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ENERGY MANAGEMENT

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SUMMARY

A study has been made of the various opportunities that exist to save energy in industrial activities through the application of existing technology and through the development of new technologies.

The underlying principles that should form the basis of any industrial energy conservation programme are established and concepts for implementing specific measures have been formulated.

Possible routes to minimising energy requirements in industrial premises and in manufacturing processes, by careful attention to energy conservation at the design stage, have been considered. The energy sequestered in different materials for component production has also been considered.

To particularise the general principles, two case studies have been made, one covering fuel and electricity requirements on a large industrial research site; and another based on a desk study of energy conservation in industrial motive power.

A review of the literature on the subject has been carried out and from the consideration of the underlying principles and concepts, and from the specific case studies, conclusions have been drawn that indicate the level of energy savings that might be set as targets for industrial energy conservation programmes. Reference has been made to existing achievements in industry and to questions of motivation and incentives to save energy in industry.

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ABBREVIATIONS

SEB	Southern Electricity Board
DIDO	Research Reactor 26 MW
PLUTO	Research Reactor 26 MW
VEC	Variable Energy Cyclotron 58 MeV
LINAC	Electron Linear Accelerator 136 MeV
GWh	Million units of electricity
AERE	Atomic Energy Research Establishment
SRC	Science Research Council
MRC	Medical Research Council
NRPB	National Radiological Protection Board
MPD	Materials Physics Division
RAF	Royal Air Force
BSIRA	Building Services Information Research Association
UKAEA	United Kingdom Atomic Energy Authority
BEPO	Experimental Reactor 10 MW (now shut down)
CEGB	Central Electricity Generating Board
CHP	Combined heat and power
CBI	Confederation of British Industries

PART I

INTRODUCTION

General Principles of Industrial Energy Conservation

1. The increasing constraints on the availability of energy needed to meet world demand has become an issue of universal concern. Existing resources will be hard-pressed to supply the energy that appears to be needed. As a consequence several courses of action must be taken, particularly by the rich energy consuming industrial nations of the world. First, the efficiency with which resources are used in manufacturing processes must be improved so that we can obtain more output from less input. Second, society must adapt its life styles and customs to accommodate the effects of energy conservation measures. (1)

2. Technology and management must play leading roles in all aspects of this problem, particularly in the efficiency issues and in organisational measures to ameliorate the effects of scarcity and higher costs of energy supplies. The basic approaches to these courses of action that are necessary for conserving energy can be divided into three broad categories;

(i) changes in the design and management of systems and subsystems so as to reduce the total energy needed to accomplish specific tasks and services,

(ii) the optimal choice and development of materials to reduce the energy sequestered in their production,

(iii) the development of manufacturing processes to minimise energy inputs and to eliminate wastage of materials.

3. Consideration of these approaches leads to some general conservation principles that will have increasing importance in the future, e.g.:

Table I

Energy requirements for basic commodities

Product	Tons of oil equivalent required per ton of product		
	for feedstock	for conversion	Total
Aluminium		5.6	5.6
Steel billet		1.0	1.0
Tinplate		1.25	1.25
Copper billet		1.2	1.2
Glass bottles		0.45	0.45
Paper & board		1.4	1.4
Polystyrene	1.3	1.88	3.18
PVC	0.55	1.4	1.95
Polythene	1.13	1.2	2.33

Source - data from Chemical World, 24 November 1974

- the reduction of in-built obsolescence,
- the sequential use and re-use of energy and materials,
- the integration and aggregation of different industrial processes and activities.

4. For example, the incremental cost of rust proofing car bodies, if it is relatively small compared to the total manufacturing cost, must be worthwhile to eliminate premature obsolescence. However, technological obsolescence might place an upper limit on the useful life span of a product. Therefore, the design and specification of products should take account of several factors including; the initial energy requirement; changes in performance and utility during the life cycle; and the end of life materials reclammation possibilities.

5. By calculating the total energy cost of a component as an annual average requirement over its life, a basis for comparison between alternative design options could be established. Such comparison should also cover the energy invested in alternative materials for specific applications; for example, plastics versus glass or metals, steel versus concrete or fibre reinforced composites. Table 1 indicates the energy sequestered by various materials.

6. The concept of sequential use of energy is not new because waste heat recovery has been traditional in many industries, but the scope for using the waste streams from one process as the inputs for another must be carefully considered even at the low grade heat stage. New technologies might make it feasible to minimise the degradation of use at each stage and to make it possible to use waste heat at, or near ambient temperatures, for example by the application of heat pumps, thermal wheels, heat pipes and other concepts.

7. Re-cycle of waste materials must take account of collection and reconstitution costs which might not always be compatible with energy conservation objectives. But in an idealised sequence, materials should first be used for their highest performance levels and ultimately

as a feedstock for some other purpose. Heat production from waste material incineration would be one example of the end use of certain materials.

