site	General hot water	Pasteuriser cooling water	173	34
Cheese site	Pasteurisation	Evaporator cooling water	1,790	56
Cheese site	Pasteurisation	Whey unit cooling water	1,311	73
Cheese site	Pasteurisation	Pasteuriser cooling water	590	56
Butter site	Air preheat	Evaporator cooling water	4,289	54
Butter site	Milk preheat	Evaporator cooling water	512	54
Butter site	General hot water	Evaporator cooling water	160	34
Sterilising site	Milk preheat	Steriliser overflow	428	54
Sterilising site	Boiler make-up	Steriliser overflow	300	60
Pasteurising site	Pasteuriser	Refrigeration condenser	140	56
Pasteurising site	Pasteuriser	Effluent	140	73
Brewery	Space heating	Refrigeration condenser	2,671	63
Brewery	Space heating	Bottle and can pasteuriser	171	70
Brewery	Bottle washing	Refrigeration condenser	172	61
Brewery	Bottle washing	Bottle and can pasteuriser	172	68
Brewery	Boiler make-up	Refrigeration condenser	855	33
Brewery	Boiler make-up	Bottle and can pasteuriser	134	40
Brewery	Flash pasteuriser	Refrigeration condenser	415	58

Notes: ΔT_{L-s} Temperature difference between load and source.

Source: Trade sources

Appendix 19 TECHNICAL PERFORMANCE RATIOS OF HEAT PUMPS AT VARIOUS TEMPERATURE DIFFERENTIALS

1. Electric motor driven heat pumps

Temperature differential - load to source T_{L-s} (°C)	PERFORMANCE RATIOS: Excluding ancillary drive			Including ancillary drive	
	COP_h	PER	CFU	PER	CFU
80	1.95	1.76	0.53	1.68	0.50
70	2.20	1.98	0.59	1.87	0.56
60	2.55	2.30	0.69	2.13	0.64
50	2.95	2.66	0.80	2.42	0.73
40	3.40	3.00	0.92	2.73	0.82
30	3.95	3.56	1.07	3.10	0.93
20	4.80	4.32	1.30	3.63	1.09

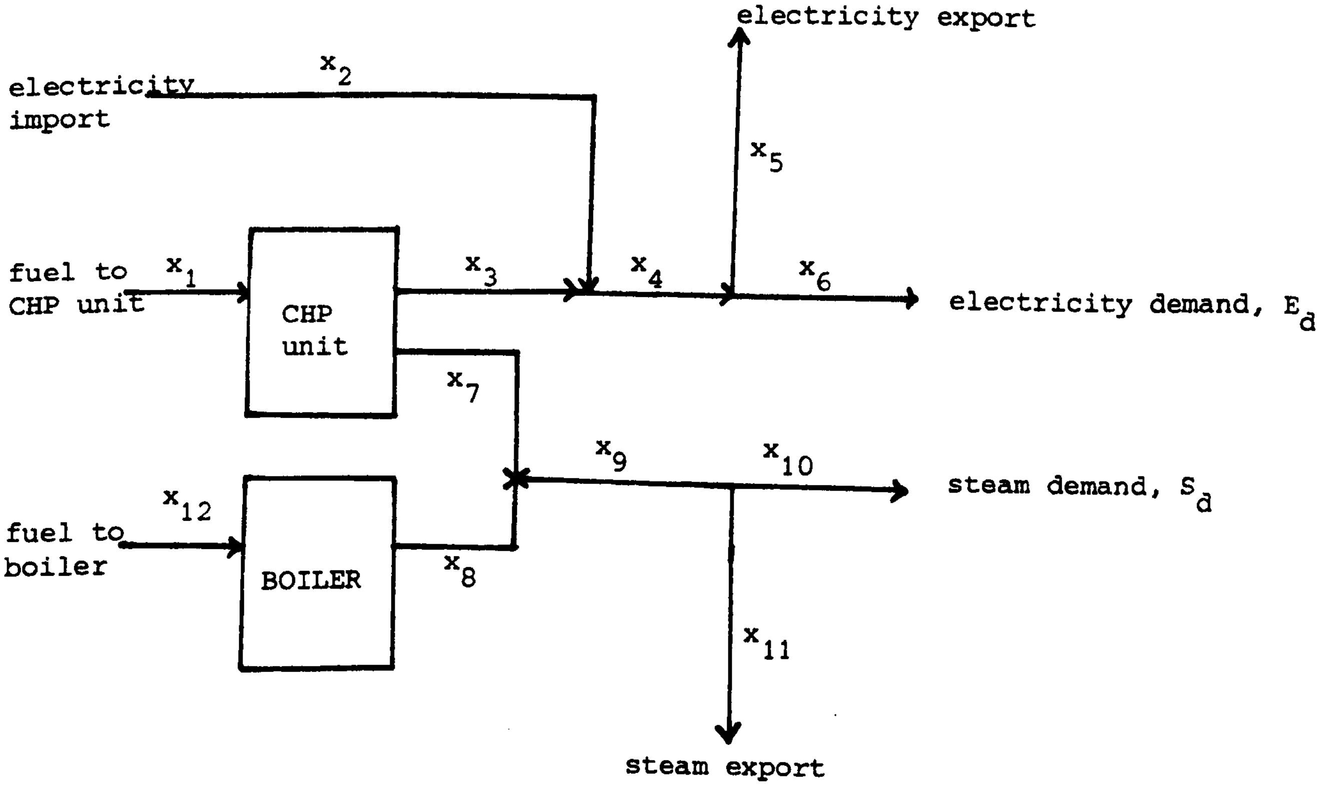
2. Gas engine driven machines

Temperature differential - load to source T_{L-s} (°C)	PERFORMANCE RATIOS: Excluding ancillary drive			Including ancillary drive	
	COP_h	PER	CFU	PER	CFU
80	2.20	1.12	1.07	1.09	1.03
70	2.50	1.20	1.14	1.16	1.10
60	2.90	1.30	1.24	1.24	1.18
50	3.30	1.41	1.34	1.32	1.25
40	3.80	1.54	1.46	1.42	1.36
30	4.40	1.69	1.61	1.53	1.45
20	5.35	1.94	1.84	1.69	1.61

Notes:
COP_h = coefficient of performance
PER = performance effectiveness ratio
CFU = coefficient of fuel utilisation
See Technical Appendix 1 for definitions

Source: Masters et al, 1980

Appendix 20 BASIC MODEL FOR FORMULATING LP ALGORITHM FOR CHP



VARIABLES

x_1	Fuel to CHP unit
x_2	Electricity imported
x_3	Electricity generated by CHP
x_4	Electricity generated by CHP and imported electricity
x_5	Exported electricity
x_6	Electricity demand
x_7	Steam produced by CHP
x_8	Steam produced by boiler
x_9	Steam produced by CHP and steam from boiler
x_{10}	Steam demand, S_d
x_{11}	Steam exported
x_{12}	Fuel to boiler

All variables are in kW.

Constraints /

Constraints

CHP capacity in kW = Q

for a 1 hour timespan, $x_3 < Q$

Steam and electricity demands must be met

$x_{10} = S_d$

$x_6 = E_d$

$- x_3 - x_2 + x_4 = 0$

$- x_4 - x_5 + x_6 = 0$

$- x_7 - x_8 + x_9 = 0$

$- x_9 + x_{11} + x_{10} = 0$

$fx_1 = x_3$ where f = fraction of fuel converted to electricity

$x_7 = Rx_3$ where R = ratio of heat to power

Costs and realisations

Stream		Price	Cost (-) / Realisation (+)
CHP fuel	x_1	P_1	-
Electricity import	x_2	P_2	-
Boiler fuel	x_{12}	P_{12}	-
Electricity export	x_5	P_5	+
Steam export	x_{11}	P_{11}	+

Objective function

MINIMISE: $[-x_1P_1 - x_{12}P_{12} - x_2P_2 + x_5P_5 + x_{11}P_{11}]\ t$

where t = time period in hours.

Appendix 21 COST-BENEFIT ANALYSIS OF SUB-METERING

1. Assume:

Steam at 150 p.s.i.g. Line size = 8"

Cost of steam = £12.00 per ton

Maximum flow = 40,000 lbs/h

Load factor = 50%

Operating for 50 hours per week

$$\text{Total steam flow per week} = \frac{40,000 \times 50}{2 \times 2,240} = 446 \text{ tons}$$

Value of steam = £5,350.00 per week

Total installed cost of metering system for this duty, giving flow rate, total flow and flow recording, is approximately £3,200.00

Assume savings due to improved monitoring = 5%

Total cost savings = 0.05 x 5,350 = £367.50 per week

$$\text{Payback period} = \frac{3,200}{267.50} = \underline{12 \text{ weeks}}$$

Internal Rate of Return = 380%

Sources: K Gervase-Williams, 1984
Gervase Instruments Ltd, technical literature

2. Assume:

6 inch line carrying 20,000 lb/h saturated steam at 200 p.s.i.g.

