THE EFFECTS OF THE CHANGING ENERGY SITUATION ON DEMAND FOR INDUSTRIAL HEAT EXCHANGERS

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DOCTOR OF PHILOSOPHY

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This research project was carried out for Serck Heat Transfer, formerly a member of the Serck Group of Companies, now a subsidiary of BTR Ltd.

The project arose during a period in which the World was still coming to terms with the effects and implications of the so called 'energy crisis' of 1973/74.

Serck Heat Transfer is a manufacturer of heat exchangers which transfer heat between fluids of various sorts. As such the company felt that past and possible future changes in the energy situation could have an impact upon the demand for its products. The thesis represents the first attempt to examine the impact of changes in the energy situation (a major economic variable) on the long term demand for heat exchangers. The scope of the work was limited to the United Kingdom, this being the largest single market for Serck's products.

The thesis analyses industrial heat exchanger markets and identifies those trends which are related to both the changing energy situation and the usage of heat exchangers. These trends have been interpreted in terms of projected values of heat exchanger demand. The projections cover the period 1978 to the year 2000.

Also examined in the thesis is the future energy situation both internationally and nationally and it is found that in the long term there will be increasing pressure on consumers to conserve energy through rising real prices.

The possibility of a connection between energy consumption and heat exchanger demand is investigated and no significant correlation found. This appears to be because there are a number of determinants of demand besides energy related factors and also there is a wide diversity of individual markets for heat exchangers.

Conclusions are that in all markets, bar one, the changing energy situation should lead to a higher level of heat exchanger demand than would otherwise be the case had the energy situation not changed. It is also pointed out that it is misleading to look at changes in one influence on the demand for a product and ignore others.

KEY WORDS: FORECASTING; HEAT EXCHANGERS; ENERGY

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Sadly the third member of my supervisory team from Aston was Tony Proudman who passed away during the course of this project. His contribution and enthusiasm were greatly valued.

It is impossible to name all others who contributed to this study but suffice to say without their help none of this would have been possible.

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CHAPTER 1.0 INTRODUCTION

1.0

INTRODUCTION

1.1

Background

This research project was industry based and I was employed as a post-graduate student by Serck Heat Transfer, the sponsoring company. During the research period I was attached to the Technology Policy Unit at the University of Aston. This unusual form of post-graduate research was organised through the Interdisciplinary Higher Degrees Scheme (I.H.D.) at Aston.

I.H.D. seeks to provide opportunities for graduates to undertake higher degree research of a practical nature to prepare them for careers in industry or public service. The problems of industry, commerce or public service are tackled with a multi-disciplinary approach by the student working from within the sponsoring organisation. Between 30 and 70 per cent of the students time is normally spent with the sponsoring organisation and the balance at the University. Projects are jointly supervised by the organisation and the University.

1.2

Origin of the Project

Serck Heat Transfer (S.H.T.) is a member of a medium sized group of engineering companies (turnover 1979/80 £106 million). S.H.T.'s turnover is over £28 million.

S.H.T. manufactures heat exchangers of various types for a range of applications, details of which are given in Section 5.3.

Heat exchangers do exactly what their name suggests, exchange heat between two fluids, normally but not necessarily separated by a metal wall. This broad definition covers a number of devices which are outside the scope of this research. A more detailed definition appears in Chapter 5.0.

Heat exchangers handle flows of heat energy and are mostly used to help channel heat away from where it is generated because it is not wanted at that point and/or it can be utilised somewhere else.

The demand for heat exchangers arises from the generation and use of heat energy. The level of that use must be subject to the price and availability of energy in its various forms.

It is logical to assume that if the price or availability of the various forms of energy change in any way, this will cause a change in the demand for heat exchangers.

In the period 1973/74 the Organisation of Petroleum Exporting Countries (OPEC) member states increased their prices for crude oil four fold. The prices of other forms of energy rose more or less in line with the oil price rises.

In general terms these rises caused major disruptions to all the Western economies. Their effects on the markets for heat exchangers are not known. The effects would be on two levels at least. Firstly, rises in the price of a major input to an economy, such as energy, would tend to reduce the level of economic activity and may even cause a recession and consequently lower the demand for the output of companies. Secondly, the markets for certain products and services may well be affected directly by energy price changes. For instance, if the real price of energy rises then there may well be an increase in demand for products which will help reduce the demand for energy. It is possible that heat exchangers are such products.

Any changes in the economy and/or S.H.T.'s markets means two things for the company; threats and opportunities.

Obviously any company implicitly or explicitly wishes to negate the threats and exploit the opportunities. To do this, decision-makers need to have information to help them in their planning. In order to do this some attempt has to be made to forecast these threats and opportunities which the company wishes to take account of.

It is against this background, therefore, that the project arose.

Serck's Original Statement on the Project

> "National and international agencies predict increasing energy prices, at least throughout the remainder of this century, above the general increase in prices through monetary inflation. Though this may not amount to an 'energy crisis', the relative importance of energy costs, as an item of operating costs, in the overall industrial scene must bring economic pressure to design plant and equipment to use less energy or to make use of sources of available energy not effectively being used now.
>
> Many applications of energy in the form of heat, whether for space or process heating or in heat engines, involve the use of

heat exchangers to transfer heat from one stream of fluid to another or one location to another. Higher energy costs (in relative terms) are likely to bring about a requirement for more or bigger or different heat exchangers, as well as for heat exchangers employed in other applications than are common at present. It is also possible that the pattern of usage of heat engines and other plant will change, again affecting the demand for various types of heat exchangers.

The Project

To examine the present usage of heat exchangers supplied to industry and to predict the likely effect of energy price increases on the demand, in terms of types, numbers, value and applications, over the next 25 years.

Some of the Stages are Likely to Be:

- understanding the present demand pattern
- considering predictions on energy price increases and appreciating the basis of these predictions
- exploring where, in industrial plant and equipment, better use of energy could be made by use of heat exchangers
- examining the likely effect on what types of heat engine will be used in the future and their requirements for heat exchangers (this will probably include electricity generating plant)
- considering the extent to which the use of alternative sources of energy to fossil fuels create demand for heat exchangers."

1.3

Objectives of the Research

There is an implicit assumption in the original statement on the project that as the real price of energy rises, it is likely that more heat exchangers will be demanded than otherwise would have been the case.

The basic premise behind the research is that there is an identifiable relationship between energy usage and heat exchanger demand. A prime objective of the thesis, therefore, is an examination of this premise.

The thesis involves forecasting the impact of changes in the energy situation on the U.K. markets for Serck Heat Transfer's products. This means that this thesis investigates forecasting methods and attempts to use the most appropriate to generate answers which will aid the company in its planning and decision making.

Prior to this research the company carried out no long term forecasting although some short to medium term forecasting (up to two years ahead) was undertaken. Firstly, financial or budgetary forecasts for up to a year ahead are generated by the financial function in the company. Secondly, market forecasts of up to two years ahead are produced by the market research department. This research project represents the first attempt to assess the impact of changes in a major economic variable on the company's markets.

Before any forecasting is carried out a knowledge of the current situation is necessary as a base for the forecasts. This thesis defines and estimates the value of current heat exchanger markets.

The issue chosen as the subject of the research could have been one of many others rather than energy. This research attempts to generate an approach to long term forecasting which the company can utilise in the future as required.

CHAPTER 2.0 SUMMARY OF RESULTS OF SECTOR FORECASTS

2.0

SUMMARY OF RESULTS OF SECTOR FORECASTS

The results of this study are divided into a number of sectors. Each sector forecast contains an estimate of the value of heat exchangers used in 1978 and forecast values of heat exchangers, at 1978 prices, for the years 1985, 1990, 1995 and 2000. The forecast values are presented in four scenarios for each sector.

Scenario 1, the base scenario, estimates the effects of the changing energy situation on demand for heat exchangers up to the end of the century based upon the estimated 1978 value for each sector. That is, all other influences on the demand for heat exchangers are held constant at the 1978 level so that the effect of the changing energy situation can be clearly seen in isolation from other factors.

Scenarios 2, 3 and 4, representing low, medium and high growth respectively, incorporate assumptions about levels of growth in each sector in order to add a more realistic dimension to the forecasts. This allows the influence of the energy situation to be assessed within the context of changing levels of activity within each sector.

The results are summarised in Table 2.1. Details of how the results were obtained and relevant discussion for each sector are contained in Chapter 9.0.

Details of the coverage of each sector are contained in Appendix A. The definition, used in this study, of the market for heat exchangers is contained in Chapter 3.0.

From the results it may be concluded that as a consequence of the changing energy situation, demand for heat exchangers in all sectors except rail transport will grow at a level above that which would have been experienced

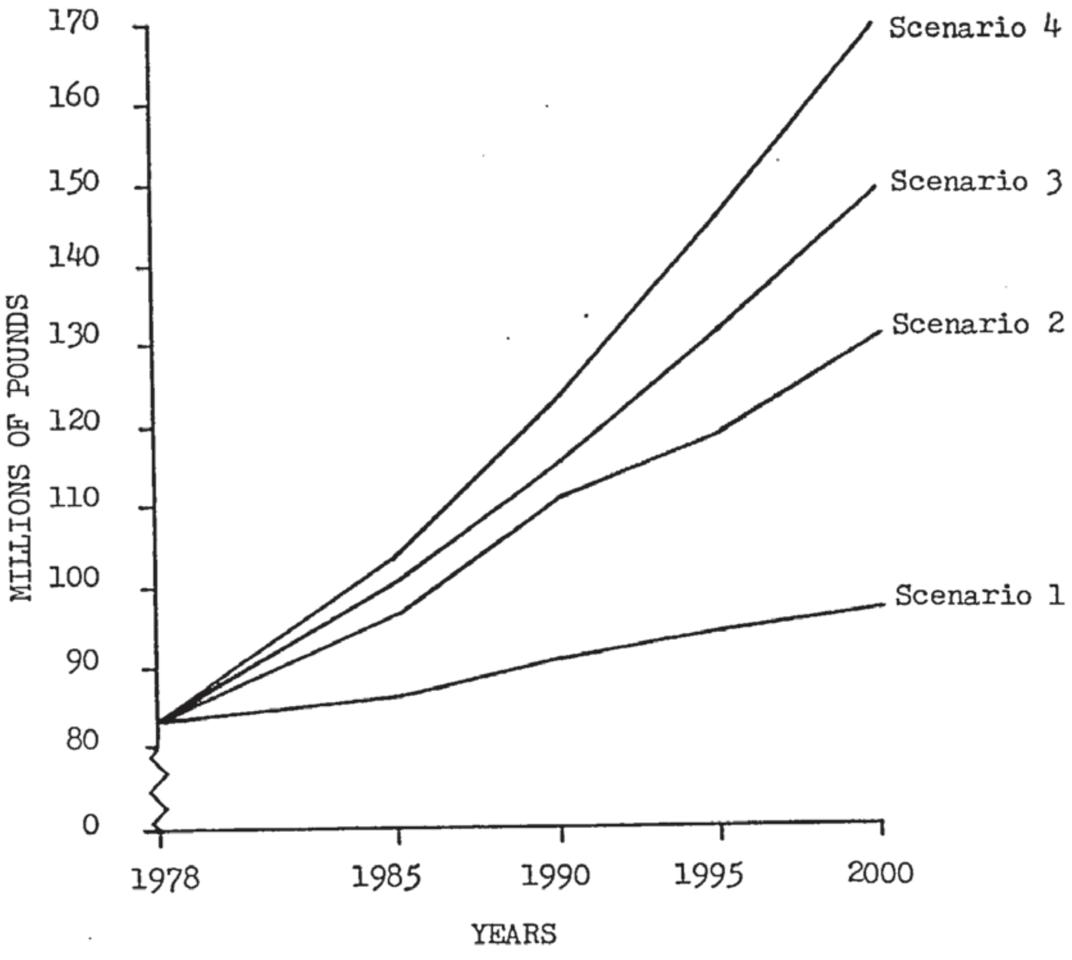
TABLE 2.1 Summary of Results (£ millions)

SECTOR	1978	1985				1990				1995				2000			
	Actual	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Road Transport	28.62	29.58	32.91	33.55	34.19	31.95	37.38	39.02	40.65	33.68	41.39	43.72	46.05	34.27	43.95	46.40	49.85
Rail Transport	1.28	0.82	2.63	2.07	1.92	1.70	6.22	2.79	2.61	1.20	2.00	2.60	2.38	1.06	2.10	2.87	2.36
Miscellaneous Machinery	6.70	7.05	7.55	7.82	8.10	7.32	8.25	8.76	9.28	7.50	8.89	9.67	10.51	7.67	9.55	10.65	11.86
Public Power Generation	0.64	0.74	1.11	1.19	1.27	0.75	1.02	1.10	1.18	0.77	1.45	1.64	1.82	0.77	1.45	1.64	1.82
Combined Heat and Power	0.90	1.13	1.14	1.15	1.15	1.13	1.15	1.17	1.18	1.13	1.16	1.19	1.21	1.13	1.18	1.21	1.24
Manufacturing Industries	1.28	2.17	2.41	2.54	2.67	3.16	3.78	4.13	4.50	4.60	5.94	6.72	7.60	6.69	9.33	10.95	12.84
Chemicals and Allied Industries	30.88	31.11	35.78	38.34	41.04	31.29	39.76	44.74	50.29	31.46	44.18	52.22	61.63	31.63	49.09	60.95	75.53
Oil Refining	13.50	13.76	13.76	13.76	13.76	13.96	13.96	13.96	13.96	14.16	14.16	14.16	14.16	14.36	14.36	14.36	14.36
TOTAL	83.80	86.36	97.29	100.42	104.10	91.26	111.52	115.67	123.65	94.50	119.17	131.92	145.36	97.58	131.01	149.03	169.86

had the energy crisis and ensuing price rises not occurred.

The totals for each scenario for all sectors are shown graphically in Figure 2.1.

Figure 2.1 Summary of Results



CHAPTER 3.0 METHODOLOGY

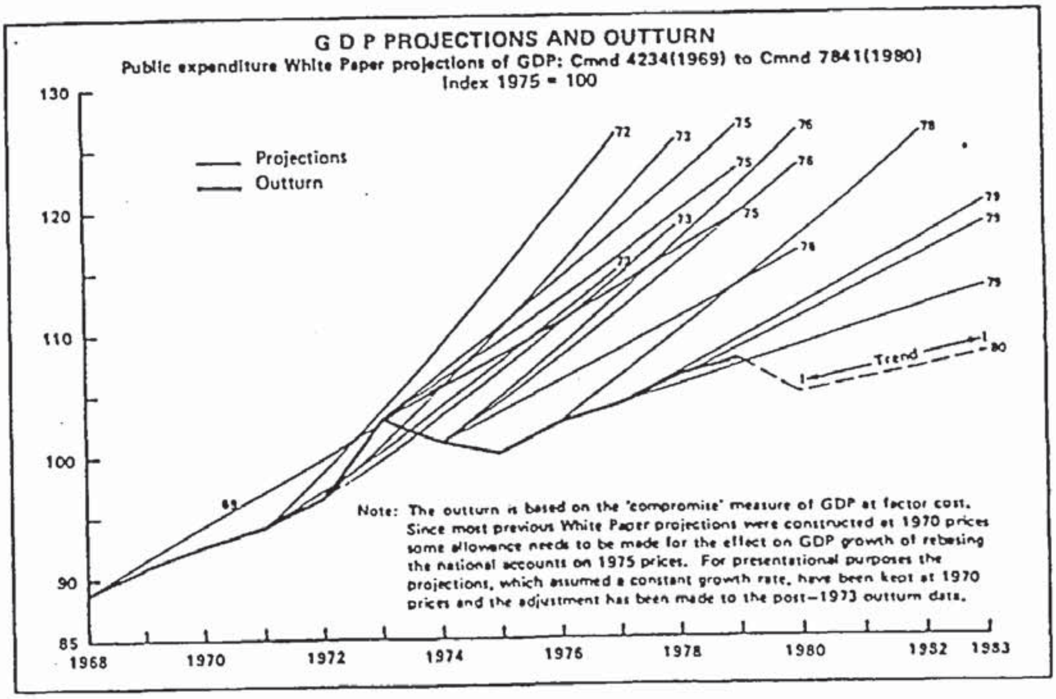
3.0

METHODOLOGY

There are many ways of approaching a forecasting problem and there may be several different, but equally acceptable, solutions in terms of the results obtained. These approaches may vary in cost, accuracy, complexity and so on and may not, therefore, be strictly comparable. Choosing the 'right' one can be a difficult task.

The mere availability of almost unlimited resources does not quarantee a good forecast. Figure 3.1 below demonstrates this. The graph compares the gross domestic product (GDP) projections which have appeared in various public expenditure White Papers with Central Statistical Office outturn data. It shows that almost all of the projections were optimistic.

Figure 3.1 GDP Projections and Outturn[1]



For all the resources available to it the Government got it wrong time after time, or so it appears from the graph. From looking at the outturn it can be seen that in fact up to the first year of each forecast was reasonably on target. This shows that uncertainty and therefore the inaccuracy of any forecast increases as the forecast time horizon extends and demonstrates the need to repeat the forecasting exercise to take account of unforeseen changes.

In theory, the forecasting approach chosen would be that one which consistently provides the most accurate results. In reality, the chosen approach will reflect many things such as the resources available for the exercise, the skills of the forecaster, the prejudices of the forecaster and the decision makers and so on. It may be that in order to choose a method, the cost effectiveness of each is estimated so that a rational economic choice may be made. This is usually impractical because the only real way to do this would be to use each method and measure the cost and compare with the returns. One problem here is if we could afford to apply each method then we would hardly need to worry about which is most cost effective. In addition it may be difficult, if not impossible, to measure the costs and returns of a forecasting exercise.

After considering the circumstances on which the forecasts were to be made in this study, it seemed that three different approaches might be possible to forecast future heat exchanger demand.

Firstly, a trend extrapolation of past heat exchanger sales data could be computed. This makes no specific reference to the effects of the changing energy situation but could form a useful comparison with other forecasts which do. The results of this approach are shown in Chapter 7.0.

Secondly, the first approach can be developed so that heat exchanger sales are linked to past energy consumption to establish a relationship between them. There are a number of forecasts of future energy consumption up to the year 2000 and beyond. If there is an identifiable relationship between heat exchanger demand and energy consumption then from a forecast of future energy consumption a forecast for heat exchangers could be derived. The investigation of this approach is shown in Chapter 8.0.

The third approach is to break down heat exchanger consumption into the various end-user sectors and examine current heat exchanger requirements. Likely technical or economic developments which result from the changing energy situation which are likely to occur over the forecast period can be assessed and their impact on heat exchanger demand determined. For example, it may be that as oil becomes progressively more expensive, oil powered vehicles may be replaced by electric vehicles which ultimately draw their energy from power stations driven by fuels other than oil.

Breaking down the forecasting exercise into sectors allows the identification and assessment of developments in individual markets. The different heat exchanger markets are not homogeneous and nor are the possible developments within them likely to be either. A disaggregated approach will give a better insight into developments in heat exchanger markets than the extrapolation of total heat exchanger demand based either on trends in past demand data or any relationship that is established with another variable.

For a product like heat exchangers the demand is derived from the demand for other products. Forecasting the demand for heat exchangers inevitably involves forecasting the demand for the other products which require heat exchangers. This fact opens up the possibility of using forecasts of developments within the markets for products which use heat exchangers. For example, if a forecast of the role that is likely to be played by electric vehicles in transport has been produced this can be used to assess the impact that this development might have on heat exchangers.

The main efforts of this research were focussed on the sectoral approach using available forecasts where relevant. A lot of effort was expended tracking down useful forecasting work that had already been done. Where forecasts did not exist information and expert opinion was used to construct forecasts. For instance, no forecasts for waste heat recovery exist but some work has been done on assessing the total potential for it. This information, along with some assumptions, is used in this study as the basis for forecasting the desire to recover waste heat in industry and the value of heat exchangers that may be required.

The methodologies to achieve the results differ considerably between sectors and are explained for each sector in the relevant part of the results.

The hope is that this sectoral approach covers quite a wide area and in reasonable enough depth to point out the way in which heat exchanger markets are likely to develop in the future as a result of the changing energy situation. Moreover, the exercise is laid out in such a way that the company can repeat it, or any part, as and when the need arises. Furthermore, it may show the way in which a similar exercise could be done for other countries.

The results of the sectoral approach are given in Chapter 9.0.

Before any forecasting was undertaken in any sector it was necessary to estimate the value of the 1978 market. This is the base year of the forecasts and acts as a reference point with which to compare the forecast values. The year 1978 was chosen as the base year for the forecasts because it was the latest for which information and data were available at the time of the research for all sectors.

The definition of U.K. market in this study differs from that used by Serck. Serck regards a home (U.K.) sale as that which is delivered to a U.K. customer. Many of these are subsequently exported. For instance, Serck may supply an oil cooler to an engine manufacturer. The engine may be exported or sold to a U.K. equipment builder. This equipment, say, a tractor, may be exported or sold in the U.K. It is this last sale that is of interest in this study. The market in this study is defined as the consumption of heat exchangers for use in the U.K. which is available to, although not necessarily satisfied by, U.K. heat exchanger manufacturers. This is a narrow definition of the market but necessary in order to examine the influence of the U.K. energy situation on U.K. demand for heat exchangers. Imports of equipment already fitted with heat exchangers are ignored. Where imported heat exchangers compete directly with U.K. produced equipment then these are included as being part of the potential U.K. market for U.K. produced heat exchangers.

The definition of the market used in this study to estimate the 1978 market can be varied to include those heat exchangers which are ultimately exported. The data is available and it is just a case of reworking the figures. The forecasts, however, cannot be similarly broadened because they relate to the U.K. only and not to any other country or the World as a whole. There may well be parallels between the U.K. situation in the future and that occurring elsewhere and so the forecasts may be used to draw general conclusions about some other countries. This should be done with caution.

The sector forecasts each appear with 4 scenarios. Scenario 1 represents the impact of the changing energy situation all other things being held constant at the 1978 level. This scenario is included to show the theoretical impact of the changing energy situation on heat exchanger markets in isolation from other factors like economic growth or recession. Scenarios 2, 3 and 4 are defined in each sector's results.

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CHAPTER 4.0 FORECASTING LITERATURE REVIEW

4.0

FORECASTING LITERATURE REVIEW

In essence a great deal of the work of this thesis has involved the reviewing of literature. This was done in order to learn about certain aspects of the study. It was also to identify those areas, and the developments within them, which seemed to be of importance in the assessment of the impact of the changing energy situation on demand for heat exchangers. This process is described where appropriate in the text. This review concentrates on long-term forecasting.

A forecast has been defined as a 'conjectural estimate of something future.'[1] Ayres defines a forecast as 'a reasonably definite statement about the future, usually qualified in the sense of being contingent on an unchanging or very slowly changing environment.'[2] This second definition is conditional, whereas the first is not. The second definition implies that whatever we forecast it is subject to some assumptions which should be stated. This is substantiated by Encel et al who state that 'Forecasting is an attempt to gain meliorative knowledge'; hence it involves assumptions about the causal roles of events, things and human endeavours in generating the future.[3] This third definition goes further than the first two in that it comments on what sorts of assumptions have to be made.

None of this indicates why we should want to forecast. To anticipate the future is one of man's oldest dreams.[4] There are many references in history and mythology to people who could foretell of events to come.

More specifically, today forecasting is an aid to, but not a substitute for, decision making. A key aspect of any decision making is being able to predict the circumstances that surround that decision and that situation.[5]

Decision makers have always wished to know what the future holds in store for them, and what the effects of their decisions will be in order that they might evaluate the alternative courses of action open to them.[6] Forecasting may be seen as an attempt to make planning more informed, more rational, or more scientific.[7]

It may appear that forecasting provides a logical and rational way of assessing the future. This has probably led many researchers to try and achieve sophistication and complexity in their forecasting methods as a way of demonstrating how scientific the whole process is. This is firmly rejected by Encel et al who say that forecasting is not, and cannot be, a purely objective exercise.[8] They add that it cannot aspire to be called a science insofar as successful forecasting requires an imaginative synthesis between what is known and what is unknown, between what is (relatively) certain and what is indefinite. This, they say, is properly described as an art.[9]

Over the years many techniques have evolved for use in forecasting. These are described in many books and papers. Some of these cover only one or a selected number of techniques. There are too many books and papers to review them all here. The description of any one technique varies little between authors. The books used here cover most different types of techniques. These books and other of general interest in forecasting are shown as references 11 to 24 at the end of this chapter. Techniques may be divided into two categories; quantitative and qualitative. Techniques which are based on past data and then, following a certain set of rules developed into a prediction of future values, fall into the quantitative methods category. Where such data is not readily available and where much more management judgement must be inserted, the application of qualitative techniques is more appropriate.

Certain techniques appear to be most appropriate to long-term and others to short-term forecasting. As this study is concerned with a period up to the end of this century, techniques which the literature indicates are not appropriate are not reviewed here.

Many techniques have been developed over the years for long-term forecasting. Jantsch found it necessary to distinguish roughly one hundred techniques or separate elements of techniques.[10] Different authors often classify techniques in different ways and use a variety of names. The techniques reviewed here may be considered the main variants. Table 4.1 lists a number of commonly used quantitative and qualitative approaches.

TABLE 4.1 Long Range Forecasting Techniques

Type	Technique
Quantitative	Naive Trend Extrapolation (curve fitting) Simple Regression Multiple Regression Econometric Models Input-Output Analysis Life Cycle Analysis
Qualitative	Expert Forecasting Delphi S-Curves Historical Analogies Morphological Research Relevance Trees Scenario Writing

Naive methods involve forecasting on the basis of very simple rules like the next value will equal the last observed value or the forecast value will equal last year's same month plus 5 per cent. An application of naive methods is to use their forecasting accuracy as a basis for comparing alternative approaches.

Curves can be fitted to historical data and then extrapolated to give forecast values. Given a finite number of N data points there exists at least one polynomial of degree N-1 which will exactly fit the data. There are also an infinite number of higher degree polynomials and other continuous functions which also fit exactly. The problem is not to find the curve that fits exactly but one that fits reasonably well. A number of standard functions, including a straight line, may approximate reasonably well to the data. Curve fitting approaches do not assume any causal relationship between variables.

Simple regression goes a step further than curve fitting by assuming a (linear) relationship between two variables; the first being dependent upon the second but the second independent from the first. Once a relationship is established between the dependent variable Y and the independent variable X, forecasts of Y can be obtained from X.

Multiple regression allows the consideration of more than one independent variable in the determination of the dependent variable Y. The relationship between the dependent and independent variables is still linear.

In many situations an assumption that there is no inter-relationship between the dependent and independent variables may not be realistic. Where inter-dependence is at all strong, regression analysis cannot be used. Instead a system of simultaneous equations that can deal with the inter-dependence must be developed. An econometric model includes a number of simultaneous equations that can be of different types and functional forms. Such models may have as few as two or as many as several hundred equations to be solved simultaneously.

An input-output table is a technique for determining the transactions between different sectors of the economy. It can also be used for regions, industries or even single business organisations. The technique is utilised mainly for planning purposes. In order to achieve a given output in one sector there must be inputs from other sectors. If a level of output is forecast for one sector this has implications for other sectors which supply inputs.

Life-cycle analysis recognizes distinct stages in sales of a product or the application of a particular technology. Typical stages may be introduction, growth, maturity and decline. To apply this concept, data from other similar products or technologies must be collected to discover whether they go through the various stages of a life-cycle and the typical lengths of each stage. This information can be used to forecast the likely life of a product or technology.

The techniques discussed so far have been quantitative approaches which rely on the collection and extrapolation or interpretation of historical data. Qualitative approaches on the other hand can be used where no historical data are available. The qualitative techniques are used mainly in two types of situations. Firstly they can be used to forecast when a given new process or product becomes widely adopted. For example a forecaster may attempt to predict when, say, laser technology is likely to become widely adopted by industry. Secondly qualitative approaches may be used to predict what new developments are likely to occur in a specific area. Qualitative methods are often referred to as technological methods.

Expert forecasting involves using specialists in a particular area to produce forecasts based on their own knowledge and experience. The simplest forecasting of this type is the prediction of a single person. There are many problems, such as individual bias, associated with one man forecasts that can be overcome by the use of opinion polls or panels of experts.

The Delphi approach seeks to make forecasting by experts more formal and to eliminate some of the problems associated with them. This approach was developed extensively by Olaf Helmer. In this technique a number of experts are consulted and their opinions used to produce forecasts.
The first stage of the process is to select a panel of experts. They are

interrogated individually (usually by means of a questionnaire) with regard to their expectations for a series of hypothetical future events. After the responses to the first questionnaires are obtained, the answers are assembled as distributions, stated in terms of means and quartiles, plus any pertinent comments by the experts. Thus, at the beginning of the second round the panellists are given the above information along with a list of anonymous comments and arguments for various positions. The respondents are then asked to submit revised estimates together with reasons for agreeing or disagreeing with the initial concensus. The procedure is then repeated for the later rounds. If all goes well the answers will tend to converge and will span a narrower range. The experts are selected on the basis that they are competent to answer the questions in a particular area. With the Delphi approach, rather than meeting physically to debate the questions, the experts are kept apart so that their judgements will not be influenced by social pressure or by other aspects of small group behaviour. Anonymity of participants is maintained in order to stimulate unconventional thinking.

Curve fitting was mentioned as a quantitative technique. Curves can also be used that are not based on past data of the parameter being forecast, expert opinion being used instead. The S-curve is commonly used for forecasting purposes, and is so-called because the function appears roughly S-shaped when plotted on graph paper. This is rather like the life-cycle approach mentioned previously. S-curves are characteristic forms of many technological developments and the sales of several products. An S-curve implies a slow initial growth followed by steep growth which finally levels out. There are many types of S-curves and indeed other functional forms of curves such as exponential or logarithmic which could be used and therefore a major problem for the forecaster is choosing the right one. This depends on the technology or product to be forecast. The forecaster has to exercise expert judgement based on past experience with other technologies or products.

The morphological method was developed by Fritz Zwicky in his work on jet engines. The method is used for identifying and counting all possible means to achieve a given end. It can be viewed as a kind of check-list which enumerates all combinations of technological possibilities in a systematic way. Zwicky used the approach to identify 576 combinations of 6 basic parameters which define all possible jet engines that can be activated by chemical energy. As an example one of the parameters was the physical state of the jet engine propellant which could be gaseous, liquid or solid. The method allows the identification of combinations of parameters which might otherwise be missed.

Relevance trees aim to show the sub-goals which must be reached before a major objective can be achieved. The tree will normally be pyramid shaped with the number of end points of branches increasing progressively down the tree. One notable example of this technique was the indication of the sub-goals necessary to put a man on the moon by 1970. The relevance tree approach is useful in checking the forecast of a final objective. All sub-goals must be attainable by the time the final objective is forecast to occur. This approach is a form of critical path analysis.

The approach to forecasting known as scenario writing was pioneered by Herman Kahn. A scenario is a logical and plausible, but not necessarily probable, set of events, both serial and simultaneous, with careful attention to timing and correlations whenever the latter are salient. The approach enables the analyst to examine many alternative possibilities instead of concentrating on straightforward surprise-free projections. This approach is particularly useful in studying future environments such as the energy scene in the year 2000.

The techniques reviewed here are the main ones used by long-term forecasters although there are variations and other techniques which sometimes find application.

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CHAPTER 5.0 HEAT EXCHANGERS, THEIR MARKETS AND SERCK

5.0

HEAT EXCHANGERS, THEIR MARKETS AND SERCK

5.1

Heat Exhangers

A heat exchanger is 'a device for transferring heat from one medium to another often through metal walls usually to extract heat from a medium flowing between two surfaces'.[1] A car radiator is an example of one type of heat exchanger in common usage.

In all branches of engineering it is often found necessary to transfer heat from hot to cold fluids by the use of a heat exchanger. There are many types and configurations of equipment available for this purpose. Different types and configurations of heat exchanger exist because of the extent to which the designer has to allow for:

- different thermal expansion rates of the materials from which heat exchangers are made;
- the conditions of pressure and temperature between the two fluids;
- the tendency of one or both fluids to cause fouling;
- the corrosive action of the fluids;
- ease of cleaning both the inside and outside of the surfaces;
- obtaining the maximum heat transfer area within a given size of heat exchanger;
- the lowest possible pressure drops of either of the fluids flowing through the exchanger;
- the necessity to avoid cross contamination of the fluids.

When a heat exchanger is being designed some or all of these factors may be taken into account.

The more common types of heat exchangers which are produced are described fully in Appendix B.

5.2

The Size, Nature and Scope of the U.K. Heat Exchanger Market

The aim of this section is to look briefly and generally at the whole U.K. heat exchanger market including areas in which S.H.T. does not operate. This will be used as a reference point for comparison with forecasts of future patterns of demand as related to projected changes on the energy scene contained in a later chapter of this thesis.

Heat exchangers in the context of this study are taken to be those types manufactured by Serck or other types which compete for business in the same or similar applications. This, therefore, excludes some devices which can be considered to be heat exchangers (such as boilers and steam generators except waste heat boilers which are included).

5.2.1

The Industry and the Product

The heat exchanger industry is a slow moving one, quite conservative in its design methods and manufacturing procedures. The trends from within the industry have been, and will continue to be, equally slow in application. Illustrating this point is the fact that Serck has been making the same products more or less for thirty or forty years.

Only a handful of companies turn over in excess of £10 million a year whilst the majority come under £3 million. Companies in the industry typically have a work force of less than 250 with many having less than 100.

There are over 180 firms listed in 'Kompass' directory as being manufacturers of heat exchangers of one type or another. Although the Government-produced Business Monitor lists less than 100 active companies.

These manufacturers tend to specialise in making certain types of heat exchanger often for a narrow range of markets. For example, around 60 per cent of S.H.T.'s output is for various diesel engine applications.

Changes in the heat exchanger field have not taken the form of fundamental changes of existing designs or radical new designs. Rather there has been a slow process of refinement of existing designs to cope with more exacting and demanding requirements. The abilities to handle higher pressures, temperatures or more corrosive fluids have been acquired by the industry. The present state of heat transfer technology is one of continuous development of existing designs and the extension of these designs into newer fields of heat transfer. The fringe specialist designs fulfil a narrow role in the whole heat exchanger field but nevertheless it is an important one.

The basic requirement of a heat exchanger is to put heat in or take heat out of a fluid without contaminating it. The factors affecting selection of a particular exchanger probably include the following:

(a) The cost of the device. It must be remembered, however, that heat exchangers often account for only a small proportion of the total cost of the plant to which it is to be attached. For example, the Process Plant Working Party give a figure of 6.25 per cent as a typical proportion of the expenditure in a large project accounted for by heat exchangers.[2] Each individual exchanger accounts for only a tiny proportion of the cost. This may mean that the two following points become much more crucial than just the plain simple cost of the unit.

(b) Delivery. This may well be more important than price. If the heat exchanger is part of a large process plant project, late delivery could hold up the project. The cost per day of the hold up may exceed price of the heat exchanger many times over. Similarly, if the heat exchanger used is a component for something like a diesel engine, which itself is a component in say a locomotive, costs caused by hold ups in delivery could again exceed the cost of the heat exchanger.

(c) Quality. If a unit fails in service, the cost associated with its breakdown could be astronomic.

(d) The duties which the exchanger will have to operate under. This includes the pressure of both fluids; the temperatures; the possible corrosive properties of either or both of the fluids.

These factors influence the choice of type of heat exchanger, the materials of construction and also which company will supply.

5.2.2

The Total Market

The definition of the U.K. heat exchanger market used in this thesis differs from that used by Serck and is given in Chapter 3.0.

There are no published statistics available on the whole U.K. heat exchanger market. The only statistics found are those recorded in the Government's Business Monitor series. These show heat exchangers sold for industrial (including process) plant applications. These figures only show direct exports and not those which are sold to U.K. customers and then subsequently exported. Heat exchangers which are exported by the heat exchanger manufacturers' customers are counted as home sales.

Serck generates its own market information but much of it is aimed at answering specific questions rather than taking a broad look at the whole market. For this reason and because Serck's definition of the home market is different from that used in this study, the market size figures used herein were estimated from scratch. Information from within Serck's marketing information system and sources outside the company were used as the basis for the estimates. Table 5.2.1 contains the estimates for the various sectors which account for most heat exchangers sold in the U.K. Some small sectors are not included because their size did not warrant the work involved in estimating them and their importance in terms of the changing energy situation was thought to be minimal.

These estimates relate to 1978 which was the latest year for which information was available in all sectors. Details of the coverage of each sector along with the methods for calculating these estimates are contained in Appendix A.

TABLE 5.2.1 The U.K. Consumption of Heat Exchangers which is Available to U.K. Manufacturers

Sector	Value £ Millions
Road Transport	28.62
Rail Transport	1.28
Miscellaneous Machinery	6.70
Public Power Generation	0.64
Combined Heat and Power	0.90
Manufacturing Industries	1.28
Chemicals	30.88
Oil Refining	13.50
TOTAL	83.80

The breakdown of the sectors was determined by the likely developments to take place as a result of the changing energy situation rather than any other method of sector classification.

5.3

The Company and Its Products

5.3.1

The Company

The founder of the company, Peter Oscar Serck, was born in St. Petersburg, Russia in 1882 of Norwegian parents. In the early 1990's he bought a partnership in the Zimmerman Engineering Company in Mannheim, Germany. It was this company that first developed and patented the Honeycomb radiator.

In 1905 Serck moved to London to set up a factory. He then moved to Coventry in 1909 to be nearer the motor industry and finally in 1911 moved to Serck Heat Transfer's present site at Greet, Birmingham.

In 1913 the partnership was dissolved, the German partner retained the business in Germany and Serck became the sole owner of the business in

England. During the 1914/18 war the 'Motor Radiator Manufacturing Company' was taken over by the British Government and run as the 'First National Radiator Factory'. After the war the factory was offered back to Serck and in 1919 he formed Serck Radiators Ltd. This was a public company in which Serck himself owned over half the shares and was its first Managing Director.

Serck Radiators, in the early years, concentrated on the production of the 'honeycomb' radiator for motor cars. This was reflected in the company's trade mark reproduced below.

The company later expanded its range of car radiators with the introduction of new designs. As the need for heat exchange equipment in other industries grew, Serck responded by producing the appropriate equipment.

<u>Figure 5.3.1 The Original Trademark</u>[3]

The Second World War saw the company move into Government control for the second time in its history. Every Spitfire, Wellington, Hurricane, Blenheim and Whitley aircraft used Serck equipment exclusively. Ships also featured Serck heat exchangers extensively; Serck coolers and heaters were fitted on such ships as HMS Ark Royal, Exeter, Illustrious and many others.

The normal output for Serck trebled during the war years. Throughout the war, the quality and reliability of Serck products was established and, afterwards, demand increased over the pre-war levels.

During the fifties and sixties Serck Radiators diversified and became a group of companies. In 1955 valve manufacturers Audley Engineering Company of Newport, Shropshire was taken over and is now called Serck Audco Valves. In 1957 Serck Services was formed to exploit the radiator aftermarket in the growing garages and fleet trade. In that same year Serck Limited became the parent company of the Serck Group, with Serck Radiators becoming part of the Group.

Another member of the Serck family, Herman Oscar, had set up a business in Manchester in 1929 to manufacture and service radiators. He retired in 1964 and sold his company to the Serck Group.

In 1968 the last car radiator was produced at Serck. Around this time the name of the company was changed to Serck Heat Transfer to reflect its activities more accurately.

In 1970 H.O. Serck became a division of Serck Heat Transfer. Overleaf, figure 5.3.3 depicts the main operating companies in the Serck Group.

Serck Heat Transfer is the third largest company in the Group in turnover terms with sales of £28.3 m accounting for around 27 per cent of the Group total. The company employs around 1,200 people out of a Group total of 5,000.

S.H.T.'s organisation is shown in figure 5.3.2 below.

Figure 5.3.2 The Division of Board Responsibilities at Serck Heat Transfer (circa 1980)

There are two manufacturing divisions, Heavy Engineering and Engine Equipment.

Heavy Engineering Division aims to supply complete cooling systems to the large diesel and industrial gas turbine markets. Its major products are tubular coolers for cooling water or lubricating oil systems, radiators for cooling air water or oil, and charge air coolers for cooling air for diesel engine combustion.

The Engine Equipment Division serves the high speed diesel engine and aviation gas turbine markets. Again its objective is to supply complete cooling systems which are often designed directly in conjunction with the engine manufacturers. The Division's major products include tubular coolers for cooling engine water or lubricating oil systems on diesel engines and for cooling aviation gas turbine engine oil systems using the aeroplane's fuel.

A new Division has been started under the aegis of the Development Director.

The Division, called Energy Systems Division, is an attempt by Serck to try a different approach to marketing heat transfer products. Traditionally Serck designs and sells heat exchangers to customer specifications and they then bolt them on to other pieces of equipment such as diesel engines or gas turbines. The new Division aims to sell solutions to customers' heat transfer problems particularly in heat recovery applications. This involves selling know-how, piping, fabrications, controls, instruments as well as heat exchangers. The Division has no manufacturing facilities as yet so it buys the equipment it needs either from the other Divisions or from outside suppliers. The Division is only in its infancy so no assessment of the success of the approach can be made.

5.3.2

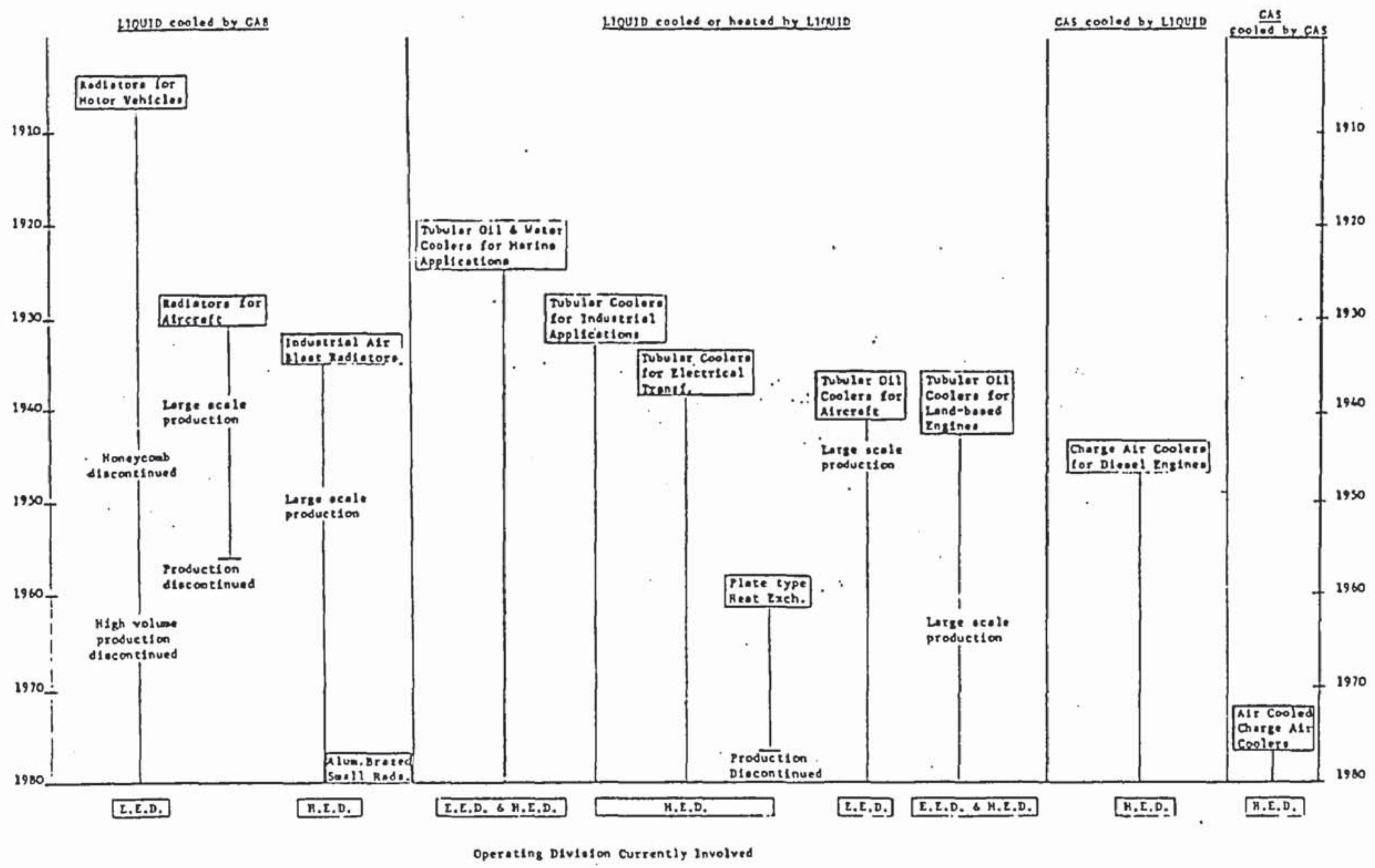
The Products

Figure 5.3.4 graphically illustrates the introduction and commercial exploitation of heat exchangers at the company from its origins to the present day.

The chart is split up into four main sections which represent different types of heat exchange problems. These are namely: liquid cooled by gas; liquid cooled or heated by liquid; gas cooled by liquid; and finally gas cooled by gas. These do not represent all the possible permutations as, for example, a liquid can be heated by a gas, but they are the situations for which Serck has manufactured heat exchangers.

From figure 5.3.4 it can be seen that the first new product after car radiators was a shell and tube design for marine applications. At about the

Figure 5.3.4 The Introduction and Commercial Exploitation of Products at Serck Heat Transfer



same time the radiator concept was being adapted for aircraft and then industrial applications.

With the growth of turbocharging in diesel engines charge air coolers were introduced in the forties to help the engine manufacturers extract more power out of engines.

Plate heat exchangers came next for Serck in the middle sixties. This type of exchanger was invented in the 1920's and is a competitor for the shell and tube type. For this reason Serck entered the market late and found some difficulty selling two competing types of exchanger. Serck never undertook full manufacture of this unit. Parts were bought in and assembled at Serck. In 1979, Serck stopped assembling plate types and now buys in complete units from another manufacturer.

In the seventies, air cooled charge air coolers were introduced into the product range for diesel engine applications.

The most recent addition in 1980, to the product range are small aluminium air cooled radiators for automotive oil cooling and other applications.

As previously mentioned, in 1968 the last car radiator was produced, ending over sixty years involvement in the industry that made Serck famous.

Complete descriptions of the heat exchangers Serck manufactures, as well as others that it does not, appear in Appendix B.

Serck's current range of products consists mainly of shell and tube and air cooled types of exchanger. A breakdown of Serck's sales for 1976/77 for the various sectors it serves is shown in Table 5.3.1.

TABLE 5.3.1 Breakdown of Serck Heat Transfer's Sales (£000's)

Industry Sector		Despatches	Company Total	%
Marine Non-Diesel		Home Export Total	1,175 1,184 2,359	5.6 5.6 11.2
Diesel	Marine	Home Export Total	3,397 985 4,382	16.1 4.6 20.7
	Vehicle	Home Export Total	1,299 250 1,549	6.1 1.2 7.3
	Rail	Home Export Total	863 38 901	4.1 0.2 4.3
	Land	Home Export Total	4,563 635 5,198	21.6 3.0 24.6
Aircraft		Home Export Total	678 476 1,154	3.2 2.3 5.5
Electricity Generation		Home Export Total	778 53 831	3.7 0.2 3.9
Process Industry		Home Export Total	83 48 131	0.4 0.2 0.6
General Industry		Home Export Total	3,298 1,330 4,628	15.6 6.3 21.9
TOTALS		Home Export Total	16,134 4,999 21,133	76.4 23.6 100.0

From the table can be seen that around 57 per cent of total sales are into the diesel industry sector. The rest of the sales being scattered over a range of applications. Serck sold about a fifth of its output directly overseas in 1976/77 which is about average for a component supplier.

Serck only sells to other manufacturers and not to the final consumers with the exception of perhaps a small number of spares and repairs. A large proportion of the equipment to which Serck heat exchangers are fitted are exported; probably in the region of 60 per cent. That means that direct and indirect exports of Serck heat exchangers are very probably around the 70 per cent mark.

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1	Nayler, J.L., Nayler, G.H.F.	Dictionary of Mechanical Engineering, George Newnes Ltd., London, 1967.
2	Process Plant Working Party	Process Plant Investment Forecasts No. 12, National Economic Development Office (NEDO), London, 1977, P.12.
3	Tomlin, P.	The History of Serck, Serck Heat Transfer, Birmingham, Undated, Circa 1977.

CHAPTER 6.0 THE PAST, PRESENT AND FUTURE ENERGY SITUATION

6.0

THE PAST, PRESENT AND FUTURE ENERGY SITUATION

6.1

The Past and Present Energy Pattern

This section looks at past and present energy patterns and chronicles the changing shares attributable to oil, coal, natural gas, nuclear and hydro-electric power since the 1950's.

The flow of energy from source to consumption is also examined.

The industrial economy in this country from the start was based on energy provided by coal. In 1970 coal's share of energy supply had fallen to just over 46 per cent, petroleum had risen to 44 per cent, with natural gas, hydro and nuclear power providing the balance. United Kingdom energy demand peaked in 1973 at 207.4 million tonnes of oil equivalent then fell back to 190.7 million in 1975. From 1976 consumption rose again towards the 1973 peak. Figure 6.1.1 shows the way in which energy consumption changed in the period 1954 to 1976. Figure 6.1.2 shows the changing proportions of total energy consumption satisfied by the various energy sources over the same period and clearly illustrates the changing energy pattern.

The 1970's saw oil prices rise at a very fast rate (in 1974 OPEC crude prices quadrupled in a matter of months). Also this period saw oil used as a political weapon on several occasions.

British energy policy since the 1973/74 oil crisis has been to expand indigenous supplies of energy as well as stepping up the nuclear programme and research into alternative sources of power such as solar, wind and wave energy and also nuclear fusion. This is very much a long term strategy with some policies not producing commercial results for many years yet.

Figure 6.1.1 U.K. Energy Consumption 1954-1976
In Millions of Tonnes Oil Equivalent
(Derived from British Petroleum Data[1])

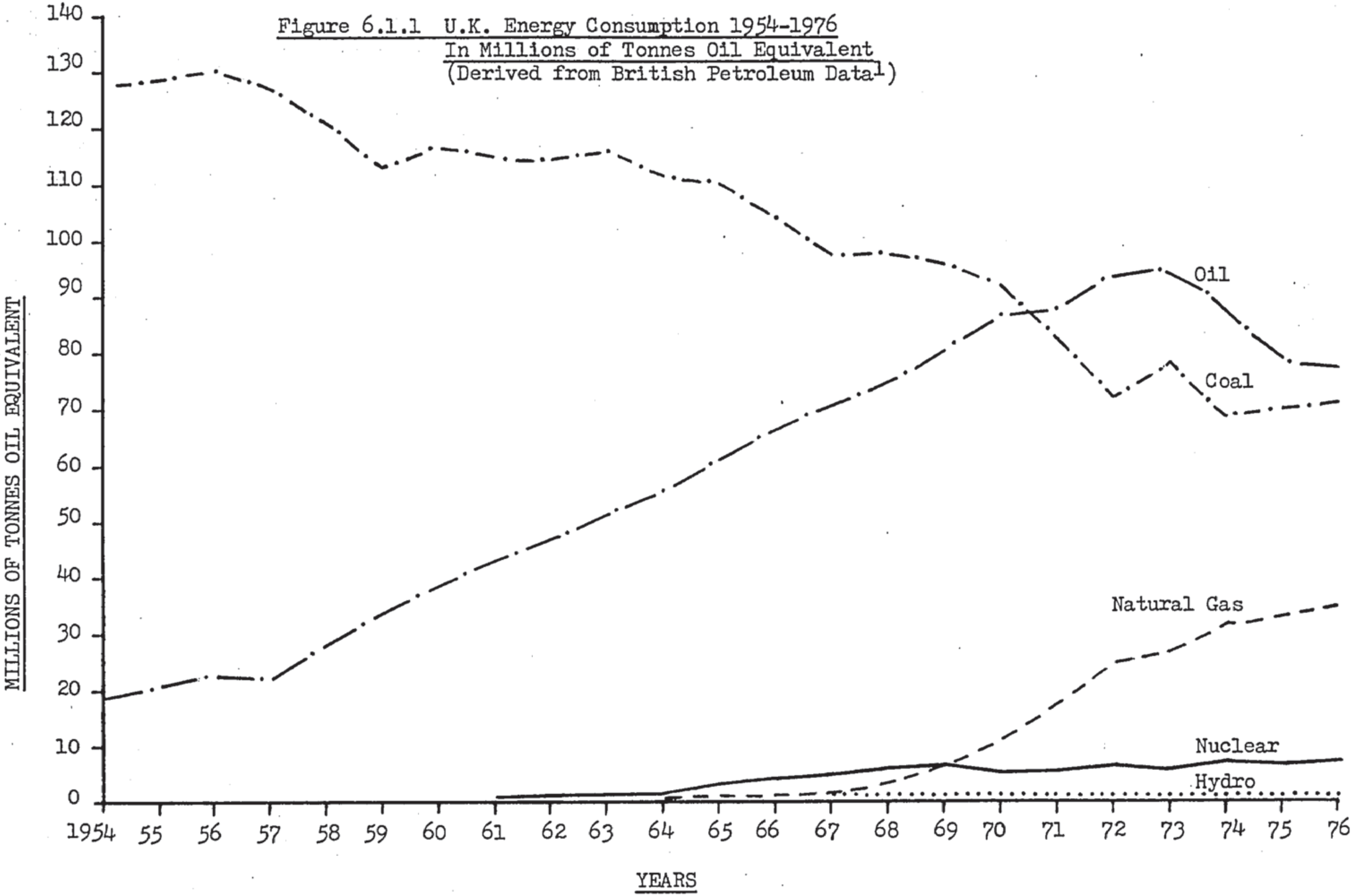


Figure 6.1.2 The Changing Energy Pattern for the United Kingdom Between 1954 and 1976

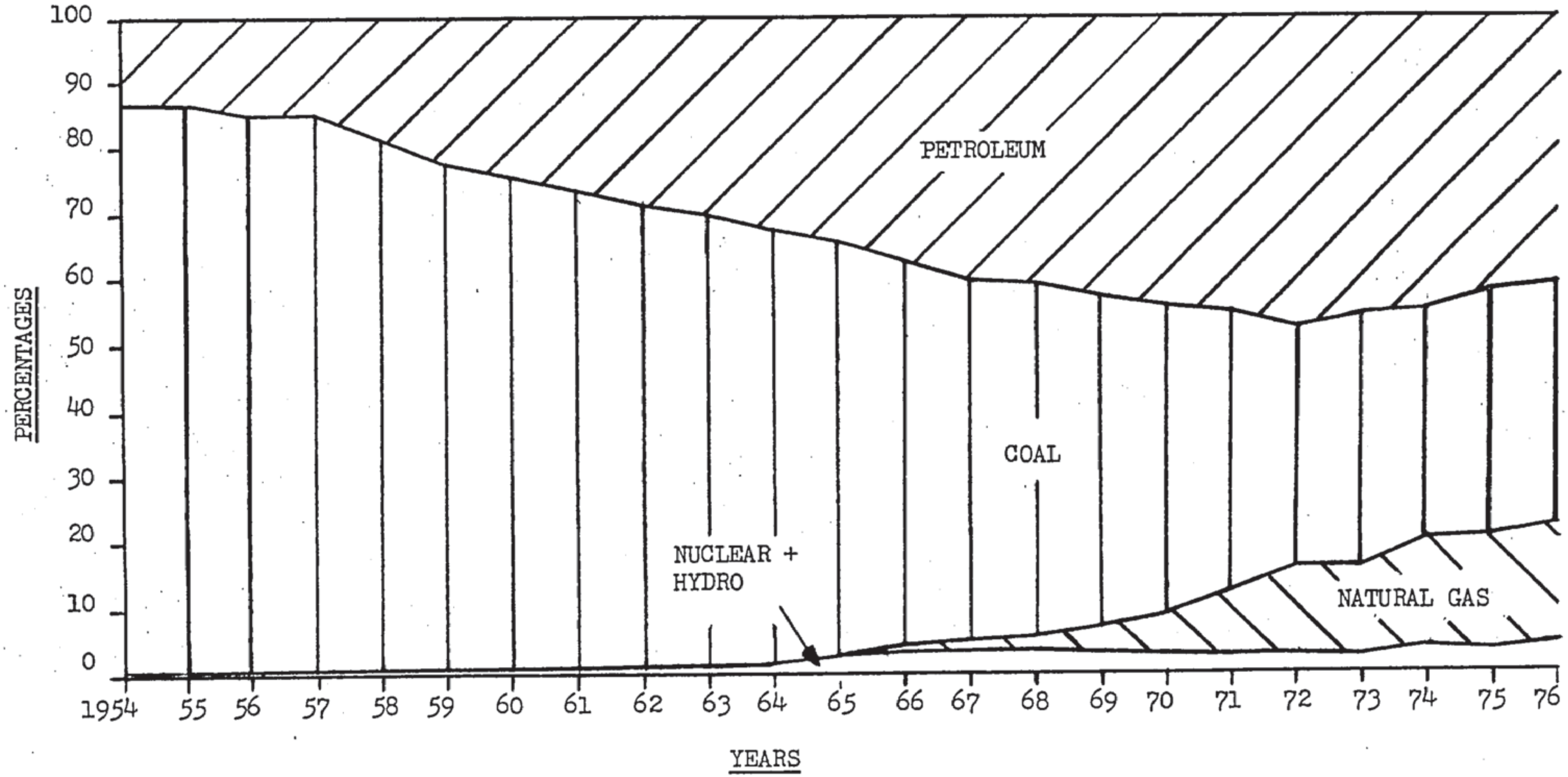
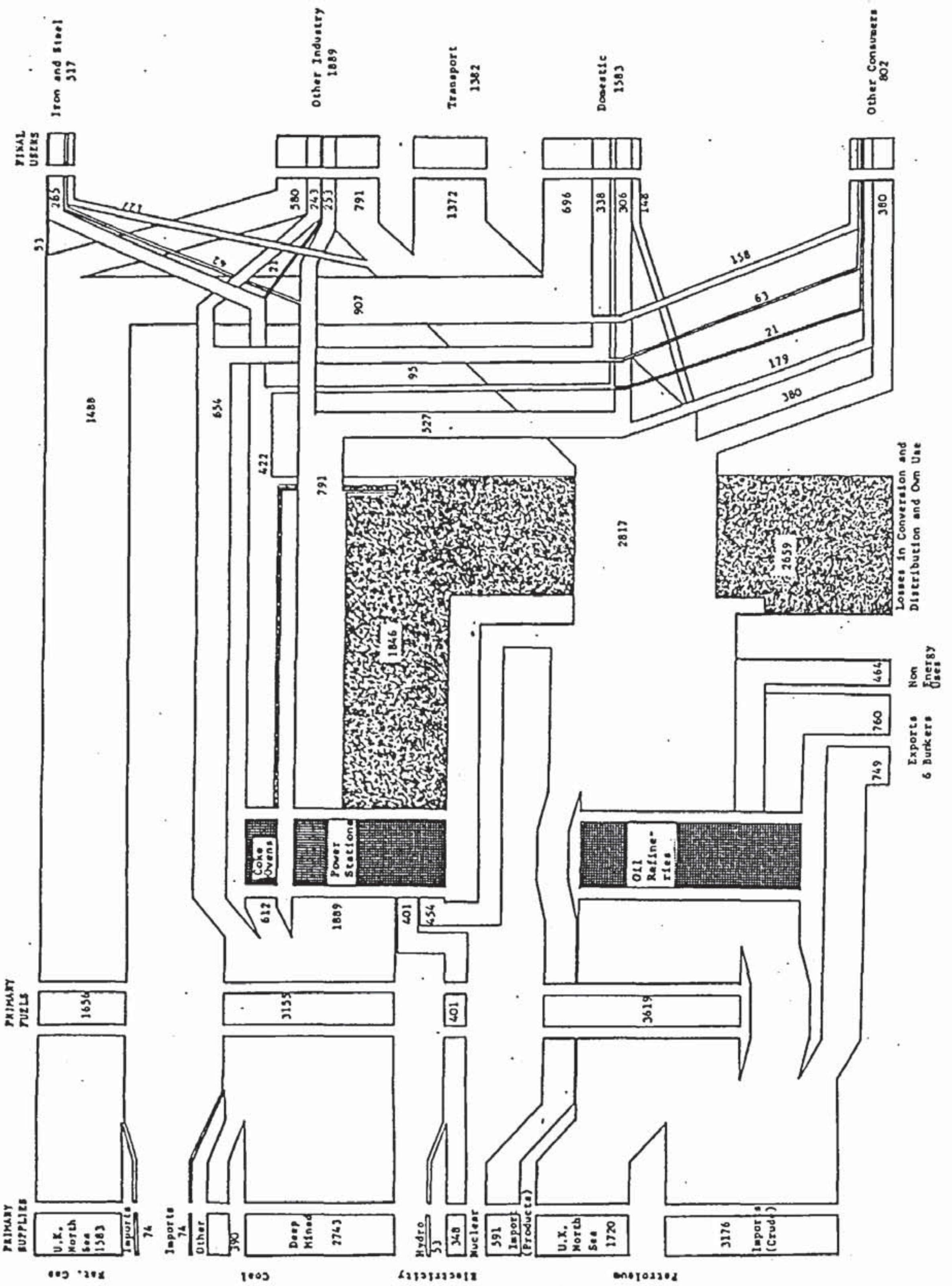


Figure 6.1.3 shows the flow of energy in the United Kingdom in 1977 in petajoules. The diagram is fairly self explanatory. It shows where energy comes from (i.e. oil, coal, gas, nuclear and hydro) and where it flows to (i.e. iron and steel, other industry, transport, domestic and other consumers). The diagram also shows losses in conversion from one form of energy to another and losses in distribution.