8. Motive power is almost universally provided in the light and heavy manufacturing industries by the electric induction motor. Although this type of prime mover has a high efficiency when operating at full load, most of the operational life is spent running on light load. Also, the demand of many processes is for a drive speed lower than that provided by induction motors. Gear trains are therefore needed, and in some instances variable gear ratios, to provide the speeds and forces required. These systems incur considerable power losses that could be avoided if the characteristics of the driving agent were better matched to the power-speed requirements of the process. Developments with power drives are needed to improve efficiencies and reduce part load losses.

9. In some manufacturing processes the individual steps in production and storage of components are often separated in time and space, thereby involving substantial non-productive use of energy. Therefore, in the delivery of products and services to users, strategies should be adopted that will minimise disaggregation. This concept should also be extended to the social considerations and life styles, so that the energy requirements of interacting industrial and social activities can be supplied in a continuous manner starting at the highest level to the final wastage stage. In the extreme case, new industrial complexes embodying all the required processes from raw materials to end products, sited in juxtaposition with residential and leisure centres would achieve the benefits of aggregation and continuous sequence use of energy resources. Transportation and associated energy costs would be reduced by such integrated systems.

10. Important examples of wasteful management of process heat includes heat rejection and re-heating during separate stages of manufacture, each requiring high temperatures, and the removal and scrapping of material during cold working manufacture. Due to disaggregation of factories and processes, heat is wasted within one establishment which could be reused

over the fence in another factory. Aggregation of the energy management function would allow the concept of total energy systems to be applied wherever the overall costs can be justified. A combination of different activities within an industrial complex would enhance the probability of cost effectivess. For example, space heating requirements in factory buildings could be provided from the cooling streams from an adjacent power plant. Laundry activities also offer usable supplies of waste heat for process heating and other applications. Economic evaluation will determine the size of pipe and thickness of insulation, and the distance over which it is cost effective to transmit recovered heat from one factory to another user.

11. A large proportion of the energy that is consumed in industry as a whole is used for space heating, therefore important opportunities exist for conserving energy through economic insulation standards and optimal design, shape, and orientation of industrial buildings. Illumination, ventilation and considerations of cybernetics and productivity are important factors that bear on heating requirements and the need for acceptable standards of environmental comfort. Clothing is also an important issue in assessing body needs and the relationship between the requirements for space heating and thermal comfort. An understanding of the thermal environment in industrial buildings on man's physical and mental performance is important to establishing the optimum energy requirements. Table II indicates the temperature required for thermal comfort.

12. The concepts mentioned above illustrate the many interacting architectural, engineering, scientific and social issues that determine the economic use of energy in industrial activities. What has been said also indicates the greater refinement that will be required in the design of premises, processes and products, compared with current practices. This implies a need to implement existing technology and also to develop new techniques and alternative materials.

13. The nature and quantities of materials required by industry depends not only on the demand for products but on the technologies used in their production. From the point of view of the purchaser and user

Table II

Building temperature required for thermal comfort

Type of clothing worn	Comfortable temperature for person sitting down	
	°C	°F
Shorts & T-shirt	25	77
Slacks & Pullover	22	71.6
Suit	18	64.4
Overcoat & gloves	14.5	58.1

Source - Design Note 16 Architects & Building Branch, DES, HMSO 1978.

Statutory Requirements:

The Energy Act (1976) prohibits the use of fuel or electricity to heat commercial and industrial buildings above a temperature of 20°C (lowered to 19°C, October 1980).

The Shops, Offices & Premises Act 1963 states that where work does not involve severe physical effort a temperature of less than 16°C shall not be regarded as a reasonable temperature after the first hour.

of products the selection of materials or of the methods of manufacture is usually not a matter of primary importance. Decisions are made on the basis of availability, cost differences and custom and practice. Goods of equal utility can often be produced from alternative materials and processes. However, fundamental changes in the pattern of technology result when large scale changes in choice of materials occur. For example, the outstanding increase in the choice of plastics that replaced the choice of non-ferrous alloys for many components, and reinforced plastics can now be considered as alternatives to steel in some applications.

14. The changes that are taking place in the range of materials and manufacturing processes available to production engineers are yielding more efficient products. Improvements to the durability of components also leads to conservation because there is a related reduction in the production volumes required, (for example, the life of rubber tyres for motor cars has been greatly extended by new technologies).

15. To meet the requirements to conserve energy, on the scale that will be required when fossil fuels become scarce and expensive, means that it is necessary to continue to develop new production systems for making, shaping and joining new and traditional materials.

Process Heat

16. There is a wide range of industrial process heating techniques, e.g. gas, oil, electric resistance, dielectric, induction, microwave. Opportunities for improvements in processes can exist by switching to the most appropriate technique and through suppressing losses and recovering waste heat. These ideas are discussed in the following paragraphs.

17. Heat pumps to upgrade the temperature of recovered heat at about $80^{o}C$ to $140^{o}C$ for drying purposes, and from about 45^{o} to $70^{o}C$ for space heating temperatures.

18. High temperature filters should enable high temperature exhaust gases containing solids to be recovered as clean hot gases for further use at say $100^{o}C$.

19. Suppressing process heat losses necessitates insulation and radiation shielding for high temperature furnaces, heat treatment vessels, storage vessels and pipework. Excessive losses from the high thermal mass of large heating plants can be reduced by reflective coatings. This is of particular importance also for furnaces that have intermittent or time cycle operation.