System cost = £3,181.00

Assume average flow of 50%

$$\text{Steam usage} = \frac{20,000}{2} = 10,000 \text{ lbs/h}, \quad 5 \text{ tonnes/h}$$

Assume steam costs £12.00 / tonne or £8.00 / tonne

Sensitivity Analysis

Variable factor: cost of steam

% saving of steam	Steam cost = £12.00/t			Steam cost = £8.00/t		
	Payback period-working hours	Payback period-years	IRR (%)	Payback period-working hours	Payback period-years	IRR (%)
1	5302	2.65	30	7953	3.9	18
5	1060	0.53	160	1590	0.79	110
10	530	0.26	350	795	0.39	225
15	353	0.18	500	529	0.26	350
20	265	0.13	720	397	0.19	490

Notes:

1. Assume one working year = 200 hours, i.e. 40 hour week, 50 weeks/year

2. One actual installation resulted in a saving of 22% of steam use.

Variable factor: capital cost

Assume: capital cost = £6,000

average flow = 50%)

steam usage = 5 tonnes/hour) as in base case

steam cost = £12.00/tonne)

% saving in steam	Payback period in working hrs	Payback period in years (1)	IRR (%)
1	10,000	5	13
5	2,000	1	83
10	1,000	0.5	170
15	667	0.3	300
20	500	0.25	365

Notes: 1. Assume 2,000h/year operation.

Variable factor: average flow

Assume an average flow of 20%

Steam usage = $\frac{20,000}{5}$ = £12.00/tonne or £8.00/tonne

% saving of steam	Steam cost = £12.00/t			Steam cost = £8.00/t		
	Payback period-working hours	Payback period-years (1)	IRR (%)	Payback period-working	Payback period-years (1)	IRR (%)
1	13,254	6.7	7	19,881	9.9	< 1
5	2,651	1.3	62	3,976	1.9	43
10	1,325	0.7	120	1,987	1.0	83
15	884	0.4	220	1,326	0.7	120
20	663	0.3	300	994	0.5	175

Notes: 1. Assume 2,000h/year operation.

3. Assume: 3" line, system cost = £2,300

A 3" line at 100 p.s.i.g. passes 6,000 lbs/h of steam

Assume the following utilisations; 20% and 50%

Flow rate	Utilisation 20%	Utilisation 50%
lbs/hr	1,200	3,000
tonnes/h	0.6	1.5

Assume steam costs £15.00 or £10.00/tonne

Sensitivity analysis - Utilisation = 20%

% saving of steam	Steam cost = £15.00/t			Steam cost = £10.00/t		
	Payback period-working hours	Payback period-years (1)	IRR (%)	Payback period-working hours	Payback period-years (1)	IRR (%)
1	25,555	12.8	< 1	38,333	19	< 1
5	5,111	2.5	32	7,667	3.8	19
10	2,555	1.3	66	3,833	1.9	43
15	1,704	0.8	105	2,556	1.3	66
20	1,277	0.6	140	1,917	0.9	90

Notes: 1. Assume 2,000h/year operation.

Sensitivity analysis - Utilisation = 50%

% saving of steam	Steam cost = £15.00/t			Steam cost = £10.00/t		
	Payback period-working years	Payback period-years (1)	IRR (%)	Payback period-working years	Payback period-years (1)	IRR (%)
1	10,222	5.1	12	15,333	7.7	3
5	2,044	1.0	83	3,067	1.5	55
10	1,022	0.5	170	1,533	0.7	120
15	681	0.3	300	1,022	0.5	170
20	511	0.25	380	167	0.08	1200

Notes: 1. Assume 2,000h/year operation.

Appendix 22 COST-BENEFIT ANALYSIS OF A LOW-ENERGY LIGHTING SCHEME

The building is a brewery keg store, constructed in six portal sections, each 60m x 22m.

Previous Lighting scheme:	320 trough reflector luminaires each incorporating two 125W, 8 ft. fluorescent lamps. Total illumination = 300 lux. Total installed load = 102.12 kW
Replacement system:	250 W 50 N lamps in Hermes 2 luminaires, 185 units installed using every other fluorescent point to reduce installation costs. Total illumination = 350 lux. Total installed load = 51.8 kW.

Increase in illumination = 50 lux.
Reduction in load = 50.32 kW

Assume electricity costs = 4p/kWh (June 1983)

Annual savings = (reduction in load)(hours run)(price per kWh).

<u>Annual savings in £</u>

	Price per kWh (p)		
Hrs run per year	3	4	8
2,000	3,019	4,026	8,051
4,000	6,038	8,052	16,102
6,000	9,057	12,078	24,153
8,000	12,076	16,104	32,204

Capital cost of actual installation was £25,000 and a two-year payback period was achieved, giving an IRR of 41%.

Assume: price of electricity = 4p/kWh
hours run = 6,000 hours/year
(2 shifts, 16 hours/day, 360 days/year)

Savings = £12,078.

Capital cost (£)	Payback period (years)	IRR (%)
25,000	2.1	39
30,000	2.5	32
35,000	2.9	27
40,000	3.3	23
45,000	3.7	19
50,000	4.1	17

Appendix 23 COST-BENEFIT ANALYSIS FOR ENERGY MANAGEMENT SYSTEM

Energy Management system for a building with an annual energy cost of £25,000 p.a. (for heating & lighting)

Estimated annual energy savings = 20%
= £5,000 p.a.

Additional cost savings through improved engineering maintenance = 20% of energy savings
= £1,000 p.a.

Thus, total savings = £6,000 p.a.

Capital cost: equipment £ 8,300
installation 1,700
£ 10,000

Simple payback = $£\frac{10,000}{6,000}$ = 1.7 years

IRR = 50%

∴ grant: 75% year 1
+ Dep?

Estimates of energy savings and savings due to improved maintenance are based on experiences in existing installations.

∴ 25% by 9 for the other years

Sensitivity Analysis

Savings (%)	10%	20%	30%
Cost savings (£)	2,500	5,000	7,500
Maintenance cost saving (£)	1,000	1,000	1,000
Total cost savings (£)	3,500	6,000	8,500
Capital cost (£)	10,000	10,000	10,000
Payback period (yrs)	2.8	1.7	1.2
IRR (%)	27	50	71

Project Cash Flow - Leasing Option from an energy management bureau

	Cash in (£)	Cash out (£)	Cumulative Net Benefit (£)
Year 1			
Cost savings	6,000		
Leasing charges		(2,300)	
Management Fee		(1,400)	
			2,300
Year 2			
Cost savings	6,000		
Leasing charges		(2,300)	
Management Fee		(1,400)	
			4,600
Year 3			
Cost savings	6,000		
Leasing charges		(2,300)	
Management Fee		(1,400)	
			6,900
Year 4			
Cost savings	6,000		
Leasing charges		(2,300)	
Management Fee		(1,400)	
			9,200
Year 5			
Cost savings	6,000		
Leasing charges		(2,300)	
Management Fee		(1,400)	
			11,500
Year 6			
Cost savings	6,000		
Leasing charges		(NIL)	
Management Fee		(1,400)	
			16,100

Annual net benefit thereafter = £4,600 p.a.

Appendix 24 COST-BENEFIT ANALYSIS OF CONDENSATE RECOVERY PROJECT

Condensate recovery

It is proposed to recover 1,500 kg of condensate an hour, which is at present beign discharged to waste.

The amount of heat recoverable and the temperature of the condensate reaching the feed tank will depend upon such site conditions as the length of travel, the presence and correct use of flash steam, efficiency of lagging and ambient temperature.

Assume condensate reaches the feed tank at 90°C, where it replaces the mains water previously used at 10°C. So by returning the condensate:

$$\underset{kg}{1{,}500} \times \underset{°C}{(90-10)} \times \underset{kJ/kg}{4.187} = 500{,}000\ \text{kJ/h},$$

a heat content of 330 kJ/kg is recovered.

Sources: Fuel Efficiency Booklet 5, Steam cost and fuel savings, Department of Energy; Trade literature.

Base Cases

Condensate recovered = 1,500 kg/hour

Assume 4,000 hours/year

Condensate recovered = (1,500)(4,000) = 6×10^6 kg/y

Heat recovered = $(6 \times 10^6)(330)$ = 1.98×10^9 kJ/y

Assume boiler efficiency = 80%

Heat saved = $(1.98 \times 10^9)(1/0.8)$ = 2.475×10^9 kJ/y

= 2.3265×10^4 therms/year

Assume price of fuel (gross) = 44p/therm (3,500s oil)

Cost saving = £10,237.

Capital cost	£10,000	£20,000	£30,000	£40,000
Payback period (y) @ 4,000 h/year	0.98	1.95	2.93	3.91
@ 2,000 h/year	1.95	2.93	3.91	7.82
@ 8,000 h/year	0.49	0.98	1.95	2.93

Sensitivity analysis - temperature differential = 70°C

Assume 4,000 hours/year

Condensate recovered = (1,500)(4,000) = 6×10^6 kg/y

Heat recovered = $(6 \times 10^6)(293)$ = $1,758 \times 10^9$ kJ/y

Assume boiler efficiency = 80%

Heat saved = $(1.758 \times 10^9)(1/0.8) = 2.198 \times 10^9$ kJ/y

= 2.0657×10^4 therms/y

Assume price of fuel (gross) = 44p/therm (3,500s oil)

Cost saving = £9,089

Capital cost	£10,000	£20,000	£30,000	£40,000
Payback period (y) @ 4,000 h/y	1.1	2.2	3.3	4.4
@ 2,000 h/y	2.2	4.4	6.6	8.8
@ 8,000 h/y	0.55	1.1	1.65	2.2

Sensitivity analysis - boiler efficiency

Assume 4,000 h/y

Condensate recovered = (1,500)(4,000) = 5×10^6 kg/y

Heat recovered = $(6 \times 10^6)(330)$ = 1.98×10^9 kJ/y

Assume boiler efficiency 70% - case (1) 85% - case (2)