The energy flow pattern is a complex picture and has changed considerably over the last 40 years and will continue to do so.

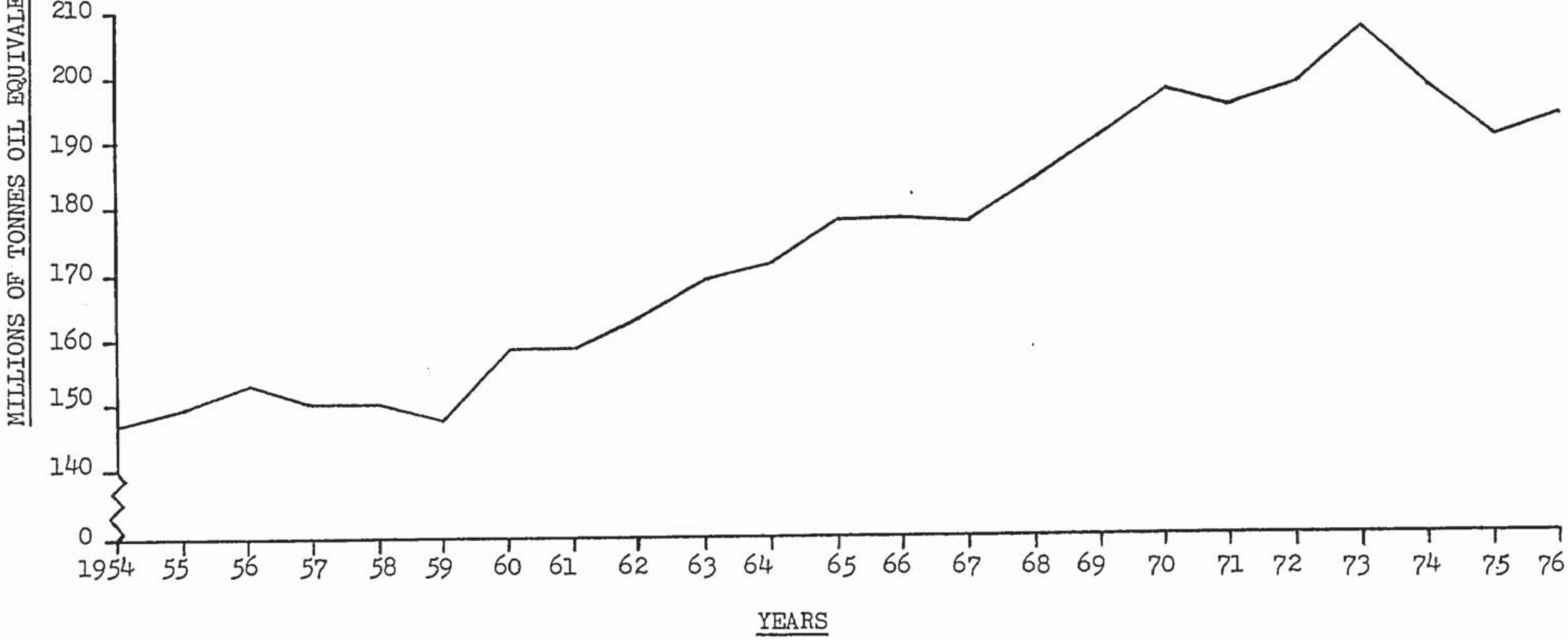
The energy picture changes in two ways. Firstly, the quantity of energy consumed in total has increased. This is shown in figure 6.1.4. Coal for the most part has been in decline with oil and natural gas very much the rising stars. The second change in the energy picture is the proportion of total energy consumption which is satisfied by the individual sources of energy (figure 6.1.2).

Figure 6.1.3 U.K. Energy Flows 1977 (Petajoules)*



* Adapted from Energy Flow Chart 1977 United Kingdom.[2]

Figure 6.1.4 Total U.K. Energy Consumption 1954-1976 in Millions of Tonnes Oil Equivalent



6.2

The Future Energy Situation

Since the 1973/74 oil crisis there has been considerable activity in the field of forecasting national and international energy requirements and the sources of supply to satisfy these. This is of course an extremely difficult area especially as many of the forecasts are for periods of up to twenty years and even fifty years ahead.

When one considers that Governmental attempts to forecast certain variables in the economy (gross national product, money supply, unemployment, prices and so on) for relatively short periods of up to a year ahead are rarely accurate, to attempt twenty year forecasts seems foolhardy. These long term forecasts are nevertheless extremely important for planning purposes.

Up to 1973, energy was in relatively plentiful supply and therefore relatively cheap. This allowed the advanced industrial nations of the world to expand their economies and improve the standard of living of their populations. The expectations of these people is for continuing and ever increasing prosperity.

The increasing prosperity of the fifties and sixties was heavily influenced by a falling real price of oil. In 1980 prices (usually fixed in U.S. dollars), the real price of oil rose from $2 per barrel in 1910 to $20 in 1918 but then reduced over the intervening years to $4 in 1972. In 1973 the price rose to $20 and by 1980 had reached $35. This has over the last few years stifled growth and contributed to the general recession.

There is pressure on Governments to get economies back on to the road to prosperity and to at least safeguard the standards of living currently prevailing. The 1973/74 oil crisis and subsequent events have stimulated

Governments into looking hard into the future to see what they need to do to realise the expectations of their respective populations.

This explains why attempts are made to forecast the energy situation, but why for such long periods like twenty years and more? When we talk of an energy crisis what we really mean is problems of oil price and supply. Coupled to this is the fact that although there are sources of supply of primary energy besides oil (coal, natural gas, nuclear power and so on) they are only partially substitutable one for another. Even when fuels can be substituted it usually takes some time for substitution to take place.

For example in the U.K. electricity is produced mainly by using oil, coal, and nuclear power. If oil supplies become short for whatever reason then to some extent electricity production can be covered by increasing output at non-oil powered power stations, always assuming that there is some spare capacity available. If, for some reason, oil supplies dry up, then new power stations would have to be built utilising other sources of fuel, or we would have to do without some electricity production permanently.

To build a major new power station takes at least eight and sometimes twelve years or more. This is why we have to forecast. Presumably if, say, oil is going to be unavailable sometime in the future we do not want to wait for supplies to dry up completely before we think about what to do about it.

In an attempt to avoid this kind of situation, forecasts are produced to help plan the introduction of say a new power station to coincide with the phasing out of the oil powered one. Obviously this way we can maintain electricity supply at the level desired instead of cutting back because the curtailment of oil supply was not foreseen.

The situation facing Governments is a great deal more complex and difficult than the relatively simple one outlined overleaf. Hence the need to forecast for long periods into the future. One of the possible options in the future is the use of nuclear fusion. This is proving to be a difficult source of power to harness. Work has been going on for over twenty years and most experts think that it will be another twenty to thirty years before fusion can be exploited commercially as a form of power.

Before considering the future U.K. energy situation it is necessary first to look at the World picture. This is because firstly, although the U.K. is currently self-sufficient in energy this will not always be the case; secondly, despite this self-sufficiency the U.K. still buys and sells on the World market and domestic energy prices are largely influenced by international factors.

6.2.1

The Future World Energy Situation

The first global study to come out after the 1973/74 oil crisis was the Report of the Workshop on Alternative Energy Strategies (WAES) entitled Energy: Global Prospects 1985-2000 published in 1977.[3]

The main conclusion of the WAES study was that oil demand would overtake supplies in the period 1985-95 and also the end of the era of growth in oil production was only at most fifteen years away. The project director, Professor Carroll C. Wilson felt that petroleum demand in the Western World could exceed supply as early as 1983.

To deal with this, the World would need to reduce its dependence on oil by increased energy conservation, increased production of coal and that nuclear power installed capacity would have to grow at between 11 and 14 per cent per year. By the year 2000 nuclear power would be providing up to 21 per cent of the World's primary energy.

The more adventurous schemes for reduction in demand for fossil and nuclear fuels by using the so-called renewable sources are largely dismissed by WAES as unlikely in global terms to make any significant difference this century.

In 1979 Shell issued a report[4] which said that energy demand over the next twenty years could only be met by a combination of conservation effort, continued oil exploration and the development of every new source of energy available. This report although more recent than the WAES study does reach many of the same conclusions.

Both see nuclear energy as having to meet an increasing share of World energy needs. They also agree that the contribution from alternative energy sources such as hydro electricity, solar and wind power, and biomass could all make valuable local contributions to supply but they are unlikely to make a significant impact within the next two decades.

A report[5] published in late 1979 by British Petroleum rather sets the scene with its title 'Oil Crisis..... Again?'. This report is more an assessment of the World situation rather than a forecast. The report contains four main messages.

Firstly, at some time in the future oil supply will cease to grow whilst the desire to consume it will continue to increase and that time is not too far away.

Secondly, many users have since the 1973/74 oil crisis cut energy consumption per unit of output on income. As there is now a better established energy conservation equipment industry than in 1973 future energy price increases will see consumers more able and willing to respond and reduce their relative energy consumption.

Thirdly, the substitution of oil by other sources of energy is a major problem. Since the events of 1973/74 industry and Government estimates of future coal, nuclear and natural gas supplies have all been reduced.

Fourthly and finally, as the United States is the World's largest energy user the decisions it does or does not take have a major impact on the World situation.

There are sometimes large differences between some of the forecasts which are produced by different groups. These occur largely as a result of differing assumptions about rates of economic growth or about the relationship between energy consumption and economic output. For instance a study published in 1978[6] saw primary energy demand rising by around 100 per cent between 1980 and the year 2000 whereas a more recent report from the oil company Exxon[7] sees primary energy demand rising by a somewhat lower 60 per cent.

All the works in long term forecasting of energy supply and demand throw up a wide range of possible future scenarios enough to confuse and bemuse even the most interested parties let alone the lay observer.

Of some things though we can be certain. Fossil fuels are a finite resource and will run out eventually although probably not until well into the twenty-first century and, in the case of coal, far beyond that. Oil will relinquish its role as the World's marginal fuel. Growth in demand for primary energy will have to be satisfied during the rest of this century in the main by coal, natural gas and nuclear power. Liquid fuels will increasingly be reserved for those applications for which there is no readily available substitute. These applications are basically transportation and petrochemicals. In the very long term substitutions may take place but are most likely to be beyond the scope of this study and well into the next century.

The role of Governments in the energy scene is crucial particularly with regard to energy conservation and none more so than the United States.

An article in the journal 'Management Today' entitled 'What Energy Crisis?'[8] tries to put the whole set of energy problems into perspective. In quite simple terms it shows that even if unconventional supplies of oil (shale oil and tar sands) and nuclear power are ignored, total World energy resources in the form of oil, natural gas and coal together would last for approximately 500 years at current levels of consumption.

The final paragraph of the article sums up the situation facing the World over the rest of this century.

> 'The answer is, of course, that the energy crisis is simply a matter of price rather than of supply. The industrial economies have become accustomed, almost throughout their history, to a steadily falling real energy price. The adjustment has occurred gradually, because the kinds of technology which exploit energy sources such as power stations take time to plan and construct. In other words, in the short-term the price-elasticity of demand for energy shows very little elasticity. It may be highly elastic in the long-term, but the long-term may be very long indeed, perhaps 20-30 years. In theory, if the long-term price trend were to change quickly and unexpectedly, the industrialised economies might not be able to adjust immediately. In practice, this is precisely what has happened, and goes far to explain why the World is going through a period of uncomfortable economic disruption'.

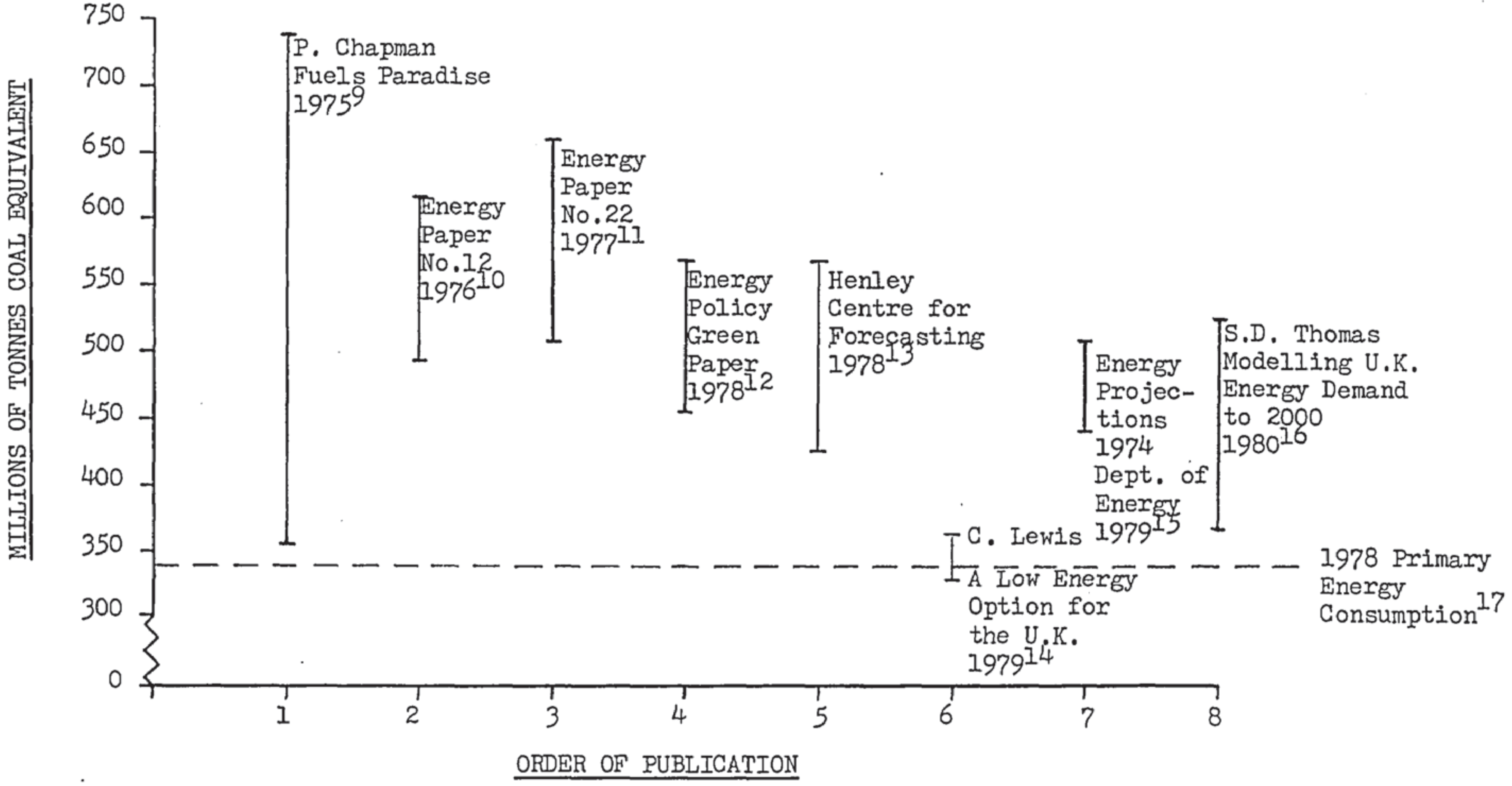
It is against this World background that the position of the United Kingdom must be considered. The U.K. situation is very different from that facing the World as a whole but certainly not independent of it.

6.2.2

The Future United Kingdom Energy Situation

With the quadrupling of oil prices from OPEC states in 1973/74 the forecasts of primary energy demand up to the year 2000 which appeared shortly after seemed to be pessimistically high but as time passed they appeared to fall, figure 6.2.1 overleaf shows this graphically.

Figure 6.2.1 Primary Energy Demand Forecasts for the Year 2000



The forecasts are arranged in the approximate order in which they were published. They represent some official forecasts (numbers 2, 3, 4 and 7) and some unofficial ones (numbers 1, 5, 6 and 8). Official means Governmental, and unofficial, non-Governmental. Looking left to right it can be seen that the forecasts seem to be falling towards the 1978 level of primary energy consumption which amounted to around 339 mtce.

It is difficult to draw any firm conclusions from this. This is because the assumptions behind each of the forecasts are different. Also the purposes for which the forecasts were to be used are different. All forecasters may claim objectively in their work but this is of course impossible. All forecasts are based on a series of assumptions and what these are very much depends on the subjective view of the forecaster. This is why it is perhaps useful to look at a series of forecasts and not one in isolation.

Overall the 'official' forecasts seem to be at a slightly higher level than the comparable 'unofficial' forecasts. Again this difference is probably through the use of differing assumptions.

So far reference has only been made to primary energy demand and not supply. This is the other side of the picture. Another important factor is the role played by energy conservation which can be seen as a way of reducing primary energy demand or as an additional, if invisible, supply of energy.

Forecasters are fond of referring to imbalances between energy demand and supply which when demand is greater than supply is popularly referred to as the 'energy gap'. Some forecasters try to predict when this energy gap is likely to occur. From their forecast of when energy supply fails to meet demand forecasters will say that certain policies will have to be adopted by Government to avoid this catastrophe. An example of this was shown in an article in the Financial Times of 28th November 1977 which was entitled 'Nuclear Investment to Beat Energy Gap'.[18]

To some this 'energy gap' would seem to appear to have a somewhat mythical quality and will never actually occur. It is true that as long as the Government does not introduce measures such as petrol rationing and allows a relatively free market in energy (that is, energy prices are allowed to rise and fall with the market) there will be no 'energy gap'. What would occur would be a rising real price of energy.

If this is so then we must conclude then that there is already an energy gap for oil as overall its real price has risen since 1973.

So what do the forecasters mean when they talk of an energy gap in the future? They are looking at the situation where over a period, maybe a relatively short period consumers will be unable to buy as much energy at a given price as they had been able to previously.

This is where forecasters subjectivity to some extent comes into play. They are implying that a rising real price of energy is a situation to be minimised or avoided. They often make recommendations about how to plug the energy gap. What they are really saying is what needs to be done to avoid, or at least minimise, the real rise in the price of energy.

6.2.2.1

An 'Official' and an 'Unofficial' View of the U.K. Energy Future

The purpose of this section is to review in detail two sets of forecasts which represent the 'official' view and an 'unofficial' view of the U.K.'s energy future. These are respectively Energy Policy: A Consultative Document[19] and 'A Low Energy Strategy for the United Kingdom'.[20] The reason for choosing these two are that; the Green Paper represents Government thinking on what the future energy situation is likely to be and the policies needed to deal with it; the low energy strategy approach of Gerald Leach et al represents a somewhat different picture of the U.K. energy future from the 'official' view.

The Green Paper was published in 1978 under the direction of Tony Benn the then Secretary of State for Energy in order to promote wider discussion of energy policy issues.

Table 6.2.1 below shows the Green Paper forecast for U.K. primary fuel demand 1975-2000 (including non-energy bunkers).

TABLE 6.2.1 U.K. Primary Energy Demand 1975-2000[21]

Millions of Tonnes Coal Equivalent

	1975	1985	2000
Higher Growth	346	422	569
Lower Growth	346	396	457

Energy supply in the year 2000 is shown in Table 6.2.2 below.

TABLE 6.2.2 Forecast Total Indigenous Energy Supply in the U.K. in the Year 2000[22]

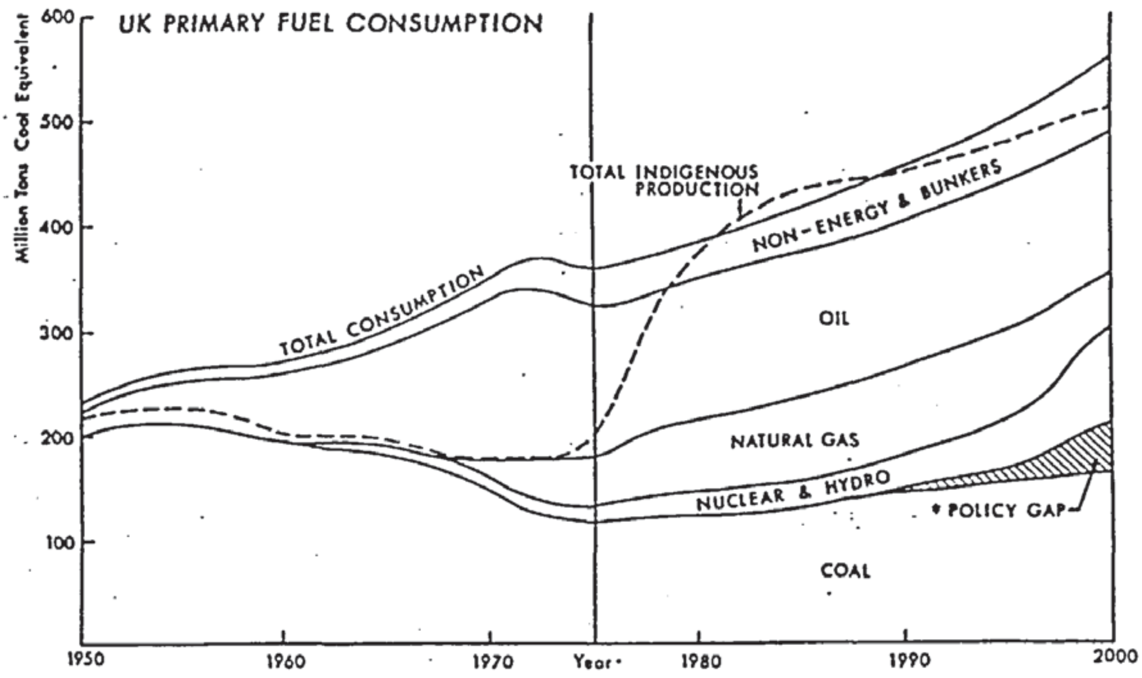
Millions of Tonnes Coal or Coal Equivalent

Coal	173
Nuclear	25-97
Natural Gas	51-91
Oil	152
Renewables	0-10
TOTAL	401-523

Any shortfall in energy demand would have to be made up from imports.

The general picture for the energy situation over the rest of the century is shown in figure 6.2.2 over. The diagram represents the Department of Energy's (DoE) reference scenario one of many such scenarios used by the DoE to take account of various assumptions.

Figure 6.2.2 Green Paper Reference Scenario for U.K. Primary Fuel Consumption[23]



In this scenario the main assumptions are that; economic growth continues to the end of the century at an average annual rate of just under 3 per cent; energy prices are related to the World price of oil which rises to double the 1978 level in real terms; an allowance is made for conservation in the forecast which is of the order of an equivalent of an overall reduction of over 23 per cent in heat supplied by the turn of the century.

There are several conclusions drawn in the Green Paper. The U.K. will be a net exporter of energy from the early 1980's with more than enough energy to meet domestic needs. In the higher economic growth case resumed energy imports may be required in the 1990's and could be around 100 million tonnes coal equivalent by the turn of the century. Even in the lower growth case imports would be required by the year 2000.

According to the Green Paper the lower level of economic activity has been used to generate a lower level of demand for energy. Such a lower level of growth could be unacceptable for social and political reasons but to achieve the lower level of demand with a higher level of economic activity could call for measures of energy economy going far beyond the levels obtainable through conservation as currently understood.

In 1979 the Department of Energy issued a paper entitled 'Energy Projections 1979'.[24] The purpose of this paper was to up-date the projections made in the 1978 Green Paper.

In this later paper total primary fuel requirements for the year 2000 are estimated to be in the range 445-510 million tonnes coal equivalent as opposed to the range 457-569 mtce in the Green Paper. There are two principal differences between the two projections. Firstly, in the more recent forecast a larger component in future economic growth coming from the less energy intensive service sector, resulting in lower forecast demand particularly for electricity. Secondly, reduced estimates for fuel requirements for steel production and for non-energy uses.

Potential indigenous energy supply by the end of the century is estimated to be in the range 390-410 mtce as compared with up to 523 mtce in the Green Paper forecasts, the greater part of the difference being due to changes in the oil and gas estimates.

The implications of this forecast is that from a period of energy surplus in 1980 the latter part of the century will see the country having to import oil. Increasing importance will be placed on the roles played by energy conservation, nuclear power and coal as the indigenous supplies of oil and gas decline. Renewable sources such as wind, waves, tides, solar and geothermal energy are not thought to contribute significantly to supply before the year 2000.

The projections suggest that even with heavy investment in nuclear power and coal extraction U.K. net energy imports in 2000 will be in the range 35-120 mtce.

Gerald Leach and colleagues' work in looking at the U.K.'s energy future presents a somewhat more optimistic picture than most others in this area. The title of the work (A Low Energy Strategy for the United Kingdom) is indicative of its contents.

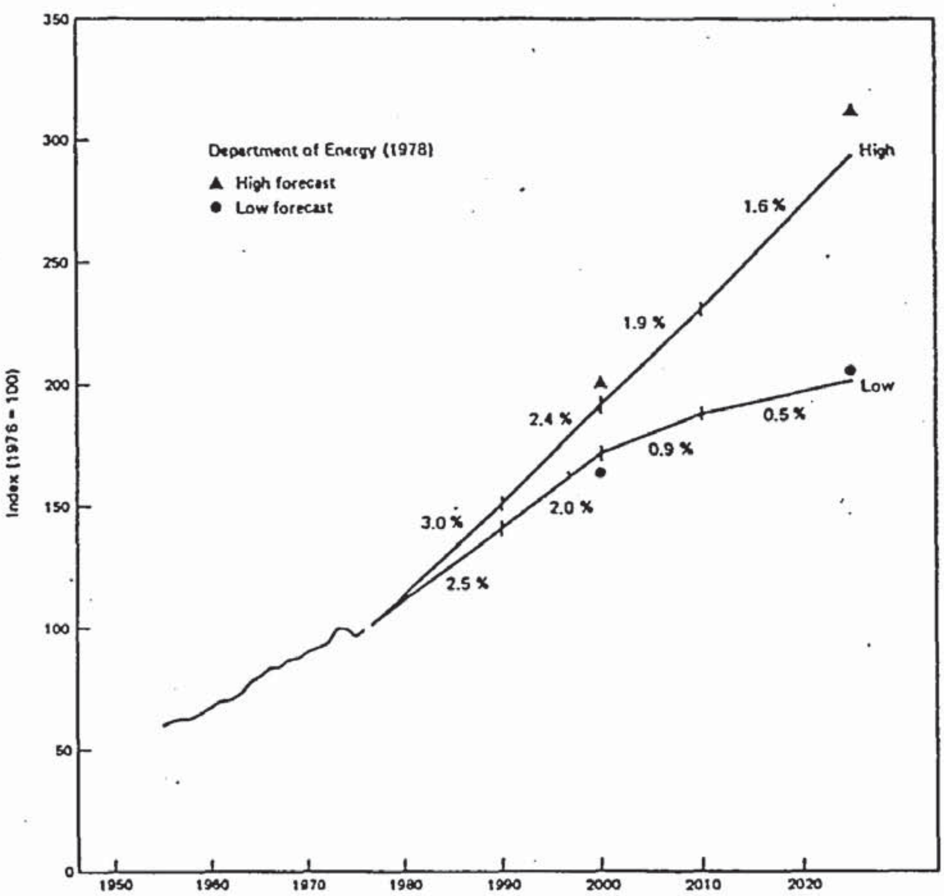
Leach's team attempt to show how the U.K. could have 50 years of prosperous material growth using less primary energy than it uses currently. The authors say that their work challenges the technical optimists of the nuclear and other supply industries who claim that they can bridge whatever energy gaps arise and suggests that it is they who are the pessimists. The team's conclusion also challenges the social optimists who believe that an energy crisis can be avoided by fundamental changes in attitudes and practices; whether nobly, by turning from acquisitiveness to altruism; austerely, by wearing pullovers and bicycling; or technically by covering the place with windmills, solar collectors and fuel farms.[25]

It is claimed that Britain can move to a prosperous low-energy future with no more than moderate change. Amongst the evidence cited to support the previous statement is the fact that the U.K. responded to the 1973/74 oil crisis with a fuel consumption in 1977 lower than in 1970 but with gross domestic product (GDP) up over the same period by more than 10 per cent.

One of the most important propositions in the low-energy strategy is that the energy-GDP link, regarded by many as being almost an economic law, is no more than a coincidental relationship. Therefore, rejected are the contentions that energy use must grow with rising GDP and, conversely a low-energy future must involve fewer goods and services, fewer jobs and belt-tightening deprivation.

Figure 6.2.3. below shows the similarity of assumptions on economic growth for the low-energy strategy and the reference scenario of the Department of Energy in the Green Paper mentioned previously.

Figure 6.2.3 Assumptions for Growth of Gross Domestic Product (GDP) by the Low-Energy Strategy Group and the Department of Energy[26]



Figures 6.2.4 and 6.2.5 over show the Leach et al forecasts for future primary energy demand for a low case and a high case.

Figure 6.2.4 Primary Energy Projections, Low Case[27]

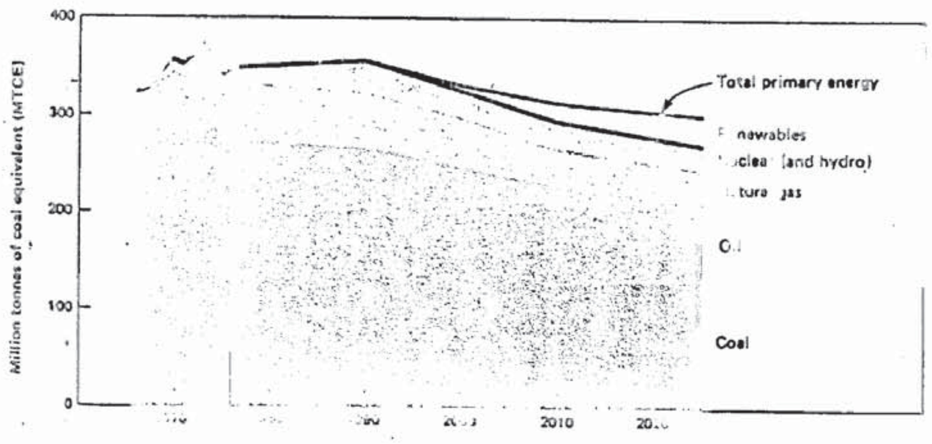
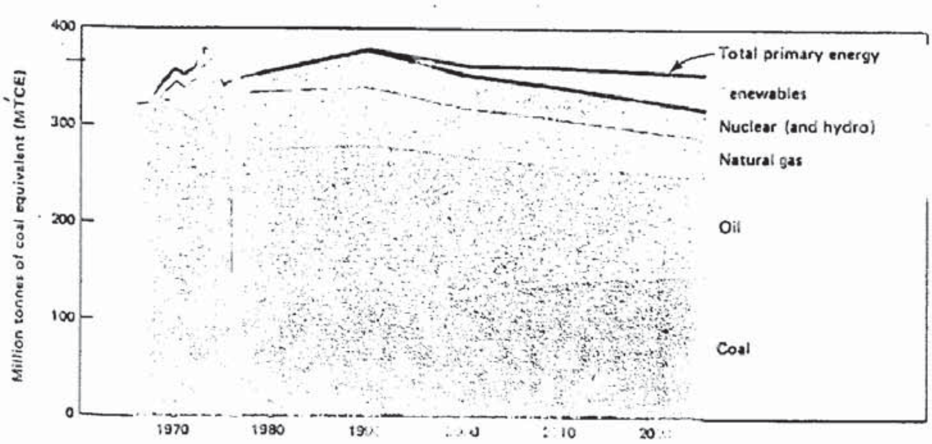


Figure 6.2.5 Primary Energy Projections, High Case[28]



Primary energy requirements according to Leach's team will be of the order of 330-361 mtce in the year 2000 compared with a figure of 445-510 mtce in the Department of Energy's Energy Projection 1979.

The low-energy team have not sought to reduce the primary energy requirement estimate by assuming large contributions from renewable sources. In fact, they estimate a contribution of around 4-5 mtce which is lower than the Green Paper estimate of up to 10 mtce.

Leach's group also assumes a smaller amount of energy is recoverable from power station waste heat than the Government estimates is potentially achievable by the year 2000.

The low-energy strategy group forecasts are mostly influenced by the enormous savings they say are possible from the application of currently available and quite conventional energy saving technology.[29]

The implications of these findings are:

- in 2000 the U.K. could still be self-sufficient in North Sea oil;
- coal production need only be 120 million tonnes a year compared to 170 million tonnes a year in the National Coal Board's 'Plan for Coal';
- from 1976-2000 it is assumed that only 4.5 to 6.5 Gigawatts (GW) of nuclear capacity will need to be constructed compared with 33-36 GW estimated in Energy Projections 1979. Total generating capacity needed over the period would be 26-30 GW compared with 40-50 GW in Energy Projections 1979;
- the U.K. could be self-sufficient in natural gas until well into the next century.

6.2.2.2

The Green Paper and The Low-Energy Strategy - Who Is Right?

The answer to this question is, of course, only time will tell. They could either of them prove to be right and then again they may both be wrong.

In 1980 S.D. Thomas produced a paper[30] which estimated the primary energy requirements in 2000 would be in the range 369-528 mtce which covers all of the ground between the Department of Energy and the Low-Energy Strategy team. So between the three forecasts there is a predicted primary energy requirement of 330-528 mtce.

Recently it has been said that many companies in the oil industry are revising downwards their forecasts of U.K. primary energy demand in the year 2000 to figures around the 1978 one of 339 mtce.[31] This is much more in line with Leach's team's forecasts than the Department of Energy's. Whether this is because the oil companies see conservation playing a much bigger role than they had previously envisaged or because they see the U.K. only growing at a rate slower than previously expected is not known for certain. It appears that it may well be a combination of both.

It has been reported that the Electricity Council are also revising their figures downwards. There has also been criticism recently from a Parliamentary select committee on the electricity generating industry's plans for expansion of nuclear capacity. The feeling is that the forecasts were too high and the planned expansion too great.

6.2.2.3

Conclusions

Overall it seems that it is quite possible that the U.K. will be self-sufficient in energy into the next century. If the Department of Energy forecast at the upper end actually happens it means that the U.K. will need to import energy mainly in the form of oil. Pressumably it will be able to purchase all the oil needed provided it is prepared to pay the price. This price should not be significantly higher than the U.K. domestic price as this is generally fixed in line with world prices.

It also appears that the electricity industry has overestimated demand and in consequence has planned for a much bigger increase in capacity, particularly nuclear, than will be needed.

The main difference between the Department of Energy and the Low-Energy Strategy team forecasts is their respective views on the relationship between energy consumption and the level of economic activity and the role that energy conservation may play in reducing energy demand.

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CHAPTER 7.0 TREND EXTRAPOLATION OF HEAT EXCHANGER SALES

7.0

TREND EXTRAPOLATION OF HEAT EXCHANGER SALES

The purpose of this chapter is to extrapolate past heat exchanger sales data with no explicit reference being made to the changing energy situation. The figures so derived can be used for comparison with those forecast in Chapter 9.0 where due consideration has been given to the changing energy situation.

Simple trend extrapolation based on past sales figures is a commonly used forecasting approach. The only historical data available for heat exchangers are from the Governments Business Monitor Series of statistics. Business Monitor PQ341.1, up to 1976, and 341.5 thereafter for sales of industrial (including process) plant contains details of total sales and exports by U.K. manufacturers and imports of similar equipment. Heat exchangers of various types are recorded in this Business Monitor. Serck in fact reports all of its output under the 341.5 heading even though a substantial proportion is for other sectors. This is because heat exchangers do not appear as a separate category under any other Business Monitor headings. It is quite likely that other heat exchanger manufacturers do the same.

Subtracting exports from total sales by U.K. manufacturers and adding imports will give a value for the U.K. market. This definition of the U.K. market is not the same as that used elsewhere in this study (see Section 5.2.2) in that heat exchangers which are sold in the U.K. but which are subsequently exported are counted as home sales not exports. Also, whilst the Business Monitor figures may well include heat exchangers which are not destined for industrial or process plant applications other types of heat exchangers such as car radiators are not included. Car radiators, for instance, are largely produced in-house by the big vehicle producers and it would be unlikely that the sales of these would be misreported under the industrial and process plant category.

The Business Monitor values cannot be compared directly with the heat exchanger market values derived elsewhere in this study as they are not measuring the same things. However a comparison and contrasting of overall trends may be possible.

The Business Monitor series which shows heat exchangers as a separate item began in 1972. This gives precious few data for extrapolation. The figures are shown below for the various years.

TABLE 7.1 U.K. Sales of Heat Exchangers Derived from The Business Monitor Series in Current Values

Year	U.K. Produced & Sold £000's	Exports £000's	Imports £000's	Total U.K. Market £000's	Reference for Derivation of Figures
1972	41,016	9,812	4,048	35,252	1
1973	40,873	8,827	4,681	36,727	2
1974	51,940	14,399	5,633	43,174	3
1975	73,332	15,575	11,501	69,258	4
1976	84,861	19,609	9,631	74,883	4
1977	97,204	25,715	9,860	81,349	5
1978	111,342	25,430	18,386	104,298	6
1979	117,680	33,946	14,593	98,327	6

The total U.K. market values contained in the last column of the table were converted into constant values at 1978 prices.

This was done by the use of an index derived from a price index of the output of the mechanical engineering industry contained in issues of the Central Statistical Office's Monthly Digest of Statistics. The corrected values of heat exchangers are shown in Table 7.2 overleaf.

TABLE 7.2 U.K. Sales of Heat Exchangers Adjusted to 1978 Values

Year	Total U.K. Market at 1978 Values £000's
1972	89,814
1973	87,570
1974	84,390
1975	105,818
1976	97,301
1977	90,933
1978	104,298
1979	87,807

These figures were used, despite the limited number of observations, to forecast values up to the year 2000. Serck uses a computer bureau which offers a statistical analysis system. The data were run through a growth rate analysis and projection module within the system. The results are shown in Table 7.3.

TABLE 7.3 Growth Rate Analysis and Projection of Heat Exchanger Sales

Year	Actual Sales £000's	Computer Estimate £000's
1972	89,814	89,931
1973	87,570	90,852
1974	84,390	91,783
1975	105,818	92,723
1976	97,301	93,673
1977	90,933	94,632
1978	104,298	95,601
1979	87,807	96,580
1985		102,670
1990		108,036
1995		113,684
2000		119,626

The annual average rate of growth is only 1.024 per cent per annum which is less than the 1.4 per cent growth in U.K. gross domestic product from 1970 onwards.[7]

The total heat exchanger market value can be sub-divided into process and non-process heat exchangers. The method for doing this is shown in Appendix C. The reasons for sub-dividing the total market are twofold. Firstly, the underlying rates of change in each sector are substantially different. Secondly, as the applications requirements for heat exchangers in each are also quite different, exchanger manufacturers tend to specialise in one or the other. Serck sells heat exchangers for non-process applications.

The figures for process and non-process heat exchangers are taken from Appendix C. These two sets of figures were put through the same computer program as the total figures. The results are shown in Table 7.4.

TABLE 7.4 Growth Rate Analysis and Projection of Process and Non-Process Heat Exchangers

Year	Actual Sales Process £M	Computer Estimate Process £M	Actual Sales Non-Process £M	Computer Estimate Non-Process £M	Sum of Computer Estimates £M
1972	45.17	45.1732	44.64	42.1413	87.3145
1973	47.06	46.8155	40.51	42.5598	89.4353
1974	42.69	48.6420	41.70	42.9825	91.4245
1975	62.73	50.4750	43.09	43.4094	93.8844
1976	52.51	52.3771	44.79	43.8405	96.2176
1977	46.58	54.3509	44.35	44.2759	98.6268
1978	59.30	56.3991	45.00	44.7156	101.1147
1985		73.0683		47.9184	120.9867
1990		87.9135		50.3457	138.2592
1995		105.7750		52.8958	158.6708
2000		127.2650		55.5752	182.8402

When analysed separately, process and non-process heat exchangers show markedly different rates of change, the average annual rates of growth being 3.77 and 0.99 per cent respectively. This is what could be expected. The process industries have been growing at a faster rate than other parts of industry. The markets in which Serck is active seem to be growing only very slowly.

Using so few observations to predict so far into the future means the forecasts can, and should, only be used for comparison purposes with the other forecasts in this thesis. They cannot be regarded as having any significance in terms of business decision making.

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CHAPTER 8.0 HEAT EXCHANGERS AND ENERGY

8.0

HEAT EXCHANGERS AND ENERGY

This chapter seeks to examine the relationship, if any, between heat exchangers and energy. Any statistical relationship could possibly be used in the forecasting of the impact of the changing energy situation on the demand for heat exchangers.

Heat exchangers and energy are inextricably linked. A heat exchanger may be defined as a device for transferring heat usually between two fluids and usually but not necessarily separated by a metal wall. This definition includes some devices not within the scope of this study, nevertheless it can be seen that the only function of a heat exchanger is to perform the task as outlined above.

The actual reasons for employing a heat exchanger may be many and varied. It may be that in a chemical process the product has to be cooled or heated before moving on to the next stage of the process. A quite different application may be the cooling of a mechanical device such as a diesel engine so that it may function properly. Heat recovered by an exchanger may be rejected to the environment or it may be re-used. Heat exchangers are sometimes used purely to recover heat that would otherwise go to waste. Heat exchangers can combine several jobs such as simultaneously cooling say, compressed air, using water that is destined for a boiler thereby pre-heating it and realising a saving in boiler fuel.

It would be reasonable to postulate that the use of heat exchangers is largely influenced by flows of heat energy and the way in which that energy is used. On the other hand it would be reasonable to say that the flow of heat energy, the use to which it is put and the amount consumed depends to some extent on the use of heat exchangers. There is a relationship between heat exchangers and energy flows as heat is used or given off as a by-product in most situations where energy is being mined, drilled for, harnessed, processed, transmitted or used. The relationship is two way, and there is a certain amount of interdependence.

The real determining factor is a desire to indulge in wealth creation and consumption. This creates a demand for energy and for heat exchangers.

Heat exchangers may be divided into several groups, in terms of the uses to which they are put. Most can be put into two basic groups; process and non-process. Process heat exchangers are those which are used in the process industries (mainly chemical processing, oil refining and gas processing) for heating or cooling process product or recovering heat from product to be used for heating other product, boiler feedwater or space heating. The non-process heat exchangers are found in a wide range of industries and applications. The majority of non-process heat exchangers are used for cooling and these mainly on various machines such as diesel engines. In these applications the function of the heat exchanger is to be a part of a system to cool the engine so that it may run efficiently. Most diesel engines have a radiator to cool the water that cools the engine and a cooler for the oil. The heat is generally rejected to the environment although in some cases it is possible to re-use the heat but this has not been common in the past. Other non-process heat exchangers are employed specifically to recover heat for re-use. For example a heat exchanger can be fitted in the exhaust of an engine to recover heat which may then be used to pre-heat boiler feed water.

8.1

Heat Exchangers, Total Inland Energy Consumption and The National Economy

To examine the way in which heat exchangers fit into the energy consumption pattern it is necessary to look for a statistical indication of a connection between output, energy and heat exchangers. In looking at output and energy first, it can be seen from Table 8.1.1 below that the relationship changes over time.

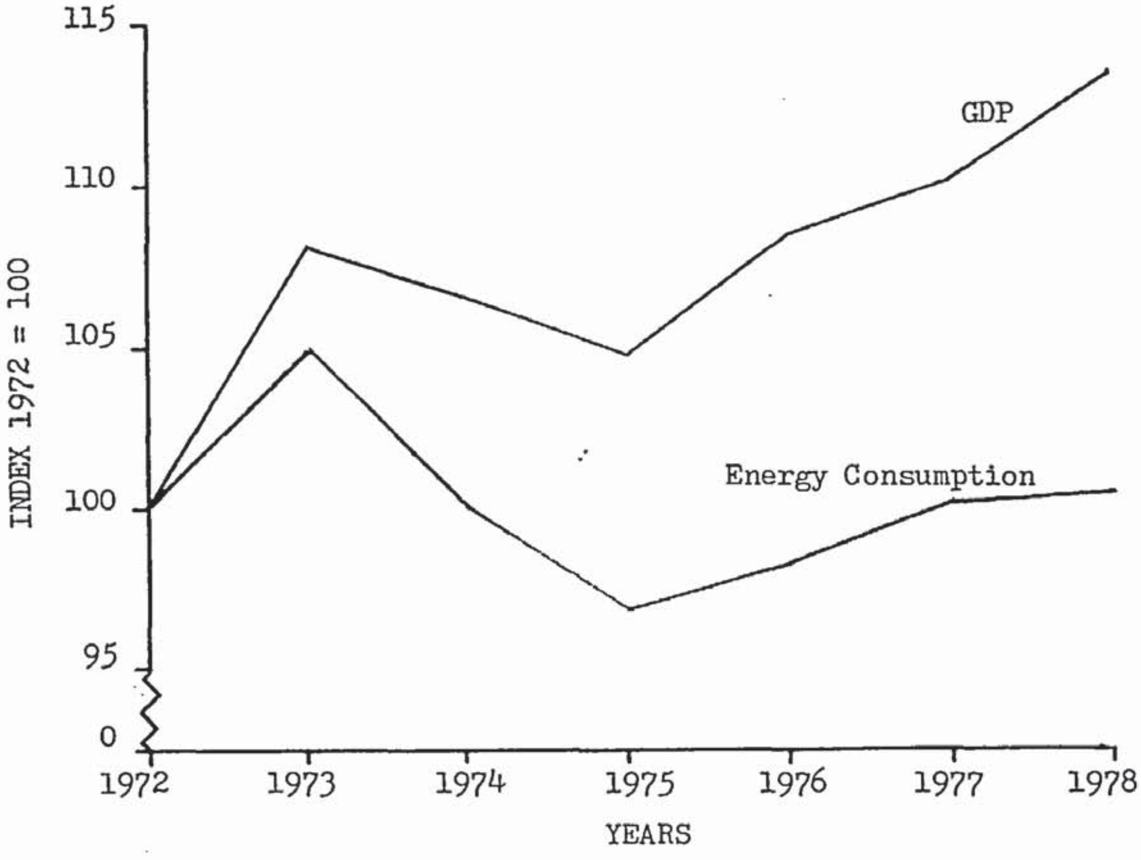
TABLE 8.1.1 The Changing Relationship Between Energy Consumption and Output[1]

	Total inland consumption of primary energy (temperature corrected)		Gross domestic product at 1975 factor cost		Energy ratio (1)/(3)	
	Million tonnes of coal equivalent (1)	Index 1975 = 100 (2)	£ million (3)	Index 1975 = 100 (4)	Tonnes of coal equivalent per £1,000 (5)	Index 1975 = 100 (6)
1950	227·7	69·7	49,034	52·9	4·6	131·7
1951	235·5	72·0	50,807	54·8	4·6	131·5
1952	234·0	71·6	50,813	54·8	4·6	130·6
1953	241·2	73·8	53,200	57·4	4·5	128·6
1954	248·6	76·0	55,125	59·4	4·5	127·9
1955	253·0	77·4	57,129	61·6	4·4	125·6
1956	255·0	78·0	58,196	62·8	4·4	124·3
1957	253·6	77·6	59,324	64·0	4·3	121·2
1958	252·6	77·3	59,120	63·7	4·3	121·2
1959	254·6	77·9	61,156	65·9	4·2	118·1
1960	270·9	82·9	63,987	69·0	4·2	120·1
1961	272·2	83·3	66,286	71·5	4·1	116·5
1962	273·6	83·7	66,909	72·2	4·1	116·0
1963	282·3	86·4	69,542	75·0	4·1	115·1
1964	291·2	89·1	73,271	79·0	4·0	112·7
1965	300·7	92·0	75,305	81·2	4·0	113·3
1966	302·8	92·6	76,958	83·0	3·9	111·6
1967	303·2	92·8	78,945	85·1	3·8	108·9
1968	312·9	95·7	81,913	88·3	3·8	108·3
1969	323·0	98·8	83,415	90·0	3·9	109·8
1970	336·3	102·9	85,210	91·9	3·9	111·9
1971	332·9	101·8	87,242	94·1	3·8	108·2
1972	337·4	103·2	88,496	95·4	3·8	108·1
1973	354·2	108·4	95,775	103·3	3·7	104·9
1974	337·9	103·4	94,326	101·7	3·6	101·6
1975	326·9	100·0	92,720	100·0	3·5	100·0
1976	331·5	101·4	95,979	103·5	3·5	98·0
1977	338·2	103·5	97,504	105·1	3·5	98·4
1978	339·1	103·7	100,473	108·3	3·4	95·7

Column 5 is the ratio of million tonnes of coal equivalent of energy consumed per thousand pounds of output. This figure has fallen steadily since the fifties. The energy crisis of 1973/74 seems to have had no particular impact on the process. It is not possible to determine whether the fall in relative consumption is through increased efficiency of energy use or through other factors such as a gradual move from the energy intensive industries to the less intensive ones like the service industries. It is most likely a combination of these and other factors which brought about the fall.

Figure 8.1.1 shows graphically the tendency for output to grow more quickly than energy consumption and when output is falling, for energy consumption to fall at a faster rate.

Figure 8.1.1 Gross Domestic Product and Total Inland Energy Consumption



N.B. These indices were derived from reference 1.

If energy conservation did play a role in the fall in relative energy consumption then heat exchangers may have contributed through their ability to recoup and/or use waste heat.

If there is a relationship between GDP, energy consumption and heat exchangers then a predictive model could possibly be constructed. To examine this possibility, a simple linear correlation was calculated between each of the variables shown overleaf in Table 8.1.2.

TABLE 8.1.2 Data for Calculation of Correlation Co-Efficient

Variable / Year	Heat Exchanger Sales £000's @ 1978 Prices	GDP £M's @ 1975 Factor Cost	Energy Consumption MTCE
1972	89,814	88,496	337.4
1973	87,570	95,775	354.2
1974	84,390	94,326	337.9
1975	105,818	92,720	326.9
1976	97,301	95,979	331.5
1977	90,933	97,504	338.2
1978	104,298	100,473	339.1

Heat exchanger sales for the U.K. are derived from business monitor figures.[2] The GDP and energy consumption figures come from Table 8.1.1.

A correlation co-efficient for each variable with each other variable was calculated and the results are shown as a matrix in Table 8.1.3 below.

TABLE 8.1.3 Correlation Co-Efficients

Variable	Heat Exchangers	GDP	Energy Consumption
Heat Exchangers	1.0000	0.2837	-0.5730
GDP	0.2837	1.0000	0.2190
Energy Consumption	-0.5730	0.2190	1.0000

The only correlation co-efficient that appears to have any significance at all is that between heat exchangers and energy consumption. If it is assumed that heat exchangers are used to recycle energy (which is not necessarily the case) then to use more heat exchangers would reduce the input demand for energy at any given level of output. Looking at the above table and assuming that energy consumption is significantly dependent on the use of heat exchangers a correlation co-efficient -0.573 would suggest several things. If heat exchanger sales rise then it would be expected that energy consumption would fall and if heat exchanger sales fall then energy consumption would rise. In other words the use of heat exchangers influences the efficiency of use of energy.

In reality heat exchangers are only one of a large group of devices and techniques which influence the level and efficiency of energy use (for a list see Appendix D). Also not all heat exchangers are used for recycling heat. For these reasons the impact of heat exchangers alone would not be so significant that variations in their use, even large variations, would be likely to be reflected as significant variations in the total inland energy consumption figures. Whilst not making an impact at a national level, significant local contributions to energy conservation could be made.

8.2

Heat Exchangers and Industrial Energy Use

Process and non-process heat exchangers need to be considered separately when looking more closely at the impact of a changing energy situation. Most heat exchangers that are used in applications where the recycling of heat is involved are to be found in the process industries. Non-process heat exchangers are, in the main used in conjunction with machines. The value of heat exchangers sold for machine cooling (mainly heat engines) is dependent upon the demand for machines. In the short-term as the demand for heat exchangers is determined by a demand for machines which is in turn determined by general economic factors, then an event such as the oil crisis will not alter the way heat exchangers are used although the numbers sold may well change. The changes in the numbers sold would not be related to changes in energy efficiency brought about by the use of extra exchangers.

This project is not, of course, simply looking for changes in the desire to recover heat brought about by ever higher energy prices. Whereas in the process industries higher fuel prices could stimulate a response in the form of increased efforts in the energy conservation field, which may include the use of more heat exchangers, in non-process applications, changes in the number or usage of heat exchangers would only result from major changes in the design or usage of, say, heat engines. For example, in the processing field a rise in fuel prices may mean that it is economically feasible to use more heat exchanger surface to recover more heat from a process or exhaust stream than before the price rise. In the non-process field on the other hand there could be a response but it would be more long-term. For example, the vast majority of cars use petrol engines. There is a possibility that as diesel engines are more efficient burners of fuel than petrol engines there is an incentive to use them more widely in cars. A development such as this may well affect heat exchanger usage but clearly, it is a long, gradual process which cannot be specifically linked to events such as the 73/74 oil crisis but which nevertheless is at least a result of that event and current and expected future situations.

In analysing the impact of the changing energy situation during the seventies on demand for heat exchangers, it is appropriate to concentrate on demand for process heat exchangers. To do this it is necessary to look closely at those industries which are large energy and heat exchanger users.

It may be possible in this way to find out if, firstly, the industries have responded to higher energy prices and, secondly, whether that involved any increase in purchases of heat exchangers.

By way of an example the chemical and allied industries will be looked at as they are large users of both energy and heat exchangers. Table 8.2.1 over shows trends in energy consumption and output for the years 1970-1977.