20. Application of the latest heating techniques, e.g. lasers and electron beams for welding conserves energy by confining the area of application of heat. The narrowness of the heat zone can be closely controlled. R.F. and Microwave systems offer special applications in plastic heating and welding, also the drying of wet materials.

21. Hot isostatic pressing of metal powders and refractory materials permits components to be formed with minimal waste of material and conserves the heat associated with melting, casting and the energy required for machining.

22. Induction heaters for melting offer potentially high efficiencies providing the shape and size of the inductor coil is closely matched to the characteristics of the product. For heat treatment, fluidised bed combustors with their high heat transfer coefficients could save energy compared with conventional oil or gas fired heating.

23. Each possibility for any particular process requirement must be examined for overall cost effectiveness and the sequential use of heat and waste heat taken into account. Development of control technology, particularly for sequential process and space heating systems to ensure that temperatures are maintained at the required levels is important.

24. Many areas mentioned above involve uncertainties associated with technical and financial risk, because, particularly if applied on a large scale, they are not well tried techniques. However, in view of the potential contribution to energy savings that they offer they merit serious consideration. For example, in some situations it would be worthwhile to consider using solar collectors for providing low grade heat or for pre-heating applications.

Industrial Building Heating

25. There is no doubt that great improvements can be obtained through adoption of existing technology, particularly by following good maintenance practices and bringing plant and premises up to modern standards. New buildings have to be designed to meet the latest insulation requirements. Although there is no legislation requiring that existing buildings be improved to meet these statutory requirements, considerations of heating costs will dictate the desirability of improving poorly insulated buildings. This involves consideration of:

- selection of new types of insulating materials and of application techniques to walls, roofs and in some cases, floors,

- fitting effective methods of sealing buildings to reduce air infiltration through doors, windows and other openings,

- attention to glazing, particularly north facing roof lights, to reduce unnecessary glazed areas and to fit films with low emissivity of infrared energy,

- optimisation of heating time cycles based on the thermal characteristics of building fabric, weather conditions and occupancy hours,

- reduction of ventilation losses, consistent with requirements to remove pollutants, and adoption of heat recovery where possible e.g. by thermal wheels or recovery loops, (2)

- selection of efficient heating appliances that are appropriate for each situation, including heat pumps,

- provision of a zone control for heating systems to take account of differential requirements on north and south facing sections of buildings,

- selection, siting and controlling heat emitters in large, lofty industrial buildings to offset the wasteful gravitational effects of heat stratification.

- consideration of air curtains in loading bays, to heat incoming air when doors are open.

Storage of Energy

26. Industries using steam systems nearly always have fluctuating flows demanded by various processes. In some industries manufacturing plant is operated on a variable throughput basis, or on intermittent batch-type production runs. In these situations storage could play an important role in energy conservation and in saving generation plant by load-levelling.

27. Energy may be stored in a number of ways, but as most energy used in industry is produced as heat, the potential for thermal storage has greatest importance. Water is a convenient medium, and at high pressures can store energy above 100°C but it is possible to utilise both sensible and latent heat properties of various media for thermal stores.

28. New technologies are expected to increase the present storage systems, e.g. innovations with chemical stores, based on reversible reactions, flywheels for recovering and storing mechanical energy.

29. The scale of storage in terms of time and quantity is of crucial importance. Nearly all potential applications are for hourly, daily or weekly storage. However, there is a great need for inter-seasonal storage for load levelling. Storage characteristics for industrial applications may be broadly defined as follows:

- space heating,
- base load process heat up to 150°C,
- single and double shift process heat,
- base load low grade heat below 100°C,
- single and double shift low grade heat
- (non-heat) storage of motive power by hydraulic accumulator.

Exhortation, Incentives and Motivations for Energy Conservation

30. The scope for conservation measures in industrial premises, to reduce energy consumption has been repeatedly stressed by Government and other International Agencies.

31. A combination of the effects of higher prices and scarcities of supply have induced 'Save It' campaigns both on the international, national and local levels, and it is generally thought that savings around 6 per cent have resulted. However, the potential savings have been estimated to be much higher than this, with various authorities putting the figure at between 20 and 30 per cent of current usage.(3)

32. Government encouragement to Industrialists to pursue effective conservation programmes in their factories can be through exhortation, financial incentives, or through the market price mechanism. In fact, all three influences for motivating firms are generally applied but there is little doubt that it is through increases in real prices of light, heat and power that the greatest incentive is felt for the need to adopt cost effective energy saving measures. In this connection, there is a widely held view that fuel prices will at least double in real terms over the next two decades as oil becomes scarce and more difficult to produce. (4)

33. Action to encourage the more efficient use of energy in manufacturing industry has been taken by various Government Departments, particularly by the Departments of Energy and Industry as part of the national energy conservation campaign.

34. In particular, the Department of Industry sponsors an "Industrial Energy Thrift Scheme" (started in 1976) which has three main objectives:

- to find out how energy is used in industry and how it could be used more economically,

- to promote the more efficient use of energy in industry through improvements in process efficiency and by adoption of good practices,

- to find out what action is needed by government to assist industry in using energy more efficiently.