Heat saved 2.829×10^9 2.329×10^9 kJ/y

2.6593×10^4 2.1893×10^4 therms/y

Assume price of fuel (gross) = 44p/therm (3,500s oil)

Cost saving £11,700 (1) £9,632 (2)

Case 1

Capital cost	£10,000	£20,000	£30,000	£40,000
Payback period (y) @ 4,000 h/y	0.85	1.7	2.6	3.4
@ 2,000 h/y	1.7	3.4	5.2	6.8
@ 8,000 h/y	0.42	0.85	1.3	1.7

Case 2 /

Case 2

Capital cost	£10,000	£20,000	£30,000	£40,000
Payback period (y) @ 4,000 h/y	1.04	2.1	3.1	4.1
@ 2,000 h/y	1.08	4.2	6.2	8.2
@ 8,000 h/y	0.52	1.15	1.55	2.05

Sensitivity analysis - fuel price

Assume 4,000 h/y

Condensate recovered = (1,500)(4,000) = 6×10^6 kg/y

Heat recovered = $(6 \times 10^6)(330)$ = 1.98×10^9 kJ/y

Assume boiler efficiency = 80%

Heat saved = $(1.98 \times 10^9)(1/0.8)$ = 2.475×10^9 kJ/y

= 2.3265×10^4 therms/y

Assume price of fuel (gross) = (p)	20	40	60	80
Cost saving (£)	£4,650	£9,310	£13,960	£18,610

Paybacks (y)	Fuel cost (p/gross therm)			
	20	40	60	80
Capital cost (£)				
10,000	2.1	1.1	0.7	0.54
20,000	4.2	2.2	1.4	1.1
30,000	6.3	3.3	2.1	1.6
40,000	8.4	4.4	2.8	2.1

Appendix 25 COST-BENEFIT ANALYSIS OF A KEG WASHING LINE HEAT RECOVERY SYSTEM

Installed cost = £51,000 (all in 1981 prices)
Marginal cost on other lines = £15,000 (reported)

Occupacity			33%	66%	100%
Savings	Heat	therms x 10^3	14.1	28.2	42.3
	Steam	lbs x 10^6	1.5	3.0	4.5
	Steam cost	£ x 10^3	4.5	9.0	13.5
	Water	gals. x 10^6	1.5	3.0	4.5
	Water cost	£ x 10^3	1.0	2.0	3.0
	Effluent disposal cost	£ x 10^3	0.7	1.4	2.1
Total		£ x 10^3	6.2	12.4	18.6
Payback period (yrs)					
Capital 15,000			2.4	1.2	0.8
Capital 50,000			8.2	4.1	2.1
IRR (%)					
Capital 15,000			33	68	105
Capital 50,000			3	17	29

Design occupacity = 100%

Actual occupacity in first two years was 50%, giving a payback period of 5.5 years (an IRR of 12%) on capital cost of £51,000.

Source: Heat Recovery on a Keg Washing Line Demonstration Project at Scottish and Newcastle Beer Production Ltd, Holyrood House, Edinburgh.
ETSU, December 1981.

Sensitivity Analysis - 50% reduction in heat and water recovered

Occupacity			33%	66%	100%
Savings	Heat	therms x 10^3	7	14	21
	Steam	lbs x 10^6	0.75	1.5	2.2
	Steam cost	£ x 10^3	2.25	4.5	6.6
	Water	gals x 10^6	0.75	1.5	2.25
	Water cost	£ x 10^3	0.5	0.75	1.5
	Effluent disposal cost	£ x 10^3	0.35	0.7	1.1
Total		£ x 10^3	3.1	5.93	9.2
Payback period (yrs)					
Capital £50,000			16.45	8.6	5.5
Capital £15,000			4.8	1.5	1.6
IRR (%)					
Capital £50,000			<1	3	11
Capital £15,000			13	32	50

Sensitivity Analysis - Capital Cost

Occupacity			33%	66%	100%
Savings	Heat	therms x 10^3	14.1	28.2	42.3
	Steam	lbs x 10^6	1.5	3.0	4.5
	Steam cost	£ x 10^3	4.5	9.0	13.5
	Water	galz x 10^6	1.5	3.0	4.5
	Water cost	£ x 10^3	1.0	2.0	3.0
	Effluent disposal cost	£ x 10^3	0.7	1.4	2.1
Total		£ x 10^3	6.2	12.4	18.6
Payback period at Capital cost £15 x 10^3		years	2.4	1.2	0.8
IRR (%)			33	68	105
Payback period at Capital cost £30 x 10^3		years	4.8	2.4	1.6
IRR (%)			13	33	51
Payback period at Capital cost £75 x 10^3		years	12.1	6.0	4.0
IRR (%)			<1	9	18
Payback period at Capital cost £100 x 10^3		years	16.1	8.1	5.4
IRR (%)			<1	3	11

Sensitivity Analysis - 50% reduction in the cost of steam

Occupacity			30%	60%	100%
Savings	Heat	therms x 10^3	14.1	28.2	42.3
	Steam	lbs z 10^6	1.5	3.0	4.5
	Steam cost	£ x 10^3	2.25	4.5	6.75
	Water	gals x 10^6	1.5	3.0	4.5
	Water cost	£ x 10^3	1.0	2.0	3.0
	Effluent disposal cost	£ x 10^3	0.7	1.4	2.1
Total		£ x 10^3	3.95	7.9	11.85
Payback period at Capital cost £50 x 10^3		years	12.6	6.3	4.2
IRR (%)			<1	8	16
Payback period at Capital cost £15 x 10^3		years	3.8	1.9	1.3
IRR (%)			19	43	66

Appendix 26 COST-BENEFIT ANALYSIS OF A PASTEURISER IMPROVEMENT PROJECT

Re-engineering a pasteuriser to include extra heat recovery will save about £100,000 p.a. and provide a twelve month payback period.

Capital cost is about £125,000. Re-engineering takes two weeks.

	Before	**After**	**Saving**	
Total Btu's utilised (Btu/h)	17×10^6	9×10^6	8×10^6	80 therms
Total raw liquor requirement (gallons/h)	15×10^3	2.5×10^3	22.5×10^3	
Total effluent discharge (gallons/h)	23×10^3	2.5×10^3	20.5×10^3	
Costs per unit	Heat 50p/therm	Water 0.7p/1000 gals.	Effluent 0.7p/1000 gals.	
Savings (units)	80 therms	22.5×10^3 gallons	10.5×10^3 gallons	
Savings (£/h)	40	0.1575	0.1435	

Total saving (£/h)	£40.1/h	IRR (%)
@ 2,000 h/year	£ 80,200	67
@ 4,000 h/year	£160,400/year	140
@ 8,000 h/year	£320,800/year	290

Utilisation	Capital cost = £125,000		Capital cost = £200,000	
	Payback period (yrs)	IRR (%)	Payback period (yrs)	IRR (%)
@ 2000 h/y	1.6	51	2.5	32
@ 4000 h/y	0.8	105	1.25	66
@ 8000 h/y	0.4	110	0.62	138

Sources: Barry Wehmiller Ltd, technical literature.

Appendix 27 LIST OF ORGANISATIONS CONTACTED DURING THE RESEARCH

Breweries

Alexander Brewery Ltd

Ballards Brewery Ltd
Bass Brewing (Alton) Ltd
Bass Brewing (Runcorn) Ltd
Bass Mitchells and Butlers
Bass North Ltd
Bellhavens Brewery Co Ltd
Boddingtons Breweries Ltd
Border Breweries Ltd
Bourne Valley Brewery Ltd

Carsberg Brewery Ltd
Charles Wells Ltd
Courage (Central) Ltd
Courage (Western) Ltd

Devenish Weymouth Brewery Ltd
Drybrough & Co Ltd

Everards Tiger Brewery Ltd

Friary Mieux Ltd

G. Ruddle & Co Ltd
Gale & Co Ltd
Gibbs Mew & Co Ltd
Greenall Whitley plc
Greene, King & Sons plc
Guinness Park Royal Ltd

Hardys and Hansons plc
Harp Lager (Northern) Ltd
Home Brewery plc

Ind Coope Alloa Brewery Ltd
Ind Coope Burton Brewery Ltd
Ind Coope Romford Brewery Ltd

J W Lees & Co (Brewers) Ltd
James Shipstone & Sons Ltd
Joshua Tetley & Sons Ltd

Lorimers Brewery Ltd

Maclay & Co Ltd
McMullen & Sons Ltd

Mitchells of Lancaster (Brewers) Ltd
Morland & Co plc

New Forest Brewery Ltd

Ringwood Brewery Ltd

Samuel Webster & Sons Ltd
Scottish & Newcastle plc

T P Buck & Sons Ltd
T D Ridley & Sons Ltd
T & R Theakston Ltd
Tetley Walker Ltd
Tennent Caledonian Breweries Ltd
The Heantree Brewery plc
Tollemach & Cobbold Breweries Ltd
The Tusbury Brewery Co Ltd
Traquir House Brewery Ltd
Trumans Ltd

Vaux Breweries Ltd

W M Darley Ltd
Watneys London Ltd
Welsh Breweries West Ltd
Whitbread & Co plc (East Penines)
Wrexham Lager Beer Co Ltd