TABLE 8.2.1 Trends in Energy Consumption and Output in the Chemical and Allied Industries 1970-1977[3]

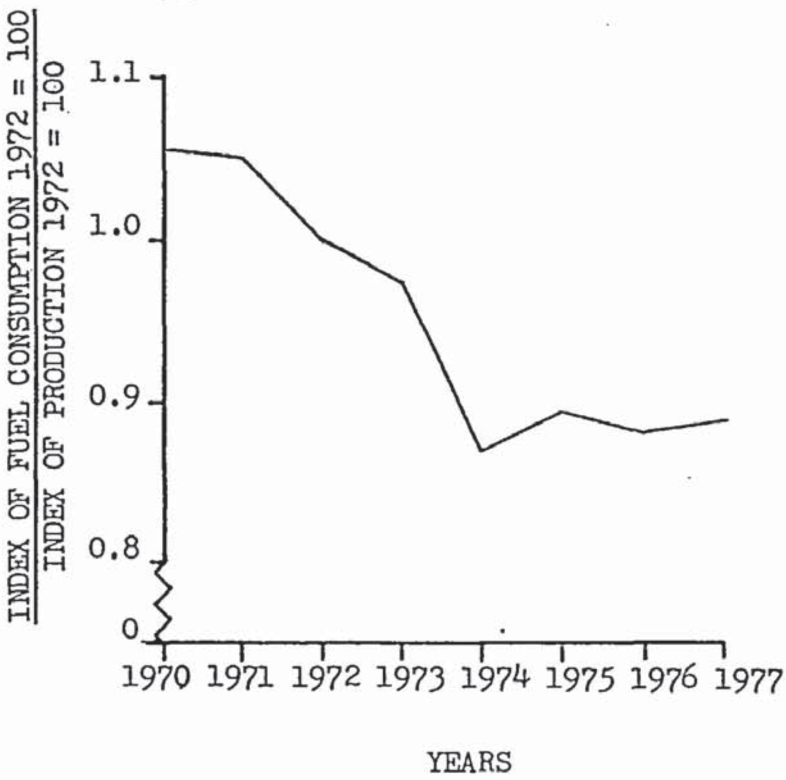
Year	Index of Production	Index of Fuel Consumption	Ratio of Indices Fuel/Production
1970	92.4	97.5	1.055
1971	94.4	99.2	1.051
1972	100.0	100.0	1.000
1973	111.8	108.8	.973
1974	118.8	103.2	.869
1975	107.6	96.3	.895
1976	118.8	104.0	.875
1977	122.9	109.4	.890

1972 = 100

This information is shown graphically on the next page.

The information contained in Table 8.2.1 and Figure 8.2.1 show that before the oil crisis of 1973/74 energy consumption per unit of output had been falling. After 1974 the improvements seem to have levelled out. According to Grant in his work on energy conservation in the chemical and process industries[4] the figures can be interpreted in the following way. In the years prior to 1973 a number of large petrochemical plants came on stream which were significantly more efficient in their usage of energy than previous plants and made a major contribution to the overall industry performance. There was a sharp improvement in 73/74 which was in direct response to the large increase in oil prices. The savings were achieved mainly through what are termed 'good housekeeping' conservation measures (see Appendix D). In the 74-77 period far less plants were completed than in the sixties and early seventies and plant capacity utilisation was often lower than the earlier period. Energy consumption per unit of output is adversely affected as individual plant utilisation falls below full capacity. These two factors tend to make energy conservation more difficult and probably explain why there was little improvement in the overall performance of the industry during 1974-77 despite increased conservation efforts.

Figure 8.2.1 Trends in Energy Consumption in the Chemical and Allied Industries



Looking at energy efficiency of use in a particular industry does not help very much then in trying to determine the effect of the energy crisis on demand for heat exchangers.

Another approach could be to look at capital investment by the process industries and see whether heat exchangers are increasing their share of the total.

Unfortunately the only source for data for heat exchanger sales in the U.K. comes from the Business Monitor series of the Central Statistical Office. This series only began in 1972 and therefore does not allow any analysis for a significant number of years before the energy situation dramatically changed in 1973. Also process plant heat exchangers are mixed in with figures for heat exchangers which are used in a variety of industrial non-process applications (the method for estimating process plant heat exchangers is shown in Appendix C).

The only other study attempting to estimate the U.K. market for heat exchangers was produced by the American market research publishers Frost & Sullivan Inc.[5] The report covered Europe as a whole but the U.K. market estimates were taken again from the Business Monitor series and in fact were incorrect.

Table 8.2.2 below shows heat exchanger expenditure compared with total capital expenditure in the process industries. The source and derivation of process plant capital expenditure are given in Appendix E.

TABLE 8.2.2 Trends in Heat Exchanger Usage in the Process Industries

A) Ratios of Indices 1972 = 100

Year	Process Heat Exchangers	Process Plant Investment	Ratio of Process Heat Exchangers to Process Plant Investment
1972	100.0	100.0	1.000
1973	104.2	95.6	1.070
1974	94.5	102.2	.925
1975	138.9	117.2	1.185
1976	116.2	100.9	1.152
1977	103.1	100.4	1.027
1978	131.3	130.6	1.005

B) Percentage of Real Values

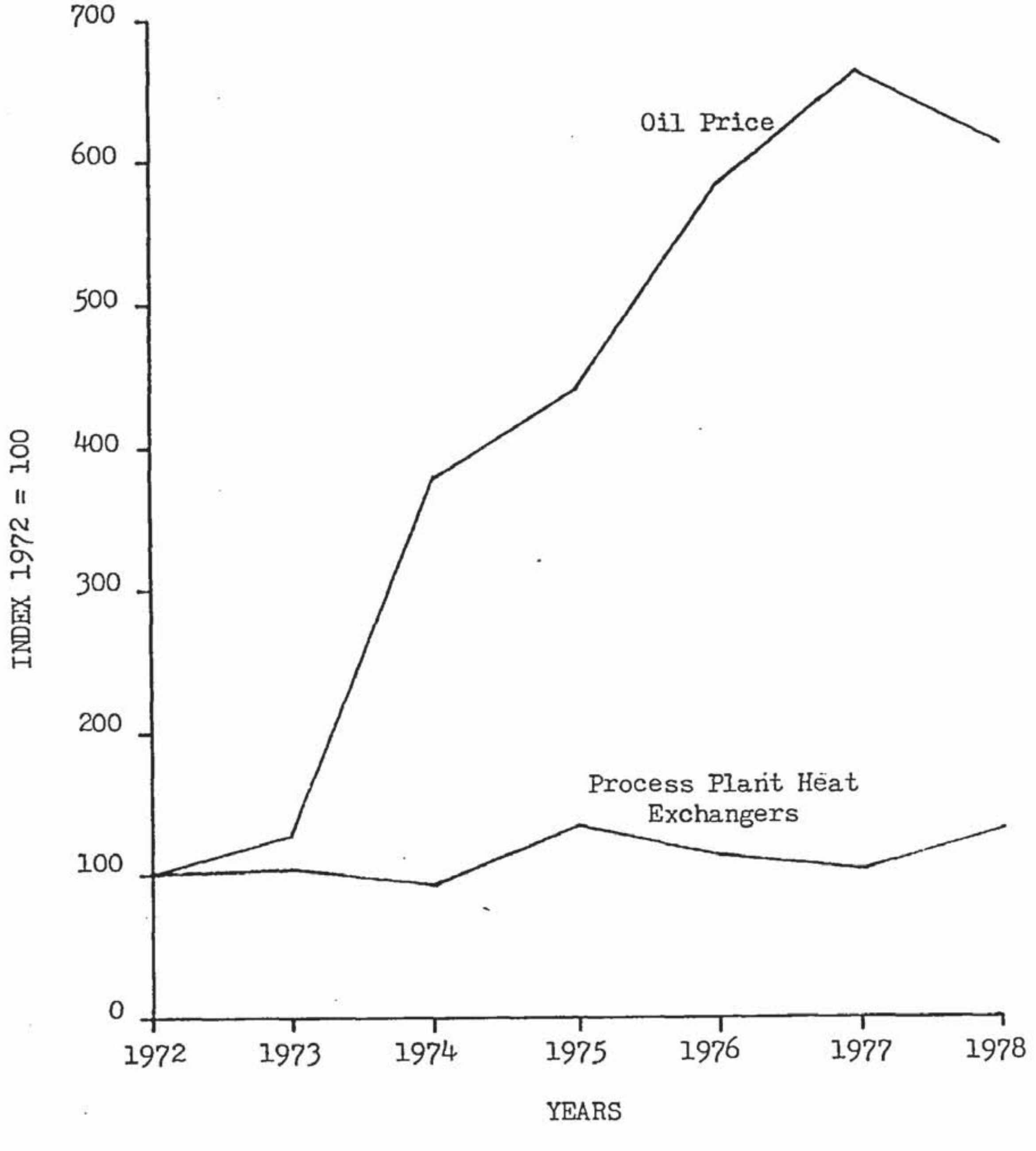
Year	£M	£M	Process Heat Exchangers as a Percentage of Process Plant Investment
1972	45.17	547	8.3
1973	47.06	518	9.1
1974	42.69	554	7.7
1975	62.73	635	9.9
1976	52.51	547	9.6
1977	46.58	544	8.6
1978	59.30	708	8.4

By way of a cross-check the Process Plant Working Party (PPWP) of the National Economic Development Office (NEDO) publishes figures for investment in the various process Industries. The reports it issues annually also contain breakdowns of expenditure on equipment on certain projects as well as a general breakdown of typical expenditure on a typical chemical plant. It gives 6.25 per cent as the typical proportion of the total cost of an average large project attributable to heat exchangers. The range for any one plant may be 0.5-12 per cent or more.[6]

Looking at Table 8.2.2 part B the percentage shown (heat exchangers as a proportion of total process plant expenditure) is higher for all years than the 6.25 per cent quoted by the PPWP but still well within the normal range of values. Whether or not the higher values reflect an increased usage of heat exchangers compared with pre-oil crisis times is impossible to say because of the lack of data. According to the figures the proportion of plant expenditure accounted for by heat exchangers actually fell in 1974 at a time when it may have been reasonable to expect the proportions to rise. The figures however rise to a peak in 1975 and 1976 then fall away again in 1977 and 1978.

To put into perspective the influence, if any, of the relative price of energy on demand for heat exchangers it is perhaps useful to look at what has happened to the price of oil since 1972 to date and sales of heat exchangers over the same period. This gives an opportunity to see the response by energy/heat exchanger using industries and find out whether or not a massive rise in the price they pay for energy has lead them to invest in more heat exchangers in order to recover and re-use more heat than was previously possible or economically acceptable. Figure 8.2.2 over shows an index of price paid for oil by industrial users and the index for heat exchangers.

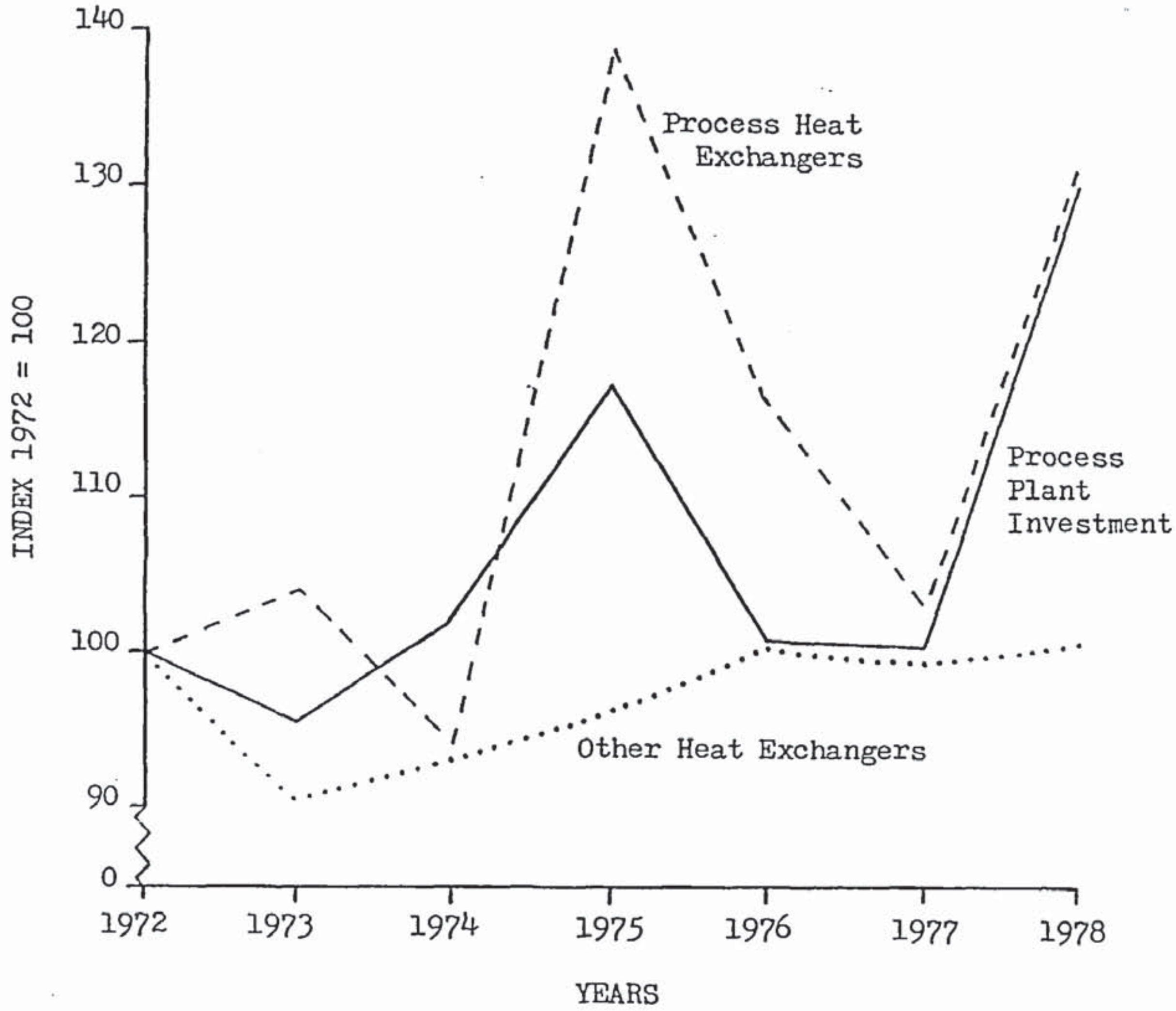
Figure 8.2.2 The Response of Heat Exchanger Sales to the Rise in Energy Price



Looking at the graph it can be seen that whilst the price for oil paid by industrial users rose sharply, process plant heat exchangers seem not to have responded in anything other than a fairly modest way and then only in 1975 after the very large price rise of 1974. After 1975 the sales figures slip back again.

Figure 8.2.3 below charts the index for sales of process heat exchangers and the index for process plant investment with the index for non-process heat exchangers shown for comparison.

Figure 8.2.3 The Relationship Between Process Plant Investment and Sales of Process Heat Exchangers 1972-78



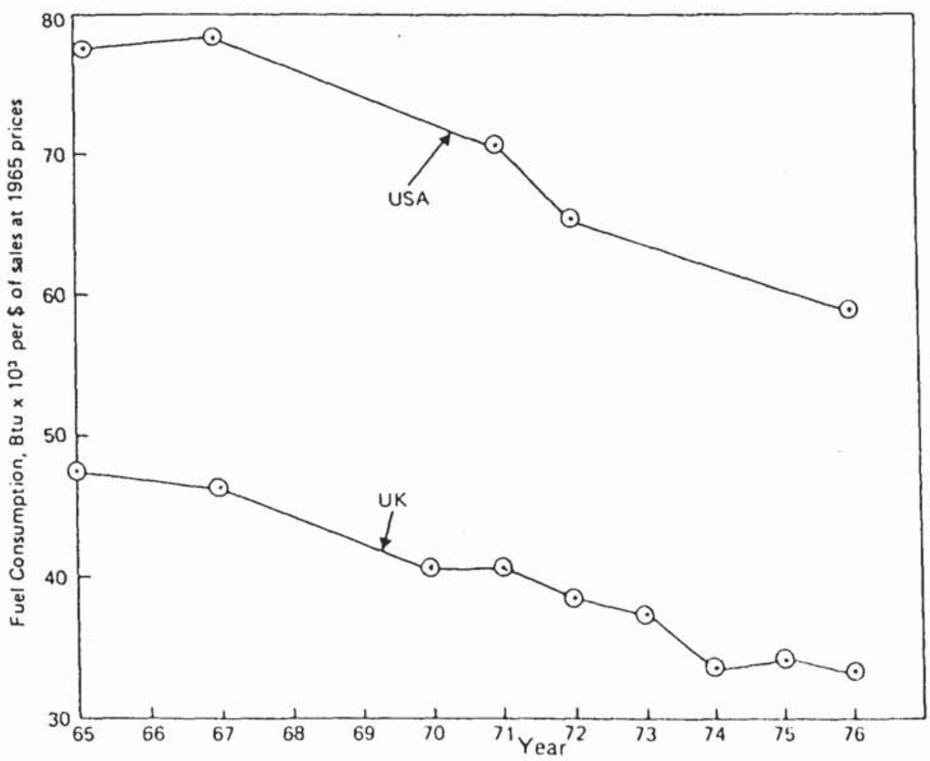
There appears to be a fairly strong linear relationship between estimated process heat exchanger sales and process plant investment. The correlation co-efficient is about 0.81. It seems therefore that the amount of process plant investment in any particular year is the major determinant of process heat exchanger sales and that the influence of energy prices has been somewhat muted. It can also be seen from figure 8.2.3 that the demand for non-process heat exchangers has been rather flat throughout the period and does not seem to have responded to rising energy prices.

There could be any number of reasons why demand for process heat exchangers seemingly failed to respond to higher energy prices. Energy cost is not the only criterion for process plant design. Maintenance costs and plant reliability are both a function of the number of items of plant. There is a desire to minimise the number of items of plant. The desire to recover heat therefore may be directly contradictory to the desire to minimise maintenance costs and maximise reliability. The total feasible heat exchanger surface to recover the maximum amount of heat could well be reduced in order to satisfy maintenance and reliability criteria and therefore recover less than the maximum theoretical potential amount of heat.

Another reason why demand for heat exchangers failed to respond to the rise in energy prices may be because, compared with its international competitors, the U.K. process industry may well be more energy efficient already. Figure 8.2.4 overleaf is a comparison of the fuel consumption per unit value of sales for the U.K. and U.S.A. chemical industries.

Compared with the U.S.A. then, the U.K. is more energy efficient and therefore the potential for energy conservation that much less, so its ability to respond to rising energy prices is somewhat more constrained than, say, the Americans.

Figure 8.2.4 Fuel Consumption Per Unit Value of Sales for the U.K. and U.S.A. Chemical Industries[7]



8.3

The Future Energy Situation and Heat Exchangers

From Chapter 6.0 it can be seen that the U.K. is likely to be self-sufficient in energy for some years to come although it is possible that during the 1990's the importation of oil will become necessary again. Within the timescale of this study it would seem that there will be oil available so that major applications for heat exchangers such as heat engines will not disappear because there is not the oil to power them to be replaced by electric motors which have little or no requirement for heat exchangers. Nor will the U.K. be without a petrochemical industry, a major user of process heat exchangers. If it becomes necessary to restrict the use of oil, action is most likely to be taken in those areas that are not major users of heat exchangers. For instance the burning of oil for space heating could be stopped.

There will be pressure however for better and more efficient use of energy by market forces and Government legislation. As heat exchangers are totally dependent on the use of energy for their existence then the changes over the rest of this century which may occur in the energy field must influence the uses and numbers of heat exchangers sold.

From looking at the reaction of the heat exchanger market to the price rises of the seventies it can be seen that any changes which do occur in the heat exchanger market as a result of energy price rises will not be sudden and large in extent. The change is much more likely to be slow and steady.

8.4

Conclusions

It appears in the short run that rises in energy prices are most likely to stimulate demand for process heat exchangers rather than those used in non-process applications. This is because process heat exchangers are more often used for heat recovery and recycling than non-process types. Non-process heat exchangers are generally components in devices such as heat engines and in the short run would not be expected to respond to energy price rises for two main reasons. Firstly, any change in the use of heat exchangers in non-process applications would only result from major design changes by engine and equipment manufacturers which they would be unable and/or unwilling to make in the short run for various technical and economic reasons. Secondly, non-process heat exchangers are not used in applications where recovery or recycling of heat is a major requirement although this may be incorporated into the design in certain special applications. Normally the prime requirement is to remove heat and reject it to the environment.

Although process heat exchangers would seem most likely to respond to the changing real price of energy, in reality there seems to have been little reaction. It may be possible that as a rising real price of energy has a depressing effect on the economy; any increased interest in the use of heat exchangers to recover heat is at least or even more than offset by an overall depressed level of economic activity which in turn depresses the demand for heat exchangers. It is impossible to discern the respective effects of these two opposing pressures on the demand for heat exchangers.

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CHAPTER 9.0 ANALYSIS OF THE IMPACT OF THE CHANGING ENERGY SITUATION ON INDUSTRIAL HEAT EXCHANGE DEMAND, BY SECTOR

9.0

ANALYSIS OF THE IMPACT OF THE CHANGING ENERGY SITUATION ON INDUSTRIAL HEAT EXCHANGER DEMAND, BY SECTOR

This study has concentrated on looking at individual sectors of the total heat exchanger market. This was done in order to see more closely developments in these sectors which occur as a result of the changing energy situation and have some impact on heat exchanger demand. The sectors were selected on the basis of size, the availability of data and other information, and the likely developments caused by the changing energy situation.

Each sector is written up in four sub-sections. The first, entitled methodology, covers the general approach used to investigate the sector. In the second, the implications of the changing energy situation for the sector are examined with supporting references where appropriate. The third section takes the form of a step by step guide to obtaining the forecasts. The fourth and final section contains a discussion of the results for that particular sector.

For a definition of the scope of, a description of the applications for heat exchangers on, and the method for calculating the 1978 market value for, each sector see the appropriate section of Appendix A.

9.1

Road Transport

9.1.1

Methodology

The first stage in this section was to identify the possible developments affecting heat exchanger usage brought about by the changing energy situation. This was done mainly through literature survey.

The developments were identified as alternative power units that could be used instead of petrol or diesel engines and the increased usage of turbocharging and charge air cooling.

An early step in any forecasting exercise is to examine the past and current situation if data exists. As with the other sectors in this study 1978 was taken as the base year for the forecasts. As outlined in Chapter 3.0 Serck's definition of the market is different to that used here and so the market for 1978 was estimated from scratch. The estimates are shown in Appendix A.

From contacts within industry it was found that a forecast of usage of different engine types in vehicles existed. There were also a number of papers and reports with which the above forecast could be compared. These were used to estimate the power unit based influences on heat exchangers.

As far as it was known no long term forecast for turbocharging and charge air cooling in engines existed but articles and papers on the subject were available. Serck did have some information and short term forecasts. Authors of articles and papers on the subject were contacted and asked to estimate the prospects for turbocharging and charge air cooling up to the year 2000. The responses along with the information contained in the literature were used as the basis for investigating this area of the project.

9.1.2

Energy, Road Transport and Heat Exchangers

In 1978 road transport used around 1100 PJ of energy.[1] This is 78 per cent of consumption in transport, 40 per cent of total petroleum and 18 per cent of all U.K. energy consumption.

As a large user of energy, road transport has become the focus of efforts to reduce consumption. From 1974 to 1979 the average fuel consumption of cars sold in Britain improved by around 10 per cent and in 1979 the motor industry announced its intention to improve it by a further 10 per cent by 1985.[2]

The demand for heat exchangers could be influenced by efforts to reduce fuel consumption. One possibility is a reduction in vehicle sales and therefore the number of heat exchangers required. This represents a decline in living standards whereas most people have rising, not falling, expectations of future well-being. Governments would be under pressure to avoid this.

There may be a trend towards smaller engined cars producing less heat and therefore needing smaller and cheaper radiators. In this study it has been assumed that in the long term, more fuel efficient cars allow manufacturers to partly, at least, offset fuel price rises and therefore the current mix of engine sizes will not change significantly. Over 70 per cent of cars made and sold in the U.K. are under 1.6 litres so are not exactly gas guzzlers when compared with, say, American cars. Another factor is that 60 per cent of U.K. registered cars are company owned and can be selected for reasons other than fuel economy.

Energy paper number 18 states that current developments will probably lead to the turbocharging of all medium and heavy duty engines in the future.[3]

A report published in 1979 by the Society of Motor Manufacturers and Traders says that from the power increase achieved by turbocharging the size and weight of petrol engines could be reduced with consequent improvements in fuel consumption.[4] There are two implications for heat exchangers. Turbocharging leads the way for charge air cooling whereby air compressed by the turbocharger is cooled in a heat exchanger to increase its density and further raise the output of a given capacity of engine. The other implication is in engines where prior to turbocharging no oil cooler was fitted. This refers mostly to petrol engines. Turbochargers produce large amounts of heat and the turbocharger lubricating system is normally connected to the engine's system and it becomes necessary to fit an oil cooler.

Another development which could affect heat exchangers is a change in the type of power units employed. Diesel engines could be used instead of petrol engines and either could be replaced by the stratified charge, Wankel, gas turbine and Stirling engines. Only diesels, gas turbines and Stirling engines would have a significant impact on heat exchangers. A discussion of the impact of the energy situation on diesel engines is contained in Appendix F.

The use of Rankine bottoming cycles on vehicles is currently in the experimental stage. The American company Thermo Electron, has developed a system in which heat from diesel engine exhaust gases is used to vapourise a liquid which turns a turbine which feeds mechanical power into the engine flywheel. A large radiator is then used to condense the vapour. The extra equipment required incurs a severe weight penalty but despite this, economy improvements are claimed. The equipment also results in space and cost penalties.

Electric vehicles are appealing because they can utilise fuels other than oil. The electric vehicle offers no fuel consumption advantages over internal combustion engines as power station generating efficiency is no higher than about 33 per cent. The energy density of batteries is typically 150 MJ per tonne compared with 47000 MJ per tonne for gasoline hence the vehicle range is limited by a heavy and expensive battery load.[5] Electric vehicles have no heat exchanger requirements.

Hybrid vehicles using an internal combustion engine and an electric motor have been developed but the cost may be as much as 20-50 per cent more than a conventional vehicle when in full production.

Interestingly, many of the developments associated with the changing energy situation are not new at all. Turbocharging dates back over sixty years, diesel engines have existed for a hundred years, Stirling engines have been around even longer and electric vehicles were used at the turn of the Century. The changing energy situation could have a significant impact on the roles played by these various technologies and therefore influence heat exchanger demand.

9.1.3

Results

These results are the outcome of, firstly, forecast production of vehicles; secondly, an assessment of changes in engine types for road transport; thirdly, the impact of increased turbocharging and charge air cooling; fourthly, the effect these have on heat exchanger demand up to the year 2000.

The production forecasts are derived from the Department of Transport's (DoT) National Road Traffic Forecasts (NRTF).[6] The 1978 figures on which the forecasts are based are from section A.1.3 of Appendix A on the 1978 market.

Car Production

Table 6 of NRTF gives low and high growth forecasts of cars per person. When multiplied by the population projections in NRTF table 7, figures for total car stock are derived, as shown in Table 9.1.01.

TABLE 9.1.01 Calculation of Forecast Total Car Stock

Year	Population	Low Growth		High Growth	
		Cars per Person	Total Car Stock	Cars per Person	Total Car Stock
1978	54,297	0.262	14226	0.262	14226
1985	54,601	0.310	16926	0.320	17472
1990	55,204	0.330	18217	0.360	19873
1995	55,745	0.350	19511	0.390	21741
2000	56,249	0.370	20812	0.420	23625

Note: The population forecast given in the table was interpolated from that given in table 7 of NRTF.

It was assumed that U.K. production as a percentage of total stock remains constant at the 1978 level of 5.12 per cent throughout the forecast period. This implies that U.K. manufacturers share of U.K. registrations and that vehicle life expectancies remain constant at the 1978 level.

From Table 9.1.01 and the overleaf assumptions, U.K. production for the home market is derived. The 1978 figure for U.K. consumption of U.K. produced cars is 728370. Table 9.1.02 shows the results.

TABLE 9.1.02 Proportion of Total Car Stock Represented by Contemporary U.K. Production

Year	Percentage of Total Stock from U.K. Producers	Low Growth		High Growth	
		Stock (000's)	U.K. Production	Stock (000's)	U.K. Production
1978	5.12	14226	728370	14226	728370
1985	5.12	16926	866611	17472	894566
1990	5.12	18217	932710	19873	1017498
1995	5.12	19511	998963	21741	1113139
2000	5.12	20812	1065574	23625	1209600

Goods Vehicles (not exceeding 30 cwt unladen weight)

Table 4 of NRTF gives forecasts of vehicle kilometres for light vans in index form, as shown in Table 9.1.03.

TABLE 9.1.03 Indices of Vehicle Kilometres for Light Vans (not exceeding 30 cwt uw)

Year	Indices	
	Low Growth	High Growth
1978	1.00	1.00
1985	1.10	1.15
1990	1.16	1.27
1995	1.22	1.51
2000	1.27	1.64

In making this forecast, the DoT assumed that the age composition of the stock of vehicles and the average distance travelled by light goods vehicles both remain constant. The latter means that forecast increases in vehicle kilometres are due to extra vehicles and not longer journeys. The number of vehicles sold in 1978 was 144400. The application of the NRTF indices to this figure gives forecast numbers of vehicles as shown in Table 9.1.04.

TABLE 9.1.04 Forecast Production of Light Vans for the U.K. Market by U.K. Producers

Year	Number of Vehicles	
	Low Growth	High Growth
1978	144400	144400
1985	158840	166060
1990	167504	183388
1995	176168	200716
2000	183388	218044

Commercial Vehicles (exceeding 30 cwt unladen weight)

Table 3 of the NRTF contains forecasts of vehicle kilometres which are reproduced in Table 9.1.05.

TABLE 9.1.05 Indices of Vehicle Kilometres for Goods Vehicles (exceeding 30 cwt uw)

Year	Indices	
	Low Growth	High Growth
1978	1.00	1.00
1985	0.98	1.04
1990	0.97	1.06
1995	0.96	1.07
2000	0.96	1.08

These are translated into numbers of vehicles in Table 9.1.06. The number of vehicles of U.K. manufacture sold in 1978 was 58890.

TABLE 9.1.06 Forecast Production of Goods Vehicles Over 30 cwt Unladen Weight

Year	Number of Vehicles	
	Low Growth	High Growth
1978	58890	58890
1985	57800	61339
1990	57211	62519
1995	56621	63109
2000	56621	63698

The average distance travelled by vehicles in this class is not assumed to be constant by the DoT. If smaller vehicles are replaced by fewer, larger ones, then the larger vehicles would, per vehicle, require a larger value of heat exchangers and this is assumed to compensate for the fact that there may be fewer vehicles.

The DoT assumed that the number of coaches and buses would remain constant. The 1978 figure of 12170 buses and coaches is added to the figures in Table 9.1.06 to produce Table 9.1.07, forecasts of vehicles over 30 cwt unladen weight.

TABLE 9.1.07 Forecast Production of All Commercial Vehicles Over 30 cwt Unladen Weight

Year	Number of Vehicles	
	Low Growth	High Growth
1978	71150	71150
1985	69970	73509
1990	69381	74689
1995	68791	75279
2000	68791	75868

Engine Types

This forecast was produced by a major motor component manufacturer using the Delphi approach.[7] The base year is 1976 with forecasts for 1985 and 2000. From this values for 1990 and 1995 were interpolated.

The results are presented in Table 9.1.08. It contains percentage penetration of each type of power unit in each application. The figures are mid-points of a range of forecasts to simplify the process.

TABLE 9.1.08 Forecasts of Percentage Penetration of Different Engine Types

Engine Type	1985			1990			1995			2000		
	Cars	Vans	Trucks	Cars	Vans	Trucks	Cars	Vans	Trucks	Cars	Vans	Trucks
Petrol	98.0	78.0	6.5	96.5	63.5	5.5	94.5	44.0	4.0	91.5	20.0	2.0
Diesel	2.0	20.0	93.5	3.0	33.5	94.0	4.5	51.5	95.5	6.5	73.5	97.0
Electric	-	2.0	-	0.5	3.0	-	1.0	4.5	-	2.0	6.5	-
Gas Turbine	-	-	-	-	-	-	-	-	0.5	-	-	1.0

Note: Vans are commercial vehicles of less than 30 cwt uw.
Trucks are commercial vehicles of greater than 30 cwt uw.

These percentages are applied to the vehicle production forecasts to give breakdowns of future engine types. The results are shown in Tables 9.1.09, 9.1.10, 9.1.11.

TABLE 9.1.09 Forecasts of U.K. Car Production Broken Down by Engine Type

Engine Type	1978 Actual	1985				1990				1995				2000			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Petrol	728370	713809	849279	862977	876675	702877	900065	940975	981886	688310	944020	997968	1051917	666459	975001	1040892	1106784
Diesel	0	14567	17332	17612	17891	21851	27981	29253	30525	32777	44953	47522	50091	47344	69262	73943	78624
Electric	0	0	0	0	0	3642	4664	4876	5087	7284	9990	10561	11131	14567	21311	22752	24192
TOTAL	728370	728370	866611	880589	894566	728370	932710	975104	1017498	728370	998963	1056051	1113139	728370	1065574	1137587	1209600

TABLE 9.1.10 Forecasts of Light Van (Commercial Vehicles of Less Than 30 cwt uw) Broken Down by Engine Type

Engine Type	1978 Actual	1985				1990				1995				2000			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Petrol	134292	112632	123895	126711	129527	91694	106365	111408	116451	63536	77514	82914	88315	28880	36678	40143	43609
Diesel	10108	28880	31768	32490	33212	48374	56114	58774	61435	74366	90727	97048	103369	106134	134790	147526	160262
Electric	0	2888	3177	3249	3321	4332	5025	5263	5502	6498	7928	8480	9032	9386	11920	13047	14173
TOTAL	144400	144400	158840	162450	166060	144400	167504	175446	183388	144400	176168	188442	200716	144400	183388	200716	218044

TABLE 9.1.11 Forecast of Commercial Vehicles of Greater Than 30 cwt Broken Down by Engine Type

Engine Type	1978 Actual	1985				1990				1995				2000			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Petrol	5692	4625	4548	4663	4778	3913	4510	4682	4855	2846	2752	2881	3011	1423	1376	1447	1517
Diesel	65458	66525	65422	67077	68731	67237	64871	67353	69834	67948	65695	68794	71892	69016	66727	70160	73592
Gas Turbine	0	0	0	0	0	0	0	0	0	356	344	360	376	712	688	723	759
TOTAL	71150	71150	69970	71740	73509	71150	69381	72035	74689	71150	68791	72035	75279	71150	68791	72330	75868

The next stage concerns forecasts of turbo charging and charge air cooling.

Table 9.1.12 gives the forecasts of turbocharging in percentages and Table 9.1.13 gives the percentage of turbochargers fitted with a charge air cooler for petrol and diesel engines. The turbocharging and charge air cooling forecasts were derived from the opinions and expectations of some experts on the subject.

TABLE 9.1.12 Forecast of Percentage Penetration of Turbochargers in Vehicles with Petrol or Diesel Engines

Engine Type	1985		1990		1995		2000	
	Cars & Vans	Trucks	Cars & Vans	Trucks	Cars & Vans	Trucks	Cars & Vans	Trucks
Petrol	2	0	10	0	15	0	15	0
Diesel	10	60	33	75	45	80	45	83

TABLE 9.1.13 Forecast of Percentage Penetration of Charge Air Coolers in Vehicles Fitted with Turbocharged Engines

Engine Type	1985		1990		1995		2000	
	Cars & Vans	Trucks	Cars & Vans	Trucks	Cars & Vans	Trucks	Cars & Vans	Trucks
Petrol	40	0	45	0	47	0	50	0
Diesel	15	20	25	30	33	40	35	50

These forecasts, applied to the forecast production of vehicles, gives results which are presented in Table 9.1.14.

TABLE 9.1.14 The Numbers of Cars, Light Vans and Trucks and Buses Fitted with a Turbocharger and of Those the Number Fitted Also with a Charge Air Cooler, for Both Petrol and Diesel Engines

Vehicle	Turbo's or CAC	Engine	1978 Actual	1985				1990				1995				2000			
				1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Cars	Turbo	Petrol	0	14276	16986	17260	17534	70288	90007	94098	98189	103247	141603	149695	157788	103247	146250	156134	166018
		Diesel	0	3642	4333	4403	4473	7211	9234	9653	10073	14750	20229	21385	22541	14750	31168	33274	35219
	CAC	Petrol	0	5710	6794	6904	7014	31630	40503	42344	44185	48526	66553	70357	74160	51624	73125	78067	83009
		Diesel	0	546	650	660	671	1803	2309	2413	2518	4868	6676	7057	7439	5163	10909	11646	12327
Light Vans (comm. vehicles under 30 cwt uw)	Turbo	Petrol	0	2253	2478	2534	2591	9169	10637	11141	11645	9530	11627	12437	13247	4332	5502	6021	6541
		Diesel	0	7220	7942	8123	8303	15963	18518	19395	20274	33465	40827	43672	46516	47760	60656	66387	72118
	CAC	Petrol	0	901	991	1014	1036	4126	4787	5013	5240	4479	5465	5845	6226	2166	2751	3011	3271
		Diesel	0	1083	1191	1218	1245	3991	4630	4849	5069	11043	13473	14412	15350	16716	21230	23235	25241
Trucks & Buses (comm. vehicles over 30 cwt uw)	Turbo	Petrol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diesel	15055	39915	39253	40246	41239	50428	48653	50515	52376	54358	52556	55035	57514	57283	55383	58233	61081
	CAC	Petrol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Diesel	3463	7983	7851	8049	8248	15128	14596	15155	15713	21743	21022	22014	23006	28642	27692	29117	30541

Heat Exchanger Values

As all petrol and diesel engined vehicles are fitted with a radiator the numbers of such vehicles forecast in Tables 9.1.09, 9.1.10 and 9.1.11 multiplied by the appropriate radiator value from Table A.1.1 in Appendix A will give the forecast value of radiators.

For oil coolers it is less straightforward. Table 9.1.15 summarises oil cooler usage on petrol and diesel vehicles. The Table also notes which Tables to refer to in these results to estimate oil cooler values. As an example to find the forecast value of oil coolers on diesel engines in light vans in 1985 given low growth, the appropriate number from Table 9.1.10 is 31768 which multiplied by the appropriate oil cooler value in Table A.1.1 of Appendix A of £17 gives a forecast heat exchanger value of £540056.

Forecast charge air cooler values are estimated by referring to the appropriate figure in Table 9.1.14 and multiplying by the correct heat exchanger value. For example, the number of charge air coolers estimated to be fitted to petrol engined cars in 1995 given high growth is 74160 which when multiplied by the appropriate charge air cooler value which from Table A.1.1 Appendix A of £24 gives a forecast value of £1779840.

Tables 9.1.16, 9.1.17 and 9.1.18, following, give the estimated value of radiators, oil coolers and charge air coolers for the years 1978, 1985, 1990, 1995 and 2000 for petrol and diesel engines for cars, light vans and trucks and buses respectively.

TABLE 9.1.15 Usage of Oil Coolers on All Types of Vehicles with Petrol or Diesel Engines

Vehicle Type	Engine Type	Oil Cooler Usage	Table in Text Used for Calculation
Cars	Petrol	All Turbocharged Engines	Table 9.1.14 Vehicles Fitted with Turbocharger and Charge Air Cooler
	Diesel	50 Per Cent of Engines	Table 9.1.9 Forecast of U.K. Car Production
Commercial Vehicles $<$ 30 cwt Unladen Weight	Petrol	All Turbocharged Engines	Table 9.1.14 Vehicles Fitted with Turbocharger and Charge Air Cooler
	Diesel	50 Per Cent of Engines	Table 9.1.10 Forecasts of Light Van Production
Commercial Vehicles $>$ 30 cwt Unladen Weight	Petrol	None as these are declining in use rapidly and will not be turbocharged but will be replaced by diesels	Not Applicable
	Diesel	All Engines are Fitted with an Oil Cooler	Table 9.1.11 Forecasts of Commercial Vehicles of Greater than 30 cwt Unladen Weight

TABLE 9.1.16 Forecast Values for Heat Exchangers Used on Cars

Heat Exch. Type	Engine Type	1978 Actual	1985				1990				1995				2000			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Rad.	Petrol	16024140	15703666	18684138	18985494	19286850	15463294	19801430	20701450	21601492	15142820	20768440	21955296	23142174	14662098	21450022	22899624	24349248
	Diesel	0	320474	381304	387464	393602	480722	615582	643566	671550	721094	988966	1045484	1102002	1041568	1523764	1626746	1729728
	Total	16024140	16024140	19065442	19372958	19680452	15944016	20417012	21345016	22273042	15863914	21757406	23000780	24244176	15703666	22973786	24526370	2607897
O.C.	Petrol	0	242692	288762	293420	298078	1194896	1530119	1599666	1669213	1755199	2407251	2544815	2682396	1755199	2486250	2654278	282230
	Diesel	0	123820	147322	149702	151215	185734	237847	248659	259471	278605	382109	403937	425728	402424	588727	628524	66524
	Total	0	366512	436084	443122	449293	1380630	1767966	1848325	1928684	2033804	2789360	2948752	3108124	2157623	3074977	3282802	348755
CAC	Petrol	0	137040	163056	165696	168336	759120	972072	1016256	1060440	1164624	1597272	1688568	1779840	1238976	1755000	1873608	199221
	Diesel	0	13104	15600	15840	16104	43272	55416	57912	60432	116832	160224	169368	178536	123912	261816	279504	29584
	Total	0	150144	178656	181536	184440	802392	1027488	1074168	1120872	1281456	1757496	1857936	1958376	1362888	2016816	2153112	228806
ALL	TOTAL	16024140	16540796	19680182	19997616	20314185	18127038	23212466	24267509	25322598	19179174	26304262	27807468	29310676	19224177	28065579	29962284	3185459

TABLE 9.1.17 Forecast Values for Heat Exchangers for Light Vans (Commercial Vehicles of Less Than 30 cwt uw)

Heat Exch. Type	Engine Type	1978 Actual	1985				1990				1995				2000			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Rad.	Petrol	2954424	2477904	2725690	2787642	2849594	2017268	2340030	2450976	2561922	1397792	1705308	1824108	1942930	635360	806916	883146	959398
	Diesel	222376	635360	698896	714780	730664	1064228	1234508	1293028	1351570	1636052	1995994	2135056	2274118	2334948	2965380	3245572	3525764
	Total	3176800	3113264	3424586	3502422	3580258	3081496	3574538	3744004	3913492	3033844	3701302	3959164	4217048	2970308	3772296	4128718	4485162
O.C.	Petrol	0	38301	42126	43078	44047	155873	180829	189397	197965	162010	197659	211429	225199	73644	93534	102357	111197
	Diesel	85918	245480	270028	276165	282302	411179	476969	499579	522206	632111	771188	824908	878645	902139	1145715	1253971	1362227
	Total	85918	283781	312154	319243	326349	567052	657798	688976	720171	794121	968847	1036337	1103844	975783	1239249	1356328	1473424
CAC	Petrol	0	21624	23784	24336	24864	99024	114888	120312	125760	107496	131160	140286	149224	51984	66024	72264	78504
	Diesel	0	25992	28584	29232	29880	95784	111120	116376	121656	265032	323352	345888	368400	401184	509520	557640	605784
	Total	0	47616	52368	53568	54744	194808	226008	236688	247416	372528	454512	486174	517624	453168	575544	629904	684288
ALL	TOTAL	3262718	3444661	3789108	3875233	3961351	3843356	4458344	4669668	4881079	4200493	5124661	5481675	5838516	4399259	5587089	6114950	6642874

TABLE 9.1.18 Forecast Values of Heat Exchangers for Commercial Vehicles Over 30 cwt Unladen Weight

Heat Exch. Type	Engine Type	1978 Actual	1985				1990				1995				2000			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Rad.	Petrol	586276	476375	468444	480289	492134	403039	464530	482246	500065	293138	283456	296743	310133	146569	141728	149041	156251
	Diesel	6742174	6852075	6738466	6908931	7079293	6925411	6681713	6937359	7192902	6998644	6766585	7085782	7404876	7108648	6872881	7226480	7579976
	Total	7328450	7328450	7206910	7389220	7571427	7328450	7146243	7419605	7692967	7291782	7050041	7382525	7715009	7255217	7014609	7375521	7736227
O.C.	Petrol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Diesel	1832824	1862700	1831816	1878156	1924468	1882636	1816388	1885884	1955352	1902544	1839460	1926232	2012976	1932448	1868356	1964480	2060576
	Total	1832824	1862700	1831816	1878156	1924468	1882636	1816388	1885884	1955352	1902544	1839460	1926232	2012976	1932448	1868356	1964480	2060576
CAC	Petrol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Diesel	176613	407133	400401	410499	420648	771528	744396	772905	801363	1108893	1072122	1122714	1173306	1460742	1412292	1484967	1557591
	Total	176613	407133	400401	410499	420648	771528	744396	772905	801363	1108893	1072122	1122714	1173306	1460742	1412292	1484967	1557591
ALL	TOTAL	9337887	9598283	9439127	9677875	9916543	9982614	9707027	10078394	10449682	10303219	9961623	10431471	10901291	10648407	10295257	10824968	11354394

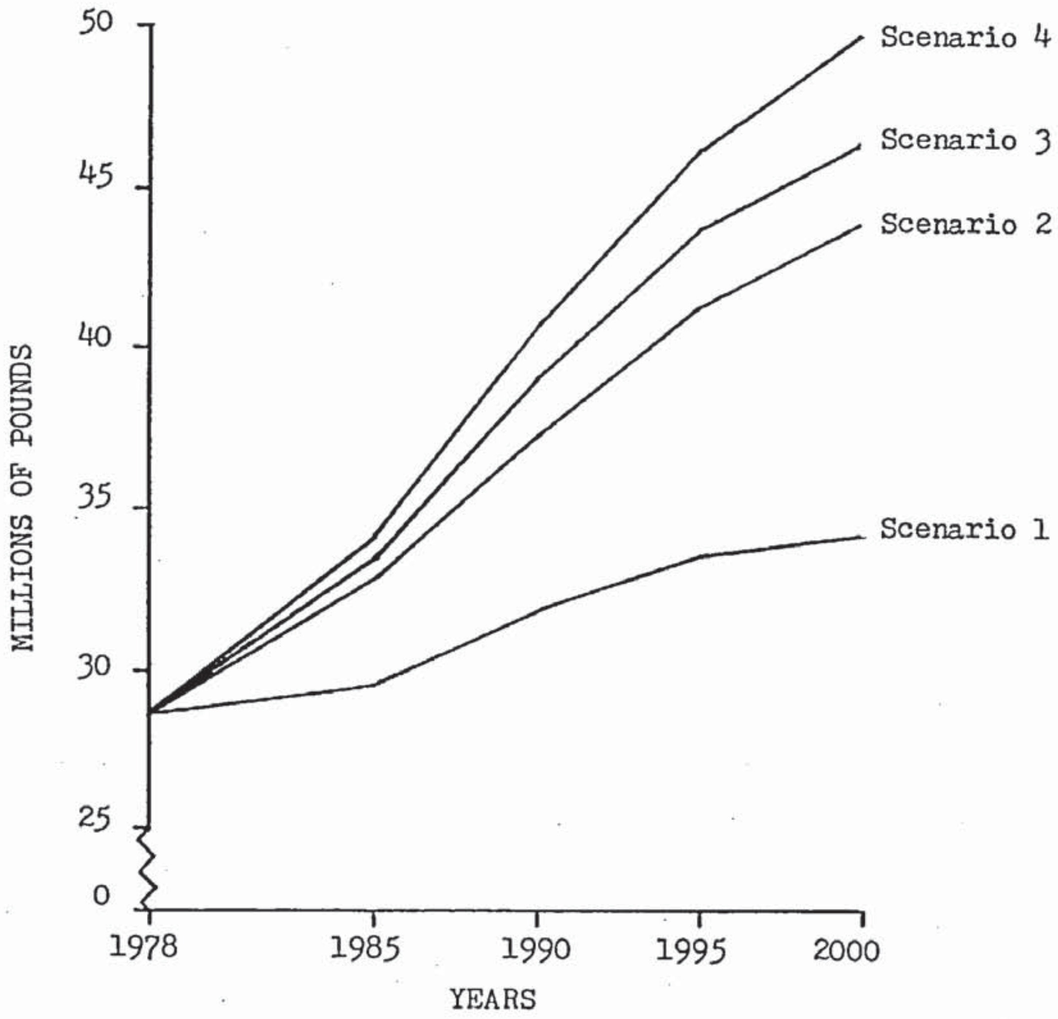
Table 9.1.19 below summarises the results of Tables 9.1.16, 9.1.17 and 9.1.18.

TABLE 9.1.19 Summary of Results for Road Transport (£ millions)

Scenario	Years				
	1978	1985	1990	1995	2000
1	28.62	29.58	31.95	33.68	34.27
2		32.91	37.38	41.39	43.95
3		33.55	39.02	43.72	46.40
4		34.19	40.65	46.05	49.85

These results are shown graphically in Figure 9.1.1.

Figure 9.1.1 Road Transport Sector Results



9.1.4

Discussion of Results

The first stage of the results was the forecasting of U.K. vehicle production for the home market. No account was taken of possible developments in the structure of the U.K. motor industry and markets. These are outside the scope of the study. However the results can, and should, be adjusted as and when major developments look like occurring.

In the results, the life expectancy of vehicles is assumed to remain constant. There are some signs that manufacturers are attempting to produce vehicles (especially cars) which last longer but this is likely to be a slow developing process over the period of the forecasts. It is not thought that the effect on the results would be dramatic.

One perhaps surprising result is the fact that the petrol engine remains the dominant power unit for cars. Some people have been of the opinion that alternatives such as the diesel engine or electric car would have important roles to play in the future. Diesel engined cars have been produced by Mercedes Benz since the 1930's but no diesel cars are made in the U.K. Diesel fuel in most continental countries is cheaper than petrol but in the U.K. until recently the reverse was the case. The diesel car market on the continent has grown considerably in recent years but the U.K. market has remained static.

A diesel in quantity production would cost around twice as much as the petrol engine equivalent, giving a break even mileage for diesels of 20,000 to 30,000 miles.[8] Energy paper number 18 says that the petrol engine is attractive for low mileage private cars and it is unlikely that this situation will change but diesels could penetrate into high mileage, medium-sized, passenger cars.[9] This substantiates the figures contained in the forecasts.

The growth of the market for diesel cars on the continent has been largely promoted by Governments providing fiscal incentives which the U.K. Government could also do. In the forecasts it has been assumed that this will not happen. A quote from Energy Paper number 33 makes the official position clear.

> 'We are not convinced that there is a case at present for actively encouraging the increased use of diesel engines in cars and light vans.'[10]

Energy Paper number 39 contains details of the exploratory scenario from the Energy Technology Support Unit's (ETSU) energy model. This takes a low surprise, orthodox view of the future where any changes which occur take place smoothly. In it the percentage of car miles accounted for by diesels is assumed to be 4 per cent in 1990 and 7 per cent in the year 2000. This supports the fairly limited role envisaged for diesel cars in the results.

The use of other power units in cars is likely to be small. The head of engine fuels development at Shell Petroleum has said that for the next twenty five years or even longer the car will be powered by engines and fuels which are already familiar.[11]

For the gas turbine to be used in cars there will have to be breakthroughs in the area of high temperature materials. Current materials have limited the efficiency of the gas turbine and are very expensive. The use of ceramics may solve both of these problems.

The Stirling engine is bulky and expensive and much work remains to be done before it is used in vehicles.

Electric cars require technical breakthroughs in battery technology before they make a substantial impact. The battery manufacturer Chloride has said that the electric car is unlikely to be a commercial proposition before the end of the century.[12] A House of Lords select committee concluded that the all electric car is not an economic proposition and may never become one.[13] The ETSU explanatory scenario assumes that there will be no electric cars before the year 2000.[14] In the results, electric cars account for 2 per cent of U.K. total car output. A level largely in line with the general consensus.

Although many commercial behicles of less than 30 cwt unladen weight cover high mileages in city driving, they currently mostly use petrol engines. The clear fuel consumption advantage of the diesel under these conditions will mean it will have a larger role to play in this sector in the future.

Electric vehicles are already in use in this sector, primarily as milk floats. A significant proportion of the operations of light commercial vehicles involves travel over relatively short distances in a day. If this is less than 50 to 60 miles a day, an electric vehicle may be suitable. The cost of the vehicle is a major problem, Lucas have given the cost of an electric van as £8,650 including batteries and recharging equipment, compared with £3,500 for a petrol engined equivalent.[15] In the results 6.5 per cent of total production of light vans are forecast to be electric. There is no strictly comparable figure in ETSU's exploratory scenario but the proportion of goods vehicle tonne miles which are accounted for by electric vehicles is 4 per cent in the year 2000. This figure confirms the limited role envisaged for electric vehicles in the results.

It is forecast in the results that only 2 per cent of vehicles of the over 30 cwt unladen weight category will be fitted with petrol engines by the year 2000. It is likely that as this is such a small figure, no petrol engined vehicles will be produced in this sector as the numbers involved are not great enough for it to be viable. It is possible for vehicles such as buses to be powered by gas turbines or Stirling engines. According to London Transport, diesel powered buses are likely to remain in use for the rest of the century.[16] Gas turbines have poor fuel consumption in part load conditions like city driving and are also likely to cost more than conventional engines.

In an article in the magazine 'The Engineer' it was estimated that diesel engines will power trucks right into the next century and gas turbine trucks will start to appear in Europe by the early part of the next century.[17] In the results 1 per cent of vehicles in this sector are forecast to be gas turbine powered. This may be an optimistic figure for the U.K. but it is so small as to make little difference to the overall results.

Fuel conservation is not the only reason for turbocharging engines. Volvo started turbocharging truck engines 30 years ago, when fuel was relatively cheap, to help bridge gaps in its product range. The volumes were too small to justify the design and tooling use costs of a new engine. As turbocharging produces more power from any given capacity of engine a small engine can emulate the performance of a larger engine. Turbocharging can also help reduce exhaust emissions.

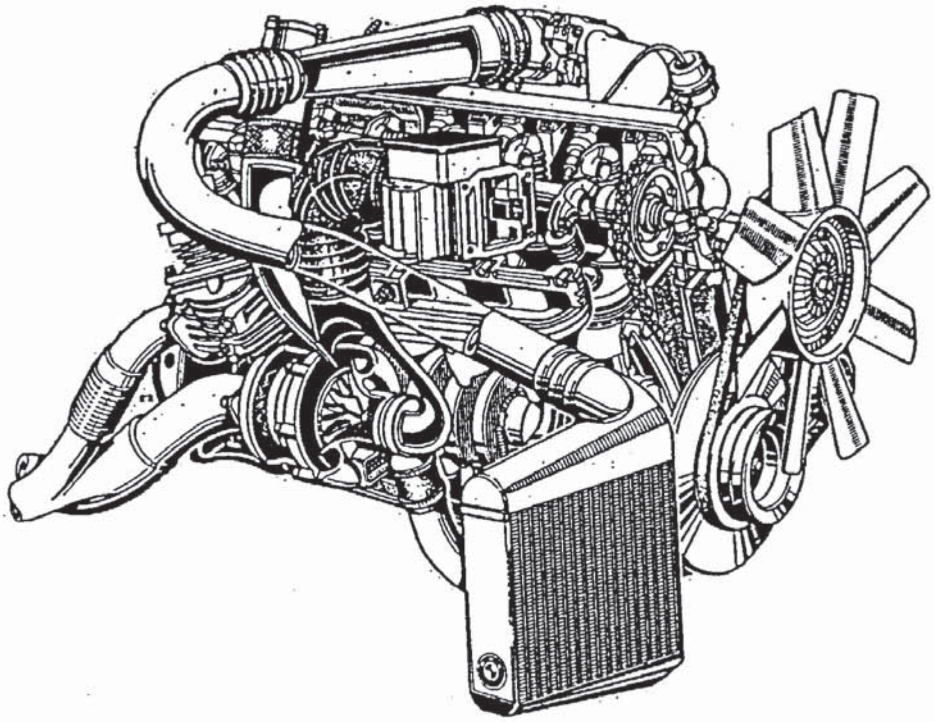
Since 1973/74 the main impetus for turbocharging has been fuel economy. In Energy Paper number 18 it was suggested that as fairly high levels of turbocharging improves fuel consumption, all medium and heavy duty engines would be turbocharged in the future.[18] Volvo expects all truck engines to be turbocharged by the end of the eighties.[19]

Only a few, high performance, cars were turbocharged when this study began and none had intercoolers. In 1981 Renault started producing the R18 turbo, a car which costs around £6,500 in the U.K. This car has a charge air cooler and the production target is 80 a day. At a low charge air cooler price of, say, £10 this business would be worth £200,000 per year. If U.K.

manufacturers follow suit then a reasonable market will emerge.

BMW, the German car manufacturer, has also introduced a turbocharged and intercooled engine into its range, a cutaway drawing of which is shown in Figure 9.1.2.

Figure 9.1.2 BMW 745i Turbo Engine[20]



Depending on the attitudes of U.K. vehicle manufacturers which seem to be behind those of their continental counterparts the market for both oil coolers and charge air coolers in all road vehicles looks set to develop strongly and it may be that the results section forecasts are conservative.