35. Following consultations with representative firms in nine different industry sectors an estimate has been made of the potential energy savings which could be obtained through application of relatively simple conservation measures.

36. More detailed studies have been started, particularly for the energy intensive industries, by the Department of Industry's Energy Unit. The aims of the studies have been to identify the research and development that is needed to achieve them. The findings of these studies are reported in an 'Energy Audit' Series of Reports published by the Departments. (5)

37. These activities are co-ordinated by committees with representatives from the CBI, TUC and industry. To achieve the potential savings good housekeeping practices are required and investment in capital projects such as the insulation of factory buildings, replacement of inefficient boilers. Although many companies understand the cost savings that can be obtained by investment in energy conservation schemes there are other demands on capital and resources, so pay-back times must be competitive with other projects.

38. The Government, in 1978 announced the introduction of a scheme under the Industry Act (1972) to encourage and accelerate investment in energy saving through selective financial support. The scheme provided for 25 per cent grants towards the capital costs of modernising boiler plants, combined heat and power projects and insulating factory buildings.

39. The Government also provides financial support under the Science & Technology Act (1965) for a wide range of energy savings R & D projects and demonstration schemes designed to reduce any technical and economic uncertainties that might impede the introduction of new technology.

40. R & D projects have been started in the Ceramics, Glass and Drop Forging Industries. Two important programmes that provide assistance for the development of new energy efficient process are:

(i) the product and process development scheme,

(ii) the microprocessor application project.

41. (i) makes support available for the development of new products and processes by manufacturing industry that cater for the conservation of energy. Help can be provided towards costs from the design stage up to the point of commercial production.

42. (ii) makes assistance available to encourage UK industry applying microprocessor technologies to production processes. The new technology is now being used to achieve efficiency in the control of many industrial processes and is likely to become a key factor in energy conservation measures.

43. Some industries have taken action, some, after adopting 'save energy' campaigns, ran out of enthusiasm, while others have been less responsive to the national programmes. The Government in 1980 has announced the closing of the Energy Conservation Scheme and has embarked on a policy of expecting voluntary action by industry and individual companies. Motivation will arise as a direct response to market prices of energy, and not as a result of Government financial assistance.

44. This point was illustrated in the House of Lords (Hansard, Vol.401, No.27) when an amendment to the Report on the Companies Bill would have required company annual reports to include particulars of fuel and electricity and of energy conservation measures. It was deemed inappropriate and the view was taken that the increasing cost of energy would inevitably compel industry to seek new means of conservation without the need for government legislation.

45. However, Government statements make it quite clear that energy conservation will continue as a main aim of Government energy policy. The Government is continuing with certain advisory and information services which will assist the efforts made by industry. Certain activities sponsored by Government Departments comprise:

- National Energy Management Courses organised by the Department of Energy,

- The Energy Quick Advisory Service (EQAS) provided by the Department of Energy,

- Publication of free Fuel Efficiency Booklets and loan of technical films,

- Regional Energy Conservation Offices operated by the Department of Industry to provide liaison type services,

- Energy Survey Scheme (ESS) which provides for one-day good housekeeping survey or a more detailed review of overall energy usage by approved consultants. Such surveys are sometimes called 'energy audits' when all the data are quantified and monitoring is possible.

46. As Government funding is phased out for specific conservation schemes, the responsibility for saving energy will rest with industrial companies and their managements, who in their turn must find the means to motivate the workforce to use energy resources economically. The setting of targets and accountability is gaining an important place as part of management practice.

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PART II

ENERGY AUDIT

Introduction

1. An audit has been made of energy consumption and use on the Harwell site where the process and space heating requirement is provided from a central steam boiler house and the electrical power requirement is supplied from the SEB grid. The general demand for heat and power is:

	Steam	Electricity
Maximum demand	50 MW	10 MW
Minimum demand	12 MW	4 MW
Average demand	22 MW	6 MW

2. In addition there are diesel engine generating sets associated with emergency supplies in special areas.

3. DIDO and PLUTO Reactors, fuelled by enriched uranium, are each operated at a power level of 25 MW(T) for experimental and isotope production purposes. The heat energy associated with both reactors is rejected via cooling towers.

4. Other experimental facilities, e.g. VEC, LINAC are supplied with power from the site electrical mains and their heat energy is also generally dissipated via cooling towers.

5. The audit covers the use of the above energy forms on the site, that in total amount to about 75 MW average load. It aims to be generally informative at this stage rather than dealing in depth with specific issues which will be covered by specific reports and recommendations. Some of the quantities stated lack precision but they are accurate enough for the purposes of presenting a broad overview.

Energy Auditing

6. The Department of Energy has published a series of informative booklets on Fuel Efficiency, that deal with the concept of energy auditing as a necessary precursor to identifying energy conservation measures.

7. It is argued that by applying internal audit techniques to the principles of energy conservation and by carrying out an operational audit it is possible to identify simple measures that can be taken to reduce consumption per unit of work or output.