Dairies

Aberdeen MMB Ltd
Associated Dairies Ltd

Calorval Ltd
Carnation Ltd
Cliffords Dairy Products Ltd
Cuthbertsons Ltd

Express Dairy Foods Ltd

Guilianotti Bros (Holborn) Ltd

Northern Foods plc

Unigate Dairies (Midlands) Ltd
Unigate Dairies (Western) Ltd

Distillers

Amalgamated Distillery Production Ltd
Arthur Bell & Sons Ltd

Benmore Distilleries Ltd
Burnbrae (Blenders) Ltd

Chivas Brothers Ltd

Hiram Walker Ltd

J & A Mitchell Co Ltd
J & J Grant Ltd
John Dewar & Sons Ltd

Low, Robertson & Co Ltd

MacDonald & Muir Distillers Ltd

Stanley P Morrison Ltd
Scottish Glen Distillers Ltd

The Atholl Distilleries Ltd
The Invergordon Distillers Ltd
Tullibardine Distillery Ltd

William Sanderson & Son Ltd
Wm. Teachers & Sons Ltd

Maltings

Bermaline Ltd

Eric Fawcett Ltd

J P Simpson & Co (Alnwick) Ltd

Moray Firth Maltings Ltd

Pauls & Sanders Ltd

Robert Kilgour & Co Ltd

Brewery Equipment Suppliers

Allied Breweries Engineering Services Ltd
APV International plc

Burnett & Rolfs Ltd

Central Bottling & Brewing Services Ltd

Davenports Brewery (Holdings) Ltd

Flow Measurement & Automation (FMA) Ltd

R G Abercrombie Ltd

Malting Equipment Suppliers

Food and Beverage Developments Ltd

Dairy Equipment Suppliers

Alfa Laval Co Ltd

Star Refrigeration Ltd

Trade Associations

The Brewers' Society

Pentlands Scotch Whisky Ltd

The Maltsters Association of Great Britain
The Dairy Trade Federation

Miscellaneous

R H M Research Ltd

The Heat Pump and Air Conditioning Bureau
The Open University Energy Research Group
The University of Newcastle upon Tyne

Science Policy Research Unit, University of Sussex

International Institute for Environment and Development

Prutec Ltd

A G Barn plc

Duncans Soft Drinks Ltd

The Coca Cola Export Corporation

3M United Kingdom Ltd

The Energy Technology Support Unit

Suppliers of Energy Conservation Equipment and Services

Absolute Energy Systems and Engineering Products Ltd
Air Aqua HRS Ltd

Babcock Power Ltd
Barry Wehmiller Ltd
Brammer Dynamics Ltd
Bran & Luebba Ltd

Corning Ltd

D J Neal Ltd

EASAMS Ltd
Endless Energy Ltd
Energy Conscious Design Ltd
Energy Conservation Systems Ltd
English Industrial Estates Ltd
Environco Environmental Engineering Ltd
ETC Ltd

Fiat Auto UK Ltd
Ford Motor Co Ltd

GEC Gas Turbines Ltd

Haden Carrier-Ross Ltd

Imperial Chemical Industries plc (Mond Division)
ITT Jabsco Ltd

James H Heal & Co Ltd
John Thurley Ltd
Johnson Matthey Research Ltd

Measurex International Systems Ltd
Mecatherm Engineering Ltd

National Industrial Fuel Efficiency Service Ltd

PA Management Consultants Ltd

Roufor Associates Ltd
Ruston Gas Turbines Ltd

Senior Economisers Ltd
Sirycon Ltd
Spooner Industries Ltd
Stordy Combustion Engineering Ltd

Trace Heat Pumps Ltd

Utilico Ltd
Utility Management Company Ltd

Vickers-Dawson Ltd

Watt, Joule & Therm (Stratford) Ltd
Welsmere Ltd
Westinghouse Electric Ltd

Appendix 28 QUESTIONNAIRE FOR BREWING SITES

This questionnaire concerns energy management procedures and energy conservation investments in breweries. Any information received will be treated in strict confidence and not used in a manner in which individual companies can be identified. It is to be completed by the person most responsible for energy management.

----

1. Which of the following size ranges includes your site? *(Please ✓)*

Production level (000s hl/annum)	0 - 99	....
	100 - 199	....
	200 - 299	....
	300 - 399	....
	400 - 499	....
	500 - 999	....
	1,000 - 1,499	....
	1,500 +	....

2. Which of the following energy conservation or cost saving measures have you installed?

Measure	Year installed	Other comments
a. High efficiency lighting	......	....
b. Replacement of over-sized electric motors	......	....
c. Power factor correction	......	....
d. Additional heat recovery from cooling of boiled wort	......	....
e. Copper vapour heat recovery	......	....
f. Heat recovery from keg washing line effluent	......	....
g. Heat recovery from other effluent sources	......	....
h. Fuel switching (please specify fuels switched to/from)	......	....
i. Others (please specify)	......	....

3. /

3. If you have not invested in fuel switching, have you made an economic appraisal of fuel switching proposals? YES NO *(delete)*

4. Is energy consumption sub-metered for individual cost centres? YES NO *(delete)*

5. Are targets set for the reduction of energy consumption for

a. the whole plant YES NO *(delete)*
b. cost centres YES NO

6. How often is energy use monitored and compared to production output? *(Please √)*

Daily ....
Weekly ....
Monthly ....
Quarterly ....
Yearly ....
Other (please specify) ....

7. What reduction (in percentage terms) have you achieved in specific energy use (i.e. energy per production output unit) in:

a. The last two years ......%
b. The last five years ......%

8. What level in the organisation do you, as manager responsible for energy conservation, report to? *(Please √)*

Plant engineer level ....
Plant manager level ....
Company general manager level ....

9. Are you responsible for a separate energy conservation budget?

YES NO *(delete)*

10. /

10. What is your background discipline/experience? *(Please √)*

Engineering	....
Brewing	....
Finance	....
Other (please specify)	....

11. Roughly what proportion of your time is spent on energy conservation projects/matters ....%

12. What other major commitments/remits do you have within the firm?

13. Which of the following journals do you read regularly? *(Please √)*

Energy Management	....
Energy Manager	....
Plant Engineering & Maintenance	....
Energy World	....
Energy in Buildings	....
Journal of the Institute of Energy	....
The Chartered Engineer	....
CIBS	....
The Brewer	....
IEE News	....
Journals and publications of the Accountancy profession	....
Management Today	....

Please specify any other professional/trade journals you read regularly:

Please return completed questionnaire to:

Steven D Fawkes
Technological Economics Research Unit
University of Stirling
STIRLING FK9 4LA
Scotland

Appendix 29 STANDARD ASSUMPTIONS FOR DCF CALCULATIONS AND EXAMPLE CALCULATION

The following standard assumptions were used in calculating all the Internal Rates of Return figures quoted in the thesis.

Project lifetime = 10 years

75% First year Capital Allowance

25% Allowance in Year 2

50% Corporation Tax

One year tax lag

No balancing charges

Company is making sufficient profit to benefit from capital allowances.

No scrap value.

The capital allowances used are those outlined in the 1984 Budget for financial year 1984/85.

A ten year life has been used as a standard throughout the thesis but it should be noted that when retrofitting to existing plant, five years may be more appropriate. Use of a five year life severely reduces Internal Rate of Return when compared to a ten year lifetime.

EXAMPLE DCF CALCULATION

(all figures in £000s)

Year	0	1	2	3	4	5	6	7	8	9	10	11
Profit and Tax												
Savings		6	6	6	6	6	6	6	6	6	6	
Allowances		(7.5)	(2.5)									
Δ Profit		(1.5)	3.5	6	6	6	6	6	6	6	6	
Δ Tax		0.75	(1.75)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	
Cash Flows												
Capital	(10)											
Savings		6	6	6	6	6	6	6	6	6	6	
Δ Tax (1 yr lag)			0.75	(1.75)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
Net Cash Flows	(10)	6	6.75	4.25	3	3	3	3	3	3	3	(3)
Discounted Cash Flows												
Discount factors @ 50%	1	0.667	0.444	0.296	0.197	0 132	0.088	0.058	0 039	0.026	0.017	0.012
D.C.F.	(10)	4.002	2.997	1.258	0.591	0.396	0.264	0.174	0.117	0.078	0.051	(0.036)

Sum of D.C.F. = 10 - 9.992 = 0.008

∴ Internal Rate of Return, IRR ≏ 50%

Negative sums are in brackets.

Appendix 30 NOTES TO STATISTICAL APPENDICES

In all chi^2 tests $X^2 = chi^2$

The numbers in the tables for chi^2 tests refer to the number of sites with the appropriate characteristic.

In all t-tests x = the declared reduction in specific energy over the last two years.

O = observed value of x

E = expected value of x

H_o = null hypothesis

All tabulated values are taken from "Mathematical Statistical and Financial Tables for the Social Sciences", Kmietowicz and Yannoulis (1976), Longman.

All test methods are taken from "Statistics for the Social Scientist: 2: Applied Statistics", Yeomans (1968), Penguin.

Notes concerning the applicability of chi^2 tests when expected values fall below 5 are to be found in Appendix 3. Although not strictly applicable in these cases the test is still commonly used. The results should be viewed with even more caution than usually appropriate for statistical tests in this sort of context. In all those tests the declared reduction in specific energy over the last two years has been used as a proxy for success in energy management. As was discussed in Section 2, the use of reduction in specific energy as a measure of success is very simplistic.