9.2

Rail Transport

9.2.1

Methodology

A literature survey was undertaken to identify the likely impact on heat exchanger usage of the changing energy situation. The energy impact on the rail industry which seemed likely to affect the use of heat exchangers was identified as the intention of British Rail to invest heavily in extending electrification of its current network.

An interim report on mainline electrification was issued in 1979 by the Department of Transport and the British Railways Board. It showed that British Rail was looking as far ahead as 2005 because of the long term nature of investment in switching from being a mainly diesel based railway to one with up to 50 per cent of its locomotives being electric.

Table 9.2.1 from the interim report, shows the number of locomotives, multiple units and coaches required over the period 1983-2005 under two options; option I for the least amount of electrification; option V for the greatest amount of electrification.

TABLE 9.2.1 Traction and Rolling Stock Requirements 1983-2005[21] (Number of Units)

	1983 - 2005	
	Option I	Option V
Diesel locomotives[1,2]	1044	407
Electric locomotives[2]	177	812
Total locomotives	1221	1219
Coaches[3]	2920	2872
DMU Vehicles	2804	1344
EMU Vehicles	4400	5521
Total Multiple Unit Vehicles	7204	6865

Notes: 1. Diesel locos include 2 HST power cars as equivalent to one locomotive.

2. Locomotives include passenger and freight locomotives. The total figures conceal considerable cascading from passenger to freight of diesel locomotives in Option V.

3. Coaches include both loco-hauled coaches and HST trailer cars.

This showed that B.R. was looking ahead over the same sort of timescale as this study and producing figures which could possibly be of use. B.R. was approached for the necessary information and they referred me to the then soon to be published final report on mainline electrification. Whilst this report did not give details of any build programme it did reveal that build programmes existed. The following short extract shows this.

> "The third component of the modelling process, the Fleet Assessment Model, matched the demand for traction and rolling stock, derived from the Traffic Models with the existing traction and rolling stock fleet available in each year, and determined the new building and refurbishing requirement".[22]

B.R. was again contacted and it was confirmed that forecast build programmes did exist. Initially B.R. refused to supply the information but assurances that it was required for academic purposes only and not for commercial gain yielded the desired result. Copies of projected build programmes for locomotives and multiple units for the various electrication options were produced. These forecasts are the result of a sophisticated modelling process used by B.R. to predict the financial and other impacts of electrification.

The data provided by B.R. was used to estimate the value of heat exchangers required for mainline locomotives and multiple units for the period 1981-2000. The results are shown in section 9.2.3.

9.2.2

Energy, British Rail and Heat Exchangers

In 1978, British Rail's energy bill was £102 million out of a total revenue of £1,658 million from its rail activities. This makes it one of the largest buyers of energy in the U.K. Over 75 per cent of this consumption was in the form of oil with the majority of the balance as electricity.

Although financial reasons are given as the main argument for increased electrification of Britain's railways, energy is mentioned as an important consideration. In the interim report it was said that it was not clear whether further electrification would save energy. The efficiency of end use of the two forms of energy are similar but diesel traction has the disadvantage of having to carry its own fuel and power plant which can incur a significant weight and therefore energy consumption penalty.

It is likely, however, that this fuel consumption advantage of electric traction over diesel traction is likely to be translated into an improved service rather than into a saving of primary energy. B.R. also say that this improved service could attract more traffic to rail and to the extent that this traffic is transferred from air or car travel, which at typical load factors are less energy efficient modes of transport, railway electrification could result in some primary energy savings in road and air transport.

These savings seem to be rather marginal. More important is the fact that railway electrification would help to reduce the U.K.'s dependence on oil. This will become more important as time passes and North Sea production declines and the U.K. once again has to become a net importer of oil. It says in the interim report that if the biggest electrification option was taken up then 120 million gallons a year of diesel oil consumption could be avoided. This is around 0.5 per cent of U.K. demand for oil products or 3.0 per cent of the demand for oil for transport purposes.

There are four main options for railway electrification which are shown in Table 9.2.2 below.

TABLE 9.2.2 The Electrification Options[23]

ELECTRIFIED MILEAGE IN EACH OPTION (excluding sidings)

	Route miles	% of present network	Single track miles	% of present network	% of passenger and freight loaded train mileage electrically hauled	
					P	F
Option I: Base	2,580	23	6,390	29	52	23
II: Modest	3,460	31	8,770	40	62	38
III: Medium	4,620	42	11,450	52	75	54
V: Large	5,750	52	13,610	62	83	68
Total British Rail network at 1.7.80	11,006		21,892			

The options are numbered I, II, III and V. There was an option IV discussed in the interim report on mainline electrification but in the final report it had largely been incorporated into option III.

Option I is called the base option. This option was established to look at the future size and shape of the railway business without substantial further electrification over present levels. The other options examine various levels of electrification as shown in Table 9.2.2.

The method of traction used has a major impact on the number and value of heat exchangers. Diesel engines use larger numbers of, and consequently a greater value of heat exchangers than the equivalent electric unit.

Any further electrification above current levels will mean less new diesel traction units and more electric units being built. Also as electric units are more reliable and need less maintenance than their diesel counterparts and therefore are available for more of time, a diesel unit can be replaced by less than one electric unit.

The greater the extent of electrification the less heat exchangers will be required in railway traction. There is the possibility of two indirect effects on the demand for heat exchangers brought about by increased electrification. Firstly, there will be a greater demand for electricity; in the case of option V it is estimated that electricity consumption could increase over time by nearly 1.8 terawatt hours, equivalent to an increase in current U.K. electricity demand of about 0.75 per cent. This could be translated into a capacity increase in the generating industry and therefore an increase in the heat exchangers required in power generation. This is likely to be small. Secondly, B.R. claim that electrification will attract people from other modes of transport which would reduce the demand for these other forms of transport and therefore could reduce the number of heat exchangers required by these other modes. This is also thought to be small. In assessing the effects of further electrification on the demand for heat exchangers the two indirect effects mentioned above are ignored.

Heat exchangers are not only used on mainline traction but also on diesel powered shunters. These shunters will remain diesel powered and consequently are not affected by the changing energy situation and they are therefore excluded from this study.

9.2.3

Results

To obtain the results for this section a simple computation was necessary.

The forecasts from British Rail were used in conjunction with heat exchanger prices quoted to B.R. by Serck as well as estimates for others which have not yet been built. These are shown in Table 9.2.3.

TABLE 9.2.3 Heat Exchanger Prices for Locomotives

Loco. Type	APT	HST	Elec. Cl. 87	Elec. Cl. 88	Dsl. Cl. 50	Dsl. Cl. 58	EMU	DMU
Heat Exch. Cost	4500	24984	4500	4500	18496	22264	Nil	13600

These locomotives are types which are either currently produced, at the design stage or already defined as technically feasible. They may be regarded as generic types.

The DMU heat exchanger cost is actually an average of two types likely to be built in roughly similar numbers; the Class 210 and some form of lightweight DMU such as a two car railbus.

B.R. have, in their investigation of the various electrification options, used several scenarios which represent different assumptions about the rates of growth for the passenger and freight businesses. The main ones are; low passenger, low freight; central passenger, low freight and central passenger, central freight. B.R. say the most likely to occur is central passenger and low freight growth. The choice of scenario for this analysis makes little or no difference to the conclusions only to the absolute level of demand for heat exchangers. Analysis is therefore concentrated on the full range of options for the central, low scenario.

There are four main electrification options in the B.R. forecasts. Option I represents the least amount of electrification, subsequent options represent a higher level of electrification with option V being the largest. Options III and V are analysed with two rates of implementation; slow and fast.

Table 9.2.4 shows the forecast numbers of each type of locomotive to be built in the years 1985, 1990, 1995 and 2000 under each option for the central, low scenario.

TABLE 9.2.4 The Number of Locomotives to be Built Under Each Electrification Option in the Central, Low Scenario for Selected Years[24]

Year	Option	Locomotive Type							
		APT	HST	Electric Cl. 87	Electric Cl. 88	Diesel Cl. 50	Diesel Cl. 58	EMU	DMU
1985	I	20	0	0	0	0	53	100	100
	II	20	0	0	0	0	23	100	100
	III S	20	0	0	0	0	23	100	100
	III F	20	0	0	0	0	28	105	100
	V S	20	0	0	0	0	33	100	100
	V F	20	0	0	0	0	21	105	100
1990	I	0	48	0	0	0	73	100	250
	II	2	0	0	13	0	33	100	240
	III S	0	0	0	17	0	24	105	210
	III F	13	0	0	32	0	0	120	190
	V S	0	0	0	17	0	21	105	210
	V F	13	0	0	39	0	0	115	175
1995	I	0	0	0	19	0	86	100	0
	II	0	0	0	27	0	100	120	0
	III S	0	0	0	38	0	98	140	0
	III F	27	0	20	36	0	100	180	0
	V S	0	0	0	44	0	100	145	0
	V F	6	0	10	19	0	100	135	0
2000	I	0	0	0	45	100	2	250	0
	II	0	0	56	16	100	12	250	0
	III S	19	0	73	18	85	28	248	0
	III F	0	0	46	36	15	100	250	0
	V S	1	0	75	23	65	46	235	0
	V F	0	0	78	55	0	79	250	0

When the numbers of locomotives in Table 9.2.4 are multiplied by the heat exchanger values from Table 9.2.3, forecast values of heat exchangers are obtained. These are summarised for the various options in Table 9.2.5.

TABLE 9.2.5 Forecast Values of Heat Exchangers Resulting from the Various Electrification Options (£ Millions)

Option	Year			
	1985	1990	1995	2000
I	2.63	6.22	2.00	2.10
II	1.96	4.07	2.35	2.44
III S	1.96	3.47	2.35	2.69
III F	2.07	2.79	2.60	2.87
V S	2.18	3.40	2.42	2.67
V F	1.92	2.61	2.38	2.36

It can be seen from the Table that for option I, the smallest electrification option, the value for heat exchangers is greater than in option V, the largest electrification option, for the years 1985 and 1990. For 1995 and 2000 the situation is reversed. This is an unexpected result because more electrification means less diesel engines so overall less heat exchangers.

Looking at individual years distorts the picture somewhat, the conclusion being that for some years at least more electrification means more heat exchangers. This is because of the way B.R. has organised its build programme.

In the discussion following these results the effect of electrification on demand for heat exchangers is shown with the distorting effect of B.R.'s planned build programme eliminated.

The results for this section appear in a different format to that used elsewhere in this study. This is because the information from B.R. was made available in great detail. In order that the results of this section may be aggregated with the results of other sections the figures have been revamped into the same four scenarios used elsewhere in this study. Scenario 1 represents the same level of locomotive building throughout the forecast period as occurred in 1978 but with the proportion of electric/diesel locomotives being derived from B.R.'s electrification option I. Scenarios 2, 3 and 4 represent different levels of electrification these being the results of B.R.'s central, low scenario electrification options I, III F and V F respectively taken from Table 9.2.4.

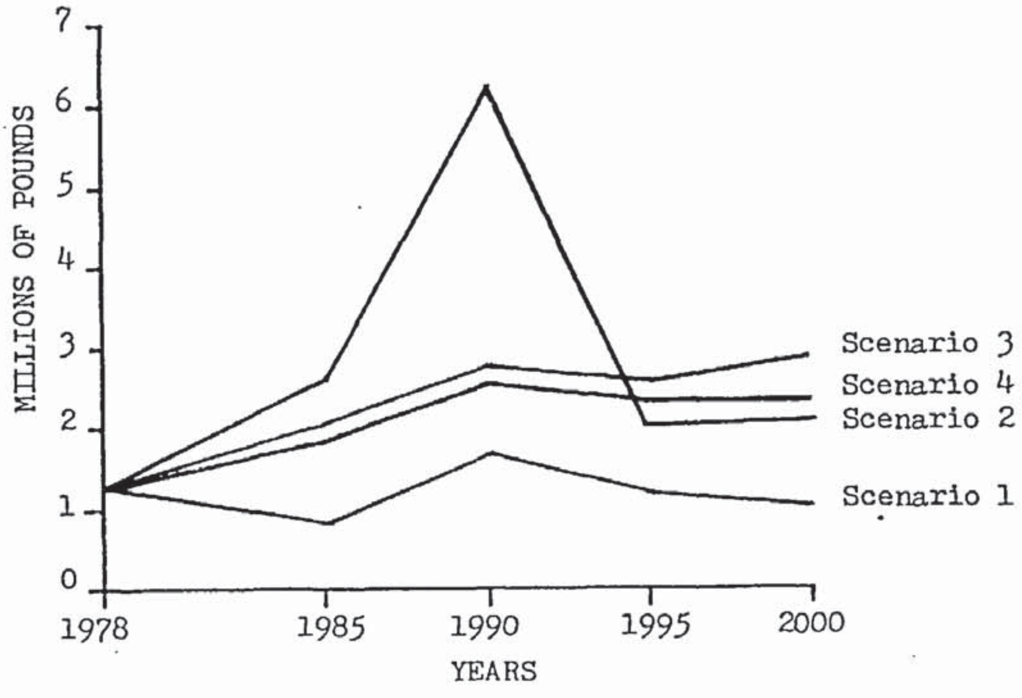
TABLE 9.2.6 Forecast Values of Heat Exchangers

Scenario	Year				
	1978	1985	1990	1995	2000
1	1.28	0.82	1.70	1.20	1.06
2		2.63	6.22	2.00	2.10
3		2.07	2.79	2.60	2.87
4		1.92	2.61	2.38	2.36

The derivation of the 1978 value of £1.28 million is shown in Table A.2.3 of Appendix A.

Figure 9.2.1 shows the information from Table 9.2.5 graphically.

Figure 9.2.1 Rail Transport Sector Results



9.2.4

Discussion of Results

The results in Table 9.2.5 all show increases in heat exchanger demand over the 1978 value irrespective of which electrification option is adopted. This result seems to indicate more electrification means more heat exchangers. The reason heat exchanger demand is higher under all options is because the number of locomotives to be built is far greater than the 1978 level. At the same time as B.R. will be extending the electrification of its rail network the opportunity will be taken to invest heavily in new locomotives and rolling stock. This investment is necessary, regardless of any electrification plans, to replace old equipment. In 1978 the newest diesel multiple units running were already fifteen years old. This situation leads to a distorted picture of the effect of electrification on heat exchanger demand. Also by picking out certain years (i.e. 1985, 1990, 1995 and 2000) for analysis, leads to further distortion because each year can represent a peak or trough in locomotive building.

These distortions can be eliminated by examining the proportions of electric and diesel vehicles to be built under each electrification option and applying these to the 1978 level of production (i.e. 55 locomotives of various types and 42 multiple units). The electric/diesel proportions were derived by summing all of the locomotives and multiple units to be built under each option up to the year 2000. This eliminates the distortion caused by year to year variations in level of production. The resulting heat exchanger values are shown in Table 9.2.7.

TABLE 9.2.7 The Impact of Various Levels of Electrification on Heat Exchanger Demand with Total Locomotive and Multiple Unit Production Held Constant at the 1978 Level (£ Millions)

1978 Actual	Electrification Option					
	I	II	III S	III F	V S	V F
1.28	1.29	0.95	0.85	0.75	0.83	0.69

It can be seen that the larger the electrification programme the smaller heat exchanger demand becomes. Option I actually works out at a slightly larger figure than the 1978 figure. This is because in 1978 no diesel multiple units were built although some electric multiple units were. This year represented quite a low point in B.R. investment in equipment and the fact that no diesel multiples units were built was as a result of low investment rather than because they were not required. Even under the largest electrification option diesel multiple units and indeed all types of diesel locomotives will be built.

Whichever electrification plan B.R. follows, the resulting heat exchanger demand will be greater than the 1978 level. The larger the electrification plan, the smaller will be the difference between the 1978 market and future levels of demand.

9.3

Miscellaneous Machinery

9.3.1

Methodology

A literature survey supplemented by talking to certain knowledgeable people revealed the areas which would most likely be affected by the changing energy situation.

Before any forecasting could be undertaken it was necessary to estimate the 1978 market for heat exchangers. This is shown in section A.3.3 of Appendix A.

The main development related to the changing energy situation is the possibility of increased usage of turbochargers and charge air cooling on industrial engines. No actual long term forecasts for turbocharging and charge air cooling in engines existed to my knowledge but articles and papers on the subject were available. Serck did possess some short term forecasts on turbocharging and charge air cooling. Some of the authors of articles on the subject were contacted and asked to estimate the prospects for turbocharging and charge air cooling up to the year 2000. The responses along with the information contained in the literature were used as the basis for investigating this area of the project.

9.3.2

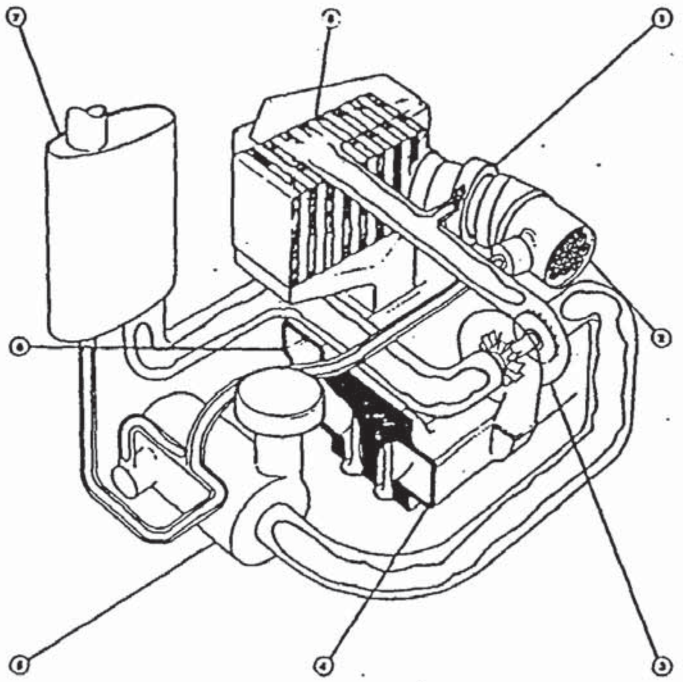
Energy, Miscellaneous Machinery and Heat Exchangers

Most of the heat exchangers used in this sector are fitted to diesel engines. These engines are used in a variety of applications from driving compressors to powering road rollers. The effect of the changing energy situation on engines has already been discussed in detail in the road transport results section and although discussed in the context of road transport the general conclusions are similar. The reader is referred to the road transport section for a more detailed discussion of rival engines such as stirling engines and gas turbines and developments in turbocharging on diesel engines.

Diesel engines are unrivalled by other power units for fuel burning efficiency and this is one reason why they dominate industrial applications for engines. Fork lift trucks is an exception where around 50 per cent are electric, 30 per cent are petrol or LPG engines and 20 per cent are diesel. There are special reasons why the diesel engine does not dominate as in other industrial, construction and agricultural applications. It has little to do with energy consumption and is unlikely to change for energy reasons alone. There is a trend towards the increased use of LPG as a fuel because of its cheapness but this has no effect on the use of heat exchangers.

As the diesel engine generally dominates in most applications already, there will be little prospect of changes in the type of power unit used up to the end of the century. A full discussion of the impact of the changing energy situation on diesel engines is contained in Appendix F. The main impact in this area will be the increased use of turbocharging and charge air cooling. Some engines are already turbocharged and a few charge air cooled as well. In tractors many are equipped with turbocharged engines but none had charge air cooling in 1978. In 1979 Ford introduced a four-wheel drive tractor fitted with a charge air cooler of compact fin plate design. The general arrangement of the turbocharger and charge air cooler is shown in Figure 9.3.1 overleaf.

Figure 9.3.1 Turbocharger and Charge Air Cooler Arrangement for Ford TW30 Tractor[25]



Arrangement of the air/air cooling system: 1. Tip-turbine fan; 2. Cooling air filter; 3. Garrett turbocharger; 4. Exhaust manifold; 5. Air intake silencer; 6. Charge air manifold; 7. Exhaust silencer; 7. Air cooler matrix

It is apparent that the number of turbocharged and charge air cooled engines produced will increase in the future.

On other equipment included in this section such as pumps, heat treatment equipment etc. there does not seem to be any major changes in the equipment brought about by the changing energy situation which would affect the number of, or way in which heat exchangers are currently used. Heat exchangers are generally used to help remove unwanted heat. In the past this unwanted heat has usually been dissipated into the outside air. It is possible in some cases that this waste heat could be utilised for space or process heating which could result in a greater demand for heat exchangers. This aspect is outside the scope of this part of the study which is examining the effect of the changing energy situation on the design or usage of machines or mechanical devices which may affect heat exchanger usage. Waste heat recovery is covered in section 9.6.

9.3.3

Results

The results of this section are split up into industrial and construction equipment diesel engines, industrial and construction equipment petrol engines and agricultural engines and miscellaneous machinery.

Table 9.3.1 below shows forecast rates of engine turbocharging and charge air cooling for selected years up to the year 2000.

TABLE 9.3.1 Turbocharging and Charge Air Cooling as a Percentage of Total Engines

Description	Year			
	1985	1990	1995	2000
Turbocharging	30.0	50.0	70.0	83.0
Charge Air Cooling	10.0	22.5	32.0	41.5

The results are presented in four different scenarios. Scenario 1 examines the effect of increased turbocharging on the 1978 market size which is held constant throughout the forecast period.

For industrial and construction equipment diesel engines it is only the use of charge air cooling which results in extra heat exchangers being demanded. Table 9.3.2 shows the results of applying the forecast percentage of charge air cooled engines from Table 9.3.1 to the number of U.K. produced engines for the U.K. market taken from Table A.3.3 in section A.3 of Appendix A on the 1978 market for industrial, construction equipment and agricultural engines and miscellaneous machinery.

The results for scenario 1 are broken down into engine size categories as the size of the engine influences the size of the charge air cooler and hence its value. The results show both the number of charge air cooled engines and the value of charge air coolers. The value of charge air coolers is derived by multiplying the forecast number of charge air cooled

TABLE 9.3.2 Forecast Values of Charge Air Coolers in Industrial and Construction Equipment Diesel Engines for Scenario 1

Year	Designation	Engine Size Categories (kW)											Actual and Forecast Charge Air Cooler Penetration (%)
		16-30	31-50	51-75	76-100	101-150	151-200	201-300	301-500	501-750	751-1000	Total	
	Number of Engines	1880	5888	6819	2061	1473	1031	1236	368	401	5	21162	
1978	Number of engines with charge air cooling							40	232	253	3	528	2.5
	Value of charge air coolers (CAC)							4040	67744	167486	2781	242051	
1985	Number of engines with CAC						608	927	276	301	4	2116	10.0
	Value of CAC's						43168	93627	80592	199262	3708	420357	
1990	Number of engines with CAC				1375	1105	773	927	276	301	4	4761	22.5
	Value of CAC's				48125	55250	54883	93627	80592	199262	3708	535447	
1995	Number of engines with CAC			1840	1546	1105	773	927	276	301	4	6772	32.0
	Value of CAC's			46000	54110	55250	54883	93627	80592	199262	3708	587432	
2000	Number of engines with CAC			3850	1546	1105	773	927	276	301	4	8782	41.5
	Value of CAC's			46250	54110	55250	54883	93627	80592	199262	3708	637682	

engines by the appropriate heat exchanger value for that particular engine size category taken from Table A.3.4 of section A.3 of Appendix A.

In the past larger engines have tended to be turbocharged and charge air cooled before smaller engines although some smaller engines are turbocharged and charge air cooled before some larger engines. There is no exact pattern in the way this happens. The way in which it happens in the future will have an impact on the results. This is because a large charge air cooled engine uses a higher value charge air cooler than a smaller engine. If it is assumed that all larger engines are turbocharged and charge air cooled before smaller engines then the forecast value of heat exchangers may be over estimated. To go part way to reducing this problem it is assumed in these results that a maximum of 75 per cent of the engines in any particular size category will be turbocharged and charge air cooled before any engines in the next lowest size category. This assumption is based on Serck's own information on what has happened in turbocharging and charge air cooling diesel engines in the past. Whilst the results show a maximum of 75 per cent of the engines in any particular size category being turbocharged and charge air cooled in reality it could be 100 per cent.

It is assumed in the results that the proportion of total engines in each size category remains stable over the forecast period.

Scenarios 2, 3 and 4 of these results represent growth rates of numbers of engines of 1, 1.5 and 2 per cent per annum over the forecast period. It is assumed in the results that import penetration remains constant over the forecast period.

The results for scenarios 2, 3 and 4 are derived from scenario 1 pro rata. For example, at a 1 per cent growth rate the 21162 engines in 1978 becomes 22689 engines in 1985, therefore the value of heat exchangers is approximately 1.072 times the value for scenario 1 in 1985.

The results for all scenarios for industrial and construction equipment diesel engines are shown in Table 9.3.3. The table shows the values for radiators and oil coolers as well as for charge air coolers even though only the usage of charge air coolers is affected by the changing energy situation.

TABLE 9.3.3 Forecast Values of Heat Exchangers for Industrial and Construction Equipment Diesel Engines

Description	1978 Actual	1985				1990				1995				2000			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Engines (Number)	21162	21162	22689	23487	24308	21162	23846	25302	26839	21162	25062	27257	29632	21162	26341	29364	32716
Radiators (Value)	2072962	2072962	2222215	2300988	2381833	2072962	2336228	2479263	2628516	2072962	2454387	2669975	2902147	2072962	2580838	2877271	3204799
Oil Coolers (Value)	674345	674345	722898	748523	774822	674345	759987	806517	855069	674345	798424	868556	944083	674345	839560	935991	1042537
CAC's (Value)	242051	420357	450623	466596	482990	535447	603449	640395	678947	587432	695519	756612	822405	637682	793914	885103	985856
TOTAL (Value)	2989358	3167664	3395736	3516107	3639645	3282754	3699664	3926175	4162532	3334739	3948336	4295143	4668635	3384989	4214312	4698365	5233192

The procedure for obtaining the results for industrial and construction equipment petrol engines was different from that used for diesel engines. The power ratings for petrol engines are not known except that they are mostly under 150 kW. Heat exchanger prices are approximate averages for this type and category of engine. Radiators are valued at £50 each, oil coolers £28 and charge air coolers £37.

Petrol or LPG powered engines are not normally fitted with oil coolers. If an engine is turbocharged an oil cooler becomes necessary to handle the extra heat from the turbocharger lubricating system. If an engine has a turbocharger then it may also be fitted with a charge air cooler.

Table 9.3.4 shows the number of engines for each scenario. Scenario 2 represents a growth rate of 1 per cent per annum, scenario 3, 1.5 per cent, and scenario 4, 2 per cent. The table also shows the number of engines fitted with turbochargers and also the number that, additionally, have a charge air cooler. The figures for turbochargers and charge air coolers were derived from Table 9.3.1.

The figures contained in Table 9.3.4 are turned into values in Table 9.3.5 using the aforementioned heat exchanger prices.

TABLE 9.3.4 Forecasts of Industrial and Construction Equipment Petrol Engines Plus the Proportion That will be Turbocharged and Those That will be Charge Air Cooled

Description	1978 Actual	1985				1990				1995				2000			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Engines	6860	6860	7355	7614	7880	6860	7730	8202	8700	6860	8124	8836	9606	6860	8539	9519	10605
Turbocharged	0	2058	2207	2284	2364	3430	3865	4101	4350	4802	5687	6185	6724	5694	7087	7901	8802
Charge Air Cooled	0	686	736	761	788	1546	1739	1845	1958	2195	2600	2828	3074	2847	3544	3950	4401

TABLE 9.3.5 Forecast Heat Exchanger Values for Industrial and Construction Equipment Petrol Engines

Description	1978 Actual	1985				1990				1995				2000			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Radiators	343000	343000	367750	380700	394000	343000	386500	410100	435000	343000	406200	441800	480300	343000	426950	475950	530250
Oil Coolers	0	57624	61796	63952	66192	96040	108220	114828	121800	134456	159236	173180	188272	159432	198436	221228	246456
Charge Air Coolers	0	25382	27232	28157	29156	57202	64343	68265	72446	81215	96200	104636	113738	105339	131128	146150	162837
TOTAL	343000	426006	456778	472809	489348	496242	559063	593193	629246	558671	661636	719616	782310	607771	756514	843328	939543

The forecasts for agricultural engines are derived in exactly the same way as for industrial and construction equipment diesel engines. Table 9.3.6 shows the forecast number of engines which will be charge air cooled along with the value of charge air coolers for scenario 1.

TABLE 9.3.6 Forecast Values of Charge Air Coolers in Agricultural Engines for Scenario 1

Year	Description	Engine Size Categories (kW)						Actual and Forecast Charge Air Cooler Penetration (%)
		16-30	31-50	51-75	76-150	151-200	Total	
	Number of Engines	220	12707	14992	932	4	28855	
1978	Number of engines with CAC						0	0
	Value of CAC's						0	
1985	Number of engines with CAC			2184	699	3	2886	10.0
	Value of CAC's			54600	31455	213	86268	
1990	Number of engines with CAC			5790	699	3	6492	22.5
	Value of CAC's			144750	31455	213	176418	
1995	Number of engines with CAC			8532	699	3	9234	32.0
	Value of CAC's			213300	31455	213	244968	
2000	Number of engines with CAC			11274	699	3	11976	41.5
	Value of CAC's			281850	31455	213	313518	

From these figures, forecasts for all scenarios can be obtained pro rata. The results are presented in Table 9.3.7.

TABLE 9.3.7 Forecast Values for Heat Exchangers in Agricultural Engines

Description	1978 Actual	1985				1990				1995				2000			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Engines (Number)	28855	28855	30936	32025	33145	28855	32515	34500	36595	28855	34173	37166	40404	28855	35916	40038	44609
Radiators (Value)	1425903	1425903	1528568	1582752	1638363	1425903	1606993	1705380	1808045	1425903	1688269	1836563	1996264	1425903	1775249	1979153	220446
Oil Coolers (Value)	492584	492584	528050	546768	565979	492584	555142	589130	624597	492584	583219	634448	689618	492584	613267	683707	761535
CAC's (Value)	0	86268	92479	95757	99122	176418	198823	210996	223698	244968	290042	315519	342955	313518	390330	435163	484699
TOTAL (Value)	1918487	2004755	2149097	2225277	2303464	2094905	2360958	2505506	2656340	2163455	2561530	2786530	3028837	2232005	2778846	3098023	3450680

The final category of application for heat exchangers in this section is miscellaneous machinery. There do not appear to be any energy induced changes in this category which will affect heat exchanger usage other than the desire to recover and re-use waste heat which is covered elsewhere in this study.

However, for completeness the growth rates of 1, 1.5 and 2 per cent per annum have been applied to the estimated 1978 value of heat exchangers. The results are shown in Table 9.3.8 with values for scenarios 2, 3 and 4. Scenario 1 will remain at the 1978 level.

TABLE 9.3.8 Forecast Values of Heat Exchangers for Miscellaneous Machinery

Description	1978 Actual	1985			1990			1995			2000		
		2	3	4	2	3	4	2	3	4	2	3	4
Miscellaneous Machinery	1448000	1552452	1607055	1663297	1631643	1731255	1836414	1714873	1865053	2027550	1802349	2009192	2238579

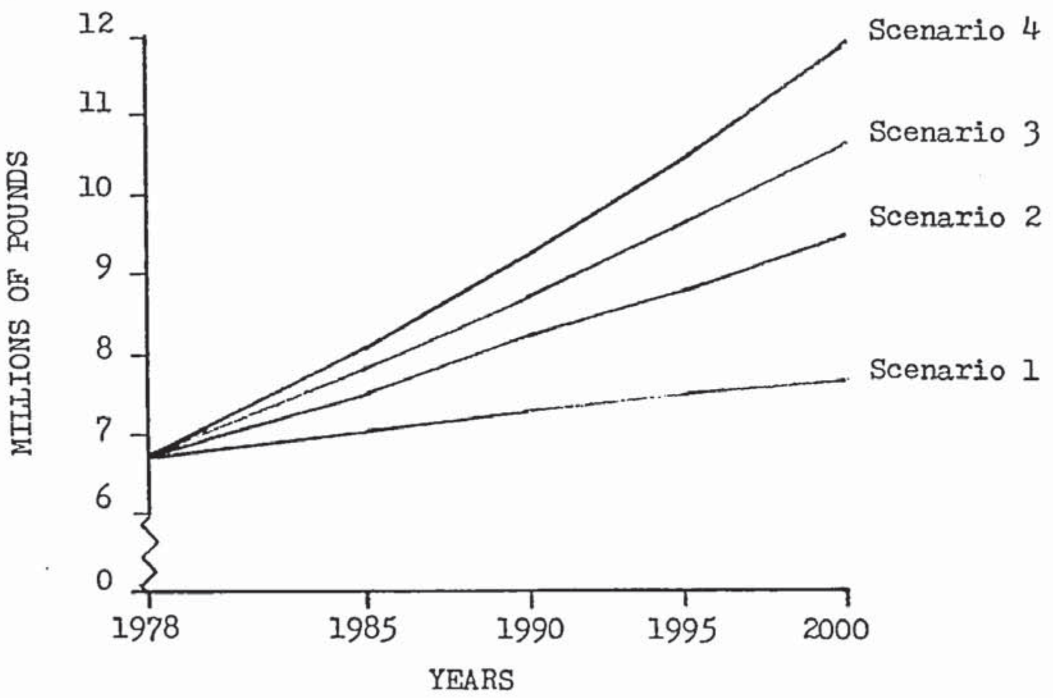
Table 9.3.9 below summarises the results of this section.

TABLE 9.3.9 Summary of the Results of the Industrial, Construction Equipment and Agricultural Engines and Miscellaneous Machinery Sector (£'s Millions)

Scenario	Year				
	1978	1985	1990	1995	2000
1	6.70	7.05	7.32	7.50	7.67
2		7.55	8.25	8.89	9.55
3		7.82	8.76	9.67	10.65
4		8.10	9.28	10.51	11.86

Figure 9.3.2 shows the results from Table 9.3.9 graphically.

Figure 9.3.2 Miscellaneous Machinery Sector Results



9.3.4

Discussion of Results

The results of this section are similar in many respects to those for road transport sector. In road transport, in addition to turbocharging and charge air cooling forecasts of changes in power plant were also considered. In road transport there is likely to be a switch to greater use of diesel engines. In industrial, construction and agricultural applications the diesel engine already dominates and there is unlikely to be a switch away from them. Some petrol or LPG engines are used for fork lift trucks and it was assumed for the results that this would not change.

In this country, LPG is a cheaper fuel than both petrol and diesel and while it stays that way it is unlikely that LPG engines will be replaced by diesel engines. In road transport LPG is not common as a fuel because the traditional petrol filling stations around the country are not geared up for it, so availability is limited. A vehicle has to be equipped for burning two fuels and this is prohibitively expensive in most cases. For industrial engines the supply of fuel problem does not cause difficulties as factories just buy and store one fuel as opposed to another.

If all the petrol and LPG engines were substituted by diesel engines there would be an impact on the value of heat exchangers demanded. Most diesel engines are fitted with an oil cooler whereas petrol/LPG engines are not unless turbocharged. In the longer term as most engines (diesel or petrol/LPG) are likely to be turbocharged most will have an oil cooler even if formerly they did not have one. So, the impact of switching from petrol/LPG engines to diesel engines on the results in the long term will be modest; one way or another most engines will have an oil cooler.

Some electric power units are used for both stationary and mobile applications. In stationary applications electric motors give reliable round the clock service although electricity is a more expensive form of energy than fossil fuels. The reason for using electric motors has more to do with reliability, cost and so on, than energy prices and so there is unlikely to be any change in their use over the forecast period.

Mobile electric power units rely on rechargeable batteries which have the same drawbacks that have been discussed in the road transport section. Electric fork lift trucks are used extensively but need recharging after each working shift. They cannot be used around the clock. Where double shift or round the clock working is required, it is usual to employ vehicles with internal combustion engines or to have spare electrics (whilst one is recharging the other would be working and vice versa). To have 'spare' vehicles would be expensive. Electrics are desirable where they are working for long periods inside a factory or warehouse and the fumes produced by internal combustion engine vehicles would be unacceptable. The reasons for using electric or internal combustion engine powered vehicles has little to do with energy and therefore their use is unlikely to be much influenced by energy considerations.

9.4

Public Sector Power Generation

9.4.1

Methodology

A literature search was conducted to identify the likely changes in this sector in response to the energy situation which would have some impact on heat exchangers.

The 1978 market for heat exchangers was estimated by relating heat exchangers to output capacity of power stations. This method and the results are detailed in section A.4 of Appendix A. Relating heat exchanger values to generating capacity meant that if forecasts of future generating capacity existed, then forecast heat exchanger values could be derived.

The literature search revealed a number of estimates of future generating capacity requirements. For the results of this section Government published forecasts were used. These figures emanate from the electricity supply industry and represent the official view. The 'official' view is used for the forecasts because it represents the views of those making the decisions about investment in power generating capacity and their decisions must be largely influenced by their own forecasts.

For comparison purposes, forecasts from a group examining low energy futures with a low nuclear power contribution are used. The work of Leach et al is used to show the effect on the results of pursuing a low nuclear power generation construction programme.

9.4.2

Energy, Public Sector Power Generation and Heat Exchangers

In the best modern power stations only 35 per cent of the energy content of the fuel is turned into electricity. The rest is given off mostly as heat and wasted. In an era of cheap, plentiful fuel this apparent wastefulness caused little concern. The events of 1973/74 drew attention to power generation and ways of reducing fuel, and more particularly oil, consumption.

On the continent, heat from power stations is used for heating homes, offices and factories but it is comparatively rare in this country. Combined heat and power, as it is known, is considered separately in section 9.5.

Around 16 per cent of the fuel input for power generation in the U.K. comes from oil. In areas such as transport or petrochemicals there are no simple direct substitutes for oil but in power generation this is not the case. Substitutes in power generation are the burning of more coal or the use of greater nuclear power. In the longer term electricity might be produced by harnessing wind, wave, tidal or solar power and using nuclear fast breeder and fusion reactors.

The possible contribution of wind, wave, tidal and solar power is unlikely to start before the next century. In energy paper 39 it says that the likely contribution of these sources of power to electricity supply even in a limited nuclear future would be less than 5 per cent of total electricity supply in the year 2000.[26] Leach on the other hand estimates the contribution at around 1 to 2 per cent in the year 2000.[27] Electricity produced from these so-called renewable sources needs few, if any, heat exchangers. If and when renewables contribute significantly to electricity supply, demand for heat exchangers will fall.

Nuclear power has been used in the U.K. for 20 years but in the wake of the oil crisis the Government and the electricity supply industry are poised to expand its role significantly. In 1978 nuclear power provided 7.6 per cent of the output capacity of the electricity supply industry.[28] The requirement for new electricity generation capacity up to the year 2000 could be 68 GW of which 35 GW could be nuclear power according to the Government's Green Paper.[29]

Nuclear plants are more complex than conventional power stations and require more heat exchangers. Any increase in the proportion of new generating capacity provided by nuclear power will increase the demand for heat exchangers.

Another possibility for generating electricity by nuclear power is the fast breeder reactor. If world energy consumption was satisfied by nuclear power, with current technology and assuming nuclear fuel reserves of 17.5 million tonnes of uranium ore then fuel reserves would last for 14 to 18 years depending on reactor type. If this fuel was consumed in fast breeders fuel supplies would be sufficient for 27000 years.[30]

There are major problems with the technology, particularly the pollution hazard from spent fuel and the safety questions surrounding all nuclear power technology. Leach et al have called the fast breeder reactor a 'costly and dangerous irrelevance'.[31]

In Energy paper 39 it is said that serious ordering of fast reactors would be unlikely before the mid 1990's at the earliest.[32] Nuclear power in general is an emotive issue but the prospect of fast breeders seems to be causing ever greater concern amongst critics of nuclear power. The uncertainties surrounding fast breeder technology are great and its possible introduction is a long way off and so it has been ignored in this study.

The final alternative for electricity production is through controlled nuclear fusion. Scientists have been working on this technology for over 20 years. The technical problems that remain to be overcome are formidable but if and when they are, fusion offers the possibility of an essentially unlimited supply of energy. In Energy paper 39 the technology is not thought to have any possibility of making a contribution to electricity supply on a commercial scale until well into the next century and therefore is outside the scope of this study.

The forecasting effort for this section centres on the future requirement for power generating capacity and the relative contribution of nuclear power.

9.4.3

Results

Government forecasts of the new generating plant capacity requirement up to the year 2000 were used to derive an average megawatts per year build programme (this approach is explained in section A.4 of Appendix A).

According to a Department of Energy (DoE) paper, 40-50 Gigawatts (GW) of new generating capacity would be required by the end of the century. Of this, about 33-36 GW could be nuclear with 7-14 GW being mainly coal fired.[33]

These figures in themselves do not give any indication of the actual year to year build programme. It was widely reported in the press that the Government intended to start a major nuclear power station building programme in 1982 which would result in an extra 15 GW of generating capacity in the following ten years.[34] From this the average annual rate of building can be deduced.

Table 8.4.1 gives the average or expected build rates for conventional and nuclear power plant for the years 1985, 1990, 1995 and 2000. There are four different scenarios. Scenario 1 is included to examine the changing proportions of power station construction which are accounted for by conventional and nuclear plant respectively. The total build does not reflect the DoE forecasts but is held constant at the 1978 level of 1425 megawatts (see Table A.4.1, Appendix A). This is to show the effect on heat exchangers of new power stations being predominantly nuclear instead of conventional. The proportions in scenario 1 are taken from scenario 3 which is the average of scenarios 2 and 4.

Scenario 2 is the low power station construction programme of 33 GW of nuclear and 7 GW of conventional plant. Scenario 4 is the high construction programme of 36 GW of nuclear and 14 GW of conventional plant.

TABLE 9.4.1 The Expected Build Rate for Power Generating Capacity in Megawatts per Year

Scenario	Plant Type	Year				
		1978	1985	1990	1995	2000
1	Conventional	1152	499	399	271	271
	Nuclear	273	926	1026	1154	1154
	Total	1425	1425	1425	1425	1425
2	Conventional	1152	610	390	390	390
	Nuclear	273	1500	1500	2250	2250
	Total	1425	2110	1890	2640	2640
3	Conventional	1152	805	585	585	585
	Nuclear	273	1500	1500	2438	2438
	Total	1425	2305	2085	3023	3023
4	Conventional	1152	1000	780	780	780
	Nuclear	273	1500	1500	2625	2625
	Total	1425	2500	2280	3405	3405

In 1978 construction of a total of around 16 GW of power generating capacity was underway. The last power station in this programme should be completed by 1986. The figures in Table 9.4.1 for 1978 are derived from the current programme of building.

The new, mainly nuclear, build programme starts in 1982. The figures for 1985 in Table 9.4.1 consists of the tail-end of the current programme plus new construction which will then be underway. For subsequent years in the Table, the figures consist only of the yet to be started construction programme.

In compiling the Table it was assumed that conventional power station construction would take place at a constant rate; i.e. in scenario 2, 7 GW in all is constructed in the period from 1982 onwards at the rate of 390 megawatts per year and in scenario 4 the rate is 780 megawatts per year. The rate of 390 MW per year implies perhaps two power stations of 2000 MW capacity or maybe three smaller ones being constructed at any one time. Under scenario 2, four or five conventional plants would be constructed up to the end of the century and under scenario 4, this would rise to between eight and ten.

It was assumed that the build rate for nuclear plants would be in line with Government announcements that 15 GW of capacity will be built in the decade from 1982 onwards. The balance of nuclear capacity that will be built before the end of the century is 21 GW for scenario 2 and 24 GW for scenario 4.

In each scenario the balance is spread equally over the remaining years up to 1999. The year 2000 is part of the next century so is not strictly speaking included in the Government forecasts but the average build rate is assumed to be the same as for 1999.

To find the value of the market for heat exchangers in each forecast year is simply a case of multiplying megawatts of conventional power station construction in Table 9.4.1 by £418 and nuclear by £571 (as shown in section A.4.3, Appendix A).

The results are shown in Table 9.4.2. below.

TABLE 9.4.2 Forecast Values of Heat Exchangers in Public Sector Power Generation (£s)

Scenario	Plant Type	Year				
		1978	1985	1990	1995	2000
1	Conventional	481536	208582	166782	113278	113278
	Nuclear	155883	528746	585846	658934	658934
	Total	637419	737328	752628	772212	772212
2	Conventional	481536	254980	163020	163020	163020
	Nuclear	155883	856500	856500	1284750	1284750
	Total	637419	1111480	1019520	1447770	1447770
3	Conventional	481536	336490	244530	244530	244530
	Nuclear	155883	856500	856500	1392098	1392098
	Total	637419	1192990	1101030	1636628	1636628
4	Conventional	481536	418000	326040	326040	326040
	Nuclear	155883	856500	856500	1498875	1498875
	Total	637419	1274500	1182540	1824915	1824915

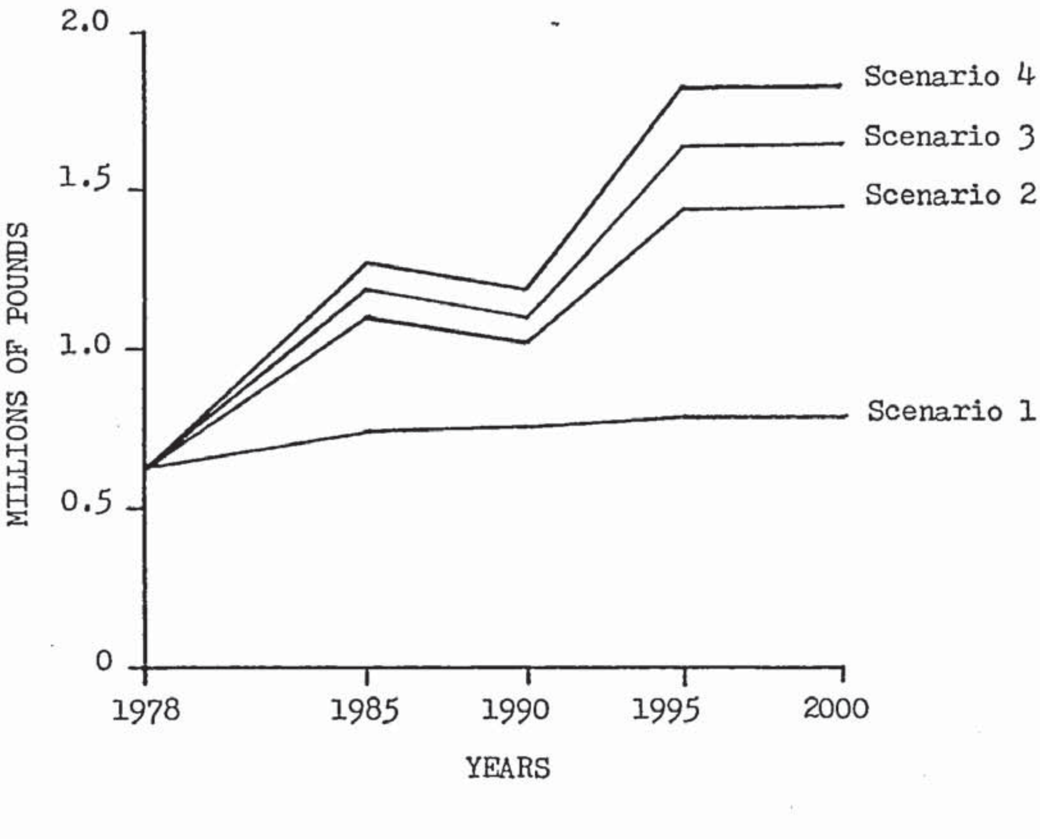
Table 9.4.3 below summarises the results from Table 9.4.2.

TABLE 9.4.3 Summary of Results (£ Millions)

Scenario	Year				
	1978	1985	1990	1995	2000
1 2 3 4	0.64	0.74 1.11 1.19 1.27	0.75 1.02 1.10 1.18	0.77 1.45 1.64 1.82	0.77 1.45 1.64 1.82

Figure 9.4.1 shows the results from Table 9.4.3 graphically.

Figure 9.4.1 Public Power Generation Sector Results



9.4.4

Discussion of Results

This discussion mainly revolves around the DoE forecasts of new power generating capacity from 'Energy Projections 1979' which were used in the results.

Predating the Energy Projections forecasts were those contained in the Government's 'Energy Policy' Green Paper in which the new generating capacity requirement was estimated to be 70 GW with nuclear contributing 35 GW.[35] The Green Paper evoked some considerable discussion especially on the emotive issue of nuclear power.

A radical alternative to the Government's approach was produced by a team headed by Gerald Leach. They differ with the Green Paper about the total requirement for new power generation capacity and the role to be played by nuclear power.

In 1979 after the publication of the work by Leach et al the DoE produced Energy Projections 1979 in which the Green Paper forecasts were revised downwards to a new capacity requirement of 40-50 GW. This level is nearer to the Leach team estimate of 26-30 GW than the Green Paper was but the two forecasts differ considerably in the proportion of total new capacity which will be nuclear.

For comparison with the DoE figures, Leach's figures can be treated in the same way by deriving an average megawatts per year build programme. This involves dividing the total capacity of plant to be built by the number of years it takes to build (e.g. if a 2000 MW station takes 10 years to build it is assumed to be built at the rate of 200 MW per year and that heat exchangers are required in the same way). It is assumed that new capacity takes an average of 10 years to construct.

Table 9.4.4 contains the forecast construction of power generating capacity in average megawatts per year for the years 1985, 1990, 1995, 2000 which have been derived from Leach.[36]

TABLE 9.4.4 The Expected Build Rate for Power Generating Capacity for Selected Years as Derived from Leach (Megawatts per Year)

Scenario	Plant Type	Year				
		1978	1985	1990	1995	2000
1	Conventional	1152	1097	1254	1268	1283
	Nuclear	273	328	171	157	143
	Total	1425	1425	1425	1425	1425
2	Conventional	1152	1310	1700	1950	2100
	Nuclear	273	350	200	200	200
	Total	1425	1660	1900	2150	2300
3	Conventional	1152	1310	1800	2050	2250
	Nuclear	273	400	250	250	250
	Total	1425	1710	2050	2300	2500
4	Conventional	1152	1310	1900	2150	2400
	Nuclear	273	450	300	300	300
	Total	1425	1760	2200	2450	2700

The results for scenarios 2 and 4 are compared with the results derived from the DoE forecasts in Figure 9.4.2 over.

One common feature of the two sets of forecasts is that future build rates, and therefore heat exchanger demand, will be greater than the 1978 level, it is just a question of by how much.

The difference between the two forecasts becomes really significant on the question of the relative contribution of nuclear power in the future. Figures 9.4.3 and 9.4.4 show how the DoE and Leach et al respectively see the mix of plant types between conventional and nuclear. The figures are based on scenario 3 of each forecast.

Figure 9.4.2 Comparison between the Implied Annual Average Build Rates of the Department of Energy and Leach Et Al Forecasts for Low and High Growth

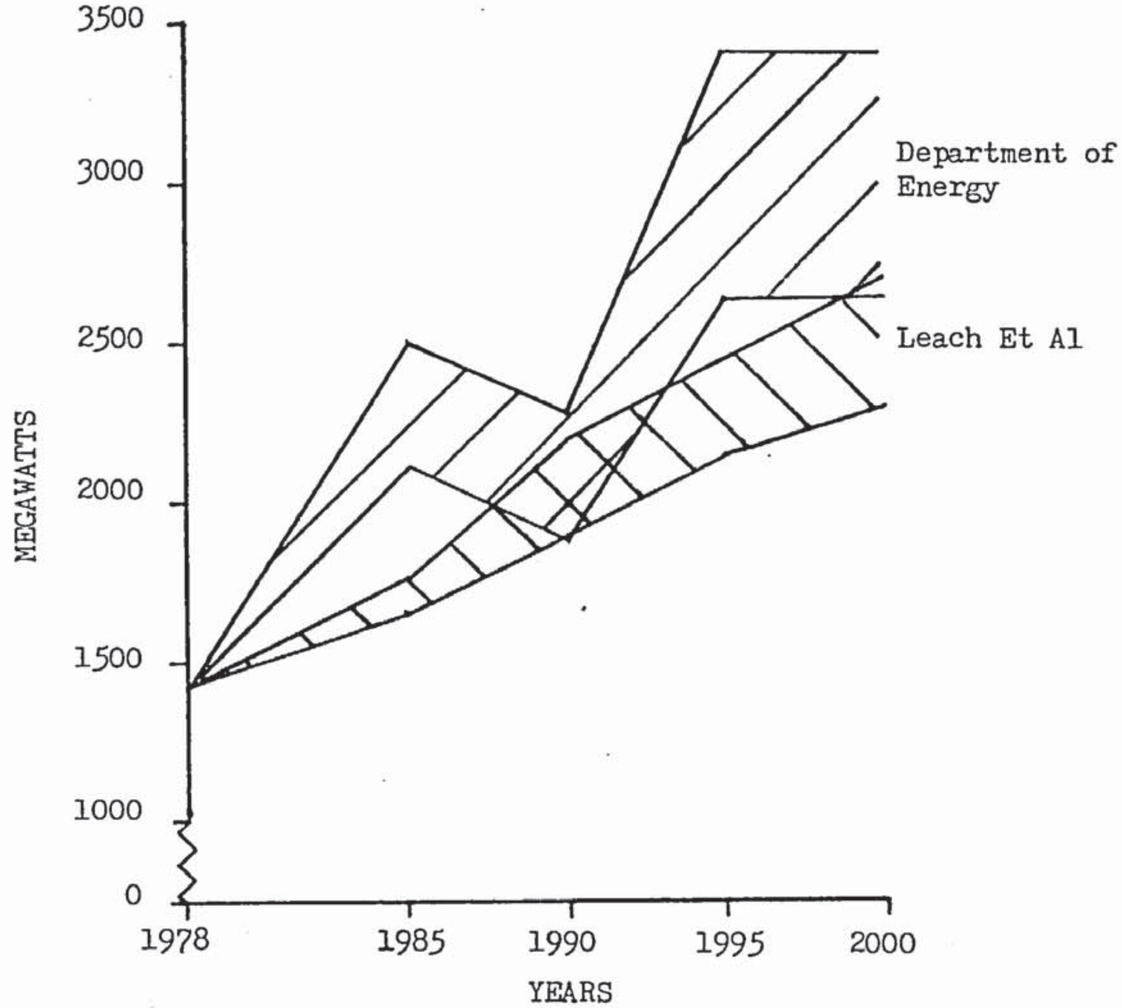
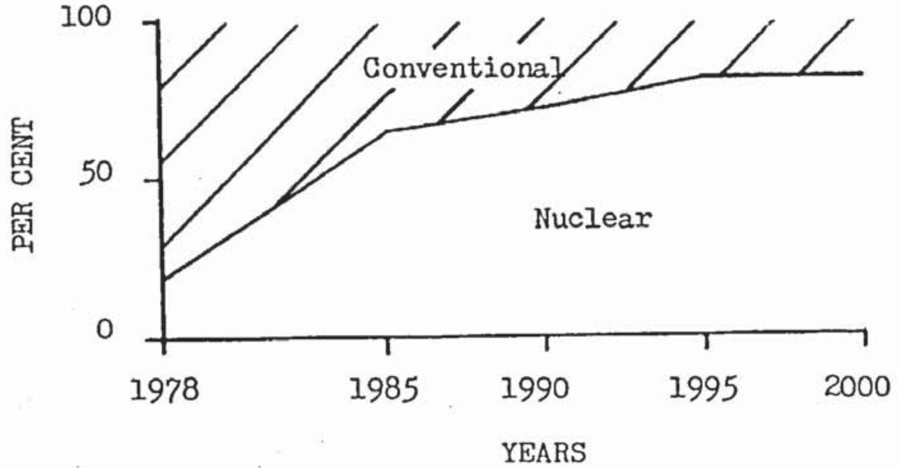
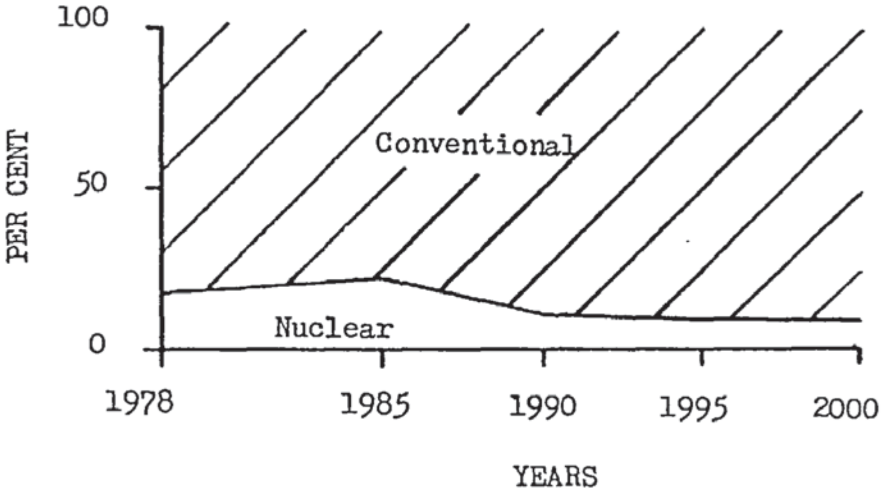


Figure 9.4.3 The Relative Contribution of Conventional and Nuclear Plant in the Construction of New Capacity Implied by Department of Energy Forecasts



The proportion of new capacity accounted for by nuclear power in the DoE forecasts rises from 20 per cent in 1978 to 80 per cent in the year 2000.