8. Initially, particularly where tight control has been lacking, an energy audit should yield up to 10 per cent savings in the short term with minimal expenditure. Further savings are usually associated with schemes involving capital outlay. The Fuel Efficiency Booklets emphasise that energy auditing is well worth pursuing whatever the economic circumstances of an organisation.

9. This approach has been adopted in this audit. It requires little ingenuity to replace consumption per unit of output with some other suitable criteria, e.g. consumption per degree day or consumption per square metre of floor area.

10. Progress with conservation measures already taken over 1974-79 to secure savings are noted. The data used for the audit have been taken from stores vouchers, meter readings and other relevant information recorded in the Finance Department.

11. Fuels used are accounted for in a variety of units, e.g. gallons, tons, cubic feet and KWh depending upon the type. To establish a common base for auditing, all the different energy forms have been expressed in THERMS using the approximate conversion factors published by the Department of Energy. These are sufficiently accurate for the purpose of a preliminary audit. (1,2).

Supply

12. Energy consumption on the Harwell site during the financial year FY 1979 - 80 is shown in Table I. It should be explained that this gives the quantities of fuels consumed in the Harwell Boiler House which supplies heat to AERE, SRC, MRC, and NRPB. The quantity of electrical energy represents that used at AERE only.

13. In this table the gross consumption of fuel has been stated because, although a proprotion of the steam produced is exported to the neighbouring establishments, AERE staff are responsible for the efficient operation of the boiler house and all the fuel that is used for steam production. Later in the report the figures will be abated by the quantities exported, where this is appropriate for the audit.

14. The gross energy consumption of 10.9 million Therms represents approximately 0.02% of final inland consumption of energy in Britain.

15. The pattern of energy use from 1975 onwards when gas fired boilers were introduced in the boiler house is shown in Figure I. It is clear that gas has displaced over half the quantity of fuel oil that would otherwise have been used. In terms of contract prices this displacement of oil by gas represents a cost savings in the last financial year of a little over £360,000 (a figure which can be deduced from Table I). The actual level of these cash savings each year is conditioned by the differential oil-gas price which has varied markedly, eg in FY 1978 - 79 the savings amounted to approximately £5000. With gas supplies at their limit, there was a swing back to coal in FY 1979 - 80 in response to a directive by the Department of Energy to conserve oil supplies. The ability to burn a mixture of fuels in the plant available provides the site with a flexibility that has considerable strategic and economic advantages.

Source	Quantity used	Energy Content Million THERMS	Cost £	Cost per therm p
Gas	465,589,480 ft^3	4.69	800,440	17.07
Oil	1,198,085 gallons	2.12	542,848	25.61
Coal	8,962 tons	2.37	233,399	9.85
Electricity	51,560,000 kwh	1.76	1,126,071	64.34
Totals		10.94	2,702,758	24.7 average

Table I Energy consumption during F.Y. 1979-80

Notes

(i) Fuel figures cover steam production for whole Harwell site, i.e. including A.E.R.E., S.R.C., M.R.C., N.R.P.B., etc.

(ii) Electricity figure is for A.E.R.E. (reference paras. 12-13).