TECHNICAL APPENDICES

Technical Appendix 1 HEAT PUMP TECHNOLOGY

1.1 Technical Principles

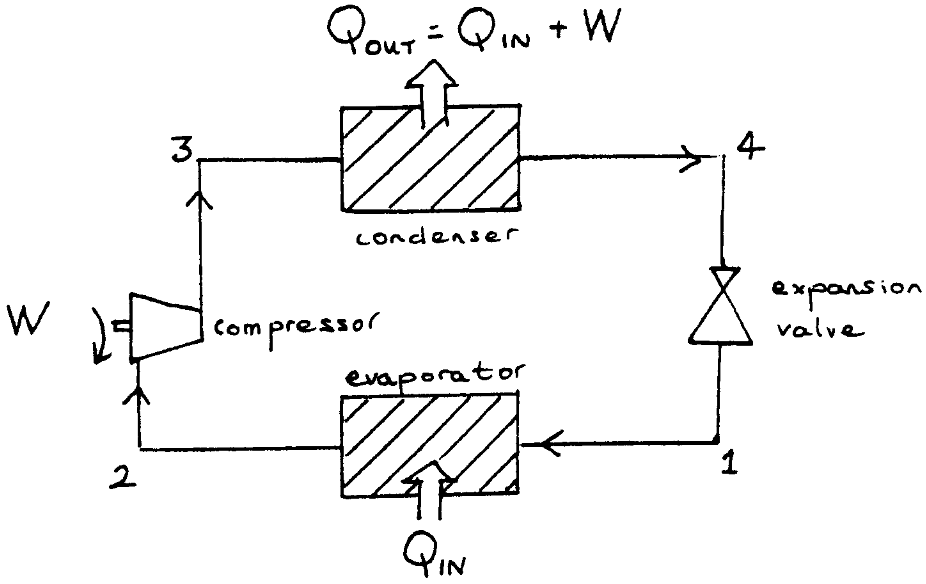
There are two main types of heat pumps, vapour compression and absorption. The former is more developed and is the basis of most heat pumps currently available in the UK market. Most commercially available heat pumps operate on the Rankine cycle which is described below.

A fluid passes round a closed circuit and absorbs heat from a source and discharges it to a load; the fluid is selected so that it will condense and evaporate at temperatures appropriate to the load and source if suitable pressures exist within the condenser and evaporator. The temperature lifts between the evaporator and the condenser is achieved by compression of the fluid, which enables the necessary temperature rise to be obtained for the minimum input of energy. Figure 1 shows the basic components of the vapour compression cycle.

Figure 2 illustrates the closed cycle with reference points on a pressure/enthalpy diagram. Starting at point 1, the working fluid enters the evaporator heat exchanger and absorbs heat from the source. The liquid evaporates at constant pressure until dry superheated vapour is formed at point 2. The vapour is drawn into the compressor where its pressure, and consequently temperature, are raised to point 3. At this point the fluid is still a superheated vapour, but now at a higher pressure and temperature. This vapour enters the condenser where, by virtue of its higher temperature, heat is transferred to the load. Whilst giving up latent heat, the vapour condenses at constant pressure until only liquid remains (point 4). The pressure of the liquid is then reduced, usually across a throttle valve, causing a fall in temperature before entry to the evaporator.

Technical Appendix 1

Figure 1 BASIC COMPONENTS OF THE VAPOUR COMPRESSION HEAT PUMP



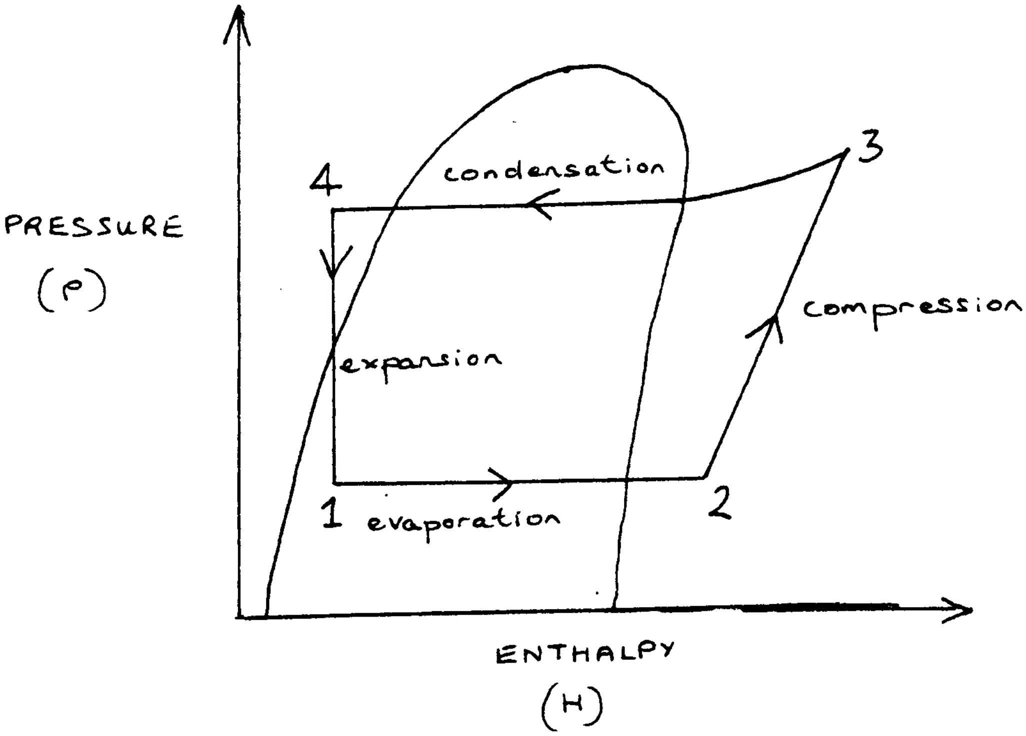
Q = heat flow

W = work

Source: Masters et al (1980)

Technical Appendix 1

Figure 2 THE VAPOUR COMPRESSION CYCLE ON A PRESSURE/ ENTHALPY DIAGRAM



Source: Masters et al (1980)

The shaft power to the compressor can be supplied by any form of motive power but the more usual forms are electric motors and gas fuelled internal combustion engines. Most heat pumps (for all purposes) currently in operation utilise electric motor drives although gas and diesel engine drives are currently in use in the UK, Japan and the USA. Gas and steam turbines may be viable in larger systems, particularly those proposed for district heating (Masters et al, 1980). A steam turbine driving an industrial heat pump is to be demonstrated in the UK in the near future (1983/84) under the auspice of the Energy Conservation Demonstration Project Scheme.

Alternative power cycles being developed for heat pump use include Stirling, closed cycle Brayton, Ericson and organic Rankine cycles (Masters et al, 1980).

1.2 Performance comparisons for heat pumps

Useful definitions of performance for any system depend upon the purpose for which they are required. The user wishes to know how much energy delivered by the heat pump costs compared to alternative sources of supply. At the national level it is the use of primary energy that is of concern. For these reasons three terms are used to discuss heat pump performance, and these are explained below.

1.2.1 Coefficient of Performance; COP:

This refers only to the heat pump cycle and is the ratio:

$$COP_h = \frac{\text{heat discharged from the condenser}}{\text{work done in driving the compressor}}$$

and is, in theory, equal to:

$$\frac{T_1}{T_2 - T_1}$$

where T_1 = source temperature

T_2 = load temperature

both in degrees Absolute (K)

This ratio represents a theoretical maximum and the practical value of COP_h is unlikely to exceed 50% of the theoretical value. The thermodynamically imperfect nature of all real machines means that the ratio of real to theoretical COP_h is unlikely to be significantly improved (Reay and Macmichael, 1979).

1.2.2 Performance Effectiveness Ratio; PER:

This refers to the complete installation, including engine heat recovery if used. It should include the power used by ancillaries such as fan or pump drives but this component is often omitted. The ratio allows the potential adopter to calculate directly the cost of energy delivered by the heat pump from the cost of gas or electricity supplied to the installation. It is defined as:

$$\text{PER} = \frac{\text{useful heat output from the complete installation}}{\text{total energy input to the installation}}$$

1.2.3 Coefficient of Fuel Utilisation; CFU:

This is the ratio of the useful heat output of the system to the quantity of primary fossil fuel used. It therefore takes into account the efficiency of generation and transmission of energy and enables broad comparisons to be made of the efficiency of primary fuel usage. It is defined as:

$$\text{CFU} = \frac{\text{useful heat output from the complete installation}}{\text{primary energy used to supply energy to the installation}}$$

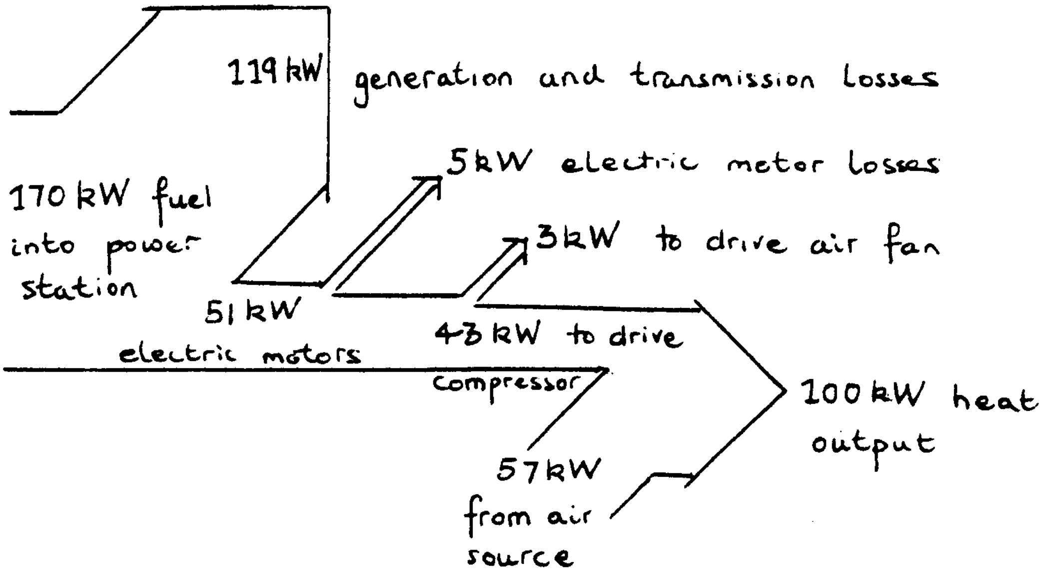
CFU is of more interest at national level rather than at the level of individual companies making investment decisions. Primary energy use is irrelevant to the potential adopter if he is using financial criteria.