Figure 9.4.4 The Relative Contribution of Conventional and Nuclear Plant in the Construction of New Capacity Implied by the Leach Et Al Forecasts



In Leach's view of the future the only reason for building any nuclear capacity is to keep the nuclear power equipment industry ticking over as a form of insurance in case the requirement for new generating capacity is higher than expected. In this view of the future, new nuclear capacity contributes 23 per cent of the building in 1985 from the 1978 level of 19 per cent. This rise is due to the fact that the Government has already committed itself to the construction of several nuclear power stations. From 1985 onwards, nuclear power's contribution falls to around 10 per cent by the year 2000.

The Leach forecasts imply levels of demand for heat exchangers which are shown in Table 9.4.5 over.

TABLE 9.4.5 Forecast Values of Heat Exchangers in Public Sector Power Generation Derived from Leach Et Al (£ Millions)

Scenario	Year				
	1978	1985	1990	1995	2000
1	0.64	0.65	0.62	0.62	0.62
2		0.75	0.82	0.93	0.99
3		0.78	0.90	1.00	1.08
4		0.80	0.97	1.07	1.17

These results are lower than those derived from the DoE forecasts but scenarios 2, 3 and 4 all show growth in demand for heat exchangers over the estimated 1978 level. This shows that power station construction in 1978 was running at a low level.

It could be expected that the Government would rely on it's own forecasts when making decisions about the building of power stations. That is why the heat exchanger forecasts in the results are based on the DoE forecasts for new capacity. It seems that non-Government forecasts may have influenced thinking on total new capacity requirements but they have had little effect in determining the role of nuclear power. In 'Energy Projections 1979' the total new capacity requirement was revised downwards from the levels envisaged in the Green Paper but nuclear power remained at more or less the same level.

This demonstrates the Government's commitment to nuclear power in spite of some pressure from groups who wished to see the position of nuclear power in future plans reduced substantially if not removed altogether.

It is possible that a future Government will revise the requirement for nuclear power perhaps more in line with the way Leach sees the future. Nevertheless it appears whatever course is taken overall electricity generating capacity is likely to be expanded and therefore demand for heat exchangers should grow as well.

9.5

Combined Heat and Power

9.5.1

Methodology

The subject of combined heat and power (CHP) has received quite a lot of attention since the 1973/74 oil crisis, mainly in respect of district heating from large power stations. As with other sections of this study a literature search was carried out. The purpose of this was twofold; firstly, to learn about CHP technology; secondly, to discover if any forecasts for the potential for CHP had been done. The first was relatively straightforward, the second less so.

No actual forecasts of potential for increased CHP exist but some opinions and assessments of potential contribution to energy saving do. To help fill in some of the gaps some of the interested parties in this field were contacted most notably the Energy Technology Support Unit (ETSU), the National Engineering Laboratory (NEL) and the combined heat and power group of the Midlands Electricity Board.

9.5.2

Energy, Combined Heat and Power and Heat Exchangers

The power generation process is a great waster of energy. In large power stations electricity is generated with efficiencies ranging between around 25 to 33 per cent depending on the age of the plant. This means that only a relatively small proportion of the energy content of the fuel, whether it be coal, oil, natural gas or nuclear, is turned into useful energy, the rest is thrown away and dissipated into the atmosphere in the form of heat. In smaller power schemes, of the sort usually found in industry, steam plant dominates with a few gas turbines and diesels also to be found. In steam plant, electricity is produced with an efficiency of between 10 to 25 per cent. The steam can then be used to supply heat for process use and the useful energy produced can be as high as 80 per cent of energy input. This type of plant has traditionally been used in industries where there is a high demand for steam, such as the chemicals industries.

The reasons for using combined heat and power in industry in the past have not been cost saving through energy saving but rather for reasons of independence from the public supply system over which companies can exercise no control.

As energy prices are forecast to rise in real terms over the remainder of this century, it would seem desirable to cut the waste of energy inherent in most electricity generating plant by trying to use the heat normally dissipated into the atmosphere. Very little in terms of the technology is new but the economics of combined heat and power schemes appears to be changing and will continue to do so. A combined heat and power group was set up by the Secretary of State for Energy in 1974 to examine the potential future role for CHP.

On the continent waste heat from power stations is used to heat homes and factories. In the U.K. district heating is found in one or two places. The Combined Heat and Power Group under the Chairmanship of Dr. Walter Marshall presented its first report in 1977.[37] The report concluded that there was no immediate economic case in most circumstances for district heating from CHP plant at current fuel prices and test discount rate levels. If real fuel prices were assumed to rise significantly however, or test discount rates lowered, then district heating becomes more attractive commercially in the next century when oil and natural gas are likely to be in short supply. As this period is beyond the time horizon of this study, the impact on heat exchangers of the desire to recoup and re-use waste heat from large power stations is not considered.

Industrial CHP was considered in the final report of the Combined Heat and Power Group published in 1979.[38] The report concluded that the potential for future development of industrial CHP was relatively limited.

This study considers the position of industrial CHP over the remainder of this century; if higher energy prices encourage the use of more CHP schemes then the value of heat exchangers demanded will also rise.

9.5.3

Results

The first stage of this exercise was to look for projections of the total potential for private CHP schemes. Energy Paper 32 details the technological potential from increased CHP. These figures are presented in Table 9.5.1 below in millions of tonnes coal equivalent (mtce).

TABLE 9.5.1 Technological Potential for Energy Saving Through Additional Combined Heat and Power in Millions of Tonnes Coal Equivalent (mtce)[39]

Description	Industrial	Commercial/ Public Sector	Total
Co-generation at point of use	4	1	5
Combined heat and power	1	2	3
Total	5	3	8

Co-generation at point of use is where the heat and electricity are consumed on site by the organisation owning the plant. Most current CHP schemes are of this type. Combined heat and power denotes where the organisation generating the heat and power utilises only part and possibly none of the output which is sold to others. The MEB's scheme at Hereford is of this type where electricity is despatched through the grid and heat is used by two firms local to the generating plant.

The MEB scheme at Hereford is rated at 15 MW electrical output with heat recovered being 13.4 MW giving an overall efficiency of 76 per cent. The scheme saves 15500 tonnes of fuel oil per year which is around 26350 tonnes of coal equivalent. This implies that around 300 such schemes would be required to fulfill the potential outlined in Table 9.5.1 above.

The next stage was to try and determine what proportion of the technological potential would be realisable before the end of the century. This cannot be done by assessing the economics of CHP schemes in the light of likely future energy prices. This is because the energy saving potential of any particular scheme is not the only criterion used to assess its desirability or viability. According to a report carried out by consulting engineers Menz and McLellan other reasons which played their part in the adoption of CHP schemes were security of supply (as a safeguard against industrial action), peak lopping duty, independence from electricity board, increased power and/or heat loads and the desire to renew old plant.[40]

There is considerable uncertainty associated with trying to predict how many CHP schemes may be installed in the future. Some interested parties have commented on the current and likely future economics of CHP. Caudle has undertaken a comprehensive analysis of the economics of new CHP schemes in the chemical industry, and he concluded that it was unlikely that major schemes for private generation of electricity would become economic when compared with purchase from the electricity supply industry.[41] Contact was made with the Energy Technology Support Unit (ETSU) who advise the Government on energy matters and the opinion is that CHP is still unattractive economically and there are apparently some industrialists whose firms already co-generate their own heat and power and who are thinking of closing their schemes down and buying in electricity and producing heat from a conventional boiler.[42]

There are two main reasons for this lack of economic incentive. Firstly, the rapid increase in the price of fuel for CHP schemes (fuel oil, natural gas or gas oil) compared with the increase in the price of purchased electricity. Secondly, the much higher capital charges which private industry must allow compared with those required by the Electricity Boards. Where companies generate their own electricity but are still not operating independently of the Electricity Boards then as Caudle points out, there are some additional problems.[43] Firstly, the charges by the

Electricity Boards for standby power are too high and secondly, buy-back prices from Electricity Boards for surplus electricity from industry are too low.

A study by consulting engineers McLellan and Partners was commissioned by the Department of Energy.[44] The idea behind the study was to look at the feasibility of installing gas turbines or diesel generating plant in industrial works but which would be operated by the CEGB, forming part of their normal investment planning and plant construction programmes. These plants would replace peak lopping plant that the CEGB plans to have operational from 1985 onwards. It was concluded that under certain conditions gas turbines or diesel schemes with waste heat recovery for space heating can be economically attractive and save fuel in the National interest. The study also concluded that diesel engines yielded greater savings over gas turbines.

It is difficult to arrive at a realiseable potential for CHP up to the end of the century especially as current prospects do not appear to be good. The Midlands Electricity Board built a 15 MW diesel CHP in 1979 and say the prospects look good and that they are hoping to install more such schemes at about the rate of one a year.[45] Discussions are currently underway for just such a scheme at Fort Dunlop in Birmingham and which will be about twice the size of the Hereford scheme.

From talking to ETSU it would appear that the potential additional savings likely to be achieved by the end of the century will be relatively small at around 1 mtce which implies the adoption of around 38 schemes the size of Hereford. Most of these will be industrial schemes but in some instances the conditions could be favourable in the commercial/public sector. Schemes have been installed at the Leeds General Infirmary and the National Westminster Bank in London. It is most likely that new schemes will be owned or joint owned by the Electricity Boards and the main customer and run by the Electricity Board. Capital costs compare favourably with large power stations. The January 1979 cost of the Hereford scheme is £330/kW for an AGR nuclear power station, the equivalent figure is £565/kW.[46]

The forecasts for this section incorporate some assumptions. Firstly, all future schemes will be based on diesel engines. Where diesel engines can be used savings appear to be greater than for other types of CHP schemes. Secondly, in a forecast by ETSU, energy savings resulting from heat generated in CHP schemes increases at a slightly slower rate than the predicted average rate of increase of industrial output. These assumed rates are 2.3 per cent for heat and 2.5 per cent for industrial growth per annum up to the year 2000. In this study industrial output is assumed to grow at between 1 and 2 per cent per annum and it is further assumed that CHP will grow at the same rate as growth in industrial production. It is also assumed that the 1978 level of new CHP which is replacement for old plant carries on throughout the period at the same rate.

The results are shown below in Table 9.5.2. The figures represent megawatts electrical output.

TABLE 9.5.2 Forecast Installation of CHP Plant for the Years 1985, 1990, 1995 and 2000

Scenario	Year				
	1978	1985	1990	1995	2000
1	33.00	48.00	48.00	48.00	48.00
2		48.92	49.74	50.59	51.49
3		49.40	50.67	52.03	53.51
4		49.89	51.65	53.59	55.73

Heat exchanger values are derived by multiplying the above figures by £27273 per MW electrical output for gas turbines and diesel plant by £15000 per MW. The derivation of the gas turbine figure is shown in section

A.5.3 of Appendix A. The figure for diesel plant was derived from the Hereford CHP scheme. On that scheme total value of heat exchangers of all types amounted to £224976 for 15 MW rated electrical output.[47] This is near enough £15000 per MW.

It is assumed that gas turbines will remain at the 1978 level (i.e. 33 MW) and that the rest will be diesel plant. Diesel plant produces more electricity per unit of fuel input than does gas turbine plant and as electricity is a higher value product than heat, diesel plant will become progressively more attractive as fuel prices rise when compared with gas turbines.

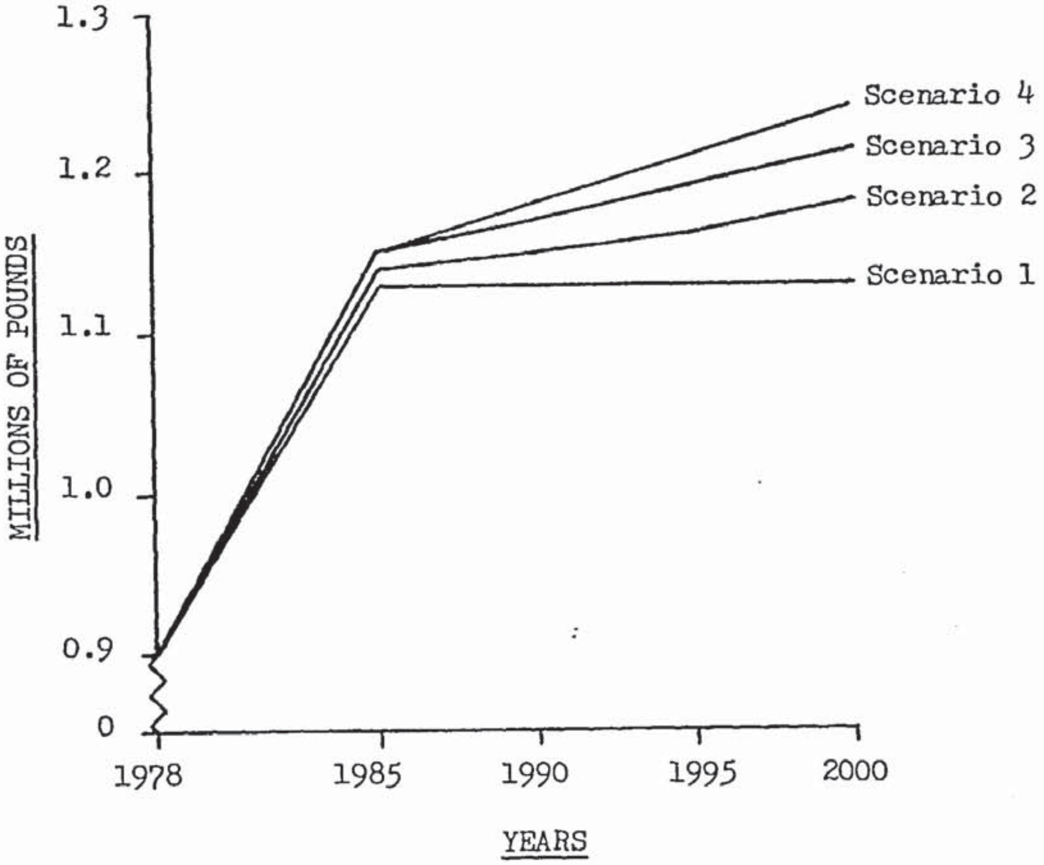
The derived forecasts of heat exchanger values are shown in Table 9.5.3 below.

TABLE 9.5.3 Forecast Heat Exchanger Values for Combined Heat and Power (£ Millions)

Scenario	Year				
	1978	1985	1990	1995	2000
1	0.90	1.13	1.13	1.13	1.13
2		1.14	1.15	1.16	1.18
3		1.15	1.17	1.19	1.21
4		1.15	1.18	1.21	1.24

The results from Table 9.5.3 are shown graphically in figure 9.5.1 overleaf.

Figure 9.5.1 Combined Heat and Power Sector Results



9.5.4

Discussion of Results

The ETSU figure for technological potential for energy saving through additional CHP of 8 mtce is very large. If this was realised before the turn of the century there would be a large impact on the demand for heat exchangers. Of the 8 mtce savings, 5 mtce is thought to be the potential savings from industrial CHP. It is thought that currently, industrial CHP is saving in the region of 2 to 3 mtce per year and is supplying about one-sixth of industrial electricity demand.[48] It has taken probably 30 to 40 years to build up industrial CHP to this point. To increase this by a further 5 mtce over the next twenty years or so would represent a major expansion.

ETSU mention a likely figure of only 1 mtce which may be realiseable between now and the year 2000. This figure implies larger demand for heat exchangers than has been forecast for any of the scenarios in the results. It would result in the following forecast of heat exchanger demand:-

	£M
1978	0.90
1985	1.23
1990	1.35
1995	1.51
2000	1.73

These are still fairly small figures. The forecast value for scenario 4 for the year 2000 is £1.24 million so the result obtained from assuming potential savings of 1 mtce is 40 per cent larger but in the context of the whole heat exchanger market either figure is small and the difference almost insignificant.

A paper[49] from the Department of Mechanical Engineering of the Imperial College of Science and Technology criticizes the contention in the Combined Heat and Power Group's final report that the potential for industrial CHP is limited. The authors argue that if the entire industrial heat load was satisfied by heat from diesel based CHP schemes enough electricity would be produced to satisfy national electricity demand. The Imperial College team feel that it is not the potential for industrial CHP which is limited in itself so much as limitations being caused by Government and the Electricity Supply Industry (ESI).

One of these limitations is the fact that the ESI only has to make fairly modest returns on its investments in order to justify them whereas industry has to treat investment in CHP like any other and achieve quite high returns. In other words, investments in the public sector are judged on entirely different criteria to investments in the private sector. Investments in the public sector have a much better chance of going ahead than private sector investment. The Imperial College paper argues that if public sector criteria are used to assess private sector investment in CHP the financial returns are greater than for investment in public sector power generation. It is therefore in the National interest for a greater proportion of electricity production in the U.K. to come from private sector CHP schemes.

For any of this to happen would require major initiatives from Government which have not yet materialised. If ever they do then the forecasts contained in this section would need to be revised.

9.6

Manufacturing Industries

9.6.1

Methodology

A literature search was conducted into waste heat recovery to discover what developments, if any, were taking place. Since the 1973/74 oil crisis much interest has been focussed on energy and ways of saving it. From the literature search it was apparent that the use of heat exchangers, as one of a range of energy conservation measures, could have quite an important role to play.

To assess the effect of rises in energy prices on demand for heat exchangers used for waste heat recovery it was necessary to find data on energy used and rejected, in the form of heat, by manufacturing industry. Two series of reports have been published; one by the Department of Industry called the Industrial Energy Thrift Scheme (IETS) reports of which there were 28 at the time of writing; the other series is published jointly by the Departments of Industry and Energy and is called the Energy Audit series, 12 of which had been published at the time of writing. Some of these reports quantify savings that are achievable with increased waste heat recovery in a variety of manufacturing industries. From these reports generalisations about waste heat recovery potential throughout the whole of manufacturing industry were made.

A literature search revealed one or two other estimates of recoverable waste heat in industry which are less comprehensive than either IETS or Energy Audit reports but which are used for comparison purposes in the discussion of results section.

In order to estimate what part of the total heat wasted might be recovered economically up to the end of the century, it was necessary to derive average heat exchanger prices and use this information with data on the number of hours per year that processes operate and forecasts of energy prices up to the year 2000. Heat exchanger prices and process operating duties were sourced from available literature and used in conjunction with energy price forecasts from the Department of Energy. It is necessary to know how many hours a year that processes operate on average because this heavily influences the return on investment in heat exchangers. A heat exchanger that operates for 2000 hours a year does not produce as good a return as one which operates longer all other things being equal.

Whenever and wherever necessary contact was made with various organisations and individuals to answer specific questions. In particular contact was made with the Government financed Energy Technology Support Unit (ETSU), based at Harwell, which advises the Government on energy matters. The unit has been responsible for many of the reports and other information already referred to in this section.

9.6.2

Energy, Industry and Heat Exchangers

In 1974 the Department of Industry started publishing a series of reports called Energy Papers. The idea was to create a wider public understanding and discussion of energy matters. Early papers concentrated on general topics rather than specific issues such as waste heat recovery. Energy paper number 5[50] examined some of the energy conservation measures adopted by some companies in response to the oil crisis of 1973/74.

The firms featured in the paper are chemical and/or oil companies and are large energy users. These sectors are actually covered elsewhere in this study. Nevertheless extra heat exchangers are mentioned as being one of many conservation measures implemented.

The chemicals and oil refining industries as large energy (and heat exchanger) users have received much more attention than the rest of manufacturing industry. It is only comparatively recently that it has emerged that although all manufacturing industry accounts for 40 per cent of total U.K. primary energy consumption, comparatively little was known about the way in which industry used energy.[51] It was not realised that a large waste heat recovery potential existed in industries other than chemicals and oil refining.

A report published in December 1977 summarised information on energy usage gathered from over 2000 manufacturing sites.[52] The opportunities for waste heat recovery are not quantified in this report but it is mentioned as one of a number of possible energy conservation measures. Subsequently, the information in the report was publshed in more detail in the Industrial Energy Thrift Scheme reports and in some sectors of industry waste heat recovery is quantified.

In 1978 the Department of Energy issued Energy Paper number 32 which summarised information from a number of sources and the potential savings available in industry from the employment of waste heat recovery equipment and techniques was estimated to be in the region of 6 to 8 million tonnes coal equivalent.[53] The relative importance of waste heat recovery as a conservation measure was now recognised and in Energy Paper number 39 was listed as one of five priority technologies for energy saving.[54]

From talking to ETSU it was found that waste heat recovery is regarded as the most important of the priority technologies. This was because most of the equipment and techniques are already well proven and many of the opportunities are thought to be attractive at current energy prices. Some indication of the importance of waste heat recovery comes from the publication of booklets on equipment and techniques by the Department of Energy,[55] the Electricity Council[56] and British Gas.[57]

In addition to the many books and articles that have appeared in newspapers and journals on waste heat recovery, a journal devoted to the subject and called Heat Recovery Systems has been published by Pergamon Press.

There has been a growing interest in waste heat recovery since 1973 and it was concluded that there would be important implications for any devices or techniques which can recover otherwise wasted energy. Heat exchangers fall into this category and therefore the subject was investigated further.

9.6.3

Results

The first stage of the exercise was to estimate the total potential for waste heat recovery. This potential is referred to as the technological potential. Table 9.6.01 below summarises the energy used and waste heat recovery potential for a range of industries.

TABLE 9.6.01 Total Energy Usage and Waste Heat Recovery Potential for a Range of Industries (in Terajoules)

Minimum List Heading	Industry Sector	Total Energy Use	Energy Saving Potential from Waste Heat Recovery	References
414	Woollen and Worsted	17800	1634	58
462	Pottery	15320	1240	59, 60, 61
461.1	Refractories	16000	2000	62, 63, 64
461.2	Bricks	28000	4100	65, 66
322	Copper	18000	700	67, 68
323	Lead, Zinc and other Base Metals	14000	2240	69, 70
413	Weaving (cotton system)	5700	171	71
417	Knitting	12180	613	72
423	Textile Finishing	26000	1685	73
431) 432) 433) 450)	Footwear, Leather and Fur	9251	1517	74
491) 492)	Rubber and Coated Substrates	33700	1683	75
TOTAL		195951	17583	

Note: Minimum List Headings are defined in the Standard Industrial Classification[76]

It was assumed that these figures were representative of the total energy used and waste heat recovery potential in all manufacturing industries with the exception of the chemicals and allied industries and mineral oil refining. A Department of Energy publication[77] gives total industrial energy consumption as 22.8 billion therms on a heat supplied basis which is 2405 petajoules (PJ). From this the energy consumption for mineral oil refining of 285 PJ[78] and chemicals and allied industries at 469 PJ[79] must be deducted to give an energy consumption of 1651 PJ for the rest of manufacturing industry. From the figures in Table 9.6.01 energy consumption of 1651 PJ implies savings from increased waste heat recovery would be 148 PJ.

It is assumed that heat recovered reduces the amount of heat required from an on-site boiler. ETSU usually assume a nominal boiler efficiency of 75 per cent. This implies that to save 148 PJ of energy 111 PJ would be recovered through waste heat recovery systems.

It should be noted that the figures contained in Table 9.6.01 were published in reports over a period of two to three years and that some figures relate 1974/75 and others to later years. This should have no significant impact on the results.

The next stage was to estimate what proportions of recoverable heat are rejected in the different durations of operation of manufacturing industries; some industries operate for around 2000 hours a year whilst others operate almost continuously at, say, 8600 hours per year. According to Klaschka[80] heat rejection by industry is in approximately the proportions shown in Table 9.6.02.

TABLE 9.6.02 The Proportion of Total Waste Heat Rejected by Different Types of Manufacturing Process

Type of Process	Hours Per Year	Fraction of Total Heat Rejection
Discontinuous (8 hr day, 5 day week)	2000	0.40
Semi-Continuous	7000	0.45
Continuous	8600	0.15

These fractions can be applied to the estimated technological potential for waste heat recovery of 111 PJ. This is shown in Table 9.6.03.

TABLE 9.6.03 Total Heat Recoverable from Different Durations of Manufacturing Process

Operating Duty Hours P.A.	Fraction of Total Heat Recoverable	Heat Recoverable PJ
2000	0.40	44.40
7000	0.45	49.95
8600	0.15	16.65
TOTAL	1.00	111.00

The next stage was to estimate an average price for heat recovery systems. Such a system consists of a heat exchanger plus any pipework, ducting, fans etc. which are necessary. To estimate an average price a literature search was conducted. Data was collected from papers and journals covering roughly a period from 1976 to 1981. All of the monetary data were converted into 1978 values by using index numbers of wholesale prices for the output of the mechanical engineering industry.[81] Where necessary data were converted to metric units. The data are shown in Table 9.6.04 overleaf.

The system cost is expressed in pounds per kilowatt (£/kW). Average system cost from the Table overleaf is approximately £71/kW. The range of values is £31/kW to £156/kW.

Klaschka quotes much higher figures for typical heat recovery scheme costs of £102 to £239 per kilowatt.[101] These prices were derived from equipment manufacturers for hypothetical heat recovery duties and may not have been economically justifiable. The system costs in Table 9.6.04 represent actual cases of implemented schemes. Klaschka's quoted prices are uneconomic at current energy prices, a fact which is substantiated later

TABLE 9.6.04 Heat Recovery System Costs

Equipment Description	Heat Recovery Capacity kW's	System Cost £'s	£/kW	Reference
Runaround Coil	115	8929	78	82
Waste Heat Boiler	6745	535714	79	83
Plate Heat Exchangers	410	40095	98	84
Gas/Liquid	170	9000	53	85
Heat Wheel	82	5357	65	86
Heat Wheel	67	7143	107	87
Heat Wheel	100	8000	80	88
Gas/Gas Plate	733	28528	39	89
Runaround Coil	183	28571	156	90
Gas/Gas Plate	176	16000	91	91
Heat Pipe	498	31000	62	92
Heat Wheel	91	4000	44	93
Heat Wheel	426	27480	65	94, 95
Heat Pipe	89	5344	60	96
Glass Tube H/E	1427	122000	85	97
Heat Pipe	988	58200	59	98
Heat Wheel	2377	80152	34	99
Heat Wheel	8667	268220	31	100

in this section, and therefore too high to be considered typical.

On the other hand is £71/kW derived from empirical data an appropriate value to use? It might be fairly expected that more economic or cost effective systems are installed before the less cost effective. The more expensive systems may become cost effective as energy prices rise. The differences in costs between schemes may be partly explained by the differing requirements of all schemes for fans, ducting, pipework and so on. Evidence to support this comes from Klaschka who says that heat exchangers typically account for 15 to 35 per cent of total costs in gas/gas systems and 50 to 60 per cent in liquid/liquid systems.[102] Reay estimates that heat exchangers represent between 20 and 40 per cent of total system costs for all types.[103]

It is possible to see if the system cost of £71/kW is low, by looking at heat exchanger costs as a percentage of total scheme costs in implemented schemes. In some cases found in the literature the scheme costs were broken down into the constituent parts. These are shown in Table 9.6.05.

TABLE 9.6.05 System Costs with the Associated Heat Exchanger Cost

Equipment Type	System Cost		Heat Exchanger Cost		H/E Cost as a % of System Cost	Reference
	£	£/kW	£	£/kW		
Heat Wheel	27480	65	16218	38	58	94, 95
Heat Wheel	37590	nk	9845	nk	26	104
Heat Wheel	80152	34	34351	14	43	99
Heat Pipe	58200	59	24000	24	41	98
Gas/Gas Plate	16000	91	5000	28	31	91, 105
Runaround Coil	28571	156	8967	49	31	90
Heat Wheel	268220	31	107985	12	40	100
TOTALS	516213	436	206366	165		

nk = not known

The proportion of total system costs accounted for by heat exchangers

is: $\frac{206366}{516213} \times 100 = 40\%$

The range of values from the Table is 26-59 per cent. Forty per cent according to Klaschka and Reay is high. The average price for systems in this rather limited sample is: $\frac{436}{6}$ £73/kW

And for heat exchangers: $\frac{165}{6}$ £28/kW

The system cost for this sample is quite close to £71/kW for the larger, slightly different sample in Table 9.6.04. It may be tentatively concluded, therefore, that £28/kW for heat exchangers is a reasonable average or typical figure to be used for market estimation.

As heat exchangers seem to account for a higher proportion of system cost than might be expected if all heat recovery opportunities could be examined, then the £71/kW derived system cost appears to be low. It seems that systems with low requirement for ancillary equipment have been exploited first because they are more cost effective than other more expensive but technically feasible systems. This would explain why in the cases where a cost break down was available, heat exchangers accounted for a relatively high proportion of system costs.

It is assumed in these results that the proportion of total system costs accounted for by heat exchangers falls to around 30 per cent on average as more schemes are implemented. This is the middle point of Reay's 20 to 40 per cent range for all types of systems referred to previously.

From Table 9.6.05 the average price for heat exchangers is £28/kW. If the figure is rounded up to £30/kW then this implies a system cost of £100/kW. This is substantially higher than the £71/kW derived from empirical data but only at the bottom end of Klaschka's £102 to £239/kW range. After discussions with relevant people at Serck it was confirmed that £100/kW for the system and £30/kW for the heat exchanger were reasonable cost estimates bearing in mind the use to which they are being put in this study. These rules of thumb should not be applied to individual heat recovery schemes in order to estimate the likely cost of equipment because of the wide variations possible in different situations. They are reasonable only in the context of overall market measurement and estimation.

Using the system and heat exchanger cost estimates it is possible to put a value on the equipment required to realise the technological potential for waste heat recovery estimated in Table 9.6.03. It should be noted that this potential exists already and it assumed that the potential will expand as industry grows. This notion is dealt with later in these results. Table 9.6.06 shows the estimated value of equipment to realise the total technological heat recovery potential.

TABLE 9.6.06 Total Value of Heat Recovery Systems and Heat Exchangers to Recover 111 PJ of Heat

Operating Duty Hrs/Yr	Heat Recoverable PJ	Gigawatt Hours	Gigawatt Capacity	System Value £100/kW (£M)	H/E Value £30/kW (£M)
2000	44.40	12334	6.167	616.7	185.01
7000	49.95	13876	1.982	198.2	59.46
8600	16.65	4625	0.538	53.8	16.14
TOTAL	111.00			868.7	260.61

The calculations in the Table are straightforward. The heat recoverable is taken from Table 9.6.03. Petajoules are multiplied by 277.8 to give Gigawatt hours (see conversion tables in Appendix G). Heat recovery system capacity is found by dividing Gigawatt hours by the relevant operating duty. Capacity is multiplied by £100 and £30/kW to find the total value of systems and heat exchangers respectively.

The next stage was to calculate what part of the technological potential for heat recovery is economically viable within the time horizon of this study (i.e. up to the year 2000). The value derived is termed the economic potential. In order to determine what is economic, some assumptions are made. It is assumed that industry requires a 2 year payback on investment. Payback is a simple form of investment appraisal and has disadvantages when compared with more sophisticated techniques such as discounted cash flow. Discussion of the relative merits of different approaches to investment appraisal is outside the scope of this study. Suffice to say that the 2 year payback occurs more often in the literature and in conversations with interested parties than other investment criteria particularly in preliminary or feasibility studies.

The more energy prices rise the more cost effective heat recovery schemes become and therefore the economic potential for heat recovery systems grows. This study uses Department of Energy price forecasts in index form which actually relates to diesel fuel. The forecasts are shown in Table 9.6.07.

TABLE 9.6.07 Department of Energy Diesel Fuel Price Forecasts

Price Rise Scenario	Year			
	1978 Actual	1980	1990	2000
Low Standard High	100	145 145 145	170 190 210	190 230 270

It is assumed that heat recovered will reduce the requirement for fuel oil for use in on-site boilers. It could in reality be natural gas that is saved.

The average price for fuel oil was about 19 pence per therm in 1978. Using the indices in Table 9.6.07 energy price forecasts in pence per therm can be calculated. The results are shown in Table 9.6.08. Values for 1985 and 1995 have been interpolated.

TABLE 9.6.08 Average Energy Price Forecasts Derived from Department of Energy Figures (Pence Per Therm)

Price Rise Scenario	Year				
	1978	1985	1990	1995	2000
Low Standard High	19	30 32 33	33 36 40	34 40 46	36 44 52

By using a simple equation the break even point for a heat recovery system in terms of hours operation per year can be calculated.

$$H = \frac{29.31 \times n \times S}{P \times Y}$$

Where:

H = break even point in hours per year

29.31 = capacity in kilowatts necessary to recover 1 therm per hour

n = nominal boiler efficiency (fixed at 0.8)

S = average system price per kilowatt

P = price in pounds per therm

Y = payback period in years.

By substituting the forecast prices in pence per therm in Table 9.6.08 into the equation, forecast break even points in hours per year operation can be derived. These are shown in Table 9.6.09.

TABLE 9.6.09 Forecast Break Even Points in Hours per Year Operation for Heat Recovery Systems

Average Energy Price	Year				
	1978	1985	1990	1995	2000
Low		3908	3553	3448	3256
Standard	6171	3664	3257	2931	2665
High		3553	2931	2548	2255

It appears that continuous and semi-continuous processes are economically viable as far as heat recovery systems are concerned. Processes which operate for only 2000 hours per year do not appear to be economically attractive before the year 2000. The economic potential for heat recovery systems is the technological potential found in continuous and semi-continuous processes. From Table 9.6.06 this gives a value of economically attractive schemes of £252 million using £76 million worth of heat exchangers. These figures represent the upper limit of the cumulative value of the heat recovery systems market up to the year 2000 without at this stage allowing for any growth in heat recovery opportunities.

The final stage was to estimate the likely market for each year up to the year 2000. It is assumed that the cumulative value for the market is realised by the year 2000 and that any growth occurs smoothly. It is also assumed that as industry expands so will the opportunities for heat recovery and therefore the market. Three different rates of growth are used which are fairly conservative; 1, 1.5 and 2 per cent per annum. The 1978 value for this market is estimated to be £1.28 million (see section A.6.3. of Appendix A).

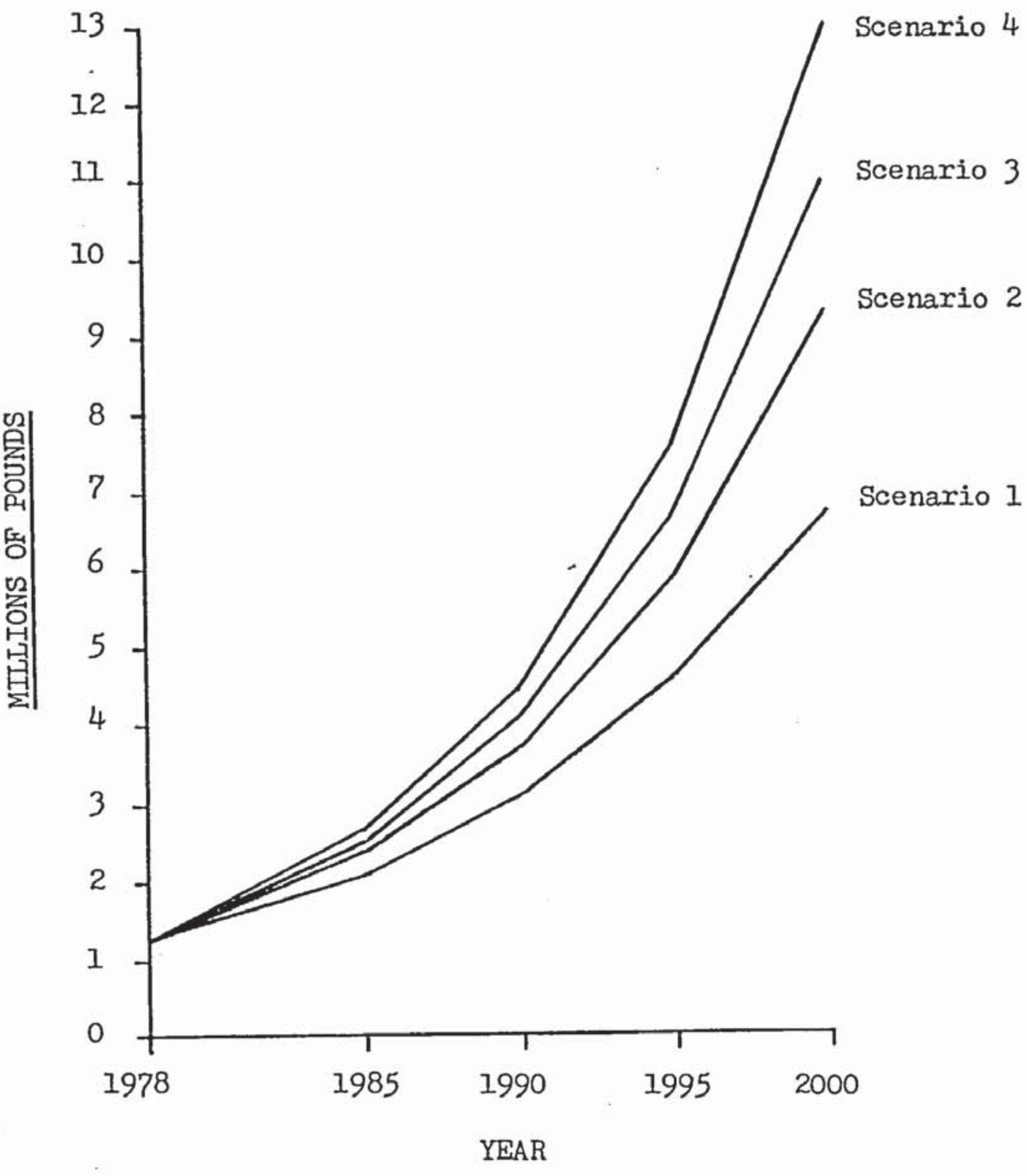
The forecasts for heat exchangers for heat recovery are shown in Table 9.6.10. Scenario 1 represents heat recovery opportunities which existed in 1978 (i.e. growth of opportunities is not taken into account). Scenarios 2, 3 and 4 represent the aforementioned levels of growth.

TABLE 9.6.10 Forecasts of Heat Exchangers in Waste Heat Recovery Applications in All Industries Except the Chemicals and Allied Industries and Mineral Oil Refining

Scenario	Year					Cumulative Total for All Years 1978-2000 (£M)
	1978	1985	1990	1995	2000	
1	1.28	2.17	3.16	4.60	6.69	76
2		2.41	3.78	5.94	9.33	95
3		2.54	4.13	6.72	10.95	105
4		2.67	4.50	7.60	12.84	118

Figure 9.6.1 shows the results from Table 9.6.10 graphically.

Figure 9.6.1 Manufacturing Industries Sector Results



9.6.4

Discussion of Results

In the first stage of the results it was estimated from Government published figures that recoverable heat in this sector amounted to 111 PJ. According to Klaschka total industrial energy usage (excluding iron and steel, chemicals and cement) was 1830 PJ in 1977.[106] Of this, Klaschka estimates 25 per cent is lost as waste heat. In the results total energy usage was estimated to be 1651 PJ, if 25 per cent of this is waste heat around 413 PJ of heat is lost. For various reasons, not all of this would be recoverable but even if it were, heat recovery systems efficiency of, on average, 55 per cent would only recover 227 PJ. The heat recoverable figure from the results of 111 PJ relates only to what is technically feasible, whereas the 227 PJ derived from Klaschka's figures includes all waste heat.

It is not known how Klaschka's figures for waste heat were estimated but the Government figures are based on extensive fieldwork by the Energy Technology Support Unit and various industry research associations. The Government based figures would appear to be reasonable and the best available on which to base this work.

The operating duties used in the results are a guide only. Clearly there are processes which operate over the whole spectrum from 2000 to 8600 hours per year. They do however, tend to be concentrated at certain levels and the division of 2000, 7000 and 8600 hours is a little arbitrary but, in the absence of anything better, is a reasonable guide.

The next part of this discussion relates the impact on the results of variations in assumptions about system and heat exchanger costs. Table 9.6.11 contains nine different pricing possibilities.

TABLE 9.6.11 Heat Recovery System and Heat Exchanger Average Price Scenarios

Scenario		Price £/kW	
		System	Heat Exch.
A	Low, Low	71	14.2
B	Low, Medium	71	21.3
C	Low, High	71	28.4
D	Medium, Low	100	20.0
E	Medium, Medium	100	30.0
F	Medium, High	100	40.0
G	High, Low	150	30.0
H	High, Medium	150	45.0
I	High, High	150	60.0

The description for each scenario refers firstly to a system price. This system price can be low, £71/kW, medium, £100/kW, or high at £150/kW. The low price was derived, as shown in the results, from a literature search for case studies; the medium price is pitched between the low price and the range of prices quoted by Klaschka; the high price reflects Klaschka's range of prices. The second part of the scenario description refers to the heat exchanger content of the system; low being 20 per cent of the total, medium 30 per cent and high 40 per cent.

Scenario C (Low, High) corresponds quite closely with the figures derived from the literature search. For reasons outlined in the results section Scenario E was used as the basis for the forecasts. Table 9.6.12 shows the effect on the values of the technological potential for heat recovery systems and heat exchangers, of different system and heat exchanger prices.

TABLE 9.6.12 The Value of the Total Technological Potential for Heat Recovery Systems and Heat Exchangers Under Different Price Scenarios

DESCRIPTION		PRICE SCENARIOS FOR SYSTEM AND HEAT EXCHANGER COSTS (£/kW)																	
		A		B		C		D		E		F		G		H		I	
Operating Duty	GW Capacity	System 71	H/E 14.2	System 71	H/E 21.3	System 71	H/E 28.4	System 100	H/E 20	System 100	H/E 30	System 100	H/E 40	System 150	H/E 30	System 150	H/E 45	System 150	H/E 60
2000	6.167	437.9	87.6	437.9	131.4	437.9	175.1	616.7	123.3	616.7	185.0	616.7	246.7	925.1	185.0	925.1	277.5	925.1	370.0
7000	1.982	140.7	28.1	140.7	42.2	140.7	56.3	198.2	39.6	198.2	59.5	198.2	79.3	297.3	59.5	297.3	89.4	297.3	118.9
8600	0.538	38.2	7.6	38.2	11.5	38.2	15.3	53.8	10.8	53.8	16.1	53.8	21.5	80.7	16.1	80.7	24.2	80.7	32.3
TOTAL	8.687	616.8	123.3	616.8	185.1	616.8	246.7	868.7	173.7	868.7	260.6	868.7	347.5	1303.1	260.6	1303.1	390.9	1303.1	521.2

From Table 9.6.11 it can be seen that the total value of systems ranges from £616 million to £1303 million, whilst heat exchangers range from £123 million to £521 million.

The price variations have an impact on the economic potential as well as the technological potential. Variations in system price affect the break even points for heat recovery systems. The various break even points in hours per year operation for different system prices are contained in Table 9.6.13.

TABLE 9.6.13 Break Even Points for Heat Recovery Systems Based on Different System Prices

System Price	Energy Price	1978	1981	1985	1990	1995	2000
		Actual					
71	Low			2775	2522	2448	2312
	Standard	4381	3468	2601	2312	2081	1892
	High			2522	2081	1936	1601
100	Low			3908	3553	3448	3256
	Standard	6171	4885	3664	3257	2931	2665
	High			3553	2931	2548	2255
150	Low			5862	5329	5172	4885
	Standard	9255	7328	5495	4885	4393	3996
	High			5329	4397	3823	3382

Using these break even points it is possible, by referring to Table 9.6.12, to find the cumulative value of the economic potential for heat exchangers up to the year 2000 for the various price scenarios. These are shown in Table 9.6.14.

TABLE 9.6.14 Economic Potential for Heat Exchangers Up to the Year 2000 for Price Scenarios A to I

Price Scenario	Economic Potential £M
A	35.7-123.3
B	53.7-185.1
C	71.6-246.7
D	50.4
E	75.6
F	100.8
G	75.6
H	113.4
I	151.2

It is difficult to estimate what impact the different price scenarios would have on the heat exchanger market year to year. Overall, compared with scenario E, which was used in the results, the market values of scenarios A, B and C would be smaller initially, but when processes operating at around the 2000 hours a year level become economic the economic potential and therefore, possibly, the yearly market value expands to a much higher level. From Table 9.6.13 this potential in discontinuous processes could begin to be exploited some time in the 1990's depending on what level energy prices have reached. With price scenarios D to I the enormous potential available in discontinuous manufacturing processes is unlikely to start to be realised before the end of the century.

The use of price scenario E in the results leads to a more conservative forecast of the cumulative value of the heat exchanger market up to the end of the century than scenarios B, C, F, H and I. Scenario A could yield a smaller cumulative value of the market depending upon when discontinuous processes become economically attractive. Scenario D yields a lower value because the assumed heat exchanger value is lower than for scenario E.

Scenario G appears to have a similar economic potential as scenario E but as the system price is greater, the market value year to year could be less.

Scenario E seems to be a reasonable choice of price scenario for the results because it does not lead to the highest or lowest market estimates although the results are on the lower side and so are fairly conservative.

All price scenarios without exception even given low energy price rises would lead to growth in the market for waste heat recovery systems over the 1978 level.

A 2 year payback is used in the results. Whilst this is a commonly used criteria in industry it can vary. When there is a shortage of funds, typically in a recession, paybacks shorten. At ICI recently when the company made its first ever quarterly loss, required payback was 6 months. This effectively excluded any investment in waste heat recovery equipment. Recessions tend to be the times when companies are under pressure to cut costs and at the same time they are short of cash. Waste heat recovery can cut costs, but in doing so uses valuable cash that is probably in short supply. When companies move out of recession pressure is taken off costs and the need to invest in such things as waste heat recovery equipment recedes. So when companies have money available they are less likely to invest in waste heat recovery. When things are going well companies are more likely to invest in expansion rather than cost cutting. This point is illustrated in the following extract from the 1980 progress report of the Heating, Ventilating, Air Conditioning and Refrigeration Equipment Sector Working Party (SWP).

> 'The SWP feels that until such time as investment in energy saving is more attractive than an investment in additional production it is to be expected that firms will use their cash resources on increasing profitable production which, unfortunately, may well waste even more energy.' [107]

This is one factor which impinges on the development of the waste heat recovery equipment market. There are other factors which impinge the development of this market. Companies which use large amounts of energy are well used to investing in energy conservation measures. In many industries energy only constitutes a small proportion of costs and therefore is not seen as being particularly important. Energy price rises tend to be passed on to the customer.

Many companies have little or no experience of energy conservation and do not possess the knowledge of equipment and techniques which would help reduce energy usage. Old habits die hard and it may be difficult for a company to change the way it has always done things in response to the relatively recent phenomenon of high energy costs.

It is possible that Government grants towards the cost of energy conservation equipment may significantly improve the prospects for waste heat recovery equipment. ETSU was contacted on this issue because it has been consulted by the Government about it. ETSU says that the Conservative Government is extremely unlikely to give grants for heat recovery equipment. This is because the Conservatives believe in a free market with little or no Government interference. They say that if industry defines a particular investment opportunity as being unattractive then they (the Government) should not interfere with the market to make the investment attractive. One could criticise this by arguing that whilst being unattractive in pure market terms, in National terms energy conservation is of prime importance (as successive Governments since 1974 have said), and therefore it is necessary to manipulate markets for reasons of National interest. The Conservative Government in fact has a policy of increasing energy prices (particularly gas) at a level above inflation so as, in part at least, to stimulate conservation. The Government is apparently prepared to interfere in some cases but not in others and could clearly be accused of being inconsistent.

For further discussions of financial incentives for energy conservation the reader is referred to the Department of Energy's Energy Paper number 33.[108]

It is assumed in the results that opportunities for waste heat recovery which are currently economic will be taken up by steady growth of the market up to the end of the century. The only guide to whether this is reasonable or not is to compare the resulting rate of growth to a forecast for this type of equipment published by the Building Services Research and Information Association (BSRIA).[109] From the figures given in the BSRIA forecasts, sales of heat recovery equipment will expand at an average annual rate of about 25 per cent between 1980 to 1985. In the results section of this study the average annual rate of growth for scenarios 1 to 4 is between 7.8 and 11 per cent. These are much more conservative figures than the BSRIA one. The BSRIA work was based on replies from manufacturers and importers of waste heat recovery equipment. It is reasonable to expect optimism from the people who sell the equipment. The market is currently relatively small but most of the equipment has been around quite a few years so the BSRIA forecasts seem to be expressing a sudden and rapid up-turn in the market. The forecasts contained in Section 9.6.3 are based on what is possible (technological potential) and worthwhile (economic potential) and seem to suugest that the BSRIA figures are over-optimistic. If the high rates of growth forecast by BSRIA are achieved they will not be sustainable over a long period of time and after reaching an early peak the market will go into decline.

If the rates of growth in the results of this section prove to be pessimistic it should be of little consequence. The results show growth rates of around 8 to 11 per cent which are well above the norm for industrial markets. So the figures denote a relatively fast growing market but just not as fast as the BSRIA paper forecasts. This would not deter a potential supplier from entering the market nor persuade an existing supplier to pull out. The fact that there is another forecast which predicts a higher rate of growth actually reinforces the confidence that can be placed on the figures resulting from this study and any decisions which may be based upon them.

9.7

Chemicals and Allied Industries

9.7.1

Methodology

The approach used here was virtually the same as that used in section 9.6 on manufacturing industries. The reader is referred to the aforementioned section for a more detailed account. A literature search was conducted to discover what developments, if any, were taking place in the chemicals and allied industries. In the literature the conservation of energy is a major topic and increased waste heat recovery one of the possible options open to manufacturers. Although this study is concerned with the U.K., literature from abroad was also consulted for comparison purposes.

To quantify the effects of changes in the energy situation on demand for heat exchangers it was necessary to find data on energy used and rejected as heat by the chemical manufacturing industries. This was done by using some of the reports published in the Industrial Energy Thrift Scheme series and others published in the Energy Audit series. Not all of the sectors defined under order V of the Standard Industrial Classification are covered in the two series' of reports. Some sectors are, however, covered in the Department of Energy's Energy Paper number 32.[110] The remaining gaps were filled by talking to the Energy Technology Support Unit (ETSU) based at Harwell.

From the data on waste heat the technological potential for waste heat recovery equipment was estimated. As processes in the chemical industry operate on a semi-continuous or continuous basis the technological potential was considered to be economic at current energy prices.

Equipment prices used in this section were the ones derived in the manufacturing industries section (i.e. £100/kW for the system, £30/kW of which is for the heat exchanger).

As all of the technological potential for heat recovery appeared to be economic now it was unnecessary to use forecasts of energy prices to determine if and when the technological potential would become economic. Suffice to say that an upward trend in energy prices would give energy users an ever increasing incentive to invest in waste heat recovery equipment.

Whenever and wherever necessary contact was made with various organisations and companies in the industry, both operators and contractors.

9.7.2

Energy, The Chemicals and Allied Industries and Heat Exchangers

There are two main aspects to the way the changing energy situation could affect the use of heat exchangers in the chemicals industries. They are, the desire to save energy by recouping heat that was formerly wasted and secondly, changes in processes brought about to reduce either the amount of energy used for manufacturing or moves to reduce the dependence on oil as a feedstock by using alternatives such as coal or vegetables.

The first may be termed a minor conservation measure in that it can be implemented on existing plant at reasonable cost in a relatively short period of time. The second is a major area involving large investments and long lead times. The first involves the application of existing technology or minor developments thereof. The second involves major development work and often new technology.

After the 1973/74 oil crisis a number of papers and reports appeared on the subject of energy conservation in the chemicals industries in both the U.K. and abroad. Others also appeared which whilst not devoted entirely to the subject did mention energy conservation in the chemicals industries.

If to minimise the reliance on oil the chemicals industries start using other feedstocks, such as coal, then this may have implications for heat exchangers.

The U.K. chemicals industry has reasonably secure supplies of feedstocks from the North Sea which may well last up to the year 2000. The issue of feedstocks for the U.K. is considered in a paper by Caudle.[111] In it Caudle points to Department of Energy forecasts which indicate that U.K. oil supplies will be sufficient for home demand until 1992 and says that even if self-sufficiency ends this soon, which he thinks unlikely, the chemicals industries will over-bid for oil supplies. That is, the industries will be able to secure oil supplies that are needed by paying more than other consumers are willing to because this is cheaper than building a whole new series of plants based on a different feedstock such as coal or vegetables. It is likely, therefore, that the process routes in use in the year 2000 in the U.K. will be largely similar to those employed currently. Very similar conclusions can be drawn from an article by Ralph Landau about the chemicals industries in the USA up to the year 2000.[112] Changes in feedstocks are unlikely to have any impact in the U.K. before 2000 and are therefore ignored in this study.

Energy Paper number 5 published in 1975 notes the installation of additional heat exchangers and heat recovery from waste gases as possible energy saving measures.[113] Better heat recovery and more heat transfer surface are mentioned as energy saving measures in a survey by Chemical Age magazine.[114] Legge and Caudle[115] see scope for increased use of waste heat by the installation of more heat exchangers.

Several papers given at the 1975 conference, Energy Recovery in Process Plants, mention heat recovery as an important energy saving measure.[116]

From these references it can be seen that higher energy prices encourage the use of more heat exchangers and therefore this area was investigated further.

9.7.3

Results

The first part of the exercise was to work out the total technological potential for waste heat recovery for the chemicals and allied industries (as defined by order V of the Standard Industrial Classification).[117] Table 9.7.1 below shows the estimated energy savings possible from increased waste heat recovery for each sector of the industry.

TABLE 9.7.1 Possible Annual Energy Savings from Increased Waste Heat Recovery (in Terajoules)

Minimum List Heading	Sector	Energy Saving TJ	Reference
271	General Chemicals	6730	118
272	Pharmaceutical Chemicals	317	119
273	Toilet Preparations		
274	Paint	15	118, 120
275	Soap and Detergents	158	121
276	Synthetic Resins and Plastics	153	122
277	Dyestuffs and Pigments	660	123
278	Fertilizers	1794	118, 120
279	Miscellaneous Other	265	124
Total		10092	

These figures were produced in reports published between 1979 and 1981 but the data used refer to a period of 1975 to 1977. It was assumed that the potential for savings in energy from increased waste heat recovery is that which exists in 1978, the base year for the forecasts.

It was also assumed that heat recovered would save heat being generated in an on-site boiler. The Energy Technology Support Unit usually assumes a nominal boiler efficiency of 75 per cent. This means to save 10092 TJ of energy shown in Table 9.7.1, 7569 TJ of heat would be recouped and re-used through waste heat recovery schemes.

If it is assumed that processes in the chemicals and allied industries operate for 7000 hours per annum on average and that the heat recovery system installed cost is £100/kW, of which £30/kW is for heat exchangers, then the value of the technological and economic potential can be estimated. The process is shown in Table 9.7.2 below.

TABLE 9.7.2 Total Value of Heat Recovery Systems and Heat Exchangers to Recover 7569 TJ of Heat

Operating Duty	Heat Recoverable TJ	Gigawatt Hours	Kilowatt Capacity	Installed Cost £100/kW	Heat Exchanger £30/kW
7000	7569	2103	300429	30042900	9012870

The calculations in the Table are straightforward. To derive Gigawatt hours from Terajoules the latter is multiplied by 0.2778 (see conversion tables in Appendix G). The capacity figure of 300429 kW is found by dividing 2103 GWh by 7000. The system value is derived by multiplying 300429 kW by the system price of £100/kW and similarly the heat exchanger value by multiplying by £30/kW. Therefore the installed cost of heat recovery equipment to recoup 7569 TJ of heat is approximately £30 million and of this, around £9 million is for heat exchangers.

The next stage was to determine if all of this potential was economic. By using a simple equation the break even point in terms of hours per year can be calculated.

$$H = \frac{29.31 \times n \times S}{P \times Y}$$

Where:

H = break even point in hours per year

29.31 = capacity in kilowatts necessary to recover 1 therm per hour

n = nominal boiler efficiency (fixed at 0.8)

S = average system price per kilowatt

P = price in pounds per therm

Y = payback period in years.

The average price of energy in 1978 was taken to be 19 pence per therm.

$$H = \frac{29.31 \times 0.8 \times 100}{.19 \times 2} = 6171 \text{ hours operation per year}$$

Given an average operating duty of 7000 hours per year all of the technical potential appears to be economic in 1978. Subsequent real rises in the price of energy will strengthen the incentive to install heat recovery equipment.

The final stage of the exercise was to estimate the likely market each year up to the year 2000. The total economic potential sets an upper limit on the cumulative value of the market up to the year 2000.

To estimate the market value in any particular year, some assumptions have to be made. The first is that the cumulative economic potential will be realised by the year 2000 and, secondly, that any growth in the market will occur smoothly.