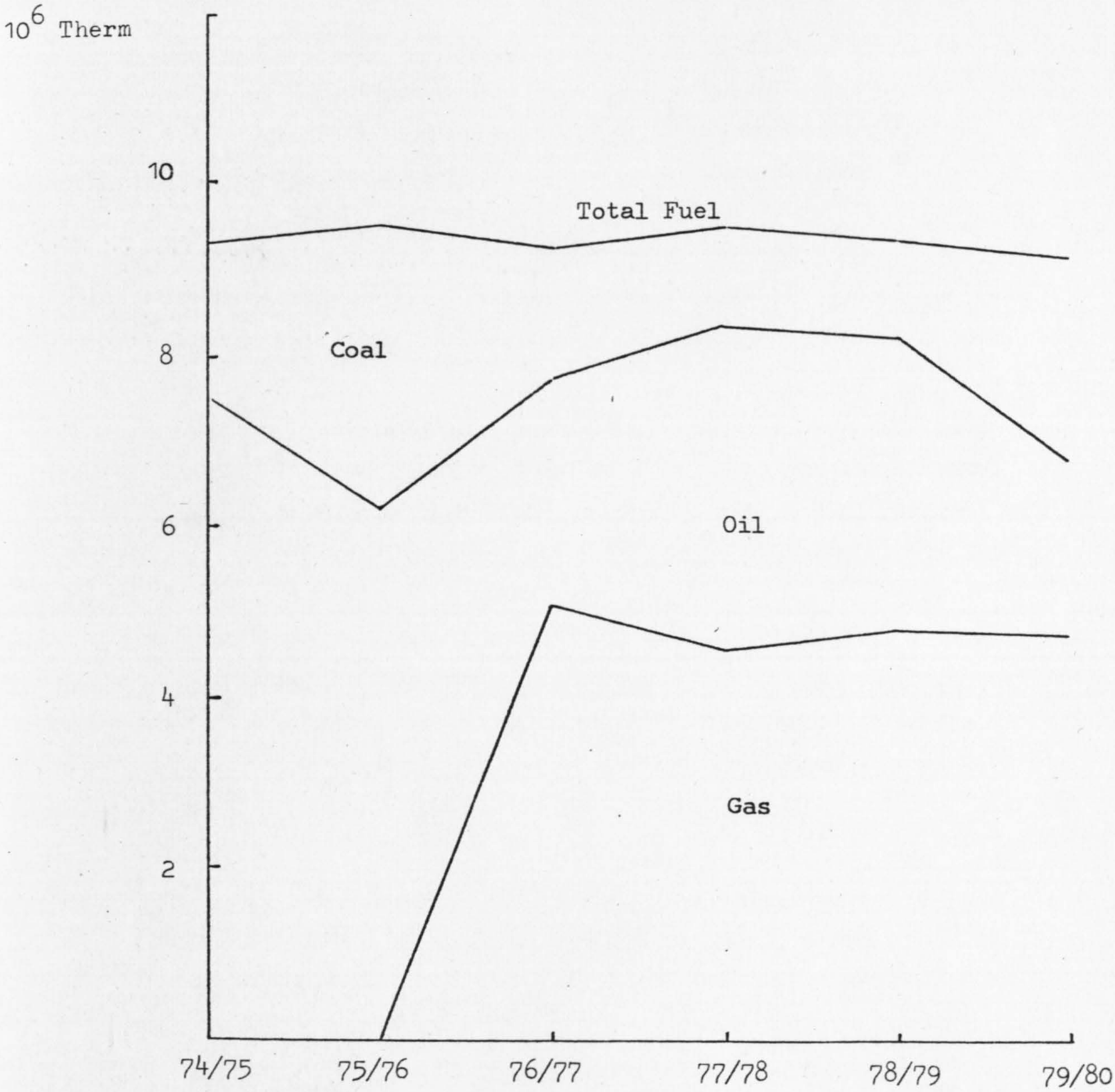


Figure 1 Fuels used for steam production in Harwell Boiler House 1974-1980

16. Although the quantities of the various fuels used has changed, the total quantity of energy consumed in the Boiler House has remained substantially constant over the past five years, at about 9¼ million Therms/y, although there have been additional buildings to heat.

17. Electricity consumption, shown in Figure II, has also remained fairly even over the same period at between just above and just below 51 GWh, equivalent to 1.7 million Therms delivered.

17A. Consumption of fuel and electricity fell slightly during last year, FY 1979 - 80. Steam production, Figure IIA, was also lower, reflecting the milder winter conditions. Consumption on a weather corrected (degree-day*) basis is also shown to have a downward trend.

18. On the other hand, the total annual cash cost of energy consumed (Figure III) has risen steadily year by year, and the total cost last year of £2.7 million (approx.) was over twice that for FY 1974 - 75.

18A. Figure III also indicates the average cost each year of energy delivered (electricity, coal, gas and oil) in terms of pence/therm. The graph shows a rise of 245% over the period 1974 - 80, compared with 282% for the official index for fuel and light (ref.Central Statistical Office).

19. The cost share of each fuel and electricity is given in Table II which shows an important point that although electricity provides only 16 per cent of total site energy, its cost share of the total Harwell energy bill in FY 1978 - 79 was 42 per cent.

20. The data in Table II indicate that gas is more attractive than heavy fuel oil in terms of cost to benefit ratio, coal has the best position and, as already noted in Para.19, electricity is the least attractive. However, this comparison is only relevant to heating applications because there is really no practical alternative to electricity for lighting and motive power in many cases. The possibility of installing a combined heat and power system has been investigated by the CEGB and is referred to in para.87 et seq.

(*See para 28)