1.3 Comparison of Performance Ratios

Figures 3 and 4 show the flow of energy to the point of use for electric and gas engine driven heat pumps respectively. The data is appropriate for a source at $0^{\circ}C$ and heat being delivered at $65^{\circ}C$. Typical values for the three performance ratios are given.

Technical Appendix 1

Figure 3 THE FLOW OF ENERGY IN AN ELECTRICALLY DRIVEN HEAT PUMP



$$COP_h = \frac{100}{43} = 2.35$$

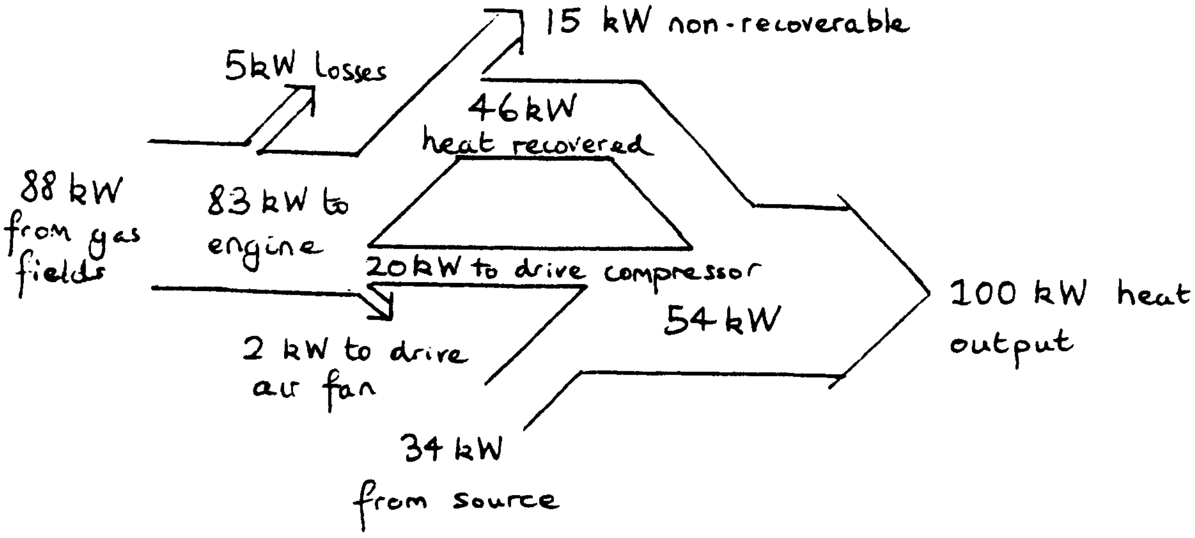
$$PER = \frac{100}{51} = 1.98$$

$$CFU = \frac{100}{170} = 0.59$$

Source: Masters et al, 1980

Technical Appendix 1

Figure 4 THE FLOW OF ENERGY IN A GAS DRIVEN HEAT PUMP



$$COP_h = \frac{54}{20} = 2.70$$

$$PER = \frac{100}{83} = 1.20$$

$$CFU = \frac{100}{88} = 1.14$$

Source: Masters et al, 1980

It can be seen in Figure 3 that for every 100kW of heat required by the user, 119kW are lost as waste heat from the generation of electricity and its transmission. This corresponds to a generation and transmission efficiency of the electricity supply system of 30%. The electric motor driving the heat pump may attain an overall efficiency of 90% and thus the overall efficiency of primary energy use to drive the compressor is 27%. It has been assumed in the analysis that the source is ambient air and that a power requirement equivalent to 5% of the evaporator heat transfer duty, is needed to drive the fan. The heat pump under these conditions will have a COP_h of 2.35. For every 100kW of heat delivered to the customer, 51kW of electricity are consumed locally and 170kW of fossil fuel are burned nationally (assuming the electricity is supplied by fossil fuel power stations). The PER therefore is 100/51 = 1.98. This ratio divided into the price of the electricity used enables the unit cost of heat from the heat pump to be calculated directly. Similarly the CFU is 100/170 = 0.59 and this term indicates the efficiency of primary energy use. This is a tremendous improvement in performance if hitherto the customer used electricity for low temperature heating at an overall efficiency of 30%.

Figure 4 shows the equivalent information for the gas engine driven heat pump. In this case for each unit of heat supplied from the gas terminal, only 5% of the energy is used in the transmission system, and the customer receives gas with a 95% overall efficiency. The generation of shaft power by the gas engine is 26% efficient and so the overall efficiency of energy use to drive the compressor is 25%. A similar assumption has been made for calculating the power requirement of the evaporator air fan as for the electrically driven machine. Under these conditions the heat pump will have a COP_h of 2.7. The PER will be 1.20 and thus for each 100kW of heat required by the consumer, 83kW of gas will be consumed. The CFU of 1:14, is higher than the electric counterpart due to the local generation of shaft power providing heat which can be gainfully used.

The data in Appendix 19 gives the performance ratios for electrically driven and gas engine machines at a range of temperature differentials. An important point is that heat pump performance drops as the temperature difference between load and source increases. This is a major barrier to wider economic use of heat pumps.

As mentioned above, shaft power efficiencies of the gas engine and electric motor have been assumed to be 26% and 90% respectively. Both figures are conservative for full load operation. Where part load is common, as is likely to be the case for space heating, shaft power efficiencies may well be lower than stated. Defrosting, which is necessary periodically, will also detract from the performance. The gas engine heat pump has the advantage that the engine heat output is still available during the defrost period.

1.4 Use of Performance Ratios

As has been shown each of the three performance ratios describe different systems and have different uses. The COP_h which is the most commonly quoted measure of performance only applies to the condenser-compressor subsystem and really has little practical purpose other than in designing the machine.

The PER covers the complete installation and is therefore most useful to the end-user. As mentioned above it allows the easy calculation of the price of heat delivered by the machine.

The CFU is primarily of interest at the national level. The effect of an installation on the national primary energy use is of little or no interest to the individual company making investment decisions.

It can be seen that from the point of view of the end-user the most useful measure of performance is in fact the PER. Most if not all technical literature, however, stresses COP_h. Obviously COP_h has a higher value than the corresponding PER and so its use in the marketing of heat pumps is understandable from the suppliers point of view. Prospective purchasers of heat pump systems should however be aware of the difference between COP and PER.

1.5 Technical Limitations

There are two main technical limitations on heat pump development, namely COP_h and output temperature. The theoretical COP_h is determined by the temperature differential between load and source and as such is fixed by thermodynamics. In practice the COP_h achieved will be much less than typically about half this theoretical value. This ratio of theoretical COP to actual COP is unlikely to be improved upon as it is a result of the thermodynamically imperfect nature of all real machines (Reay and Macmichael, 1979).

The maximum output temperature commonly achieved at present is about 70 to 80°C. Beyond this there are serious problems concerning refrigerant stability and materials. A prototype steam generating heat pump has been made which produces low pressure steam at 110°C (Reay, personal communication). Work is proceeding both in the UK and elsewhere on increasing this temperature. Westinghouse in the USA are reported to be developing an electric heat pump producing steam at 150°C (Trade sources). These improvements in output temperature will almost certainly incur additional capital cost per unit of output due to added complexity and higher materials costs. Applications for high temperature heat pumps are also likely to be limited by the need for a source at 70 to 80°C. Depending on the needs of the site it may be more attractive to recover heat from a source stream at this temperature by conventional heat recovery. Improved process integration may remove source streams at these relatively high temperatures.

Technical Appendix 2 COMBINED HEAT AND POWER SYSTEMS

2.1 Each of the main combined heat and power (CHP) techniques currently available are described. Fuel cells are also described as they are likely to be available on the UK market as a CHP technique at the end of the 1980s (trade sources).

2.2 Steam turbine systems

Steam turbines have long been used in industry to generate power. Conventional steam turbine technology is employed in the majority of present industrial CHP installations. Components of steam systems (boilers, turbines, generators) have reached high levels of reliability and well known performance characteristics. A schematic of a steam turbine CHP system is shown in Figure 1.

Conventional dual purpose steam systems employ turbines which extract a portion of the energy present in the steam by partially reducing the pressure of the inlet steam and then releasing the steam at a lower pressure for subsequent process use.