In section A.7.3 of Appendix A the market for heat exchangers in the chemicals and allied industries was estimated to be £30.875 million. This is the starting point for any forecast. As has been stated previously the economic potential for heat recovery is based on opportunities that were available in 1978. It is further assumed that as the industry expands (if indeed it does) the number/volume of processes producing waste heat will also expand, thereby increasing the opportunities for waste heat recovery. Three different rates of expansion are postulated here; 2, 3 and 4 per cent per annum. These rates are double those used in section 9.6 on manufacturing industries. In the period 1966-1976 the growth trend for all manufacturing was 1.5 per cent per annum whilst the chemical industry over the same period grew at an annual average of 5 per cent.[125] The levels postulated above are lower than that achieved in the past but there are various reasons why the rate of growth of the industry is expected to be lower in the future. These factors are discussed in Caudle's paper 'Chemicals and Energy: The Next 25 Years'.[126]

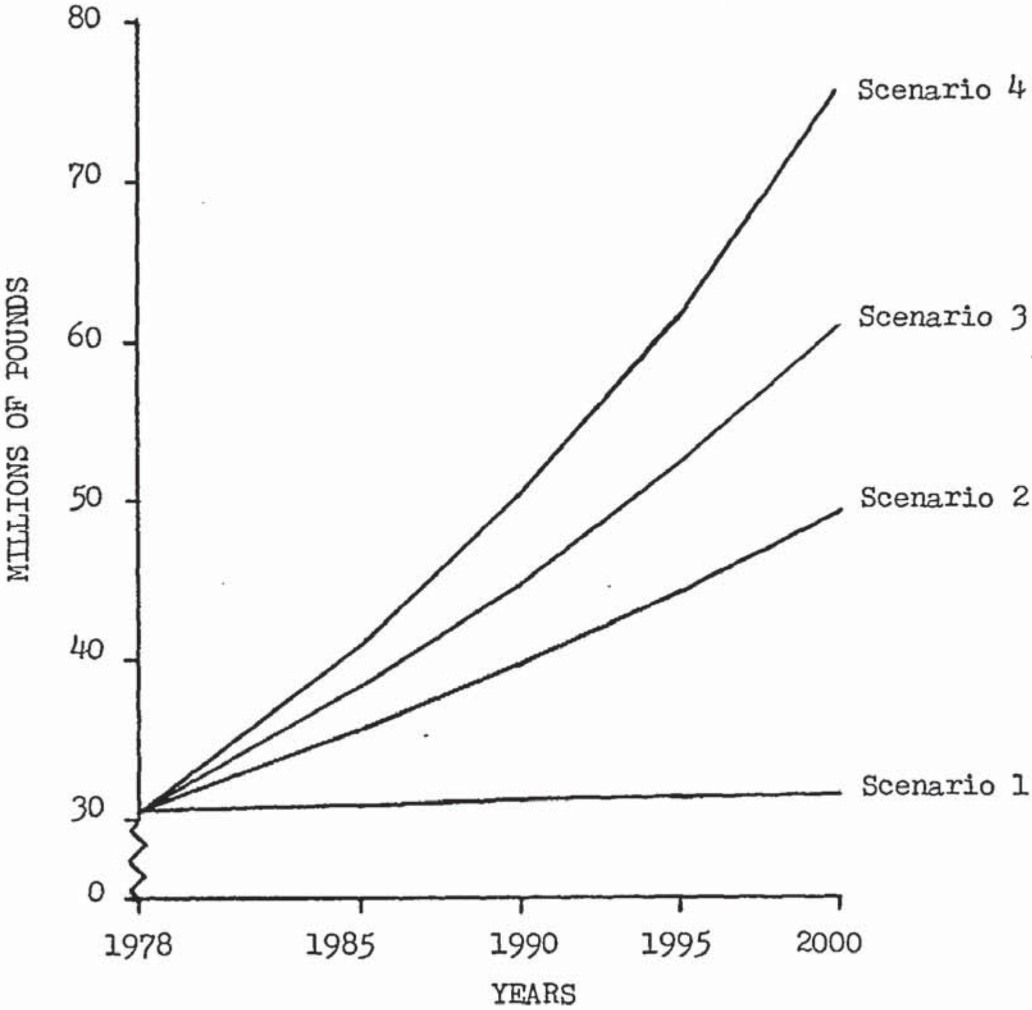
Table 9.7.3 below shows the forecasts for heat exchangers in the chemicals and allied industries for a base case and the three growth scenarios. The base case is the 1978 sales level with no expansion from growth of the industry only growth in the usage of heat exchangers.

TABLE 9.7.3 Forecasts of Heat Exchangers in the Chemicals and Allied Industries (£ Millions)

Scenario	Year					Cumulative Total for All Years 1978-2000
	1978	1985	1990	1995	2000	
1	30.88	31.11	31.29	31.46	31.63	719
2		35.78	39.76	44.18	49.09	904
3		38.34	44.74	52.22	60.95	1019
4		41.04	50.29	61.63	75.53	1152

The results from Table 9.7.3 are shown graphically in Figure 9.7.1.

Figure 9.7.1 Chemicals and Allied Industries Sector Results



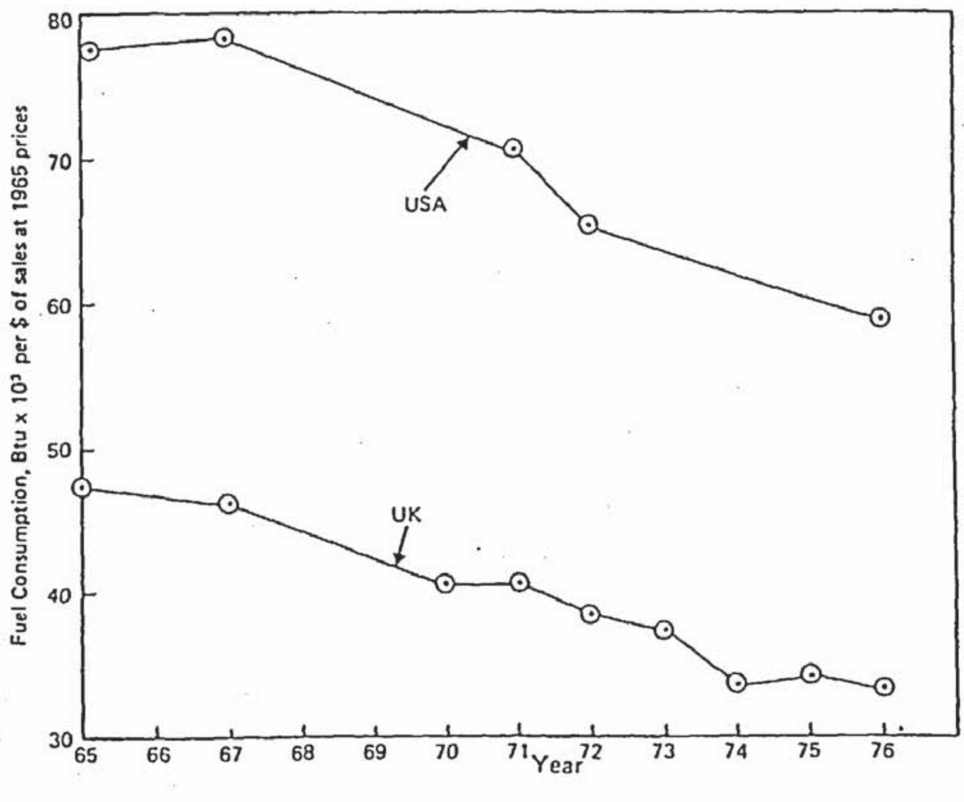
9.7.4

Discussion of Results

In the first stage of the results, savings from increased heat recovery are estimated to be 10092 TJ which is a little over 2 per cent of total energy consumption. In a study of the United States' chemical industry total energy consumption was given as 2805 PJ and estimated fuel savings from increased heat recovery 209 PJ or 7.45 per cent of total consumption.[127]

The difference in potential between the two industries is, in part at least, explained by the relatively greater consumption of energy per unit of output by the U.S. industry. This point is well illustrated by Caudle.[128] Figure 9.7.2 below is the data from Caudle's paper as presented by Grant.[129]

Figure 9.7.2 Fuel Consumption Per Unit Value of Sales for the U.K. and U.S.A. Chemical Industries



As shown in Figure 9.7.2 the consumption of energy per unit of output is much higher in the U.S. than the U.K. The low price of energy to the U.S. chemical industry has probably been the main reason for this. European energy prices are about 60 per cent higher than for the U.S. Energy usage in U.K. chemicals production is about 60 per cent of that in the U.S. As Caudle points out, U.S. chemical plants are as much 'gas guzzlers' as their automobiles. The apparently relatively greater potential for energy conservation in the U.S. industry is obvious. This is largely explained by the differences in energy usage between the U.K. and U.S. brought about by a large energy price differential rather than any underestimation of the U.K. heat recovery potential.

In section 9.6 on manufacturing industries it is estimated that around 9 per cent of energy consumption could be saved by waste heat recovery. Again this is much higher than the chemical industry. Chemicals manufacturing is on the whole an energy intensive industry well used to the technology of heat recovery which had been practised long before the 1973/74 oil crisis. Other manufacturing industries, amongst them some large energy users, do not on the whole have this tradition of energy conservation through waste heat recovery and hence the relatively greater potential for energy saving than in the chemicals industry.

There is more similarity in energy use and saving between U.K. and European chemicals industries than between the U.K. and U.S. industries. Further evidence indicating why the potential for increased waste heat recovery in the U.K. chemicals industries is relatively low appears in a report from the Netherlands published in 1974. There is a section in the report which refers to ammonia synthesis which is a large energy user and an important part of the Dutch chemicals industries (ammonia production is also an important part of the U.K. chemicals industries). The following is an extract from the report:

> 'An increase in the energy price would certainly act as an added stimulus for saving energy, but its effect would be slight. The reason for this is that all the main incentives for cutting energy costs are already operating ....'[130]

This refers to energy saving in general and not just waste heat recovery. P. S. Harris of ETSU is quoted by Leach on the subject of heat recovery in U.K. ammonia production.

> 'Opportunities for heat recovery in ammonia production are not significant; recovered heat already provides 60 per cent of the steam requirement and also preheats the boiler feed.'[131]

From this quote it can be seen that heat recovery is extensively practised but that the opportunities for increased heat recovery are limited. It would be reasonable to suppose that these comments could be equally applied to the rest of the U.K. chemicals industries to explain the large differences in waste heat recovery potential between chemicals and other manufacturing industries and also between the U.K. and U.S. chemicals industries.

It may, therefore, be concluded that the fairly modest possibility for increased waste heat recovery, cited in the results section, for chemicals is a reasonable estimate.

The equipment used in the chemicals industries for heat recovery is sometimes different from that which is used elsewhere. This is because the waste heat in other industries is mostly in the form of hot gases.[132] In the chemicals industries much of the waste heat has been in liquids and so liquid/liquid heat exchangers such as shell and tube types have tended to dominate. There are opportunities for gas/gas or gas/liquid heat recovery in chemicals.

The main difference between the chemicals industry and other manufacturing industries is that when a chemicals manufacturer is installing a heat recovery scheme only the heat exchanger is bought from the exchanger manufacturer and the other items will be bought as required from other suppliers. Other industries, not having the same expertise as the chemicals industries, would tend to want to buy a complete package from the exchanger manufacturer, which includes all of the ancillary items like ducting and pipework, and installation. For this reason in the section for manufacturing industries the price which includes all these extra items is called the system price. In this section the price that includes everything is called the installed price. These different terms are used to distinguish between the different requirements of these two markets.

A 2 year payback was assumed to be the normal investment criterion used in the chemicals industries. Although more sophisticated techniques are used, Grant notes that most investment in the chemical industries is assessed by simple payback and that discounted cash flow methods are not widely applied.[133] According to Grant most companies consider the maximum payback for energy conservation measures to be 2 to 3 years, whereas Clarke[134] cites 1.5 years as an average value. The 2 year payback adopted for this study seems to be a reasonable and commonly used criterion for the assessment of investment in heat recovery schemes.

The total economic potential for heat exchangers in heat recovery is valued in the results at around £9 million. As this is a modest amount the industry could realise the potential well before the year 2000. There are several factors which are likely to make exploitation of this potential a slow process. The chemical industries have already exploited most of the better heat recovery opportunities; the ones that remain are relatively small and so their individual contribution to savings is likely to be regarded as fairly insignificant in terms of overall energy costs.

I found from talking to companies that heat recovery as an investment is not treated any more favourably than any other investment opportunity. This may well slow down investment in currently economic schemes.

The installation of a heat recovery scheme cuts running costs but increases maintenance and capital costs. Plant reliability is inversely proportional to the number of items of plant. There is a reluctance to increase the number of items of plant for this reason. Plant downtime costs may far exceed the benefits from the installation of a heat recovery system.

Kantyka has discussed some of the problems which impede the installation of heat recovery schemes.[135] He argues that as far as heat exchangers are concerned the main non-financial problems appear to be fouling by fluids which often contain solid matter and/or impurities which tend to deposit and the problems caused by interrupting production to modify plant and install more heat transfer surface.

For these reasons it was assumed in the results that it would take until the year 2000 to realise the full potential for heat recovery within the chemicals industries.

It could be argued that Government financial aid would speed up the adoption of heat recovery schemes. As the chemicals industries have long experience of energy conservation, have built up a high degree of expertise and also have the funds available for worthwhile energy conservation schemes,[136] Government help, financial or otherwise would probably have little impact on the implementation of heat recovery schemes.

9.8

Mineral Oil Refining

9.8.1

Methodology

In common with other sections the first stage was to read around the subject area. This was done for familiarisation and to see what the impact of rising energy prices might be as far as the use of heat exchangers was concerned. As refineries are large users of energy, conservation is a much discussed topic. Although this study is concerned with U.K. refineries only, literature from abroad was consulted where relevant.

To quantify the effects of changes in the energy situation on demand for heat exchangers it was necessary to have data on energy used and rejected in the form of heat by refineries. Unlike sections 9.6 and 9.7 there was no published information such as that contained in the Industrial Energy Thrift Scheme reports or the Energy Audit Scheme reports. A confidential report on energy use in the refining industry was prepared for the Energy Technology Support Unit but not published. However some estimates are given in the Department of Energy's Energy Paper number 32. Individuals in the refining industry were also consulted.

From the estimates of savings possible from waste heat recovery the technological potential for waste heat recovery equipment was established.

The equipment prices used are the same as the ones in the manufacturing industries section (i.e. £100/kW for the system, £30/kW of which is for the heat exchanger).

The technological potential appeared to be economic at current energy prices so it was unnecessary to use forecasts of energy prices to determine if and when the technological potential would become economic. The upward trend in energy prices will provide an ever-increasing incentive for investment in waste heat recovery equipment.

Wherever and whenever required, contact was made with various organisations and individuals concerned with mineral oil refining.

9.8.2

Energy, Mineral Oil Refining and Heat Exchangers

Possibly three main effects could result from the changing energy situation. Firstly, a reduced requirement for oil refineries either because oil is in short supply or because demand for oil reduces as a result of rising prices. Secondly, a close substitute for oil is produced. Thirdly, more heat exchangers are required in refineries for increased heat recovery.

The demand for oil is fairly insensitive, particularly in the short term, to changes in price. In many situations oil is not easily replaced by other sources of energy. To change from oil central heating requires a new boiler with the extra cost that involves. Demand for oil could be reduced by, say, driving fewer miles in cars, but most people would find it difficult, if not impossible, to go without their cars altogether. In the longer term it would be possible to switch from using oil altogether in areas such as power generation and space heating. Also the efficiency of oil consuming products could be improved. For example cars can be made smaller, lighter and therefore more efficient in their consumption of petrol. In fact there are many ways of reducing demand for oil. These savings have to be offset against the inevitable increases in demand for oil as and when the economy expands.

The second main effect of the changing energy situation, the attempts to find substitutes for oil, is not in fact new. During the 1950's at least one brand of petrol was marketed in the U.K. which had a significant alcohol content. Brazil is one country where alcohol derived from vegetation is being used at least as a partial substitute for petrol. As the U.K. currently has relatively large quantities of oil and, unlike Brazil, limited land area for growing vegetation, this does not seem to be a likely option for the U.K. for the remainder of this century. Substitution of oil is possible by processing coal and turning it into a liquid fuel. It has been suggested that the commercialisation of gasoline from coal is still a hundred years away.[137] It is not that the technology does not work but rather that it is not likely to be economic for a long time to come.

A 'Watt Committee on Energy' report says about the production of liquid hydrocarbons from coal that 'synthetic liquids would not be required on a significant scale this century.'[138] It would seem that the demand for liquid fuels will be satisfied this century by oil.

The third main effect of the changing energy situation which could influence demand for heat exchangers is the desire to recover and re-use waste heat. Lazenby and others[139] noted in a paper in 1974 that although energy conservation in the refinery industry prior to 1973/74 had been neglected, high energy prices had changed the situation. The authors said that there was potential for increased heat recovery by improving the efficiency of transfer of heat from hot streams through heat exchangers to cold streams. Savings could also be made by recovering heat normally lost in furnace flue gases.

In Energy Paper number 5, British Petroleum noted possible savings in furnace energy consumption by the re-arrangement of existing heat exchangers or by the installation of additional heat exchanger surface. Esso and Shell U.K. Limited in the same paper mentioned the installation of additional heat exchangers to improve heat recovery.[140]

It seemed clear from the literature that more heat exchangers would be installed in response to higher energy prices so this was investigated further and the results are presented in the next section.

9.8.3

Results

The first stage of the exercise was to estimate the total technological potential for waste heat recovery in oil refining. ETSU commissioned a study of energy use in oil refining in the U.K. but the report was not published in order to protect the commercial interests of the refinery companies. However, in Energy Paper number 32 a figure for energy saving by waste heat recovery is given as 13.5 PJ.[141] This figure is derived from the ETSU report.

It was assumed that heat recovered would save heat being generated in an on-site boiler. ETSU usually assume a nominal boiler efficiency of 75 per cent. This means to save 13.5 PJ of energy, 10.125 PJ would have to be recouped by heat recovery schemes.

Refineries operate continuously so the operating duty was taken to be 8600 hours per year. The installed cost of heat recovery systems is £100/kW of which £30/kW is for heat exchangers. The value of the technological potential for heat recovery is estimated in Table 9.8.1.

TABLE 9.8.1 Estimation of the Value of Heat Exchangers to Recover 10.125 PJ of Heat

Operating Duty	Heat Recoverable PJ	Gigawatt Hours	Kilowatt Capacity	Installed Cost £100/kW	Heat Exchanger £30/kW
8600	10.125	2812.725	327061	32706100	9811831

The calculations in the Table are straightforward. To obtain Gigawatt hours, Petajoules are multiplied by 277.8 (see conversion tables in Appendix G). The kilowatts are derived by dividing Gigawatt hours by 8600. The installed cost and heat exchanger value are derived by multiplying 327061 kW by £100/kW and £30/kW respectively. The value of heat exchangers to recoup 10.125 PJ is estimated to be around £10 million.

The next stage was to determine what proportion of the technological potential was economic. This is done by using the equation below.

$$H = \frac{29.31 \times n \times S}{P \times Y}$$

Where:

H = break even point in hours per year

29.31 = capacity in kilowatts necessary to recover 1 therm per hour

n = nominal boiler efficiency (fixed at 0.8)

S = average system price per kilowatt

P = price in pounds per therm

Y = payback period in years.

The average price of energy in 1978 was taken to be 19 pence per therm.

Hence: $H = \frac{29.31 \times 0.8 \times 100}{.19 \times 2} = 6171$ hours operation per year

With refineries operating continuously it can be seen that all of the technological potential was economically attractive to exploit in 1978. Any energy price rises will increase the incentive to install heat recovery equipment.

The last part of the exercise was to estimate the likely market each year up to the year 2000. The total economic potential sets an upper limit on the cumulative value of the market, for opportunities which already exist, up to the year 2000.

To estimate the market value in any particular year some assumptions had to be made. The first is that the cumulative economic potential will be realised by the year 2000 and, secondly, that any growth in the market would occur smoothly.

In section A.8.3 of Appendix A the market for heat exchangers in the oil refining industry was estimated to be £13.5 million. This is the starting point for the forecast. Unlike the other forecasts, there were no assumptions made about rates of growth for the industry. The reasons for this are outlined in the discussion following these results.

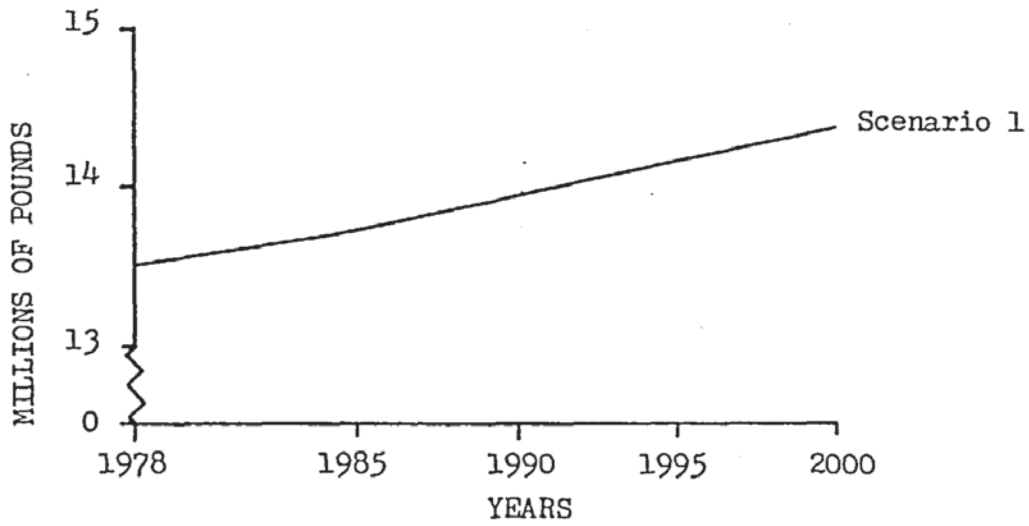
Table 9.8.2 below shows the forecast for heat exchangers in mineral oil refining for the base case only. The base case is the 1978 sales level with no expansion or contraction of the industry only growth in the use of heat exchangers.

TABLE 9.8.2 Forecast of Heat Exchangers in the Mineral Oil Refining Industry (£ Million)

Scenario	Year					Cumulative Total for All Years 1978-2000
	1978	1985	1990	1995	2000	
1	13.50	13.76	13.96	14.16	14.36	320

The results from Table 9.8.2 are shown graphically in Figure 9.8.1.

Figure 9.8.1 Mineral Oil Refining Sector Results



9.8.4

Discussion of Results

The first stage in obtaining the results was to look at the energy saving potential of increased heat recovery. The figure used comes from Energy Paper number 32 which in turn was based on a report written for ETSU (Energy Technology Support Unit). Other figures for potential savings through heat recovery have been published. Only one relates to the U.K. refining industry but the situation in other countries is relevant.

One study[142] of the U.S. refining industry, published in 1974, estimated potential savings in energy from increased heat recovery at 7.5 per cent, whilst another,[143] published in 1975 puts the savings at just over 3 per cent. There is, obviously, some disagreement over what can be achieved. As in the chemicals industries, there are differences between U.K. and U.S. practices in energy usage. The ETSU figures for U.K. refining indicate potential energy savings of around 4.7 per cent. This includes an amount for savings from increased insulation but this is thought to be small and is ignored.

A study of energy conservation in the Netherlands, published in 1974, says that energy savings from increased heat recovery of 3.5 per cent in an existing refinery and 5 per cent in a new refinery could be achieved.[144] These figures for the Dutch industry tie up reasonably well with the ETSU figure for the U.K.

A paper, published in 1979, puts savings from heat recovery from flue gases in U.K. oil refineries at £68 million.[145] This, the author says, corresponds to a 20 per cent saving in heavy fuel oil usage. This is a high figure but it can be partly explained by the fact that it represents a theoretical maximum and not what is likely to be achieved. The ETSU figure is based on a fairly comprehensive look at energy usage in the U.K.

oil refining industry. Orr's work does not have the same empirical base as it is not derived from the ETSU study which is the only reasonably complete examination of energy usage in the U.K. refining industry.

With the exception of Orr there seems to be some level of agreement about the scale of savings possible from increased heat recovery. The ETSU figure lies somewhere in between the other estimates.

The savings in refining are less than those estimated for other manufacturing industries which are around 9 per cent. This can be explained by the fact that heat recovery and the use of heat exchangers are well established and understood in the oil refining industry, much more so than in other industries with the exception of chemicals manufacturing.

Potential energy savings from heat recovery in the chemicals industries are lower than for refining at about 2 per cent. The demand for oil is normally fairly insensitive to changes in price and the oil companies have been in a strong position to pass on higher costs to the consumer. U.K. consumption of petroleum peaked in 1973 at 68.92 million tonnes and fell to a low of 59.97 million tonnes in 1975.[146] Over the same period oil prices quadrupled and oil companies total revenue rose. Chemicals manufacturers are not in such a strong position and there has, in all probability, been more pressure on them to keep costs down than on oil refiners.

It was shown in the results that the technological potential for increased heat recovery was economic with a payback of 2 years. The 2 year criterion used is a stringent one and returns over the life of the heat recovery scheme are ignored. Discounted cash flow methods of investment appraisal which do take account of returns over the life of the investment are likely to make investment in heat recovery look more attractive than they do under the payback method. As all of the heat recovery potential appears economic with the 2 year payback other criteria would not change the position.

However, heat recovery schemes have to compete for capital with other investment opportunities and may or may not appear sufficiently attractive for money to be invested in them.

Other factors are also likely to slow down the adoption of viable heat recovery schemes. The main barriers to such investment are increased capital and maintenance costs, disruption to production when new plant is installed and the increase in unreliability of a whole manufacturing complex brought about when the number of items of plant increases.

The potential savings from increased heat recovery are relatively small and they could be realised very quickly by the industry. If this were so sales of heat exchangers would rise for a time and then fall away again. In Chapter 8.0 on heat exchangers and energy it was shown that the effect of large oil price rises on the sales of heat exchangers has up until now been small. Robinson, in a paper published in 1980, noted that the exploitation of energy conservation opportunities takes a long time and is a slow developing process.[147]

For these reasons it was assumed in the results that the realisation of heat recovery opportunities in oil refining would take place slowly.

Unlike other results sections there are no assumptions about possible growth of industry output because of some major uncertainties. In 1974 industry capacity peaked at 148.6 million tonnes per annum whilst output reached only 70 per cent of this. By 1978 capacity had fallen to 133.1 million tonnes and output only 67 per cent of this.[148] This spare capacity was at a time when 50 per cent of North Sea crude was being exported. This is because U.K. refineries were designed for Middle East crude and cannot refine North Sea crude as economically as purpose built units. Whilst it is possible to convert existing refineries for North Sea crude many operators may be unwilling to invest in them for what may turn out to be a relatively short life. It has been forecast that the U.K. may be a net importer of oil by the 1990's.

An additional problem is that more and more petroleum exporting countries want to sell higher value refined products rather than crude oil. The U.K. may find itself importing refined products in the 1990's rather than just crude oil.

A report by the Watt Committee on Energy examines what resources will be needed over the period 1975-2025 to satisfy U.K. energy demand. Forecasts of required oil refining capacity for seven scenarios are made, which are shown in Table 9.8.3.

TABLE 9.8.3 Oil Refining Capacity Required for the Years 1990 and 2000 (Millions of Tonnes Per Annum)[149]

Scenario	1990	2000
0	109	116
1	79	81
2	78	98
3	78	79
4	111	115
5	104	106
6	129	124

Oil refining capacity in 1978 was 133 million tonnes per annum and it can be seen from Table 9.8.3 that for all scenarios the capacity is forecast to be smaller in the future.

It would have been possible to have scenarios 2, 3 and 4 of the results section representing different levels of decline. I have spoken to several people in the industry and although the concensus is that capacity will perhaps remain constant or fall over the next 20 years, capital spending may rise. Some companies will convert their refineries for North Sea crude whilst others will invest in plant to 'whiten the barrel'. This is the term used to describe efforts by refiners to get more high value, lighter products out of each barrel of oil like gasoline rather than low value products such as heavy fuel oil. As it is capital spending which is important when trying to determine the market for heat exchangers rather than capacity, it becomes difficult to forecast the effects on the heat exchanger market of the various changes taking place within the refining industry. Hence figures were only estimated for the base scenario.

9.9

Aggregation of Results

Table 9.9.1 shows the results for the eight different sectors. The Table shows the estimated 1978 value of the various markets (the methods for calculating these estimates are shown in Appendix A). The remainder of the Table shows forecast values of heat exchangers for four scenarios for the years 1985, 1990, 1995 and 2000.

The totals from Table 9.9.1 are shown graphically in Figure 9.9.1 below.

Figure 9.9.1 The Results for All Sectors

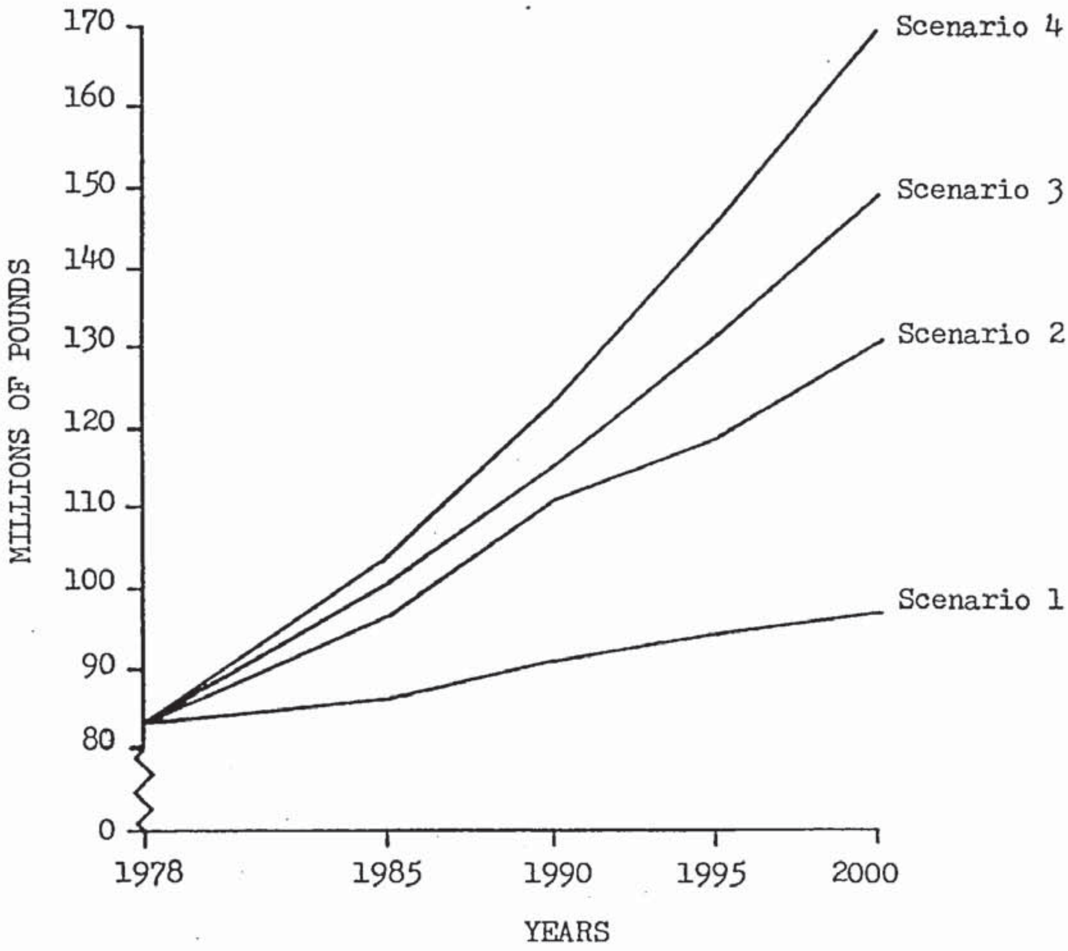


TABLE 9.9.1 Summary of Results

Sector	1978	1985				1990				1995				2000			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Road Transport	28.62	29.58	32.91	33.55	34.19	31.95	37.38	39.02	40.65	33.68	41.39	43.72	46.05	34.27	43.95	46.40	49.85
Rail Transport	1.28	0.82	2.63	2.07	1.92	1.70	6.22	2.79	2.61	1.20	2.00	2.60	2.38	1.06	2.10	2.87	2.36
Miscellaneous Machinery	6.70	7.05	7.55	7.82	8.10	7.32	8.25	8.76	9.28	7.50	8.89	9.67	10.51	7.67	9.55	10.65	11.86
Public Power Generation	0.64	0.74	1.11	1.19	1.27	0.75	1.02	1.10	1.18	0.77	1.45	1.64	1.82	0.77	1.45	1.64	1.82
Combined Heat and Power	0.90	1.13	1.14	1.15	1.15	1.13	1.15	1.17	1.18	1.13	1.16	1.19	1.21	1.13	1.18	1.21	1.24
Manufacturing Industries	1.28	2.17	2.41	2.54	2.67	3.16	3.78	4.13	4.50	4.60	5.94	6.72	7.60	6.69	9.33	10.95	12.84
Chemicals and Allied Industries	30.88	31.11	35.78	38.34	41.04	31.29	39.76	44.74	50.29	31.46	44.18	52.22	61.63	31.63	49.09	60.95	75.53
Mineral Oil Refining	13.50	13.76	13.76	13.76	13.76	13.96	13.96	13.96	13.96	14.16	14.16	14.16	14.16	14.36	14.36	14.36	14.36
TOTAL	83.80	86.36	97.29	100.42	104.10	91.26	111.52	115.67	123.65	94.50	119.17	131.92	145.36	97.58	131.01	149.03	169.86

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CHAPTER 10.0 DISCUSSION OF RESULTS

10.0

DISCUSSION OF RESULTS

Detailed discussion of the results for each sector can be found by looking at the appropriate sections of the results in Chapter 9.0. This section is devoted to discussion of all the sectors together.

The changing energy situation affects the demand for heat exchangers to different extents. This is shown in Table 10.1.

TABLE 10.1 Average Annual Percentage Growth in Demand for Heat Exchangers 1978 to 2000

Sector	Average Annual Growth %	Rank
Road Transport	0.82	4
Rail Transport	-0.85	8
Miscellaneous Machinery	0.62	5
Public Power Generation	0.84	3
Combined Heat and Power	1.03	2
Manufacturing Industries	7.81	1
Chemicals and Allied Industries	0.11	7
Mineral Oil Refining	0.28	6
TOTAL	0.69	

The figures relate to scenario 1 of the results (i.e. changes in heat exchanger demand brought about by the changing energy situation only). Manufacturing industries show the highest rate of growth with 7.81 per cent per annum. This is due entirely to the large potential for waste heat recovery in this sector. Both the chemicals and allied industries and mineral oil refining sectors are large users of energy and it constitutes a much higher proportion of costs than for the other manufacturing industries. Most of the opportunities for waste heat recovery in these two sectors have already been exploited and this is mainly because of the importance of energy costs and heat recovery is relatively straightforward. Hence they are ranked only sixth for mineral oil refining and seventh for chemicals and allied industries in terms of average annual percentage growth.

Combined heat and power for industry is the second fastest grower at an average 1.03 per cent per annum followed closely by public power generation at 0.84 per cent, road transport at 0.82 per cent and miscellaneous machinery at 0.62 per cent.

Rail transport is the only sector that shows a decline as a result of the changing energy situation and so comes bottom of the average annual percentage growth league.

If the absolute monetary increases in the various sector heat exchanger markets over the period 1978-2000 are used then the rankings change. This is shown in Table 10.2, again for scenario 1.

TABLE 10.2 The Monetary Increase in Market Value of the Year 2000 Over 1978 for Scenario 1

Sector	Increase in Market Value £M	Rank
Road Transport	5.65	1
Rail Transport	-0.22	8
Miscellaneous Machinery	0.97	3
Public Power Generation	0.13	7
Combined Heat and Power	0.23	6
Manufacturing Industries	5.41	2
Chemicals and Allied Industries	0.75	5
Mineral Oil Refining	0.86	4
TOTAL	13.78	

Road transport is number one in terms of growth of market value with manufacturing industries a close second. The rest register growth of less than a million pounds each with rail transport actually falling.

It is dangerous to look at these markets in terms of the impact of the energy situation alone. Scenario 1 of the results is rather artificial and constructed only to examine the impact of the energy situation on heat exchanger demand in isolation from other factors. The other scenarios used incorporate various assumptions about possible growth of the various markets. This was done in order to incorporate a more realistic dimension to the projections and to put the figures from scenario 1 firmly into context. As an example the figures from scenario 3 (medium growth) have been used to rank the sectors. This is shown in Table 10.3.

TABLE 10.3 The Monetary Increase in Market Value of the Year 2000 Over 1978 for Scenario 3

Sector	Increase in Market Value £M	Rank
Road Transport	17.78	2
Rail Transport	1.59	5
Miscellaneous Machinery	3.95	4
Public Power Generation	1.00	6
Combined Heat and Power	0.31	8
Manufacturing Industries	9.67	3
Chemicals and Allied Industries	30.07	1
Mineral Oil Refining	0.86	7
TOTAL	65.23	

The rankings of the different sectors have changed again with chemicals and allied industries taking the number one position with a heat exchanger demand that is just about double the 1978 level by the year 2000. Road transport registers a large increase of £17.78 million to put it second but this is perhaps over-rating its appeal to a company like Serck because much of the increase is in extra radiators for cars. The large car manufacturers produce their own radiators in-house and so much of the apparent increase in market value would not be available to independent heat exchanger manufacturers.

Perhaps the most interesting result is the move of rail transport from bottom to fifth place with a market value in 2000 which is over double the

1978 value. This is because although heat exchangers will suffer a relative decline in rail transport with the onset of further electrification, the future levels of investment in locomotives by British Rail will be significantly higher than that in 1978 if current investment plans are allowed to go ahead.

None of the sectors stands out as a potential high-flier in terms of extra heat exchanger demand brought about by the changing energy situation. Nevertheless, significant new business will arise even if it takes the form of a slow steady development over a long term rather than meteoric increases within the next couple of years.

It is interesting to compare the projections based on past trends in demand for heat exchangers contained in Chapter 7.0 with the projections discussed in this section. The actual yearly figures are not directly comparable as they are constructed on different bases. Nevertheless a comparison of rates and proportions of change is possible. From Chapter 7.0 the projected increase of demand for the whole heat exchanger market is around 15 per cent by the year 2000 compared with 1978. The comparable figure for scenario 1 of the sector analysis results from Chapter 9.0 is a little over 16 per cent. This seems to indicate that future demand for heat exchangers will grow at a rate very similar to that achieved in the period 1972 to 1978 but as a result of the changing energy situation only with no account be given to growth related to underlying economic expansion. If there is economic expansion in the period 1978 to 2000 then heat exchangers should outperform the levels of growth recorded during the seventies.

CHAPTER 11.0 CONCLUSIONS

11.0

CONCLUSIONS

11.1

On Forecasting

Forecasting is an area fraught with difficulties. This is not an excuse for not doing it but a reason why some forecasting is unsuccessful.

One area which can lead to difficulties is the fact that the forecaster is not usually the decision-maker although he will sometimes outline options suggested by the results. Therefore, before any work can be undertaken the forecaster has to be sure that he and the decision-maker are agreed on what the problem is and how it is to be tackled. The problem should be well specified and agreed between decision-maker and forecaster right at the beginning of the exercise. This can then be reviewed periodically throughout the work so that the decision-maker gets what he needs.

Availability and quality of data can be a problem if quantitative forecasting techniques are to be used but are less so if a qualitative approach is employed.

The skills required of the forecaster should not be under-estimated. There are the obvious requirements such as command of techniques and knowledge of the area being forecast as well as general experience of problem formulation and solution. There are less obvious but no less important skills required. Apart from his relationship with the decision-maker the forecaster will need the participation and support of other people who will supply or give access to necessary information. These people may be from within or outside the organisation for which the research is being conducted. It is the forecaster's job to seek and get this co-operation if at all possible. Failure to do so may impair the results.

When the results are presented either written or orally, the forecaster must be capable of getting the message over clearly and concisely. It is always worth bearing in mind that presentations are to laymen in the main and should be non-technical and jargon free where at all possible.

The resources available for forecasting will often be major constraints. This is not to say that useful work cannot be done with limited resources. In fact whilst the scale of available resources for forecasting may have a major impact on the kinds of techniques used, the amount of data collected or the number of people engaged on a project, it may have little impact on forecast accuracy or usefulness. The main resources which are likely to have an impact on forecasting activity are probably money, time in which to complete the project, the number of people involved in doing the work, the availability of computing facilities and so on.

Most people assess the worth of forecasting in general, or any particular technique by the accuracy and cost of it. In fact it is difficult to compare one forecasting method with another as each will probably yield different levels of accuracy and costs vary. A more expensive method need not produce better results in which case the cheaper approach should be used. If a more expensive method produces better results then the decision-maker must decide whether it is worth paying the extra. In some cases a given level of accuracy is adequate for making decisions in others it will be necessary to have a higher level and therefore incur the extra expense. Accuracy is not a criterion which should be used in isolation. A forecast may be accurate but not necessarily useful. This can occur where a problem has been wrongly or badly defined.

It could be assumed that there will be a free choice between different techniques but this is unlikely. As has been pointed out already there are factors which impose limits on forecasting maybe as far as making it impossible to produce useable results. Normally some forecasting should be possible under most circumstances although in many instances it will not necessarily be the ideal approach.

The achievement of good useable results, if they occur, are not the only benefits from forecasting. For instance if a company undertakes a forecasting exercise it means it is trying to come to terms with the future which although uncertain is almost sure to bring with it change. In forecasting and using the results the company will be thinking about its objectives for the future. This involves looking at its current position in relation to its markets and competitors. This assessment of the present position is very important because no forecast can have much meaning without reference to it. As a consequence of forecasting, and irrespective of the results, a company is likely to learn much about itself and its markets which will be of value in themselves. Companies often feel they know all they need to about these things so forecasting will possibly show how little they do know and improve their knowledge and awareness.

It is often the case that forecasting results prove to be disappointingly inaccurate. This tends to be more the case the greater the time period of the forecast. In other words, uncertainty, and therefore inaccuracy, increases with time. Even if a forecast has a sound methodological and theoretical base, assumptions have to be made and the greater the time horizon, the more likely that the assumptions will not hold true. Forecasts which are made at any one point in time are static whereas the environment is dynamic. A positive improvement may be achieved by the forecasts being reviewed and up-dated regularly. This is well illustrated by the projections of gross domestic product (GDP) shown in Figure 3.1 in Chapter 3.0. In this diagram five year forecasts of GDP are compared with the outturn. There are a whole series of forecasts which in the graph look grossly optimistic in comparison with actuality. On closer examination it is apparent that for some of the projections up to the first two years of the results are not too far off the mark. Repeating the exercise certainly seems to improve performance even if ultimately the extremities of all the forecasts prove to be wildly inaccurate.

Forecasting is an aid to decision-making, not a substitute for it. The decision maker should not see forecasting as a threat or view the forecaster as usurping decision-making power. Equally importantly the decision-maker should not have unrealistically high expectations of what forecasting can do. This has happened in the past and much of the blame must lie with the forecasters who have sometimes been guilty of over-selling forecasting and what it can do. Forecasting is simply a useful tool and should be treated as such by decision-makers and forecasters alike.

11.2

The Need for Companies to Forecast

It seems in the forecasting literature that few authors are concerned with why companies need to forecast. They assume that if you are reading a book on the subject you are already convinced of its merits.

Overall, there is only one reason for companies in the private sector of the economy to exist and that is to make money. To do this company managements have to make decisions continuously. A key aspect of making decisions is being able to predict the consequences of such action. Companies always have choices open to them. They try to assess what the future has in store for them and what the effects of their decisions might be in order that alternative courses of action can be evaluated.

Within every decision in business some estimate of the future is made. This can be done implicitly or explicitly . Implicit forecasting can be seen as being part of the 'seat of the pants' business philosophy which is an intuitive approach relying on the wit and experience of the decision-maker. This type of philosophy can, and has been, highly successful in many instances however intellectually unattractive it may seem. This is not to say that where intuition has been used successfully that more formal methods could not improve decision making. Implicit and explicit approaches to forecasting can be complementary. In fact, implicit (i.e. intuitive) forecasting has been formalised through such approaches as the Delphi technique.

There are many ways in which forecasting can assist managers in making decisions. An advantage of formal forecasting over pure intuition is that it is a conscious attempt to find out what the future has in store. Relying on intuition alone may mean that day to day pressing problems will always occupy the time of the decision-maker, concentrating his mind on the short term. In this way he may not see events until they are almost on top of him, by which time the company will probably be unable to react to them. All companies need time to react to a likely development although this will vary from company to company and industry to industry.

Through formal forecasting, companies can scan their environment to see developments which could have an impact on the companies' future particularly on their products and markets. Change can mean both threats and opportunities. A threat could be turned into an opportunity if recognised early enough. A missed opportunity can rarely be recaptured.

Apart from foreseeing developments, forecasting can help identify the likely timing of events. The importance of the timing is in relation to the lead time required by a company to take account of an event. If the event seems likely to be very close to the company's current planning horizon then this will have an impact on the corporate strategy so that account can be taken of the event. If the timing of the event appears to be beyond the company's planning horizon then continued monitoring is all that is required. This means that the importance of events can be ranked in relation to the timing of the impact rather than the size of the impact. It can be the case that seemingly small scale events are glossed over and attention is devoted to larger but more distant events. Examples of this occured shortly after the 1973/74 oil crisis when there was much talk of oil running out and how technologies must be developed immediately to replace oil using technologies. It has only been subsequently that more attention has focussed on the way oil is used and efforts concentrated on ways of improving current oil consuming technology to make it last longer and give the World more time to develop new energy sources and technology.

To sum up, forecasting can help avoid the bad and exploit the good. If forecasting provides the decision-maker with a clearer picture of the future and its consequences and he uses it to improve the quality of his decisions then the effort and allocation of resources to it are justified.

11.3

The Role of Forecasting at Serck

As has been noted already all decision-makers speculate about the likely future and the consequences of their actions. It is inherent in decision making and may be implicit or explicit.

All but the smallest companies undertake budgetary type forecasting for periods of normally up to a year ahead. This involves forecasting sales levels, purchasing expenditure, and so on, enabling the operational requirements and short term objectives of the business to be satisfied. A smaller number of companies undertake formal research into current and possible future markets with current and possible future products usually for periods of up to two years ahead and possibly longer. Whilst market research can provide information for budgetary purposes it normally has a wider role in determining the future objectives and direction of the company.

Serck up until recently had been using budgetary and market research based forecasts for decision making. The recession with its tendency to push companies into cost-cutting in order to survive has led Serck to curtail its market research efforts to the extent that most former market analysts have left the company. The market research function, however, still exists along with a market information system which has been built up over the years, but unless it is up-dated continuously, will soon have a rapidly diminishing value. Such is the transient nature of this sort of information.

The low priority given to market research expenditure may be for two different reasons. The first is that operational problems absorb all managements time and company resources and there is little or nothing to spare for other activities. Secondly managers' attitudes to the value of market research may be such that they have low expectations of it, consequently devote few resources to it, making it highly likely that their expectations are realised. It is hard to say which of these led to a downfall of market research at Serck, as its demise was at a time of management changes at the top of the company and a sharply declining manufacturing industry. It would seem to be more likely that the present economic situation is largely, if not solely, to blame.

This leaves the company only engaged in doing short term forecasting for budgetary needs with effectively no market research and certainly no long term global work of the type contained in this study. Ignorance of the future, for whatever reasons, leaves the company in the position where it is more likely to miss opportunities and fail to negate threats than if it was to look at the future explicitly and beyond the requirements of budgets.

11.4

Results and Policy Issues for Serck

The results show for all sectors, bar one, that the changing energy situation will lead to an increased demand for heat exchangers albeit only marginally in some sectors. This means that whatever level of growth is obtained in any of the sectors with the exception of rail transport the demand for heat exchangers should exceed that growth.

The rail transport sector illustrates the danger of reaching conclusions on the basis of changes in one parameter only; in the case of this study, energy. Although it has been shown that the demand for heat exchangers will fall as British Rail employs more electric locomotives at the expense of diesel units this is a relative decline only. Future investment by British Rail is likely to be on such a scale that the actual demand for heat exchangers will rise well above the 1978 level to perhaps as much as £6 million by 1985. This makes rail possibly one of the most attractive sectors as far as Serck is concerned.

The heat exchanger industry is a mature one and change tends to take place at a fairly slow rate. The changing energy situation will add some impetus but this is likely to take the form of a modest upturn rather than a dramatic acceleration of market demand. Much more variation in demand will be due to the general level of economic activity prevalent at any point in time which is likely to mask the effect of the changing energy situation on demand for heat exchangers.

Like most opportunities, the developments taking place in the various heat exchanger markets will have to be actively pursued by Serck in order to derive any benefit from them. In fact in at least one area Serck has already done this, namely in the form of Energy Systems Division. This division was set up shortly after the inception of this study. Having a separate unit to exploit opportunities in waste heat recovery is almost certainly the right approach. The markets and some of the products are new to Serck but most importantly the philosophy of solving a customer's waste heat recovery problem often involves the bringing together of expertise and equipment from many areas. This 'turnkey' approach is different from the product manufacturing and selling approach adopted elsewhere in the company and will function best with a certain amount of independence.

Turbocharging and charge air cooling is not new and Serck has many years experience in this area, mainly in large diesel engines. It appears that in the future many more of the smaller high speed diesels will be turbocharged and intercooled. With its past experience Serck should be well placed to exploit these opportunities. There is the further possibility of turbocharging and charge air cooling petrol engines. This will bring with it opportunities for oil coolers as well as charge air coolers through, most probably, small aluminium radiators. This market will take the form of relatively high volume and low margin products sold to the motor car manufacturers. Serck pulled out of the motor industry in the late sixties because it was unable to produce an acceptable return from the business. The large car producers in the U.K. largely manufacture their own radiators in large quantities.

The demand for oil coolers and charge air coolers, although large volume by Serck standards, will be quite small by motor industry standards. As an example Renault have a target of 80 a day of the R18 turbo saloon which is around 20,000 a year (see section 9.1.4). All of these are fitted with a charge air cooler making a substantial, although by no means large in motor industry terms, demand for heat exchangers. Serck could use its experience and knowledge of charge air cooling to establish itself in this developing market.

Another area which appears to have reasonable growth potential for heat exchangers, although for reasons largely unconnected with energy, is the chemicals and allied industries. The possible expansion of potential here is really outside the scope of this study because it's not, on the whole, related to energy but nevertheless deserves a mention. Growth in this sector over the last twenty years or so has been greater than for the economy as a whole and this is likely to be the case in the future, although not to the same extent as it has been in the past. Serck does not supply this sector as the products, although superficially similar, are in fact quite different to Serck's as far as detail design, production and marketing goes. To tap this market would require either the setting up of a process equipment division largely independent of the rest of the company, or perhaps the acquisition of a company which already supplies this sector.

The chemicals and allied industries sector also appears to be moving away from the almost complete dominance of shell and tube types and towards greater use of plate type heat exchangers where operating conditions permit. This trend was reported during the research by several engineers, one even saying that he felt that plate types would eventually account for the majority of applications currently satisfied by shell and tube type exchangers. Serck already sells plate types but does not manufacture them, although the idea has been considered several times in the past but has always been rejected. Selling plate types to the chemicals and allied industries sector might be one way to expand Serck's range of markets and products.

The developments taking place in public and private power generation through more nuclear power and small scale combined heat and power schemes can be accommodated through Serck's existing modus operandi.

This study has shown that energy related developments will affect the various heat exchanger markets mostly in a favourable way. Serck is in a good position to exploit any opportunities with what really amounts to in most cases a modest effort.

11.5

The Value of the Study and the Approach Used

This study has possible utility on several levels. Firstly to the company, secondly to myself and thirdly to others who may wish to undertake a similar exercise under similar circumstances.

For the company there are several possible benefits. Firstly there is the identification and estimation of current and future markets, some of which Serck operates in and others which it does not, which has not been done and presented in this form before. Secondly, the identification of some particular opportunities which the company may wish to exploit in the future. Thirdly, the company now has someone (Me) with in-depth knowledge of its own and other related markets. Fourthly, the methodology of the study, although quite complicated in application, is quite simple philosophically and could be repeated quite easily by almost anybody with access to the appropriate information. This is an important point because I believe to have a lasting value, a forecasting study needs to be up-dated (repeated) periodically. To do this it is helpful if the approach is fairly straightforward and perhaps more importantly, inexpensive. Because the main part of the study is broken down into sectors it is possible just to repeat individual sectors.

For myself this study has been a challenge. This is because most things worth doing are not at all easy and this was certainly the case with this thesis. One big problem was the availability of data and if the exercise is repeated at some stage in the future there is now a pool of data and indications of further sources on which to base the next effort. I now know something about various techniques which, although not utilised in this study, could be used elsewhere at a later date.

As a result of doing this work I was invited to give a talk on the future of the diesel engine to an informal discussion group comprised of diesel engine manufacturers and component suppliers called the Engine Market Study Group. This talk was given in June 1979 and the paper on which it was based is reproduced in Appendix F.

Others may find this study interesting if they are considering doing something similar for an industrial company.

A study such as this is as good as the use to which it is put and the impact it has. This does not mean that whoever reads this study should necessarily agree with what is written, but that it should stimulate logical thought and discussion and promote action.

APPENDICES

APPENDIX A COVERAGE, USES FOR HEAT EXCHANGERS AND ESTIMATES OF THE 1978 MARKETS FOR EACH OF THE SECTORS CONTAINED IN CHAPTER 9.0

A.1 Road Transport

A.1.1 Coverage of the Section

This section covers cars, and commercial vehicles manufactured and sold for use in the U.K. only. Specialised construction equipment such as bulldozers, dumpers, excavators etcetera are not included here, they are to be found in section A.3 for miscellaneuous machinery. Agricultural equipment such as tractors and combine harvesters are also included in section A.3.

A.1.2 Uses for Heat Exchangers

The vast majority of U.K. produced vehicles use either a petrol (spark ignition) or diesel (compression ignition) engine. In 1978, only 5 electric cars and 1173 electric goods vehicles were registered.

Although petrol and diesel engines may be air cooled all U.K. manufactured vehicles use water cooled engines. This necessitates the use of a radiator to dissipate the heat from the engine jacket water to air.

Most diesel engines down to 100 HP (75 kW) are fitted with a lubricating oil cooler. Below this level about 50 per cent are so equipped. Oil coolers are only occasionally fitted to petrol engines; usually they are only to be found on high performance engines in sports cars.

A transmission oil cooler may be fitted to commercial vehicles with automatic gearboxes but often the gearbox oil is cooled via the lubricating oil cooler. On petrol engined cars with automatic gearboxes a transmission oil cooler only becomes necessary when the car is used for towing.

Oil coolers may be small air cooled units or they may utilise the engine jacket water as the cooling medium through a shell and tube type heat exchanger with the heat ultimately being dissipated to air by the engine radiator.

Some commercial vehicles are fitted with a turbocharger for increased output and if so may also be fitted with a charge air cooler to further increase output. If a petrol engine is turbocharged it would almost certainly require an oil cooler to cope with the extra heat dissipated into the lubricating oil.

Electric vehicles have no heat exchanger requirement.

A.1.3 The 1978 Market

The market in this sector consists of heat exchangers fitted to all U.K. produced vehicles for sale in the U.K. This is smaller than the total number of heat exchangers sold for fitting to U.K. produced vehicles because many of these are exported. The number of vehicles involved in 1978 was 728370 cars and 215550 commercial vehicles. These numbers were derived from Business Monitor figures for U.K. production and export of vehicles.[1]

The value of heat exchangers used on any particular vehicle depends upon:-

- the engine type (petrol or diesel)
- the engine output because this will determine the amount of heat to be dissipated
- whether or not the engine is turbocharged and charge air cooled.

The heat exchanger prices for the different categories of vehicles are shown in Table A.1.1 over. It has been assumed that where it is necessary to cool gearbox oil that this is done through a combined lubricating oil/transmission oil cooler and not through a separate heat exchanger

TABLE A.1.1 Average Heat Exchanger Prices (1978 Values £'s)

Heat Exchanger	Vehicle Type		
	Cars	Commercial Vehicles Under 30 cwt Unladen Weight	Commercial Vehicles Over 30 cwt Unladen Weight
Radiator	22	22	103
Oil Cooler	17	17	28
Intercooler	24	24	51

The data in Table A.1.1 are derived from Serck information on heat exchanger costs.

Table A.1.2 shows the number of vehicles of each type broken down into petrol and diesel engined. This petrol/diesel breakdown was derived from a Society of Motor Manufacturers and Traders (SMMT) publication[2] which shows vehicle registrations of petrol, diesel and electric types. The breakdown of commercial vehicles into less than and greater than 30 cwt unladen weight was derived from the aforementioned SMMT publication and Serck's own marketing information.

TABLE A.1.2 Breakdown of Vehicles into Type and Power Unit

Engine Type	Vehicle Type		
	Cars	Commercials < 30 cwt Unladen Weight	Commercials > 30 cwt Unladen Weight
Petrol	728370	134292	5692
Diesel		10108	65458
TOTAL	728370	144400	71150

Note: There were 5 electric cars and 1173 electric goods vehicles registered in 1978[3] but it is not known whether or not they were made in the U.K. For this reason and because the numbers involved, when compared to the total is small, they have been ignored.

The next stage in estimating the market size is to look at the proportion of vehicles of each type which use the various heat exchangers. This information, which is derived from Serck's own market research data, is shown in Table A.1.3 below.

TABLE A.1.3 The Usage of Various Heat Exchangers on Vehicles with a Petrol or Diesel Engine (Percentage Penetration)

Engine Type	Heat Exchanger	Vehicle Type		
		Cars	Commercial Vehicles	
			<30 cwt uw	>30 cwt uw
Petrol	Radiator	100	100	100
	Oil Cooler	0	0	0
	CAC	0	0	0
Diesel	Radiator	100	100	100
	Oil Cooler	50	50	100
	CAC	0	0	5.29*

*Note: 23 per cent of vehicles above 30 cwt unladen weight with a diesel engine were fitted with turbochargers in 1978. Of these, 23 per cent were further equipped with a charge air cooler making 5.29 per cent of the total engines in this class (source: Serck marketing information).

If the percentage penetrations of the different heat exchangers in Table A.1.3 are applied to the numbers of vehicles in Table A.1.2 then the number of heat exchangers of different types fitted to vehicles can be shown, as in Table A.1.4.

TABLE A.1.4 The Number of Heat Exchangers of Different Types Used on Vehicles in 1978

Engine Type	Heat Exchanger	Vehicle Type		
		Cars	Commercial Vehicles	
			<30 cwt uw	>30 cwt uw
Petrol	Radiator	728370	134292	5692
	Oil Cooler	0	0	0
	CAC	0	0	0
Diesel	Radiator	0	10108	65458
	Oil Cooler	0	5054	65458
	CAC	0	0	3463

From these figures and using the heat·exchanger values in Table A.1.1 the market value can be estimated. The results are shown in Table A.1.5.