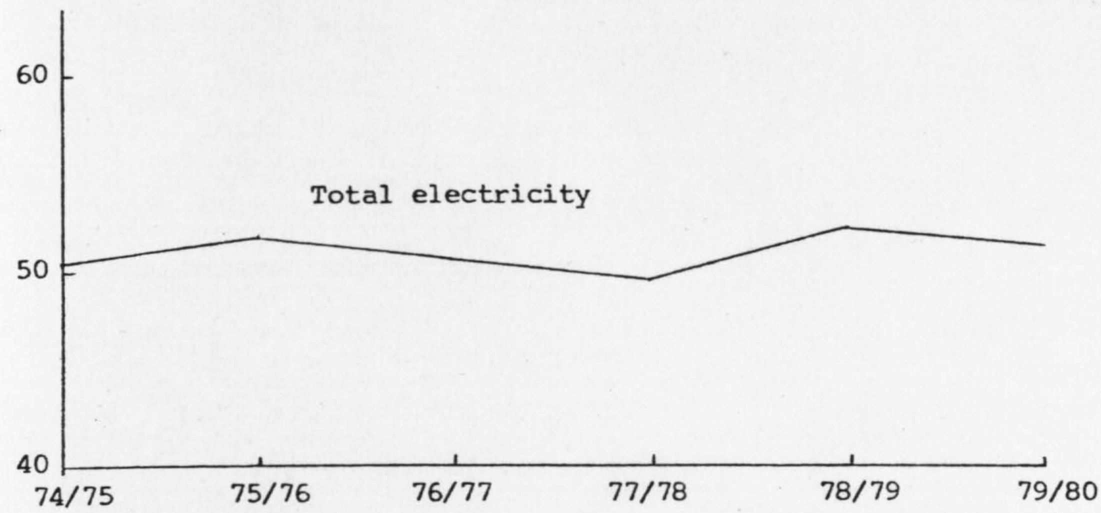


Figure II Electricity Consumption 1974-80

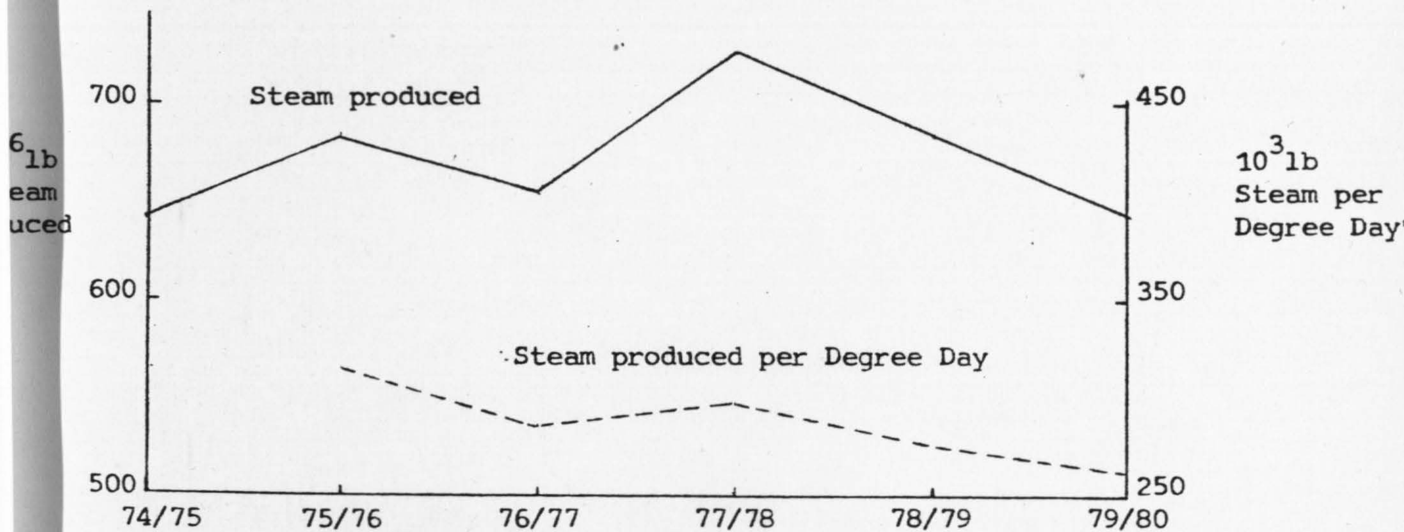


Figure IIA Steam Production 1974-80

(*See para 28)