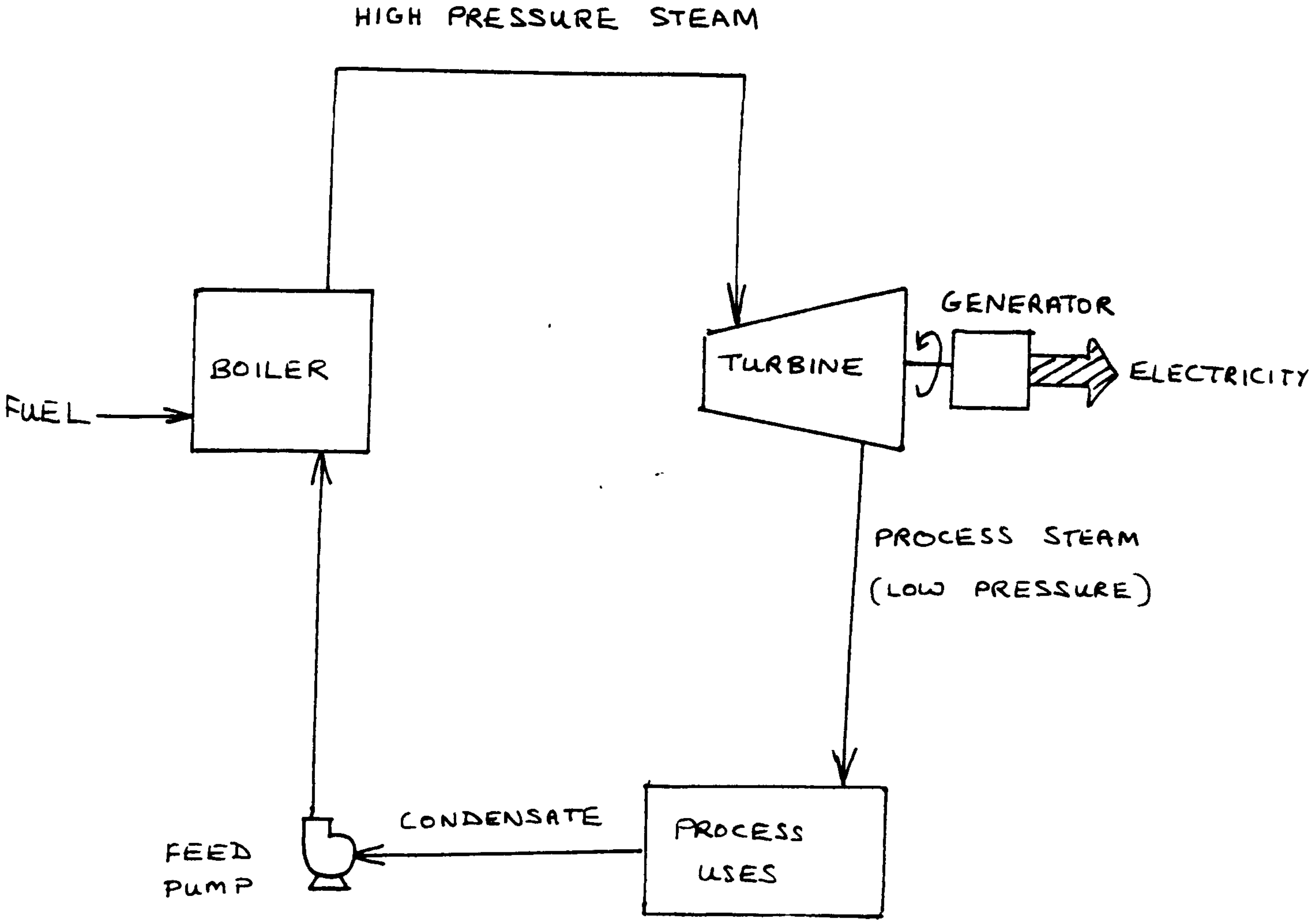
2.3 Gas turbine systems

Starting with their heavy use by the aircraft industry in the 1950s, gas turbines have been developed into highly efficient and reliable prime movers. Since about 1960 they have been used in industrial power systems. A schematic of a gas turbine CHP system is shown in Figure 2.

The gas turbine is a Brayton cycle engine and attains maximum efficiency at high operating temperatures. Consequently the typical turbine operates above 815°C (1500°F) and exhausts combustion products at 427 to 538°C (800 - 1000°F). Passing these gases through a heat recovery boiler produces steam and recovers much of the thermal energy that would otherwise be lost. Though there are a few industrial applications where the hot exhaust gases from a gas turbine can be used directly for process heat, the discussions will be confined to steam generating systems.

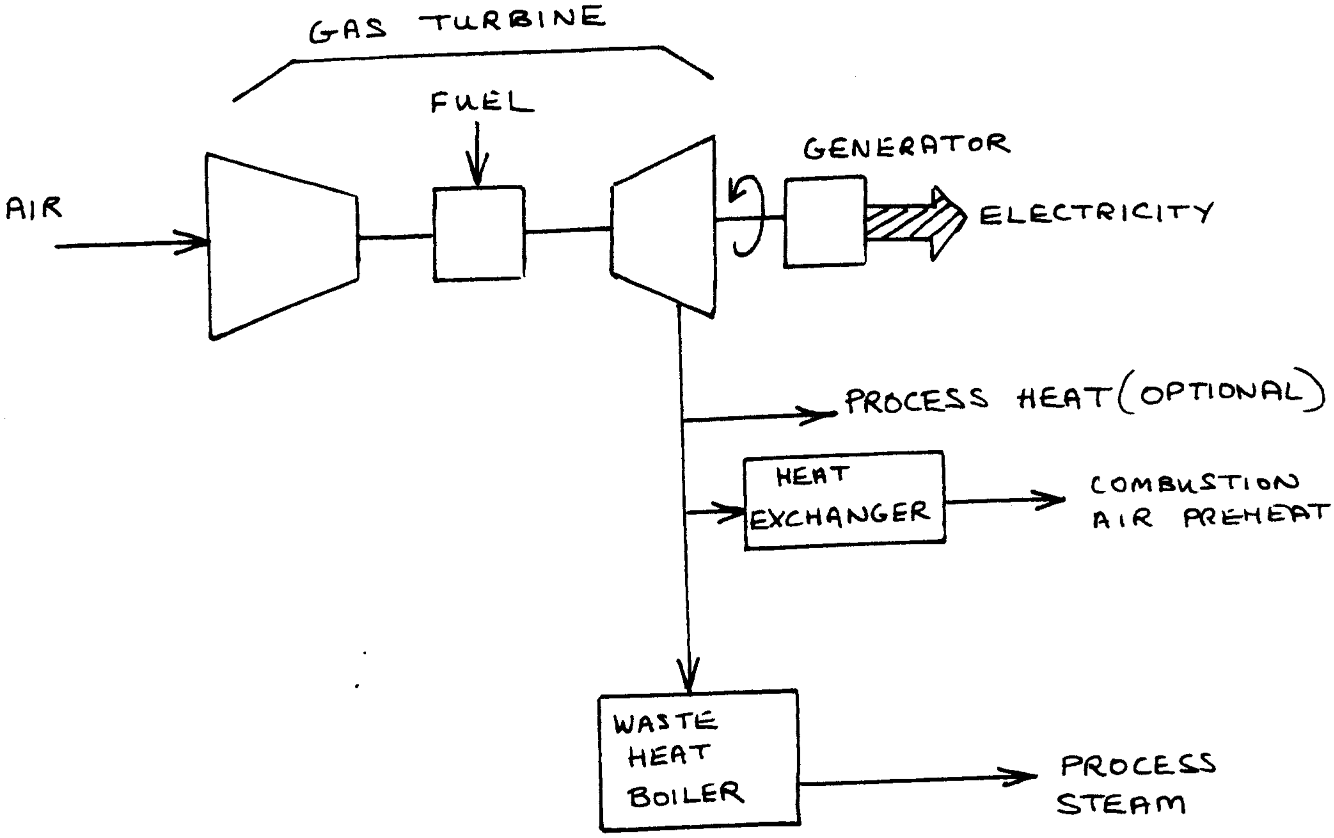
Technical Appendix 2

Figure 1 COMBINED HEAT AND POWER CYCLE USING A STEAM TURBINE



Technical Appendix 2

Figure 2 COMBINED HEAT AND POWER CYCLE USING A GAS TURBINE



A serious limitation of commercially available gas turbines is their requirement for "clean" fuels. Gas and distillate oils are the principal alternatives. Treated residual oils have been used successfully in some turbines, but it becomes necessary to shut down the turbine for cleaning at frequent intervals. Certain types of turbines can be installed in a "closed" cycle whereby almost any type of fuel is burnt in a suitable furnace, and circulating air (or other gas) glowing through heat exchanger tubes in the furnace, is heated to the temperature and pressure needed to drive the turbine. Closed systems however operate at 10 to 20% lower thermal efficiency than open systems. Currently closed systems are only available in larger sizes, above 20 MW. As this is considerably larger than the size required at sites in the four sectors closed systems will not be considered in the economic analysis.

When a gas turbine (Brayton cycle) is coupled to a heat recovery boiler and the steam is used to operate a steam turbine (Rankine cycle) the system is termed a "combined cycle" operation.

Gas turbine CHP systems are particularly attractive in their ability to satisfy a wide range of operating conditions. Industrial rated gas turbine-generator sets are commercially available in sizes from approximately 500 kW (100 kW in the USA) up to more than 50,000 kW.

Gas turbines can be quickly started up or shut down, to follow changing steam and electricity loads. In a combined cycle type of operation a significant (e.g. threefold) range of variation in the ratio of electricity to steam can be achieved while still keeping a high overall thermal efficiency.