TABLE A.1.5 1978 Market Estimates

Engine Type	Heat Exchanger	Vehicle Type			Total
		Cars	Commercial Vehicles		
			<30 cwt uw	>30 cwt uw	
Petrol	Radiator Oil Cooler CAC	16024140 0 0	2954424 0 0	586276 0 0	19564840 0 0
Diesel	Radiator Oil Cooler CAC	0 0 0	222376 85918 0	6742174 1832824 176613	6964550 1918742 176613
TOTAL		16024140	3262718	9337887	28624745

The market estimate for 1978 is £28.6 million. A considerable proportion of this total is captive sales to the big car manufacturers. Leyland for instance has its own radiator manufacturing company, Llanelli Radiator. Some of the small production run vehicles like trucks and buses have heat exchangers produced by independent heat exchanger manufacturers (independent from the vehicle manufacturers that is). Most cars are massed produced so the radiators used are manufactured in-house. Smaller car manufacturers which only produce a few hundred vehicles, like TVR, buy their radiators from outside suppliers.

Probably less than £10 million worth of business is available to independent producers of heat exchangers, from the U.K. manufacture of vehicles for the U.K. market.

A.2 Rail Transport

A.2.1 Coverage of the Section

This section includes mainline passenger and freight locomotives as well as diesel and electric multiple units used by British Rail. Shunters are not included because none have been built for British Rail for a number of years and also rising energy prices will not have any effect on the way heat exchangers are used on shunting engines.

A.2.2 Uses for Heat Exchangers

The majority of heat exchangers used in locomotives are to be found on diesel engines. Heat exchangers are used on electric locomotives but to a much lesser degree than on diesel locomotives.

On mainline diesel locomotives for passenger and freight duties heat exchangers are used for the diesel engine jacket water cooling, lubricating oil cooling, and charge air cooling as well as for transmission, gearbox oil and brake cooling. Typical engine sizes are in the 1500-2500 kW range.

Much smaller engines are used on diesel multiple units (DMU) which run on local services. Typically a DMU will have three cars, a power car at each end and a trailing (unpowered) car in the middle. Each power car is fitted with a diesel engine of about 112 kW output. Each of these engines is fitted with a jacket water cooler and an oil cooler. These engines are not turbocharged and therefore do not use a charge air cooler. The duties required of these trains is much lighter than for mainline locomotives as indicated by the small engine size and therefore no gearbox or brake cooling is required.

On mainline electric locomotives there is no requirement for heat exchangers on the electric motors as relatively little heat is given off by them. Heat exchangers are however used to cool the transformer oil and the gearbox oil.

On electric multiple units (EMU) there is no heat exchanger requirement.

The heat exchangers used are a mixture of shell and tube and air cooled types. Generally shell and tube being used for lubrication oil cooling transmission cooling and so on and the air cooled heat exchangers used for the main cooling water circuit.

A.2.3 The 1978 Market

In 1978 British Rail Engineering Ltd. (BREL) built four types of locomotives for use by British Rail. These were the Class 56 diesel freight locomotives, the electric Advanced Passenger Train (APT), the diesel powered High Speed Train (HST) and some electric multiple units. Table A.2.1 below shows the build rate for these locomotives plus the number of each type withdrawn during the year for both 1978 and 1979.

TABLE A.2.1 Builds and Withdrawals of Various Types of Locomotives for 1978 and 1979[4]

Loco. Type	No. Built 1978	No. Withdrawn 1978	No. Built 1979	No. Withdrawn 1979
Diesel	18	40	16	25
Electric	0	8	0	2
APT	2	0	3	0
HST	35	2	27	0
DMU	0	20	0	9
EMU	42	44	204	87

As can be seen from the Table in both 1978 and 1979 the number of locomotives built is less than the number withdrawn. This is some indication of the state of the market which was and had been in a state of decline for a number of years.

The value of heat exchangers used in locomotives in 1978 is shown in Table A.2.2 over.

TABLE A.2.2 The Estimated Value of Heat Exchangers Used in Locomotives in 1978 and 1979

Loco. Type	Value of H/E Per Vehicle	Heat Exchanger Value in 1978	Heat Exchanger Value in 1979
Diesel	22264	400752	356224
Electric	N.A.	0	0
APT	4500	9000	13500
HST	24984	874440	674568
DMU	N.A.	0	0
EMU	0	0	0
TOTAL		1284192	1044292

Since being formed in 1970 all British Rail locomotives are built by BREL with the private sector only picking up sub-contract work.

The heat exchanger values are from Serck's own figures in 1978 values.

A.3 Miscellaneous Machinery

A.3.1 Coverage of the Section

Heat exchanger applications in this section fall into two main categories; engine and non-engine. The engine category covers all engine applications except road and rail transport. This includes engines used for powering the following:

- compressors
- welding and generating sets
- fork lift trucks
- mobile cranes and other materials handling
- dumpers and off-highway dump trucks
- excavators
- pumps
- shovels
- crawler tractors
- road rollers
- concrete mixers (including truck mixers)
- miscellaneous construction equipment
- miscellaneous industrial equipment
- combine harvesters
- tractors

The non-engine category includes heat exchangers used on the following:

- compressors
- pumps
- transformers and power transmission equipment
- heat treatment plant.

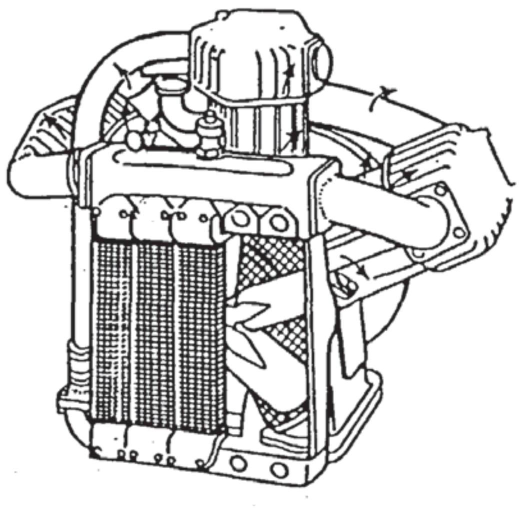
A.3.2 Uses for Heat Exchangers

All the heat exchangers in this section are used on machines generally cooling the machine to get rid of unwanted heat. On diesel engines a radiator is used to cool the engine jacket water and an oil cooler for the lubricating oil. If the engine is fitted with a turbocharger then it may also have a charge air cooler.

Petrol engines normally only require a radiator for the engine jacket water. It is possible to turbocharge petrol engines. The turbocharger dissipates large amounts of heat into its lubricating oil which is usually connected to the engine lubricating oil. An oil cooler would probably be required. In much the same way as on diesel engines petrol engines which are turbocharged can also be fitted with a charge air cooler.

In other equipment like machine tools and heat treatment plant heat exchangers are used to channel away unwanted, or waste, heat. On compressors heat exchangers can perform two different tasks. Some compressors work in several stages and if the air is cooled between stages it increases the air density, as in turbocharger charge air cooling, and reduces the amount of energy used in the compressor to reach the desired level of compression. Figure A.3.1 below shows an airblast intercooler fitted to a three stage reciprocating compressor.

Figure A.3.1 Air Cooled Heat Exchanger Fitted to a Three Stage Reciprocating Compressor for Intercooling[5]



The second function of heat exchangers fitted to compressors is to cool air after it has been through all the stages of compression. This cooling allows water contained in the air to be condensed out. This is to stop water condensing out in the piping carrying the air or in the tools which are air powered.

A.3.3 The 1978 Market

Serck's own definition of the U.K. market for heat exchangers in this sector differs from that used in this study. Serck's definition of the U.K. market is those heat exchangers which are delivered to U.K. customers. This does not recognise that the customer (the engine manufacturer) then exports some engines and sells the rest to U.K. producers of equipment such as, say, bulldozers. Some of this equipment is exported. The rest that are left are sold to customers for use in this country. It is this final customer that this study is concerned with.

The market for heat exchangers can be estimated from the number and size of engines sold for use in the U.K. The number of engines sold to U.K. producers of equipment is shown in Table A.3.01 over broken down by application and engine size.

To find the number of these engines which are eventually sold for use in the U.K. the number which are exported have to be subtracted. This was done by looking at figures contained in the Government's Business Monitor series. The Business Monitor figures show sales of goods by U.K. manufacturers, exports and imports. These figures are quite detailed so that for some applications, contained in Table A.3.01, the proportion which are sold to U.K. users could be derived. In other cases the nearest equivalent category was used. The proportions used are contained in Table A.3.02.

TABLE A.3.01 Diesel Engines Supplied to U.K. Manufacturers of Equipment

SECTOR	APPLICATION	ENGINE SIZE CATEGORIES (KW)										
		16-30	31-50	51-75	76-100	101-150	151-200	201-300	301-500	501-750	751-1000	TOTAL
Industrial and Construction Equipment	Compressors	1787	2230	4197	407	380	531	135	3			9670
	Welding and Generating Sets	1202	2072	2619	1154	560	810	1666	551	637	6	11277
	Fork Lift Trucks	5	5455	2864	1314	78	12					9728
	Mobile Cranes etc.		344	546	152	924	194	50	2			2212
	Dumpers etc.		76	57	7	16	75	143	33	1		408
	Excavators			616	661	283	34	34	7			1635
	Pumps		130	279	132	129	37	30	9	7	1	754
	Shovels		10	489	289	497	71	45				1401
	Crawler Tractors		7	88	118	60		19				292
	Road Rollers		133	220	107							460
	Concrete Mixers		81	579								660
	Miscellaneous Construction	5	72	271	234	176	83	22	29			892
	Miscellaneous Industrial	10	481	644	183	98	17	57	13	4		1507
Sub-Total		3009	11091	13469	4758	3201	1864	2201	647	649	7	40896
Agricultural Equipment	Combines		2	796	216	4	7					998
TOTAL		3009	11093	14238	4974	3205	1871	2201	647	649	7	41894

TABLE A.3.02 Derived Proportions of U.K. Produced Industrial, Construction and Agricultural Equipment Which are Delivered to the Home Market

Sector	Proportion for U.K.	Business Monitor from which Proportion was Derived
Compressors	0.63	PQ333.3 Compressors, 3rd Quarter 1980
Welding and Generating Sets	0.62	PQ361 Electrical Machinery, 3rd Quarter 1980
Fork Lift Trucks	0.47	PQ337 Mechanical Handling Equipment, 1st Quarter 1980
Mobile Cranes etcetera	0.62	PQ337 Mechanical Handling Equipment, 1st Quarter 1980
Dumpers etcetera	0.13	PQ336 Construction and Earth-moving Equipment, 3rd Quarter 1980
Excavators	0.13	PQ336 Construction and Earth-moving Equipment, 3rd Quarter 1980
Pumps	0.64	PQ333.1 Pumps, 3rd Quarter 1980
Shovels	0.13	PQ336 Construction and Earth-moving Equipment, 3rd Quarter 1980
Crawler Tractors	0.13	PQ336 Construction and Earth-moving Equipment, 3rd Quarter 1980
Road Rollers	0.13	PQ336 Construction and Earth-moving Equipment, 3rd Quarter 1980
Concrete Mixers	0.13	PQ336 Construction and Earth-moving Equipment, 3rd Quarter 1980
Miscellaneous Construction	0.13	PQ336 Construction and Earth-moving Equipment, 3rd Quarter 1980
Miscellaneous Industrial	0.60	No Business Monitor equivalent. Approximates to compressors, welding and generating sets and pumps.
Combines	0.50	PQ331 Agricultural Machinery (except tractors), 3rd Quarter 1980

These proportions applied to the appropriate figures in Table A.3.01 give the number of engines for each application which are sold for use in the U.K. The results are shown in Table A.3.03 over.

Based on Serck's own data the following Table contains prices for heat exchangers for each size category of engine.

TABLE A.3.04 Heat Exchanger Prices for Diesel Engines

Heat Exchanger Function	Engine Size (kW)									
	16-30	31-50	51-75	76-100	101-150	151-200	201-300	301-500	501-750	751-1000
Radiator	24	37	57	80	114	214	305	488	763	1068
Oil Cooler	20	20	20	26	37	52	74	207	461	645
Charge Air Cooler	-	-	25	35	50	71	101	292	662	927

These prices are only approximate. They do however reflect the fact that in the larger engine sizes heat exchangers become progressively more expensive as quantities produced are much less than in the smaller engine sizes.

From the number of engines contained in Table A.3.03 and the heat exchanger prices in Table A.3.04 the 1978 market for radiators, oil coolers and charge air coolers in industrial and construction equipment engines can be derived. At this stage engines for industrial and construction equipment applications are treated separately from engines for agricultural applications. These latter engines are returned to later in this section.

TABLE A.3.03 Diesel Engines Sold for Use in the U.K. Broken Down by Application

SECTOR	APPLICATION	ENGINE CATEGORIES (KW)										
		16-30	31-50	51-75	76-100	101-150	151-200	201-300	301-500	501-750	751-1000	TOTAL
Industrial and Construction Equipment	Compressors	1126	1405	2644	256	239	335	85	2			6092
	Welding and Generating Sets	745	1285	1624	715	347	502	1033	342	395	4	6992
	Fork Lift Trucks	2	2564	1346	618	37	6					4573
	Mobile Cranes etc.		213	339	94	573	120	31	1			1371
	Dumpers etc.		10	7	1	2	10	19	4			53
	Excavators			80	86	37	4	4	1			212
	Pumps		83	179	84	83	24	19	6	4	1	483
	Shovels		1	64	38	65	9	6				183
	Crawler Tractors		1	11	15	8		2				37
	Road Rollers		17	29	14							60
	Concrete Mixers		11	75								86
	Miscellaneous Construction	1	9	35	30	23	11	3	4			116
	Miscellaneous Industrial	6	289	386	110	59	10	34	8	2		904
Sub-Total		1880	5888	6819	2061	1473	1031	1236	368	401	5	21162
Agricultural Equipment	Combines		1	385	108	2	4					500
TOTAL		1880	5889	7204	2169	1475	1035	1236	368	401	5	21662

Table A.3.05 contains the estimated value of heat exchangers used in each size category of engine in 1978. The information on which engines are fitted with what heat exchanger comes from Serck's own market data.

In the industrial and construction equipment sector some spark ignition engines (petrol and liquified petroleum gas powered) are used. These are in the main for use in fork lift trucks. Some small petrol engines are used for driving pumps, compressors, small generators etcetera but they do not require heat exchangers and are therefore ignored in this study.

Fork lift trucks use a variety of power units. Of the total production of fork lift trucks, roughly 50 per cent are electric, 30 per cent petrol or LPG and 20 per cent diesel.[7] The total number of diesel engines (from Table A.3.03) which are produced in the U.K. for use in fork lift trucks for sale in the U.K. is 4573. From the above proportions this implies that around 1.5 times 4573 petrol and LPG engines were sold by U.K. manufacturers for use in the U.K.; that is, 6860 engines.

Spark ignition engines currently use a radiator only in fork lift trucks. An oil cooler would only be required if a turbocharger was fitted. Turbochargers produce large amounts of heat which are dissipated into the engine lubricating oil system necessitating an oil cooler. In 1978 there were no petrol/LPG engined fork lift trucks fitted with turbochargers so there was no requirement for oil coolers or charge air coolers. Based on Serck data the average price for a radiator for a petrol LPG engined fork lift truck would be around £50. The estimated market in 1978 is:
6860 x 50 = £343000.

The approach for the agricultural engines sector is slightly different from the industrial and construction equipment sector. This is because the data for tractors are from a different source to the data for other engines and is

TABLE A.3.05 Estimated Value of Heat Exchangers Used on Diesel Engines for Industrial and Construction Equipment Engines in 1978

HEAT EXCHANGER TYPE		ENGINE SIZE CATEGORIES (KW)										
		16-30	31-50	51-75	76-100	101-150	151-200	201-300	301-500	501-750	751-1000	TOTAL
Radiators	Number of engines equipped	1880	5888	6819	2061	1473	1031	1236	368	401	5	21162
	Value of radiators	45120	217856	388683	164880	167922	220634	376980	179584	305963	5340	2072962
Oil Coolers	Number of engines equipped	540	3385	3921	2061	1473	1031	1236	368	401	5	14421
	Value of oil coolers	10800	67700	78420	53586	54501	53612	91464	76176	184861	3225	674345
Charge Air Cooler	Number of engines equipped	0	0	0	0	0	0	40	232	253	3	528
	Value of charge air coolers	0	0	0	0	0	0	4040	67744	167486	2781	242051
TOTAL HEAT EXCHANGER VALUES		55920	285556	467103	218466	222423	274246	472484	323504	658310	11346	2989358

in a slightly different format. The figures also relate directly to the U.K. market for U.K. produced equipment and therefore, unlike the other engine data, needs no estimation of the proportion of total production which is intended for the home market.

Table A.3.06 below shows the number of engines used in the agricultural equipment sector in 1978.

TABLE A.3.06 Diesel Engines in Agricultural Applications Sold for Use in the U.K.

Sector	Application	Engine Size Category (kW)					Total	Source
		16-30	31-50	51-75	76-150	151-200		
Agricultural Equipment	Tractors	220	12706	14607	822	0	28355	Ref.8 Table A.3.03
	Combines	0	1	385	110	4	500	
Total		220	12707	14992	932	4	28855	

Heat exchanger prices for agricultural equipment are shown in Table A.3.07 below.

TABLE A.3.07 Heat Exchanger Prices for Agricultural Diesel Engines

Heat Exchanger Type	Engine Size Category (kW)				
	16-30	31-50	51-75	76-150	151-200
Radiator	24	37	57	102	214
Oil Cooler	20	20	20	33	52
Charge Air Cooler	-	-	25	45	71

From Tables A.3.06 and A.3.07 the 1978 market for radiators, oil coolers and charge air coolers on agricultural diesel engines can be estimated. Table A.3.08 contains the estimated value of heat exchangers used in each size category of engine.

TABLE A.3.08 The Estimated Value of Heat Exchangers Used on Diesel Engines for Agricultural Equipment

Heat Exchanger Type		Engine Size Category (kW)					Total
		16-30	31-50	51-75	76-150	151-200	
Radiator	Number of Engines equipped	220	12707	14992	932	4	28855
	Value of Heat Exchangers	5280	470159	854544	95064	856	1425903
Oil Cooler	Number of Engines equipped	91	10547	12443	932	4	24017
	Value of Heat Exchangers	1820	210940	248860	30756	208	492584
Charge Air Cooler	Number of Engines equipped	0	0	0	0	0	0
	Value of Heat Exchangers	0	0	0	0	0	0
Total Heat Exchanger Values		7100	681099	1103404	125820	1064	1918487

The final part of this section contains a fairly mixed bag of machine based applications for heat exchangers. Table A.3.09 lists some heat exchanger using areas which are reasonably substantial along with the estimated value of heat exchangers on U.K. produced equipment for the U.K. market. The information comes from Serck's own market research data, the U.K. proportion of which was derived from looking at the appropriate Business Monitor figures as previously described in this section.

TABLE A.3.09 Consumption of Heat Exchangers on Miscellaneous U.K. Produced Equipment for the U.K. Market in 1978

Application	Heat Exchanger Value £
Compressors	622000
Heat Treatment Plant	67000
Power Transmission Equipment	288000
Hydraulic Equipment	95000
Machine Tools	86000
Pumps	79000
Transformers	211000
TOTAL	1448000

The heat exchangers for two applications from Table A.3.09, compressors and pumps, are those used on the equipment itself and not any engine which may drive the equipment. Heat exchangers for engine drives have already been dealt with previously in this section.

The total value of heat exchangers for this section is £6.7 million made up from the items shown in Table A.3.10 below.

TABEL A.3.10 Total Heat Exchanger Value

Application	Heat Exchanger Value £
Industrial and Construction Equipment Engines	3332358
Agricultural Engines	1918487
Miscellaneous Equipment	1448000
TOTAL	6698845

A.4 Public Sector Power Generation

A.4.1 Coverage of the Section

This part of the study covers power generation by the public sector. The combined generation of heat and power is considered in section A.5.

A.4.2 Uses for Heat Exchangers

It is difficult to give a complete list of applications of heat exchangers within a power station. This is because power stations are extremely complex. For instance the Dungeness 'B' nuclear power station has more than 400 pages of systems diagrams to describe its workings. Most of the applications are for cooling the wide range of items of plant within a power station.

Some of the typical applications are:

- electrolyte coolers
- fluid coupling oil coolers
- distilled water coolers
- stator liquid coolers
- transformer oil coolers
- gearbox oil coolers
- turbine oil coolers
- feed pump gland seal water coolers
- pump air coolers
- service water coolers
- compressor oil coolers.

Nuclear power stations generally require more heat exchangers than fossil-fired power stations. Hydro-electric power generation schemes have no heat exchanger requirements and nor do pumped storage schemes.

A.4.3 The 1978 Market

Only one estimate of the value of heat exchangers used in this sector was derived. This estimate covers all types of heat exchangers. Through their own market research work, Serck have produced an estimate for the 1978 market size for shell and tube type heat exchangers only. These types constitute the majority of heat exchangers used in power generation with the balance being air cooled types. Serck's estimate provides a cross-check for the shell and tube part of my own estimate.

The reason that the Serck method for deriving the market value for heat exchangers was not used in this study, other than for comparison, was because the method for estimating the 1978 market had to be applicable to the forecasts as well. This meant that for this study it was necessary to relate the value of heat exchangers used to the size or number of power stations being built and also the type of station. Serck's method of estimating the market was derived, in part at least, from the actual sales of heat exchangers to the power generating industry.

There are several problems with trying to relate the value of heat exchangers to power stations. Firstly, power stations take a number of years to construct and heat exchangers for the station are bought over the period of the construction. Secondly, many sub-contractors are involved in the construction of a power station some of which will buy the heat exchangers required in their part of the project.

A way of getting around these problems is to try and derive an average value of heat exchangers per megawatt of power station capacity and also an average build rate for the power station in megawatts per year. For example if a 1200 megawatt power station uses, say, £360,000 worth of heat exchangers and the station takes 8 years to build then the yearly market can be estimated.

The value of heat exchangers per megawatt is:-

$$\frac{360000}{1200} = £300 \text{ per megawatt}$$

The build rate for the station is:-

$$\frac{1200}{8} = 150 \text{ MW per year}$$

Therefore the estimated annual market for heat exchangers is:-

$$300 \times 150 = £45000$$

For this particular power station the average annual market for heat exchangers is £45000. In reality there would be some years for which there would be little demand for heat exchangers and other years a much higher demand. For individual projects, this method would probably be a poor estimator of the year by year demand for heat exchangers. More often than not there are several power stations under construction at any one time which are started and finished at different times. This would probably iron out most of the overall fluctuations in demand for heat exchangers that would be associated with individual projects.

To derive a market value for 1978 involves first determining the average build rate of power stations in megawatts. The Electricity Supply Handbook 1979[9] gives details of power stations under construction with the starting date and expected completion date. The power stations under construction during 1978 are given in Table A.4.1 overleaf.

TABLE A.4.1 Generating Plant Under Construction in 1978

Station	Type	Capacity MW	Start/ Completion	Fraction Completed in 1978	MW's Built in 1978
Drax	Coal	1980	78-86	1/9	220
Isle of Grain	Oil	2000	71-82	1/12	167
Ince B	Oil	1000	72-82	1/11	91
Littlebrook	Oil	1980	74-83	1/10	198
Peterhead	Oil/Gas	1320	73-80	1/8	165
Kilroot	Oil	1200	74-83	1/10	120
Bulls Bridge	Gas Turbine	280	75-80	1/6	47
Letchworth	Gas Turbine	140	74-79	1/6	23
Ocker Hill	Gas Turbine	280	74-79	1/6	47
Taylor's Lane	Gas Turbine	140	75-80	1/6	23
Watford	Gas Turbine	140	74-79	1/6	23
Cowes	Gas Turbine	140	78-82	1/5	28
Total Non-Nuclear					1152
Dungeness B	Nuclear	1320	68-82	1/16	83
Hartlepool	Nuclear	1320	70-82	1/15	88
Heysham	Nuclear	1320	66-81	1/13	102
Total Nuclear					273
TOTAL ALL TYPES					1425

The final column in the Table is derived from the fraction completed in 1978 column which is in turn derived from the start/completion column. The figures in the last column are hypothetical.

Serck have extensive experience in supplying heat exchangers for the power generating industry. From Serck's own information, 1978 prices per megawatt of installed power generating capacity are £305 for shell and tube heat exchangers and £113 for air cooled heat exchangers in non-nuclear plant. Nuclear plants use about 1.5 times the value of shell and tube heat exchangers than non-nuclear plants use giving £458 per megawatt with no significant difference in the value of air cooled heat exchangers.

From this information and the information contained in Table A.4.1 the market estimate for 1978 can be derived:-

Shell and Tube in non-nuclear plant = 1152 x 305 = £351360

Air Cooled types in non-nuclear plant = 1152 x 113 = £130176

Shell and Tube in nuclear plant = 273 x 458 = £125034

Air Cooled types in nuclear plant = 273 x 113 = £30849

Therefore the total market for heat exchangers in this sector is:-

351360 + 130176 + 125034 + 30849 = £637419

with £476394 being shell and tube and £161025 being air cooled.

Serck's own estimate for shell and tube types only in the U.K. power generating industry is £540000 in 1978 prices. This compares reasonably well with the £476394 for shell and tube types calculated by my average build method.

The total value for all types of £637419 is taken as a reasonable indicator of the market size for 1978. The method of estimating the market size is used also as the basis for the forecasts for this sector contained in the results.

A.5 Combined Heat and Power

A.5.1 Coverage of the Section

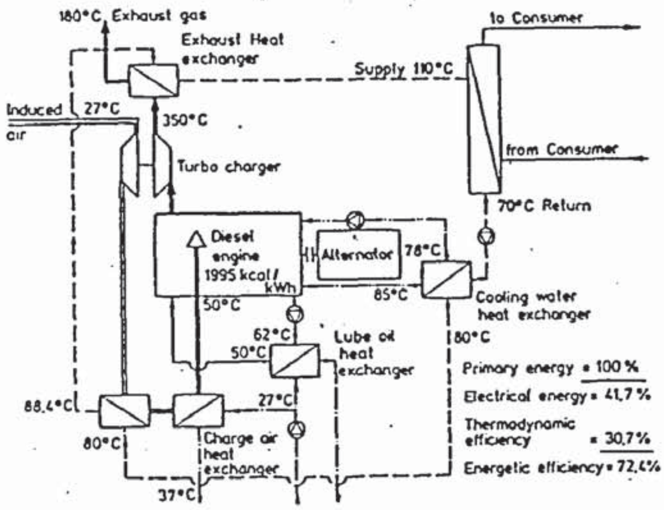
This covers large publicly owned power stations and privately owned power generation plant where this is used to produce all or a significant part of a company's power requirements. Power plant used for standby purposes only, in the event of interruption of the public supply, is not included.

A.5.2 Uses for Heat Exchangers

In combined heat and power schemes heat exchangers are used to recoup heat that would normally be lost in the generation of electricity. On gas turbines, heat exchangers in the form of waste heat boilers are used to recover heat from the engine's exhaust. As most of the heat generated in a gas turbine is dissipated through the exhaust this is the only point at which heat may be recovered. On diesel plant, heat is dissipated through the exhaust, the engine jacket water and the lubricating oil. Heat exchangers can be used in these various places to recover heat. A charge air cooler may also be used on a diesel engine and heat is recoverable from this point as well.

Figure A.5.1 over shows a typical diesel combined heat and power scheme showing the various heat exchangers.

Figure A.5.1 Diesel Engine CHP Scheme[10]



A.5.3 The 1978 Market

The planned new capacity for electricity generation in 1978 is given in the 'Enquiry into Private Generation of Electricity in Great Britain 1977' which was published by the Department of Energy.

Table A.5.1 below gives details of the type of plant plus the rated output for electricity and heat generation.

TABLE A.5.1 Output Capacity for Planned New Plant in 1978 (in Megawatts)[11]

Plant Type	Electricity MW
Steam Plant	135.2
Gas Turbines	33.0
TOTAL	168.2

Steam plant, even where steam from the turbine is recovered and used, has no requirement for heat exchangers that are covered by this study. Cooling is by means of cooling towers. Gas turbines can use waste heat boilers and economisers to recover heat from the exhaust giving an overall efficiency in excess of 70 per cent.

The cost of recovery equipment for gas turbines is taken from a report by McLellan and Partners. In it is the cost of waste heat boilers for two gas turbine CHP sets. The combined shaft output of the two sets is 22 MW and the cost of the waste heat boilers is £600000.[12] This gives a figure of £27273 per MW of engine shaft power.

The market estimate is obtained by multiplying the output of gas turbines of 33 MW by £27273 giving £900000.

A.6 Manufacturing Industries

A.6.1 Coverage of the Section

This section includes all manufacturing industries as defined in the Standard Industrial Classification (SIC) 1968[13] except order V (chemicals and allied industries) and minimum list heading (MLH) 262 (mineral oil refining) from order IV (coal and petroleum products). These two areas are already large users of heat exchanges and practice energy conservation extensively and have done so for many years. Therefore they are considered separately from the rest of manufacturing industry.

The full list of industries covered is shown below. The list is broken down into orders according to SIC 1968 which are broad groupings of manufacturing industries:

Order	Industry
II	Mining and Quarrying
III	Food, Drink and Tobacco
IV	Coal and Petroleum Products (except MLH 262 mineral oil refining)
VI	Metal Manufacture
VII	Mechanical Engineering
VIII	Instrument Engineering
IX	Electrical Engineering
X	Shipbuiling and Marine Engineering
XI	Vehicles
XII	Metal Goods not Elsewhere Specified
XIII	Textiles
XIV	Leather, Leather Goods and Fur
XV	Clothing and Footwear
XVI	Bricks, Pottery, Glass, Cement, Etcetera
XVII	Timber, Furniture, Etcetera
XVIII	Paper Printing and Publishing
XIX	Other Manufacturing Industries
XX	Construction

Only heat exchangers which are used in conjunction with space and process heating and cooling are included in this section. Other heat exchangers which are used on machines (mainly engines) are covered elsewhere.

A.6.2 Uses for Heat Exchangers

Heat exchangers of interest in this section are used to recover heat rejected from industrial processes. The heat may be contained in hot liquids or hot gases and be used to heat liquids or gases. A typical example might be recovery of heat from a boiler flue in order to pre-heat the boiler feedwater.

The heat exchanger will only be a part of a heat recovery system. The system may well involve pipe work, ducting, fans and so on. The heat exchanger typically accounts for less than half of the total cost of such systems.

All the types of heat exchangers detailed in Appendix B can be used for waste heat recovery. Some of them, however, are used extensively or even exclusively for waste heat recovery. These are plate fin, rotary regenerator or heat wheel, heat pipe heat exchanger, gas/gas plate and run around coil. These are used mainly in gas/gas applications. The run around coil is in fact two finned tube heat exchangers connected by a pumped liquid circuit. The way they operate is as a gas/gas heat exchanger between two streams which are remote from each other. In liquid/liquid applications shell and tube and plate heat exchangers are commonly used.

The heat recovery systems described so far simply recoup heat from a source for re-use elsewhere. There are two other systems which use heat exchangers to recover heat but which operate slightly differently from the systems described above. The first is the heat pump. This device takes heat from a source, upgrades it (raises the temperature) and then the heat is used (via a second heat exchanger) for either space or process heating.

The second device recoups heat through a heat exchanger which evaporates an organic fluid. The vapour is used to turn a turbine to produce electricity or mechanical power and then the vapour passes into a condenser where it gives up heat and changes back into a liquid. The process carries on like this continuously.

Both heat pumps and organic Rankine cycle systems can use various types of heat exchangers but are generally gas/liquid or liquid/liquid depending on the nature of the heat source and heat sink.

A.6.3 The 1978 Market

The industries included in this section use heat exchangers for a wide variety of applications. Only a proportion of these are used for waste heat recovery. As it is the waste heat recovery applications which are of interest, the market estimate only includes these types of heat exchangers.

The estimate of the market comes from a Building Services Research and Information Association (BSRIA) publication.[14] The estimate only includes equipment for recovering heat from gases and not liquids. In the industries in this section the vast majority of heat that is already recovered will be from gases.

The figures given in the BSRIA report are for all industries whereas this section does not include chemicals and allied industries or mineral oil refining. In the past these two areas have practised waste heat recovery extensively but in the main using shell and tube and plate type heat exchangers recovering heat from liquids and not very many of the types which are included in the BSRIA estimate.

Overall, the BSRIA estimate is appropriate to this section. The estimate for waste heat recovery heat exchangers is found by adding the figures quoted for industrial applications to that quoted for nationalised industries in the BSRIA estimate. Hence:-

1,112,000 + 170,000 = 1,282,000.

A.7 Chemicals and Allied Industries

A.7.1 Coverage of the Section

This section covers the chemical and allied industries as defined under order V of the Standard Industrial Classification 1968.[15] The industrial sectors which make up order V are shown below along with their respective minimum list heading (MLH) numbers:

MLH	Sector
271	General Chemicals
272	Pharmaceuticals and Preparations
273	Toilet Preparations
274	Paint
275	Soap and Detergents
276	Synthetic Resins and Plastics, Materials and Synthetic Rubber
277	Dyestuffs and Pigments
278	Fertilizers
279	Other Chemical Industries

A.7.2 Uses for Heat Exchangers

As the largest market for heat exchangers, the chemicals and allied industries uses examples of almost every type available. However, up to 90 per cent of the heat exchangers used in this sector are shell and tube types with the balance being taken up by plate, air cooled, spiral plate, spiral tube, graphite and other types. Descriptions of most types of heat exchangers that are available are contained in Appendix B.

The type of heat exchanger used will be largely dictated by the duty which it is required to perform. This said, individual types of heat exchanger will be capable of performing most of the different heat transfer duties found in a chemical plant. As they are so popular it is quite obvious shell and tube types are capable and also more cost effective in most chemical industry applications than other types of exchanger. Other types have special advantages under certain circumstances. When the fluids being handled are very corrosive then graphite, glass or plastic heat exchangers may be cheaper than a shell and tube type made from corrosion resisting stainless steel or titanium. If the fluids being handled have a high degree of viscosity then a spiral plate type is the most likely choice. Glass or glass tube types can be used where fouling is a problem with the normal shell and tube type.

Most of the alternatives to the shell and tube type are used where shell and tubes cannot be used or cannot be used as cheaply. The plate type is the real exception to this as it is a direct competitor and replacement for the shell and tube type in many applications. Plate types are better than shell and tube types in terms of heat transfer efficiency, ease of maintenance, and east of repair. Also plate types take up less room than the comparable shell and tube type and therefore require less civil engineering work. A plate type is capable of taking extra plates at any time to extend the surface area which cannot be done with shell and tube types.

The shell and tube type is superior at high temperatures and pressures and also where the pressure difference between the two fluids in the exchanger is high.

As far as the prices of the two types of exchanger are concerned, Walker[16] has drawn up the following table of relative costs with plate types having an index value of 1.

TABLE A.7.1 Relative Costs of Plate and Shell and Tube Heat Exchangers

Type	Relative Cost
Plate: stainless steel; rubber gaskets	1
Shell and Tube: all carbon steel	0.9-3
Plate: stainless steel; compressed asbestos gaskets	1.3
Shell and Tube: carbon steel shell; stainless steel tubes	1.5
Shell and Tube: all stainless steel	2
Plate: titanium plates	2
Plate: hastelloy plates	8

In all but the simplest duties, which can be accomplished with a simple all carbon steel shell and tube type, the plate type is cheaper to buy than the comparable shell and tube type.

The Table only compares differences in purchase price and not installed cost. The installed cost can be as much as 2 to 5 times the purchase price.[17] This is because of the concrete platforms necessary for the exchanger to stand on plus craneage for heavy lifting or scaffolding may be necessary when extensive maintenance or repair is necessary. When considering installed cost, plate types are significantly cheaper than the equivalent shell and tube type.

In the case of the shell and tube type the concrete platform to support the exchanger has to be twice as long as the exchanger to allow for the removal of the tubestack for which a crane may be required. On the plate type the concrete platform only needs to be the size of the exchanger and no crane is required as the heat transfer surface is made up of separate plates which can easily be handled by one or two men.

Many of the duties found within chemical plants are within the temperature and pressure limitations of the plate type but it is not very widely used even though it would often be cheaper than the comparable shell and tube unit. This is probably because process plant contractors and chemicals manufacturers are conservative in their design philosophies, and they stick to tried and trusted designs. They distrust the plate type which was designed primarily for the food and drink industry. There have in the past been problems with gasket failures on plate types and these have now been largely overcome but the chemical industry is very wary of equipment failing in hazardous environments.

Amongst the engineers I have spoken to there is definitely a greater acceptance of plate types from the younger ones and greater resistance from the older.

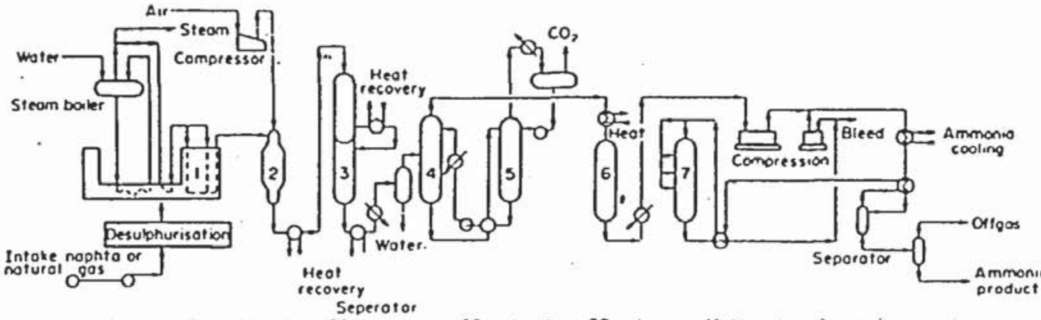
So far I have talked about types of heat exchanger used in the chemicals and allied industries as defined by configuration or material of construction. They can also be classified according to the various functions they perform. Table A.7.2 over contains a comprehensive list of functions drawn up by Donohue.[18]

TABLE A.7.2 Heat Exchanger Functions

Equipment	Function
Chiller	Cools a fluid to a temperature below that obtainable if water only were used as a coolant. It uses a refrigerant such as ammonia or freon.
Condenser	Condenses a vapor or mixture of vapors, either alone or in the presence of a non-condensable gas.
Partial Condenser	Condenses vapors at a point high enough to provide a temperature difference sufficient to preheat a cold stream of process fluid. This saves heat and eliminates the need for providing a separate preheater (using flame or steam).
Final Condenser	Condenses the vapors to a final storage temperature of approximately 100°F. It uses water-cooling, which means the transferred heat is lost to the process.
Cooler	Cools liquids or gases by means of water.
Exchanger	Performs a double function: (1) heats a cold fluid by (2) using a hot fluid which it cools. None of the transferred heat is lost. (The extent to which the cold fluid picks up the available heat in the hot fluid measures the efficiency of heat transfer).
Heater	Imparts sensible heat to a liquid or a gas by means of condensing steam or dowtherm.
Reboiler	Connected to the bottom of a fractionating tower, it provides the reboil heat necessary for distillation. The heating medium may be either steam or a hotter process-fluid.
Steam Generator	Generates steam for use elsewhere in the plant by using the available high-level heat in tar or a heavy oil.
Vaporizer	A heater which vaporizes part of the liquid.
Waste-Heat Boiler	Produces steam, similar to steam generators, except that the heating medium is a hot gas produced in a chemical reaction.

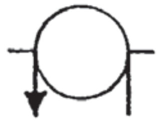
As an example of how heat exchangers fit in to a chemical plant, figure A.7.1 below shows a scehmatic diagram of a large ammonia plant.

Figure A.7.1 Schematic Diagram of a Large Ammonia Plant[19]

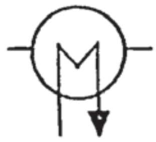


Primary step 1 Secondary step 2 CO-conversion 3 CO_2-absorber 4 CO_2-stripper 5 Metharator 6 Ammonia converter 7

In the diagram three different symbols are used to designate heat exchangers which fulfill different functions. They are:-

heat recovery 

cooler 

exchanger 

The terms cooler and exchanger are defined in Table A.7.2 and the meaning of heat recovery is self-evident.

A.7.3 The 1978 Market

The market for heat exchangers in the chemicals and allied industries can be estimated in three separate ways. The first, and possibly most satisfactory way, is to derive the value for heat exchangers from total capital expenditure in this industry.

Figures for total expenditure on process plant and the percentage accounted for by heat exchangers are given in a publication by the Process Plant Working Party of the National Economic Development Office. Expenditure on process plant by the chemicals and allied industries in 1978 was £494 million.[20] Typical expenditure on heat exchangers on an average large project is given as 6.25 per cent with a range of 0.5 to 12 per cent.[21] Therefore the market for heat exchangers is estimated as:-

0.0625 x 494 = £30.875 million.

A second way of estimating the market is to find out how much a large chemicals manufacturer with a wide spread of interest spends on heat exchangers and then, based on the company's size as a proportion of the total industry, estimate a value for the whole industry.

In 1978 Imperial Chemical Industries (ICI) spent approximately £10 million on heat exchangers.[22] In 1976 ICI employed 125,000 people in the U.K. out of a total workforce for the industry of 423,000.[23] By making the perhaps naive assumption that the proportion of total chemicals industry heat exchangers bought by ICI is the same as the proportion of total employees that work for ICI, the total value of heat exchangers bought by the industry can be estimated thus:-

10 ÷ .2955 = £33.84 million.

The figure 0.2955 is the proportion of total employees in the industry that work for ICI

$$\frac{125,000}{423,000} \times 100 = 29.55\%$$

The third and final estimate is based on a breakdown of the total U.K. and Ireland heat exchanger market for 1975 in a market research report published by consultants Frost and Sullivan.[24] According to this report, in 1975 the chemicals industry accounted for around 25 per cent of total market for heat exchangers. Using Business Monitor figures for sales of heat exchangers less exports plus imports a figure of £104,298,000 is derived as the total 1978 U.K. market.[25]

Therefore the U.K. market for heat exchangers in the chemicals industry is estimated thus:-

104.298 x .25 = £26.07 million.

There is a reasonable level of agreement between the three estimates with the first, £30.875 million being somewhere near the middle of the other two. Therefore the market estimate is taken to be £30.875 million for this study.

A.8 Mineral Oil Refining

A.8.1 Coverage of the Section

This section covers mineral oil refining as defined under Order IV (Coal and Petroleum Products), Minimum List Heading 262 (Mineral Oil Refining) of the Standard Industrial Classification.[26]

A.8.2 Uses for Heat Exchangers

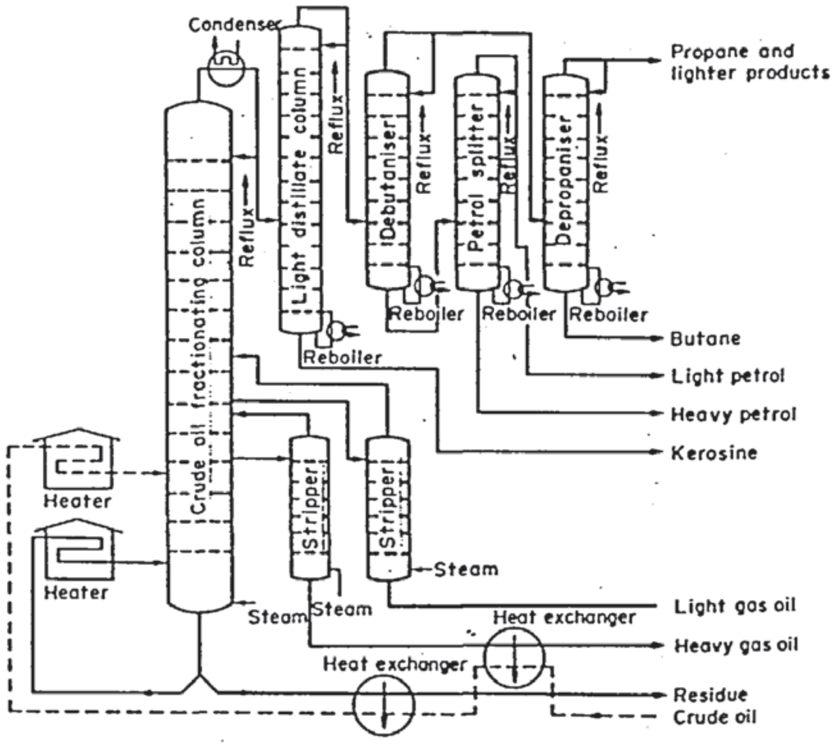
The duties required of a heat exchanger in an oil refinery are somewhat similar to those found in the chemicals and allied industries. For this reason the reader is referred to the section on uses for heat exchangers in the chemicals and allied industries for a detailed discussion of duties and the relative merits of the various types of exchanger.

The shell and tube type of exchanger dominates in the refinery industry with the plate type having made little impact. The refinery industry is fairly conservative in its design philosophies and has yet to be convinced of the plate heat exchanger's abilities. The main concern is about the possibility of hot product escaping to atmosphere if a gasket failure between the plates occurs.

Heat exchangers are used to heat cold feed streams, cool hot product streams, exchange heat between two product streams, cool and condense gases or recover heat from products or waste gases. For a full range of descriptions of the various duties see Table A.7.2 in section A.7.2.

Figure A.8.1 shows the layout for a crude oil distillation plant. In the diagram heat exchangers, reboilers and a condenser are shown which are all types of heat exchangers performing the functions suggested by their names.

Figure A.8.1 Crude Oil Distillation Plant[27]



Distillation is the one indispensible process in a refinery. Other processes such as catalytic reforming or cracking will also be found in a refinery. The diagram clearly shows the various heat exchangers. The term heat exchanger in this study refers to a whole range of such devices, whereas in the process industries the term has a more specific meaning and describes the device's function. In the process industries a heat exchanger is so termed because it performs a double process function; a cold process fluid is heated up by a hot process fluid which is in turn being cooled by the cold process fluid. Other heat exchangers are referred to as coolers or condensers because of the kind of job they do but physically they may appear to be very similar to each other. Within the context of this study they are all heat exchangers.

A.8.3 The 1978 Market

The market for heat exchangers in the mineral oil refining industry can be estimated in two different ways. The first is calculated by looking at total process plant expenditure by the industry and estimating heat exchangers from that figure. The Process Plant Working Party (PPWP) of the National Economic Development Office publishes every year investment forecasts for process plant broken down by end-user sector. Investment in process plant by the petroleum refining and distribution sector in 1978 was £135 million.[28] The American journal Hydrocarbon Processing International publishes breakdowns of expenditure by the hydrocarbon industry on process plant by product group. This data is published sometimes in the annual Process Industries Investment Forecasts by the PPWP. In 1974 the proportion of total expenditure by the Worldwide hydrocarbon processing industry on process plant accounted for by heat exchangers was 10 per cent.[29] The hydrocarbon processing industry is the name given to all the plants which process oil or oil related products such as oil refineries, petrochemical plants and so on. If this proportion is assumed to apply to U.K. refineries then an estimate for 1978 expenditure on heat exchangers can be obtained:- 135 x 0.1 = £13.5 million.

A second estimate can be obtained in the following way. A report on the West European heat exchanger market was published by Frost and Sullivan Inc. in 1978. In it is an estimate for expenditure on heat exchangers by the petroleum and fuel conversion sector in the U.K. and Ireland for 1975. The petroleum and fuel conversion sector includes petroleum production, natural gas production and liquefaction, petroleum refining and interchange of fuels such as coking or coal gasification. Refining is the only significant heat exchanger user the others purchase only negligible quantities. According to the Frost and Sullivan report the market size for heat exchangers in petroleum and fuels in 1975 for the U.K. and Ireland was $24.3 million out of a total market for heat exchangers of $188.4 million.[30]

Petroleum and fuels account for 12.9 per cent of the whole heat exchanger market.

The total U.K. heat exchanger market can be estimated from figures published in the Government statistical series, Business Monitor and in 1978 it stood at around £104 million.[31] By applying the proportion derived from the Frost and Sullivan report to the total market estimate a figure for the refining industry can be derived:-

$104 \times 0.129 = 13.416$.

This is extremely close to the first estimate. It must be emphasised that both methods of estimation necessitated assumptions and one would expect errors to result. The fact that the figures are close may merely mean they both have the same degree of error. However there is not to my knowledge (certainly not within Serck) a better estimate for this particular market. The market for the purposes of this study is taken to be £13.5 million.

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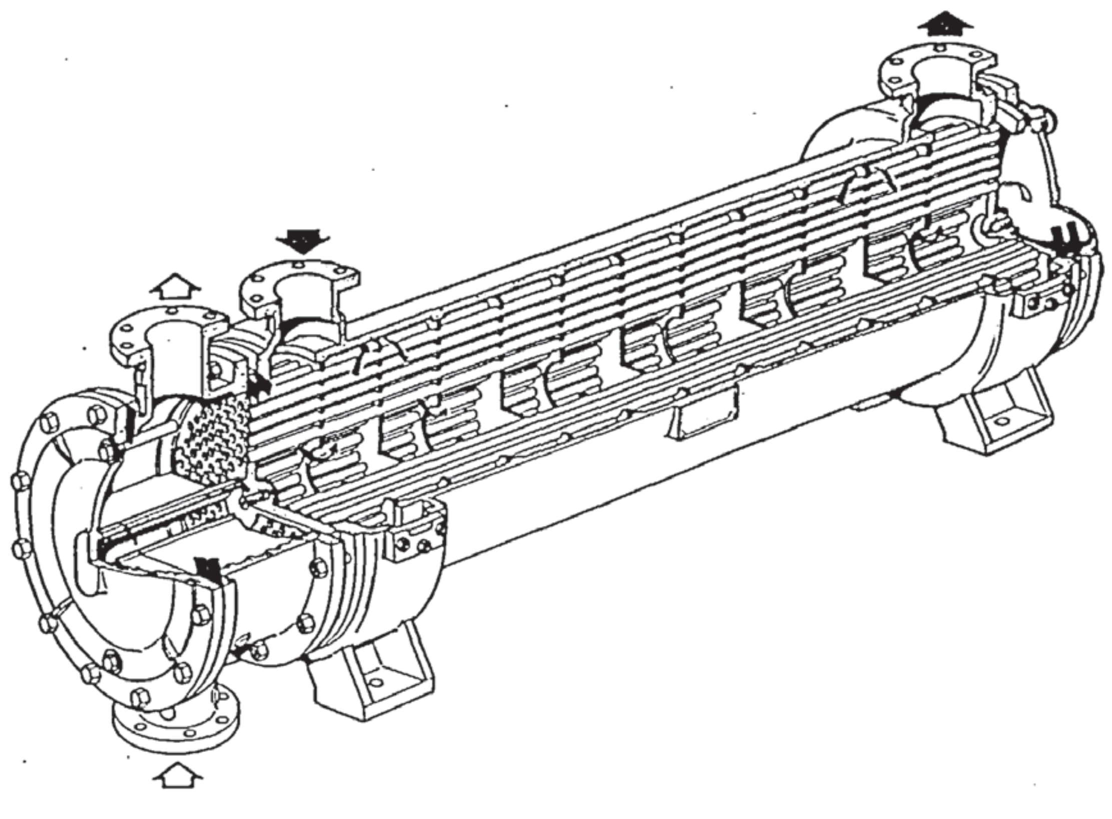
APPENDIX B TYPES OF HEAT EXCHANGERS

This appendix is a review of most of the types of industrial heat exchangers produced commercially.

B.01 The Shell and Tube Type

This type consists of a large cylinder or shell inside which there is a bundle of tubes as shown in figure B.01.

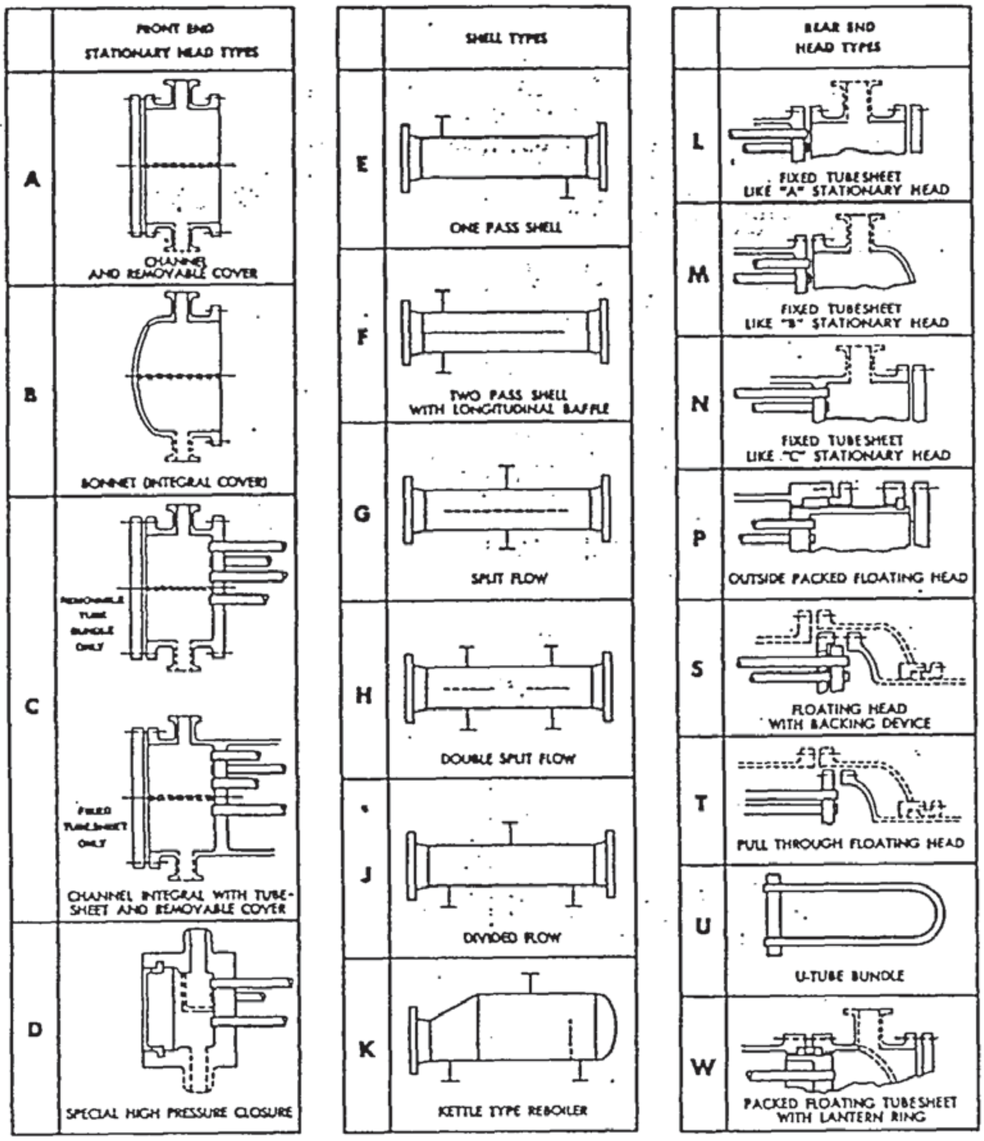
Figure B.01 Cutaway Drawing of a Typical Shell and Tube Heat Exchanger[1]



One fluid stream flows over the outside of the tubes and the other fluid flows through the tubes. The fluid flowing through the tubes can flow once through the bundle or it can be directed up and down the length of the exchanger. The fluid flowing over the tubes can be directed back and forth as shown in figure B.01 by the black arrows.

There are many designs of shell and tube heat exchangers, many of which are covered by the Tubular Exchanger Manufacturers' Association (T.E.M.A.) of the U.S.A. These are shown in figure B.02.

Figure B.02 T.E.M.A. Type Designations for Tubular Heat Exchangers[2]

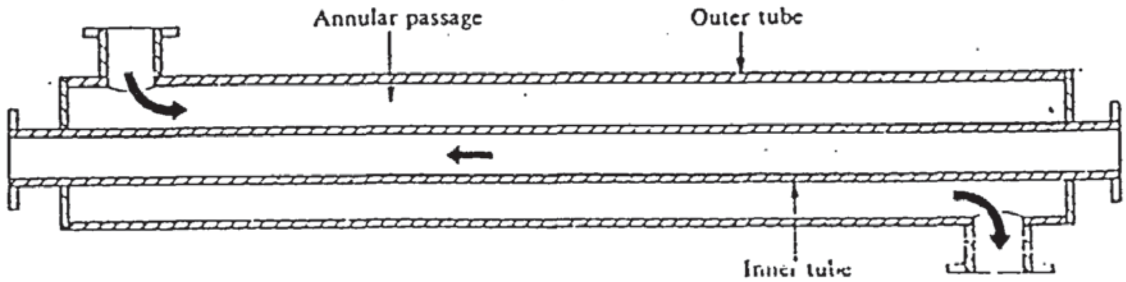


Shell and tube type heat exchangers are made from a variety of materials including almost any metal, from mild steel to titanium, or from ceramic materials such as graphite and glass or from plastics. Exchangers are most often made from metal with the shell usually of mild steel which can be lined for increased corrosion resistance. Non-metals are usually used in corrosive applications such as acid cooling.

B.02 Double Pipe Exchanger

This is really the simples form of shell and tube heat exchanger. It consists of a single pipe running through a shell. One stream runs inside the inner pipe and the other flows between the two. See figure B.03 below.