A vital factor in the viability of CHP schemes using gas turbines is that heat can be raised in the waste heat boiler by burning fuel in the exhaust which contains 18% wt. of oxygen. This increases the load to power ratio by a factor of 6.

2.4 Diesel engine systems

It should be noted that although we distinguish this class of prime movers by the name "diesel", it is entirely feasible to use recriprocating piston engines fueled with natural gas, biogas, gasoline, or even residual oil.

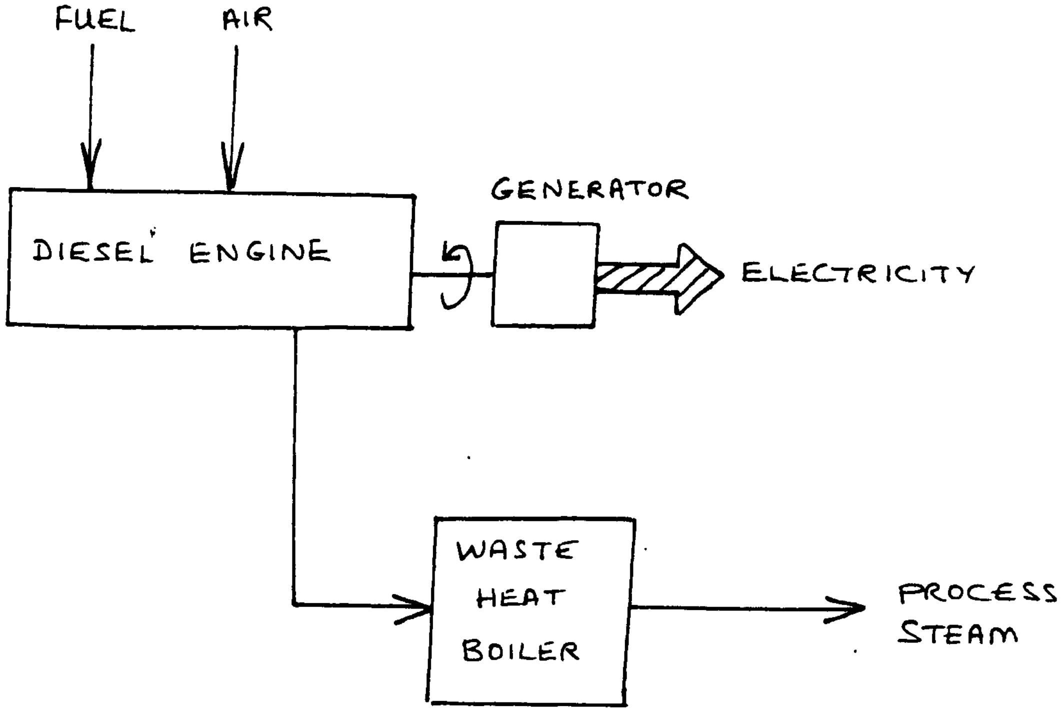
Diesel engines for the continuous duty, CHP type of services are commercially available in sizes from 4 up to 30,000 kW. It is common practice in diesel power systems to use multiple engines.

Heat is removed from the diesel engine in two principal streams. One is the combustion product exhaust which contains 50 to 60% of the heat leaving the engine. The other is the engine coolant fluid which removes about 30% of the heat. The exhaust gases reach a maximum temperature of $454^{\circ}C$ ($850^{\circ}F$) and can be passed through a heat recovery boiler to generate steam. Only about two-thirds of the heat in the exhaust can normally be recovered because the gases contain potentially corrosive components and must exit from the boiler at a temperature above the dew point. For most diesel engines the cooling fluid has a maximum temperature of $87^{\circ}C$ ($150^{\circ}F$). Industrial uses for this heat flow are very limited, and often no attempt is made to use the cooling fluid heat. A schematic of a diesel CHP system is shown in Figure 3.

Most so called 'gas' engines require the injection of oil to facilitate combustion, typically 8% (Ryan, personal communication 1983) of the fuel input is liquid fuel. As the price of oil dermatives is higher than that of gas, this increases the average price of fuel used by the prime mover. Recently (1983/84) a chemical company has installed the first large spark ignition (i.e. not a diesel strictly) gas engine in the UK (trade sources). Use of such engines overcomes this disadvantage of gas fuelled internal combustion engines.

Technical Appendix 2

Figure 3 COMBINED HEAT AND POWER CYCLE USING A DIESEL ENGINE



2.5 Fuel cell systems

A fuel cell consists of two electrodes separated by electrolyte which transmits ions but not electrons. The fuel, hydrogen or a hydrogen enriched gas, is supplied to the anode where hydrogen is dissociated into hydrogen ions releasing electrons to the anode. The hydrogen ions migrate through the electrolyte to the cathode, where they react with oxygen and electrons to form water, in the form of steam. The electrons produced on the anode flow through the external electric circuit providing direct current electric power.

Early practical fuel cells, developed for the space programme, utilised hydrogen and oxygen directly. As hydrogen is not widely available as a fuel, terrestial fuel cells utilise natural gas or a similar fuel, e.g. bio-gas. A fuel cell system for CHP is shown in Figure 4. This is passed through a steam reformer, utilising steam produced in the fuel cell itself.

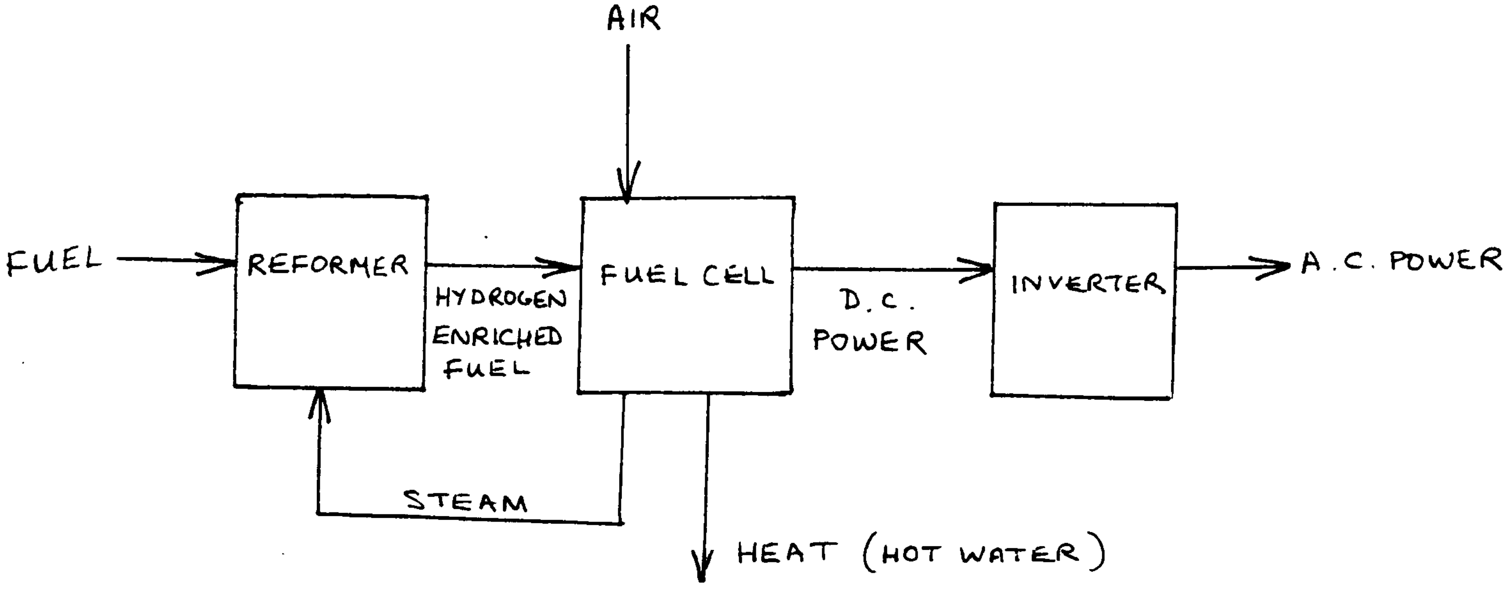
Although fuel cells are currently not available for CHP applications, a range of units between 40 and 400 kW(e) output are being developed. They are expected to be available in the late 1980s (Ryan and Cameron, 1984) and are projected to cost approximately £1,000/kW(e), a cost which could reduce to £500/kW(e) with market expansion.

Fuel, which can be natural gas or bio-gas, is passed into a steam reformer which produces hydrogen enriched gas for use in the fuel cell itself. The dc power produced by the reaction between the hydrogen enriched gas and the oxygen in the air within the fuel cell, is converted to ac in an inverter or power conditioner.

Fuel cells have several advantages over conventional power generation equipment. Firstly there are environment benefits. The only effluent is pure water, no combustion products are given out, less heat is dumped into the environment and noise levels are too low. Other advantages also stem from the way in which chemical energy is directly converted into power in a fuel cell. Conventional power generation equipment converts chemical energy in fuels into heat energy which is then converted into mechanical energy. Fuel cell systems circumvent the limitations on total system efficiency imposed by the second law of thermodynamics.

Technical Appendix 2

Figure 4 COMBINED HEAT AND POWER SYSTEM USING A FUEL CELL



REFERENCE for Technical Appendix 2

RYAN, F and CAMERON, D S (1984) Fuel cells: a potential means of energy saving by on-site co-generation of heat and power. *in* Energy World, February 1984, No. 111.