Figure B.03 Double Pipe Heat Exchanger[3]



This design is very simple and cheap to build but suffers from the disadvantage that the amount of space it occupies is generally fairly high when compared with other types.

Some double pipe exchangers have plain inner pipes but most feature longitudinal fins for enhanced heat transfer.

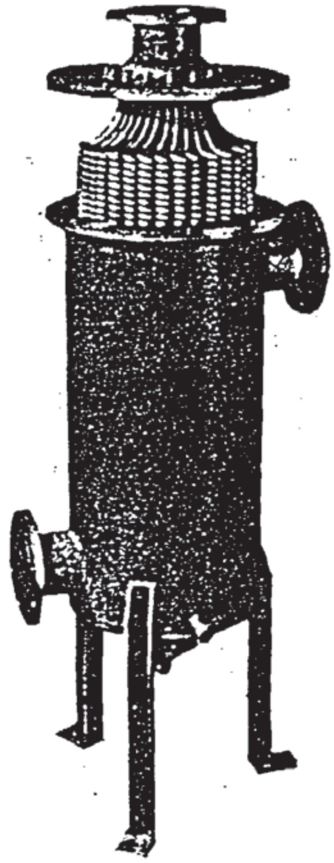
The double pipe design offers almost complete counterflow allowing very close temperature approaches between the two fluids.

B.03 Spiral Tube

This type of exchanger consists of a group of concentric spirally wound coils. It is a development of the shell and tube type.

The features of this type of exchanger are counter-current flow, elimination of differential expansion difficulties, constant velocity and compactness.

Figure B.04 Spiral Tube Heat Exchanger with Tubestack Partly Withdrawn from the Cylinder to Show Tube Arrangement[4]



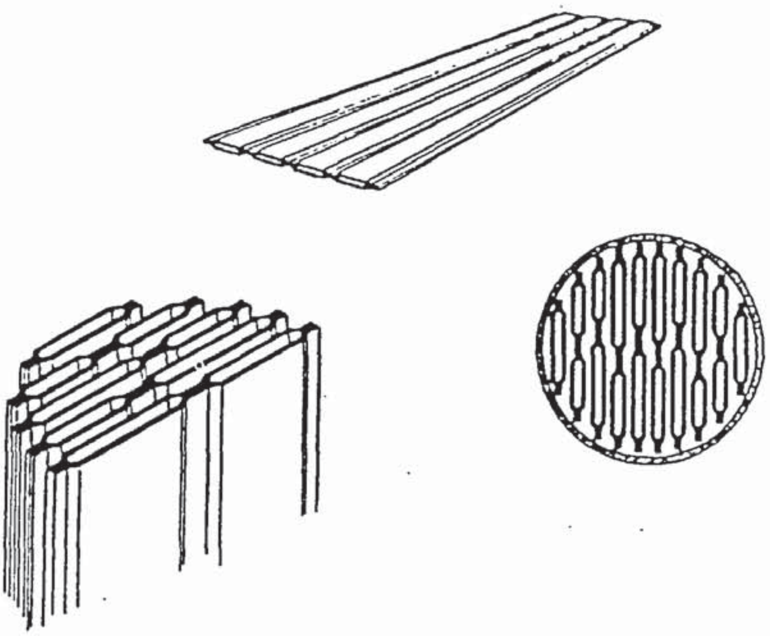
This type of unit is especially suited to low flows, small heat loads and viscous fluids. Shellside cleaning is easy but tubeside cleaning can only be done chemically.

B.04 Lamella Heat Exchanger

This type is a variant of the basic shell and tube type. It is designed for longitudinal flow on both sides. The tube bundle consists of a series of flattened tubes called lamellas. These are shown in figure B.05 over.

The lamellas are welded into a tube plate and installed in a rectangular or cylindrical shell.

Figure B.05 A Lamella Heat Exchanger[5]



B.05 Glass Heat Exchangers

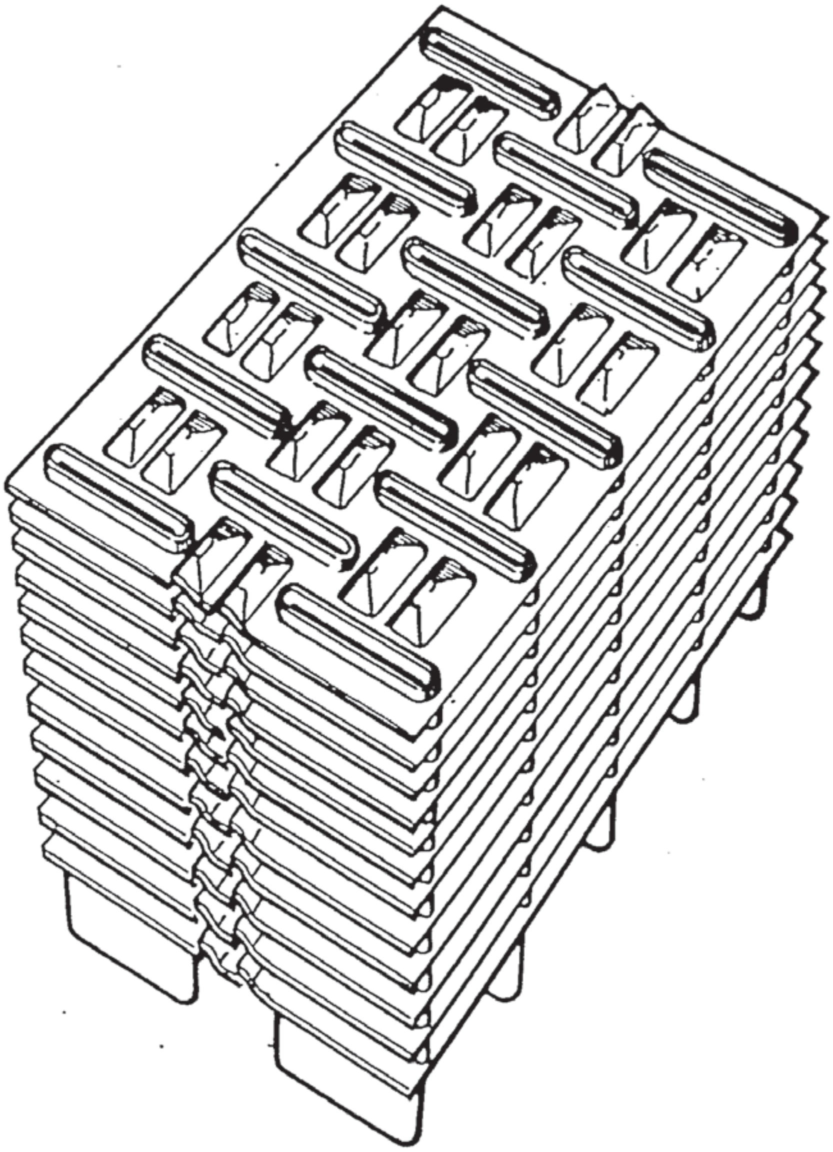
Two types of heat exchangers are constructed from glass; straight tube and coiled tube types. They are very similar to types already described. They have a low thermal conductivity but their smooth surface ensures a low fouling tendency.

These heat exchangers are found in applications where corrosive fluids are being processed and where, if other types of heat exchangers were employed, fouling would occur.

B.06 Fin and Tube and Ribbon Tube Types

This type of heat exchanger consists of a rectangular bundle of tubes several rows deep. The fluid to be cooled flows through the tubes whilst air flows across the tubes. Air heat transfer co-efficients are low, therefore fins are added to the tubes to increase the heat transfer area on the air side. Figure B.06 over illustrates a typical section.

Figure B.06 Section of a Typical Air Cooled Heat Exchanger[6]



Air cooled heat exchangers can also be made up of a series of ribbon wound tubes. Ribbon fin tubes as they are called, have a secondary surface, usually made of aluminium wound on to the tube in a helix.. An example is shown in figure B.07 over.

Air velocities are usually low and a fan or fans would normally be used to blow or suck air past the tubes.

Figure B.07 Cutaway Section of a Ribbon Fin Tube[7]

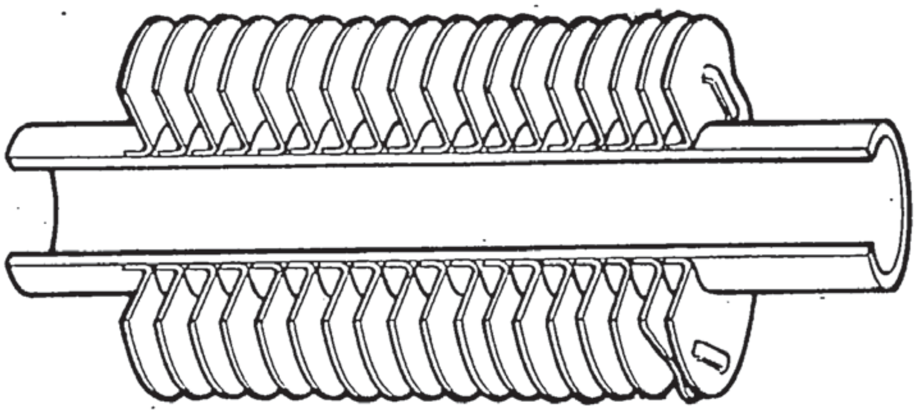
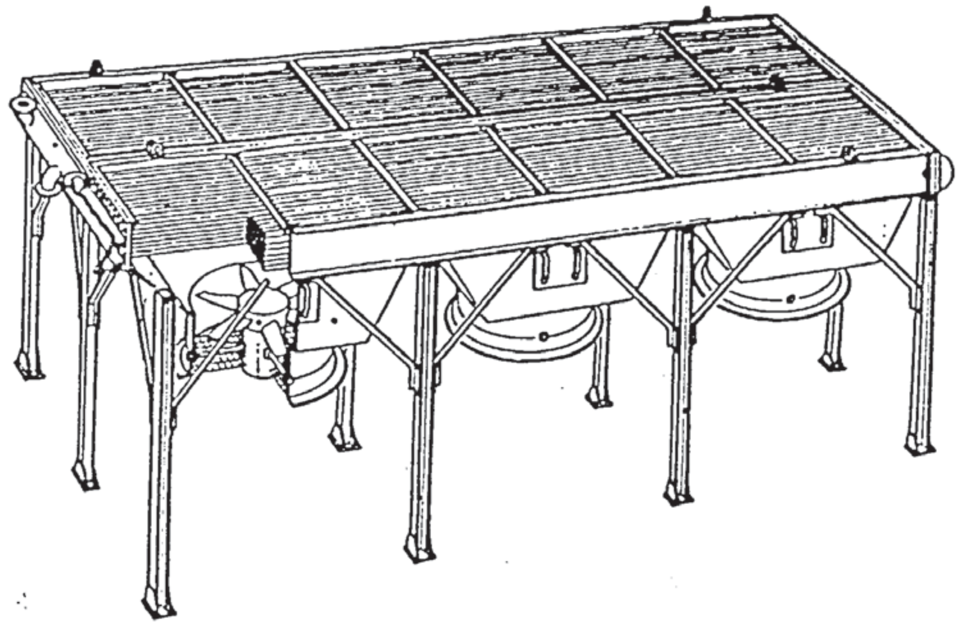


Figure B.08 A Typical Air Cooled Heat Exchanger[8]



The tubes are most often made of aluminium but steel is also used.

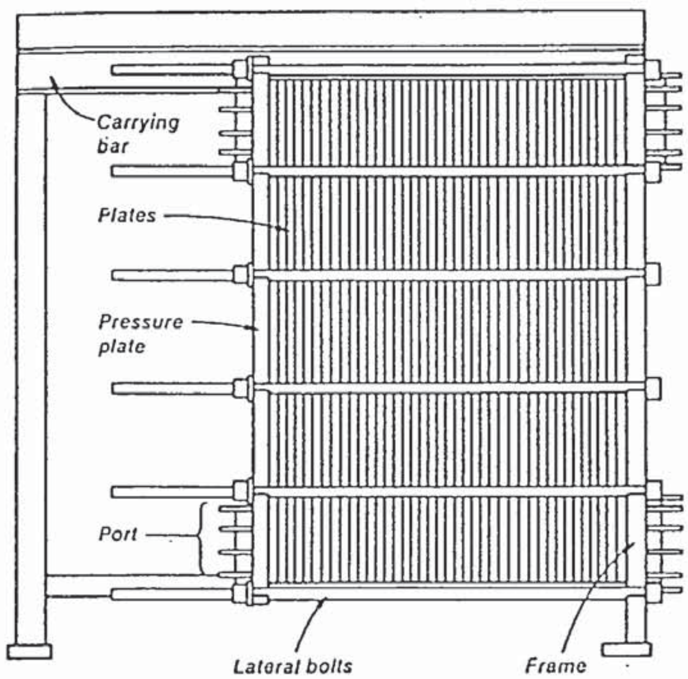
Air cooled heat exchangers are normally used where the availability of cooling water is limited. Their main disadvantage is that the fans cause noise problems.

A smaller version of this type of exchanger is that found in air conditioning systems or in vehicle cooling systems.

B.07 Plate Type

This type of heat exchanger was developed from the plate and fram filter press. It consists of a number of corrugated metal sheets, mounted vertically on a frame. At one end of the group of plates is a fixed frame plate and at the other a moveable pressure plate. Figure B.09 below shows a diagram of a plate type heat exchanger.

Figure B.09 Diagram of a Plate Heat Exchanger[9]

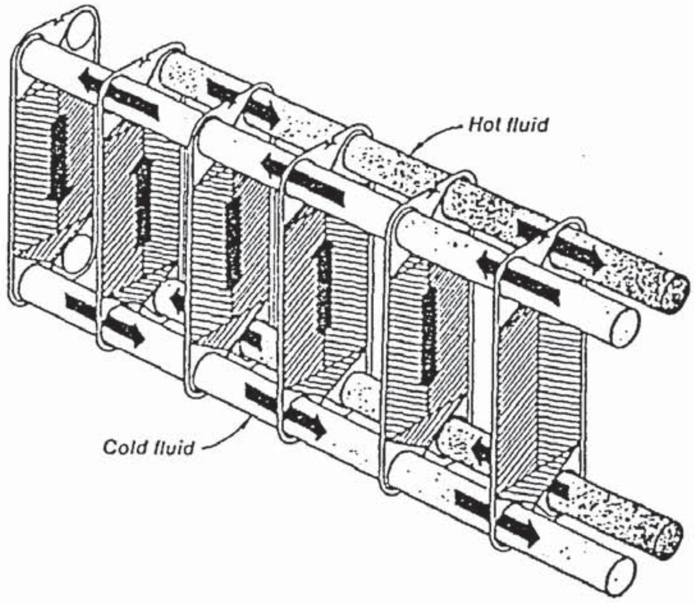


The flow of fluids through the exchanger is shown in figure B.10 over.

The plate type has the advantage that any part is easily accessible for cleaning and inspection. Another advantage is that plates may be added or taken away to adjust the total heat transfer area of the exchanger.

A disadvantage is that the design will not cope with such high temperatures and pressures as a shell and tube exchanger will.

Figure B.10 The Flow of Fluids Through a Plate Type Heat Exchanger[10]



B.08 Spiral Plate

This type was originally designed to solve the various heat exchange problems of the cellulose industry which were often cases of severe fouling or corrosion.

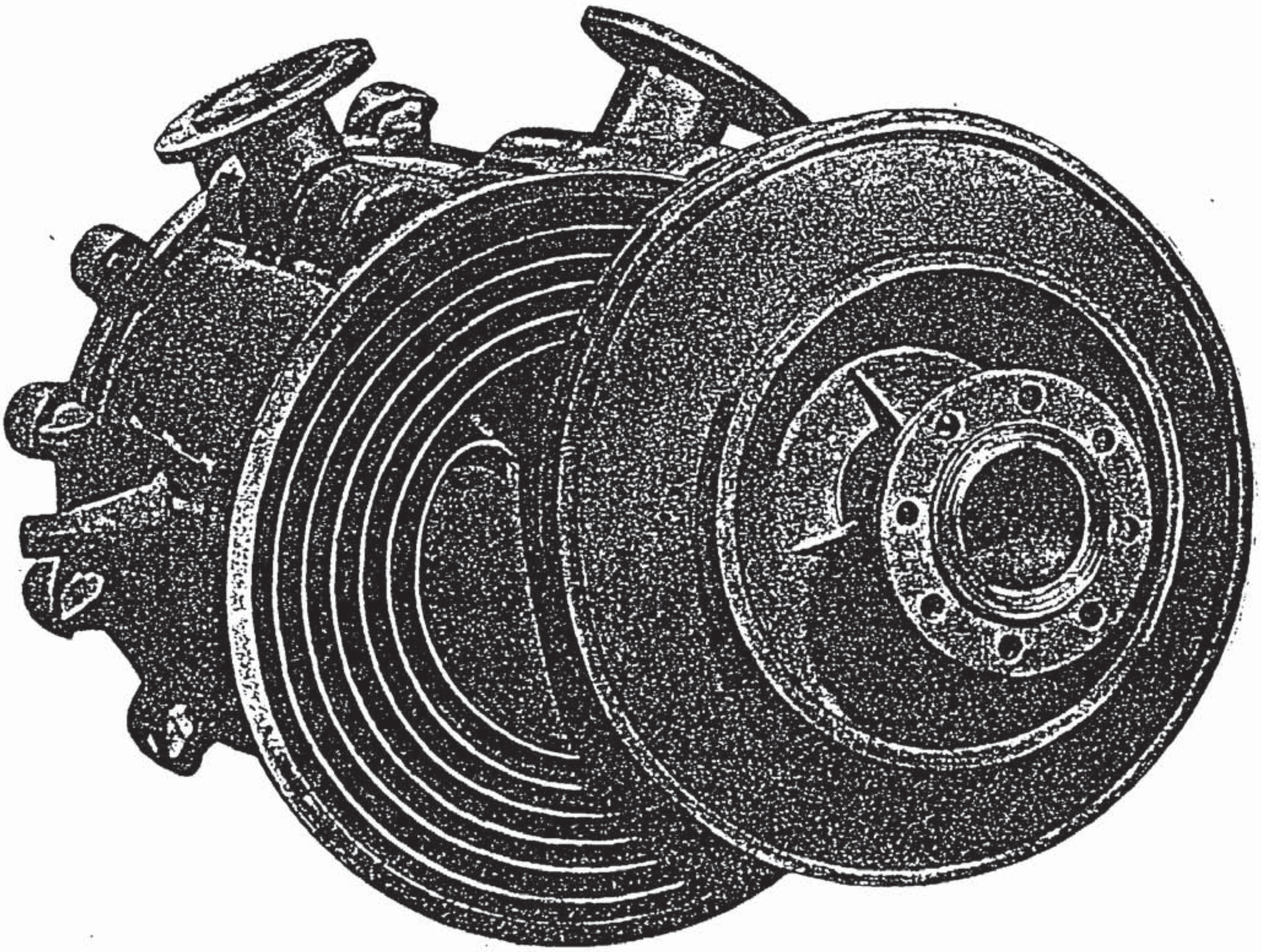
The heating surface consists of two relatively long strips of plate which are wound around an open split centre to form a pair of concentric spiral passages. The spacing between the plates is maintained by studs welded to the plate surfaces.

Figure B.11 over shows the general arrangement of a spiral heat exchanger.

Figure B.11 Spiral Plate Heat Exchanger[11]

The fouling up tendency of this type of unit is low because the fluid paths are long and good flow distribution and turbulence are obtainable without by-passing or stagnation. Counter-current flow is also achieved with this type of exchanger allowing close temperature approaches between the two fluids.

Figure B.12 Spiral Plate Heat Exchanger with End Plate Removed[12]



The spiral plate exchanger is not suitable for high pressure applications.

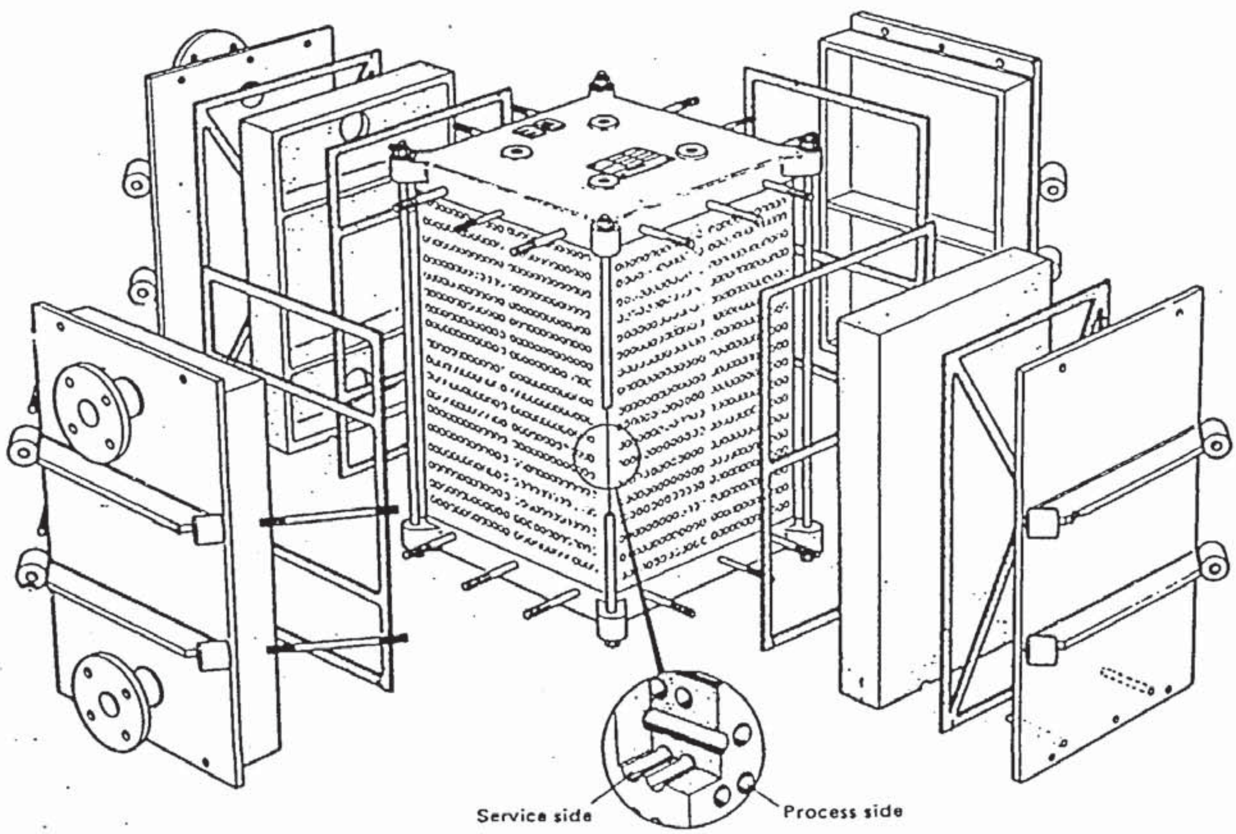
B.09 Graphite Heat Exchangers

There are two main types of heat exchanger which use graphite; shell and tube and graphite block types. The shell and tube types are more or less like conventional shell and tube types described in Section B.01.

Graphite shell and tube types use graphite for tubes and the tube plates whilst the shell is made from the conventional mild steel.

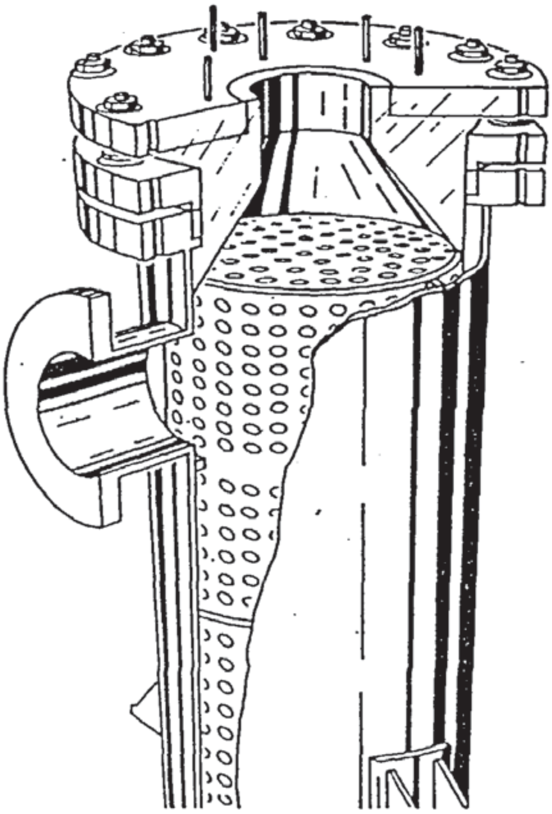
The cubic or rectangular block heat exchanger consists of a graphite block perforated with rows of parallel holes. See figure B.13 below.

Figure B.13 Exploded View of a Graphite Block Heat Exchanger[13]



Graphite block heat exchangers are also made in cylindrical designs shown below in figure B.14. This type has a conventional mild steel shell.

Figure B.14 Cutaway of a Cylindrical Block Graphite Heat Exchanger[14]



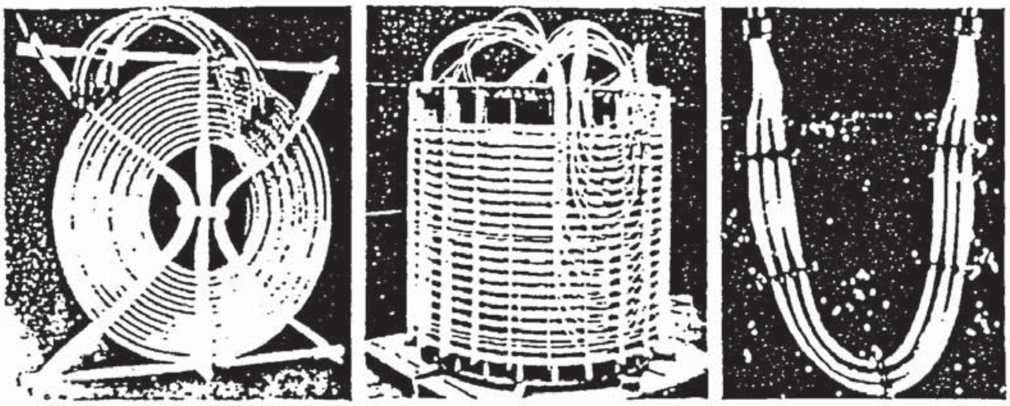
The graphite blocks themselves consist of a series of accurately machined plates of graphite laminated together. These plates are glued together with thermosetting resins.

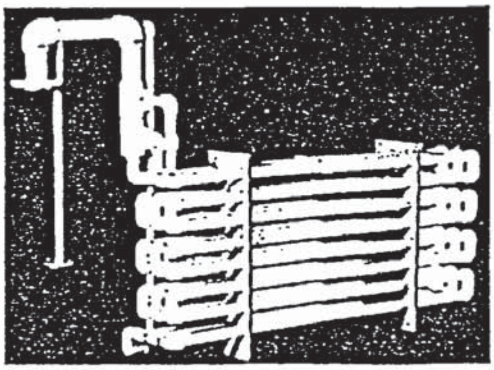
The features of graphite heat exchangers are resistance to all but the strongly oxidising chemicals and a high level of thermal conductivity.

B.10 Plastic Heat Exchangers

These units are made in a variety of configurations as shown in figure B.15 over.

Figure B.15 Various Configurations of Plastic Heat Exchangers[15]





The main advantage of these units are that the overall cost is lower when compared with heat exchangers made from some of the more exotic metals. This is in applications where a high degree of corrosion resistance is necessary and the whole life of the unit is taken into consideration.

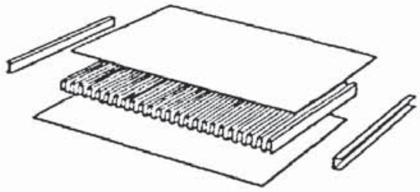
Another advantage of these units is their high resistance to fouling.

B.11 Plate Fin

These exchangers consist of packs of layers of corrugated sheets sandwiched between flat separating plates. See figure B.16 over.

These units are usually constructed from aluminium.

Figure B.16. Exploded View of a Typical Plate Fin Arrangement[16]



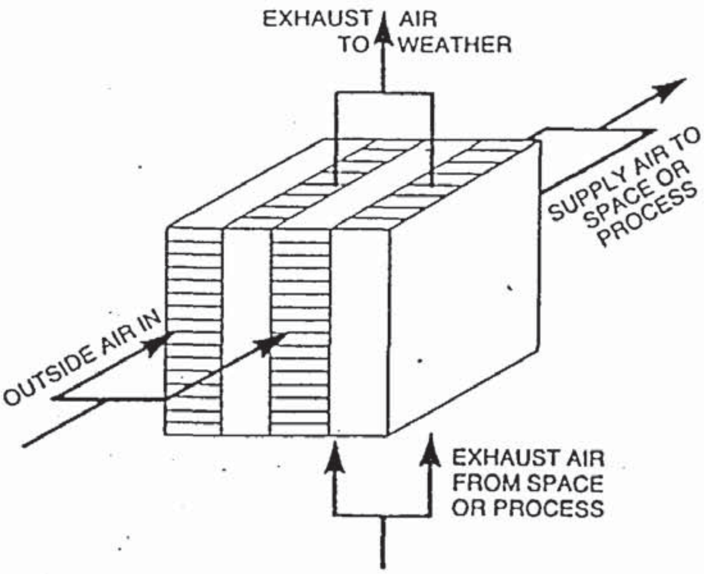
The corrugations make flow channels for fluids giving either counter-flow, parallel-flow or cross-flow.

The whole pack is brazed together to form the necessary seals and to make the whole structure rigid. As a result these exchangers are very compact with up to nine times as much transfer area per unit volume as in a shell and tube exchanger.

Plate fin heat exchangers were first manufactured for aircraft applications during the Second World War. Currently they are used in the process industries particularly for low temperature applications.

The plate fin type can be used for gases and liquids. Illustrated below is a typical gas-gas application.

Figure B.17 Plate Fin Heat Exchanger[17]

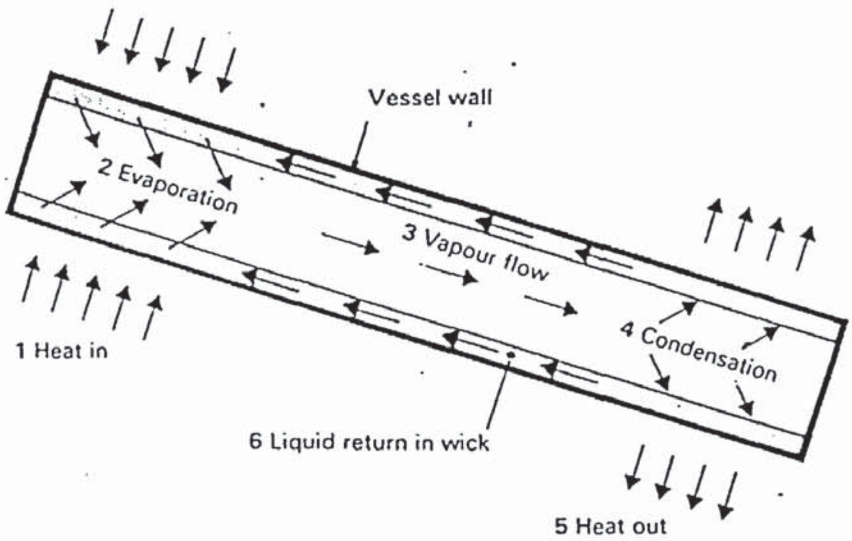


B.12 Heat Pipe Heat Exchangers

This exchanger is a bundle of finned tubes which looks like a conventional fin or ribbon tube heat exchanger. The tubes are not like the tubes in a conventional heat exchanger they are heat pipes.

A heat pipe is a sealed unit which contains a working fluid and a wick lining. The operation of a heat pipe is shown in figure B.18 below.

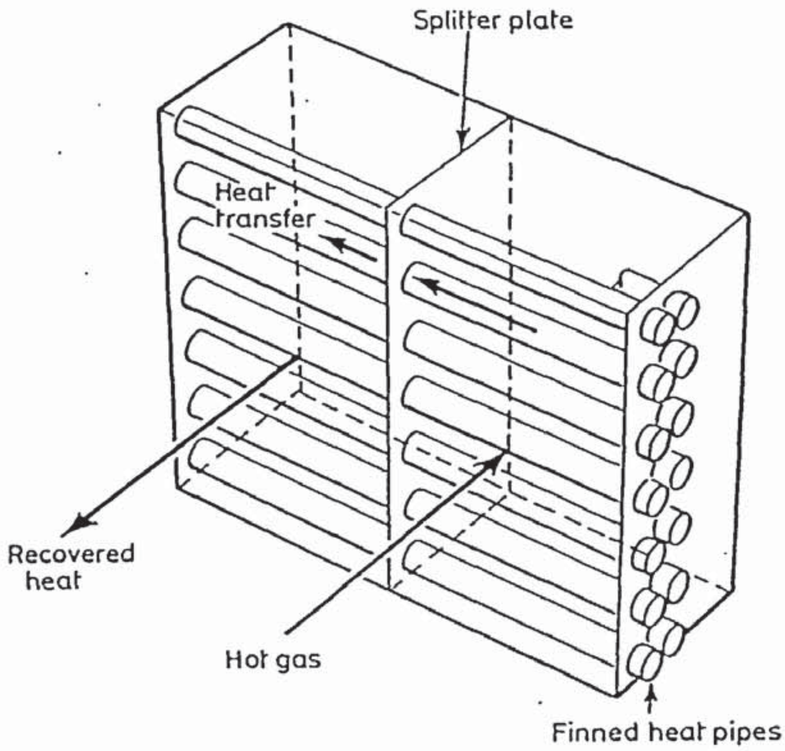
Figure B.18 Operation of the Heat Pipe[18]



If heat is applied at the evaporation end of the heat pipe, the working fluid contained in the wick evaporates. The increase in pressure causes the vapour to flow along the central vapour space to the slightly cooler condenser section. The fluid condenses and the heat is given up and rejected to the outer surface. The condensate flows back to the other end through the capillary action of the wick.

Over in figure B.19 is the general layout of a typical heat pipe heat exchanger.

Figure B.19 Heat Pipe Heat Exchanger[19]

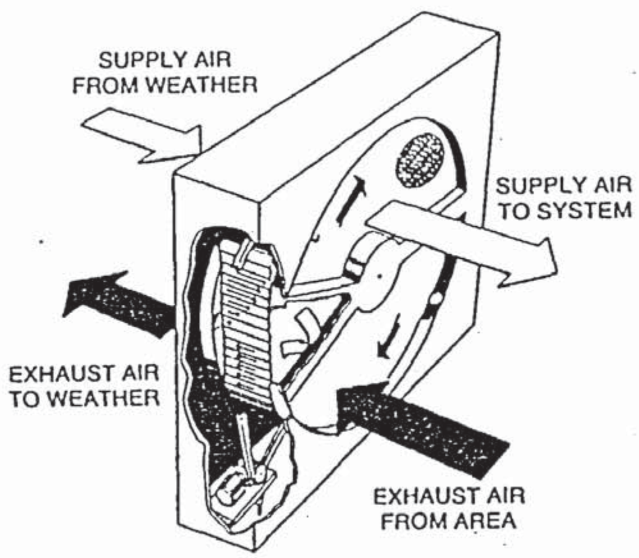


Heat pipe heat exchangers are used particularly for heat recovery applications where it is important for the two flows not to mix.

B.13 Heat Wheel

This device, a rotating regenerator, was invented by a Dane called Ljungstrom.

Figure B.20 Rotary Wheel Exchanger[20]



The regenerator wheel spans two adjacent ducts, one carrying exhaust gas and the other the gas flow which requires heating. The wheel rotates absorbing heat from the hot gas passing through it and transfers the heat to the cooler gas flow.

The wheel itself consists of a matrix which can be made from knitted aluminium or stainless steel wire; a second type which uses a corrugated matrix resembling a small-pore honeycomb; or a third type which is non-metallic and can transfer moisture as well as heat.

Most heat wheels are driven by electric motors at typical speeds of around twenty revs per minute.

The heat wheel has been used for over fifty years for heat recovery in large power-plant combustion processes. It has also found wide application in air conditioning and a number of industrial process heat recovery applications.

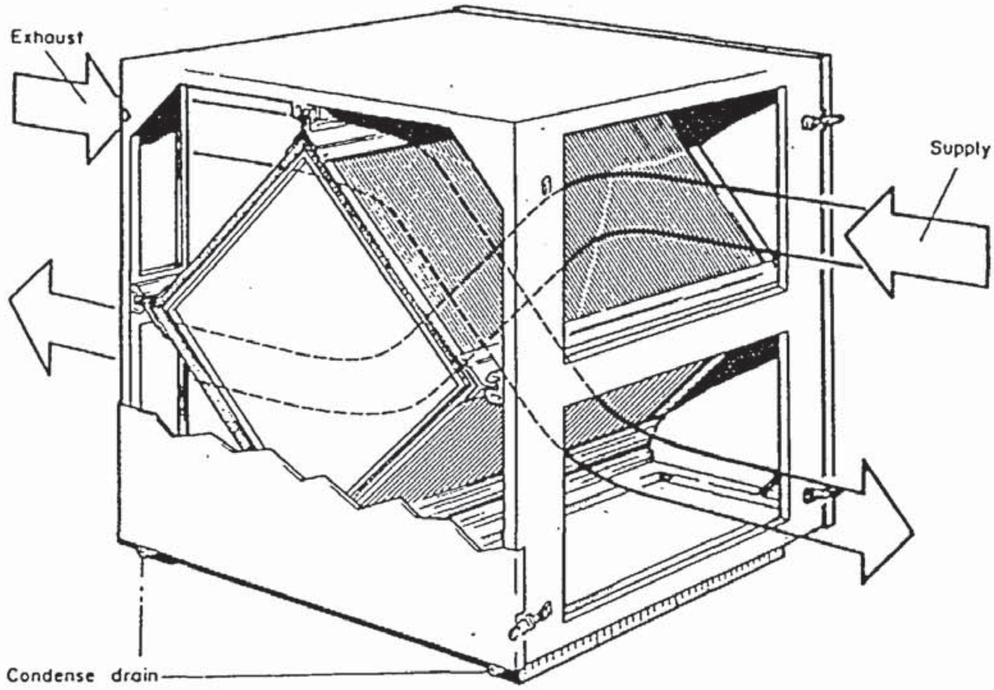
B.14 Plate Type Gas to Gas Heat Exchanger

These are quite different to liquid-liquid plate heat exchangers and the two should not be confused. Gas to gas plate types consist of a framework containing a number of thin plates which are usually made of metal but can be made in glass. The plates are located so that each one is a small distance from the adjacent plate.

The two airflows can be arranged in cross or counter-current fashion. The hot and cold gases pass each other separated by the plate through which the heat flows.

These heat exchangers are used mainly for air conditioning applications but are also used for process heat recovery.

Figure B.21 Cutaway Section of a Gas-Gas Plate Heat Exchanger[21]



B.15 Run-Around Coil

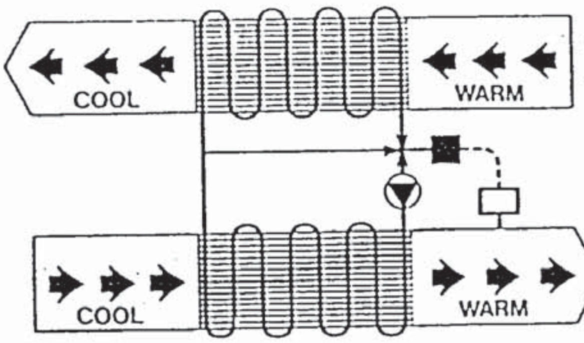
These are also known as liquid coupled indirect heat exchangers. The device consists of two fairly standard finned tube heat exchangers connected by piping filled with water, glycol, or thermal fluid solution.

The configuration of a run-around coil system is shown in figure B.22 over.

One heat exchanger is placed in the exhaust duct and the other in the duct carrying incoming fresh air. The heat in the exhaust is recouped and transferred to the other exchanger via the liquid circuit. The heat is then taken up by the incoming fresh air.

The advantage of the system is that heat recovery is possible between heat source and heat sink even though they may be fairly remote from each other.

Figure B.22 The Run-Around Coil System[22]



These systems are used in air conditioning installations in office buildings and also in gas to gas process heat recovery.

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APPENDIX C THE ESTIMATION OF PROCESS AND NON-PROCESS HEAT EXCHANGER MARKET VALUES

The Business Monitor derived heat exchanger market figures can be divided into process and non-process heat exchangers. Serck sells heat exchangers to non-process sectors. Serck's market research department estimate the value of it's markets (i.e. the non-process heat exchangers) at £45 million for 1978 in the U.K. Serck's own sales in the U.K. were £17.45 million in 1978.

It was felt that Serck's market share throughout the 1970's had remained fairly static. Using this assumption and Serck's historical sales figures (adjusted to 1978 values) the values of the non-process heat exchanger market for the years 1972-1978 are as follows:

Year	SHT Sales £M	Non-Process Heat Exchangers £M
1972	17.31	44.64
1973	15.71	40.51
1974	16.17	41.70
1975	16.71	43.09
1976	17.37	44.79
1977	17.20	44.35
1978	17.45	45.00

From the total market values derived from the Business Monitor statistics and the estimated non-process heat exchanger values, the values for process heat exchangers can be estimated as follows:

Year	Total U.K. Market £M	Non-Process Heat Exchangers £M	Process Heat Exchangers £M
1972	89.81	44.64	45.17
1973	87.57	40.51	47.06
1974	84.39	41.70	42.69
1975	105.82	43.09	62.73
1976	97.30	44.79	52.51
1977	90.93	44.35	46.58
1978	104.30	45.00	59.30

Some support for these figures is given by the fact that the values for process heat exchangers have a reasonably high degree of association with figures for total process plant investment. This is as might be expected (for further details see Chapter 8.0). The correlation co-efficient is around 0.81.

APPENDIX D OPPORTUNITIES FOR ENERGY SAVING IN INDUSTRY

		Typical Pay-back Period in Years
Stage 1		
Space Heating		
1	Improve insulation of building structure	4
2	Repair or improve building structure	5
3	Improve/re-adjust control - thermostats, timeclocks, etc.	½
4	Control heat loss through doors, loading bays, etc.	½
5	Use localised air extraction/intake	1
6	Others	1
Services		
7	Insulate steam pipes, hot water pipes, hot air ducts or boilers, etc.	¾
8	Maintain or adjust boilers, steam pipes etc, improve control of boilers	1
9	Replace existing lighting by more economic system, improve switching arrangements	2
10	Clean luminaires, windows, paint walls in a lighter colour, etc.	4
11	Improve compressed air system - repair leaks, duct intake to outside, etc.	1
Process Plant		
12	Improve insulation	¾
13	Improve control	¾
14	Turn off idle equipment	0
15	Improve maintenance of heating equipment	½
16	Improve scheduling	0
17	Make minor modifications to equipment	1
18	Other measures	1
Stage 2		
Space Heating		
19	Replace existing heating units by new or more suitable ones	2
20	Recover heat from extracted air or use recirculatory ventilation	1
21	Other	1
Services		
22	Return condensate, use flash steam, other boiler improvements	1
23	Replace boilers (if old or grossly unsuitable) including replacement by non-boiler fed heating systems	2
24	Others	1

	Typical Pay-back Period in Years
Process Plant	
25 Recover waste heat for space heating	1½
26 Recover waste heat for process heating (including recuperators)	1½
27 Re-line furnaces and other major maintenance of heating equipment	1½
28 Major rescheduling or re-organisations	1
29 Modify equipment (including minor replacements)	1
30 Use waste products as fuel	½
31 Others	1

Source: Clarke, P.T. A Preliminary Analysis of the Potential for Energy Conservation in Industry, Department of Industry, London, 1978, P.19.

APPENDIX E PROCESS PLANT INVESTMENT

The values for process plant investment used in this study were taken from the 'Process Industries Investment Forecasts' series by the Process Plant Working Party (recently renamed the Process Plant Economic Development Committee) which is published annually by the National Economic Development Office, London.

The following figures for the chemicals industries, petroleum refining and distribution and gas processing are actual values for capital expenditure taken from the process industries investment forecasts series.

TABLE E.1 Process Industries Capital Expenditure

Year	Industry			Total
	Chemicals	Petroleum Refining and Distribution	Gas	
1971	168	58	51	277
1972	139	35	35	209
1973	126	51	40	217
1974	172	43	76	291
1975	258	60	119	437
1976	288	48	102	438
1977	369	40	85	494
1978	494	135	79	708
1979	490	227	105	822

The figures in Table E.1 were changed into 1978 values. This was done by using price indices for plant and machinery bought as fixed assets by specific industries from Table 1 of 'Price Index Numbers for Current Cost Accounting' April 1980 published by HMSO London.

The revised figures are shown in Table E.2.

TABLE E.2 Process Industries Capital Expenditure Adjusted to 1978 Values (£ Millions)

Year	Industry			Total
	Chemicals	Petroleum Refining and Distribution	Gas	
1971	462	164	136	762
1972	361	93	88	542
1973	301	125	92	518
1974	325	83	146	554
1975	369	86	180	635
1976	357	60	130	547
1977	406	44	94	544
1978	494	135	79	708
1979	431	200	95	726

APPENDIX F THE ENERGY 'CRISIS' AND THE DIESEL ENGINE UP TO THE YEAR 2000

This short paper was written in 1979 during the early part of the study in response to a request from the then Managing Director of Serck Heat Transfer. As Serck was (and is) so dependent on the diesel engine sector for much of it's sales, the Managing Director wished to know if the changing energy situation and, more particularly, shortages of suitable fuel would threaten the widespread use of diesels.

The paper was also used as the basis of a talk I gave to an informal group of diesel engine manufacturers and component suppliers, known as The Engine Market Study Group, on 14th June 1979 at the offices of Hawker Siddeley Ltd., London.

INTRODUCTION

The quadrupling of oil prices in 1973/74 and the ensuing crisis brought home to the industrial nations of the World the importance of energy and, in particular, oil. Such changes in the price of oil can have dramatic effects on the performance of any country's economy.

The effects of changing energy prices on individual companies are similarly far reaching. Considering Serck Heat Transfer's own position, it can be seen that as a company it is highly dependent upon the use of oil creating a large demand for heat exchange equipment. The largest section of this oil-based demand is for diesel engine applications. S.H.T. sales to the diesel engine sector account for around 57% of turnover (1976/77 figures).

Any problems occurring in the various diesel markets which the company serves can seriously affect the company's performance. The oil crisis of 1973/74 undoubtedly played a part in Tubular Cooling Division's loss of business in the marine sector although some of this loss was in non-diesel marine. This points to the fact that not only is the company highly dependent upon the diesel engine industry for business but also it is even more dependent upon the price and availability of oil.

Given that in general oil prices are going to rise and that also the supply of oil will start to diminish sometime in the future, how will this affect the diesel engine? Unfortunately the situation is not as clear cut as it would at first seem. There are many and differing estimates of when oil will start to diminish in supply. Coupled to this there are problems of estimating to what extent oil may be replaced by other sources of power such as coal and nuclear energy. Also, anticipated technological changes in the diesel engine and its competitors have to be considered.

DIESEL FUELS: AVAILABILITY AND QUALITY

As diesel engines, particularly those employed in transport, are regarded as premium users of oil then as long as oil is being produced there will be the fuels available with which to run the engines. Oil is a finite fossil resource and will eventually cease to be available in commercially exploitable quantities. Estimates of when this might happen vary greatly but the consensus amongst experts is that it will not be before well into the next century. However, sometime before the oil runs out the World will be faced with shortages, the timing and extent of which depend upon levels of consumption. Many factors influence the rate at which oil is consumed including the level of economic activity, the price and availability of alternative sources of energy and Government policy. Most experts seem to agree that oil shortages will become a major problem by the mid to late 1990's although according to at least one expert, major shortages could be with us by the mid to late 1980's unless Governments, particularly the United States Government, take action soon to cut consumption.[1]

Cutbacks in oil usage will be achieved through increased effort in energy conservation and the replacement of oil used in space and process heating by electricity, natural gas, coal, and possibly solar energy.

Severe short term availability problems can be caused by local or international political developments. These events are difficult to predict in most cases and the disruption they cause can be dramatic; the situation in Iran which has caused Worldwide problems demonstrates this. These short term shortage problems should not adversely affect the market for diesel engines in the long term and may even provide a stimulus for growth in demand. This is because the diesel is a more efficient fuel burner than any of its rivals and is therefore favoured increasingly as fuel becomes more scarce.

A problem that diesel engine manufacturers and users may have to face is that of wide variations in diesel fuel qualities. Greater demands in the future will be made on available oil resources and oil refiners may find that there are shortages of some of the crude oils they use for blending to produce the final refined product. This may mean that refiners will be unable to produce diesel fuels of a sufficient standard that is necessary for them to be burnt in current designs of engines. It is most likely that manufacturers will be able to cope with these problems by developing new designs of engine that can operate successfully with a wider range of fuel qualities than are currently acceptable.

THE DIESEL ENGINE AND ITS COMPETITORS

The main attraction of the diesel engine over its competitors is its fuel burning efficiency. For this reason alone one could conclude that as oil becomes more and more expensive the diesel engine becomes economically more attractive when compared with other prime movers. It is possible, however, that technological changes in the competitors to the diesel engine could alter the situation.

The competition to the diesel engine from now to the turn of the century are likely to be the following. Firstly, in the smaller sizes (3-100 HP) which include the small industrial and passenger car types the main competitor is the spark ignited petrol engine. The stratified charge engine may also make some impact in the smaller horsepower range. These engines occupy a position somewhere between spark ignited petrol engines and diesel engines. Ignition is the result of a spark but the fuel/air charge is not uniformly mixed during combustion.

Secondly, in the 100-1500 HP range for such applications as trucks, buses, civil engineering and mechanical handling equipment competition may come from gas turbines for use in luxury buses and coaches. Also the Stirling engine may be used for a low noise city bus.

Thirdly, in the 1000-5000 HP range which are used for locomotive and industrial applications diesels may be displaced to some extent on densely used railway lines by electric power.

Fourthly, in the 5000-10000 HP range medium speed diesels which are used in marine and industrial applications competition may come from greater use of electric power on the industrial side and possibly gas turbines across the range of applications.

Fifthly, and finally, in the 8000-40000 HP low speed range of diesels which are used in marine and generating applications competition may come from gas turbines and steam turbines particularly if residual fuel quality becomes very bad.

The impact of these competitors will depend largely on how efficiently they burn fuel and any other particular advantages each may have such as cheapness of construction or maintenance. Currently the competitors offer few, if any, advantages and there will have to be some major technical breakthroughs for them to pose any sizeable threat.

There is, of course, scope for further developments of the diesel engine which if widely adopted will strengthen its position. This being so then it is important to mention briefly some of the possible developments of the diesel engine. An 8 to 10 per cent improvement in fuel economy could be achieved in the high speed, light duty category of diesel engines. These are the types used in passenger cars, taxis and light commercial vehicles. If direct injection of fuel instead of indirect injection, as currently used, was adopted better cold starting and the aforementioned improvement in fuel economy would be achieved. There are problems with using direct injection in this type of engine because of the wide speed ranges encountered. It may be possible that these problems will be overcome in the future.

In the larger range of engines which do use direct injection and where the best only convert around 40 per cent of the heat energy of the fuel into useful work, there is the possibility of using insulating materials, ceramic or metallic, to reduce heat loss to the coolant. In an engine with a simple working cycle the gains in fuel economy may be up to 8 per cent.

The gain in economy could be as great as 20 per cent with a high load factor on an engine with a compound working cycle. In such an engine the exhaust gas driven turbine and the supercharging air compressor are both geared in with the engine so that any surplus power from the turbine, above that required to drive the compressor is available as shaft power from the power unit.

The addition of a Rankine bottoming cycle to either a simple turbocharged diesel engine or to a compound cycle engine is another possible development. This cycle is identical to that of a steam engine but employs an organic fluid as opposed to water as the working fluid. A 30 per cent or so gain in efficiency at high power is possible but at the expense of greatly increased complication with the need for such equipment as an evaporator, an expansion turbine and a condenser to reject the waste heat.

It is impossible to predict whether or not the diesel engine of the future will offer any more or less advantages than it currently does over its rivals. It does seem that from current evidence that the diesel will continue to offer substantial advantages in fuel economy over its rivals but the competitors may offer specific advantages in limited specialised applications.

ECONOMIC EFFECTS OF FUEL PRICE RISES

So far in this paper, discussion has been limited to the direct or what an economist might term micro-economic effects of changes in the energy scene. These are the effects which happen directly in the market place; for example when the price of oil rises, we would expect the demand for oil consuming products (e.g. diesel engines) to fall. The situation may be of course that the demand for prime movers in total is not very dependent upon the price of fuel but the choice of type could well be. If this is so when the price of oil rises those types of prime mover which are the most efficient in terms of fuel burning performances will be favoured. To some extent this can be seen in the motor car market where, traditionally, the petrol engine has been the overwhelmingly dominant power plant. The large rises in fuel prices in recent times have seen many large manufacturers offering a diesel unit as an alternative to the petrol engine. In the U.K., truck and bus production fell from 408,100 in 1972 to 386,400 in 1977 but the number of diesel units in this sector rose from 236,800 to 253,380 in the same period. Diesel engine penetration in buses and trucks rose from 35 per cent to 40 per cent.[2]

One can reasonably suggest that an important determinant of the level of demand for engines is the level of economic activity currently occuring and expected in the future. Levels of economic activity can be heavily influenced by fuel price changes (in the aftermath of the 1973/74 quadrupling of the price of crude oil there has been much evidence to support this). These effects may be termed macro-effects of changes in fuel prices because they influence the overall performance of an economy not just individual markets and companies. It can be seen from past experience that large rises in the price of crude oil have a depressing effect on the economies of the western industrial nations in particular.

One of the first and worst hit sectors of any economy would be the capital goods sector. Table 1 below shows the index of U.K. industrial production for the years 1972 to 1977 inclusive.

TABLE 1 U.K. Index of Industrial Production[3]

	Year					
	1972	1973	1974	1975	1976	1977
Index	102.3	110.0	106.3	100.6	101.3	102.6

(1970 = 100)

From the Table it can be seen that industrial output declined significantly after the 1973/74 oil crisis. The effects were mainly spread over 1975 and 1976 but even by 1977 production had not recovered back to pre-crisis levels.

There are those economies which gain from oil price rises namely the Organisation of Petroleum Exporting Countries (OPEC) member states. OPEC members Iran and Nigeria have provided substantial growth markets for capital goods such as diesel engine generating sets. The sales of diesel generating sets over 1 MW to Iran in 1972 was 12 units; in 1977 the figure had risen to 80 units.[4] (This is an almost sevenfold increase in market size between pre- and post oil crisis years).

SUMMARY

It is likely that the next twenty or so years will see a rise, in real terms, in fuel costs and a levelling off and eventually declining supply of oil. As diesel engines are used in applications which are regarded as premium consumers of oil they will exist as long as oil continues to. With regard to the diesel engine's competitors in the size ranges in which S.H.T. is interested they may have some impact but it will be minor in comparison with the economic effects of fuel price rises. Before competitors have any impact they will have to offer significant advantages over the diesel engine which currently they do not. As the price of fuel increases, the attraction of the diesel over its competitors becomes stronger because of its fuel burning efficiency.

Increases in the price of crude oil have depressing effects on the economies of oil importing countries which in turn depress the capital goods market for such items as diesel engines. For oil exporting countries fuel price rises mean more money available for capital goods purchases (most OPEC countries attach great importance to broadening their industrial scope and spend large parts of oil revenues to achieve this). The desire on the part of OPEC countries to expand provides some industries in the West with expanding demand that in some cases more than offsets depressions in the economies of the oil importing nations.

The future of the diesel engine seems fairly well assured for the remainder of this century, so it would appear that the diesel market is an attractive one for S.H.T. to be in. The main threat to Serck is over-dependence on a too narrow range of activities because even seemingly strong markets are subject to cycles and the occasional unpredictable hiccup such as the shortage of money in Nigeria or revolution in Iran.

REFERENCES

1 Wilson, Carroll. L. — Comments Made in Horizon Documentary About Energy Shown on BBC 2, 1979.

2 Serck Heat Transfer — Data From Market Information System.

3 Central Statistical Office — Monthly Digest of Statistics, H.M.S.O., London.

4 Serck Heat Transfer — Data From Market Information System.

APPENDIX G CONVERSION TABLES

Energy

Btu	x	1.055	= kJ	x	0.9478	= Btu
Therms	x	105.5	= MJ	x	0.009478	= Therms
Therms	x	29.31	= kWh	x	0.03412	= Therms
kWh	x	3.6	= MJ	x	0.2778	= kWh
GWh	x	3.6	= TJ	x	0.2778	= GWh
GWh	x	0.0036	= PJ	x	277.8	= GWh

Power, Heat or Energy Flow Rate

Therms/h	x	29.31	= kW	x	0.03412	= Therms
HP	x	0.7457	= kW	x	1.341	= HP

Other Equivalents

GJ	x	0.0379	= Tonnes Coal Equivalent	x	26.4	= GJ
PJ	x	0.0379	= Millions Tonnes Coal Equivalent	x	26.4	= PJ
Tonnes Coal (Equivalent)	x	0.6	= Tonnes Petroleum (Equivalent)	x	1.6667	= Tonnes Coal (Equivalent)
Tonnes	x	0.9842	= Tons	x	1.016	= Tonnes

Metric Multipliers

kilo = 10^3

mega = 10^6

giga = 10^9

tera = 10^{12}

peta = 10^{15}