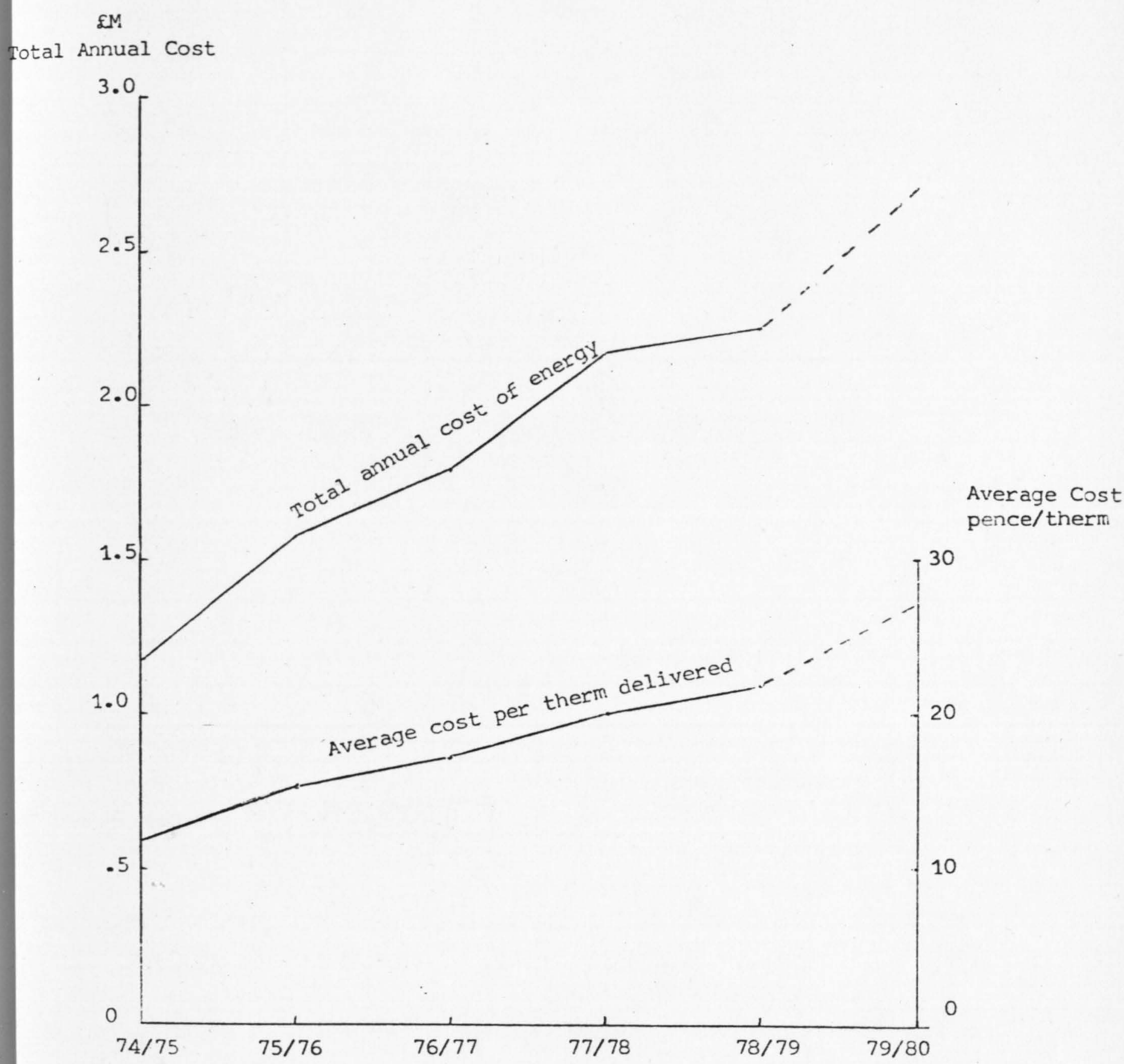


Figure III Total Annual COST of Fuel and Electricity 1974-1980

	Delivered Cost Share	Energy Share	Ratio: Cost Share Energy Share
Electricity	42%	16%	2.6
Gas	30%	43%	0.7
Oil	20%	19%	1.0
Coal	8%	22%	0.4
	100%	100%	

Table II Energy & Cost Shares of Fuels & Electricity
F.Y. 1979-80

Fuel	Price per therm FUEL delivered to site	Price per 1000 lb STEAM produced	
		Fuel Cost	Total Cost*
Gas	17.72 p	212	227
Oil	25.61	365	503
Coal	9.85	198	442

*Total cost includes maintenance and operating costs.

Table III Fuel & Steam Costs F.Y.'79/80

21. When comparing the costs of different fuels on the price per therm delivered basis, it is important to take into account the thermal efficiency with which each fuel is used to produce steam in the site boiler house. Because of the age and deterioration of the existing coal fired boilers, the price of steam produced turns out to be rather more expensive for coal firing than for gas, (ref.Table III). However, this should not necessarily be used as a criterion for selection of new boilers because modern coal fired boilers should have combustion efficiencies comparable with gas or oil burners, (ref.Para.121 et seq).

Uses of Energy

22. Fuel burnt in the AERE boiler house is used to produce saturated steam at 100-120 psig which is distributed via a pipe line, either buried or in underground ducts, to buildings on the AERE, SRC, MRC and NRPB sites. The distribution system also feeds the Harwell shopping area, the Nursery School, Hostels and Messes, Housing Estate and the greenhouses of the grounds department.

23. Steam is delivered to buildings and used, either directly or indirectly via calorifiers, for space heating, process heat and hot water services. Condensate is returned to the boiler house via a pipe system in the same ducts as the steam main. The total length of main is estimated to be about 6,000 metres varying in diameter from 2 inches to 12 inches.

24. The dominant use of steam is for space heating during the months October through to April when 78 per cent of annual steam consumption is used.

25. During the summer months, May through to September, when space heating systems are shut off, the heat load is due to the requirement for process heat and hot water in cloakrooms, restaurant and laboratories; with a further amount, depending on weather conditions, for the ventilation systems in special buildings, eg Building 220, where it is necessary to warm the plenum air, particularly at night. This residual summer

heating load together with the process heat and hot water demand accounts for 22% of the annual demand.

26. Figure IV broadly indicates the difference between the summer and winter energy consumption. It must be borne in mind that although there is such a wide variation in seasonal demand, the temperature of the steam distribution main is constant throughout the year. Therefore, the losses will be approximately constant throughout the year, but they are proportionately much higher in summer than winter. It appears from this argument that the major part of the summer load is simply the steam required to maintain the main at the required operating pressure, together with the stack losses.

27. It is, of course, an important characteristic of all systems that at part-load the losses are more dominant. This issue will be considered in greater depth in Para.70 et seq when the policy of operating the site boiler house and steam main during the summer will be reviewed.

Monthly Steam Consumption

28. As noted in para.26, steam demand is mainly determined by the spece heating requirement. The latter is determined by the weather conditions, notably the outside air temperature. In this respect it is universally accepted that the heat load can be described by the number of Degree-Days recorded, or forecast by the Meteorological Office.*(3)

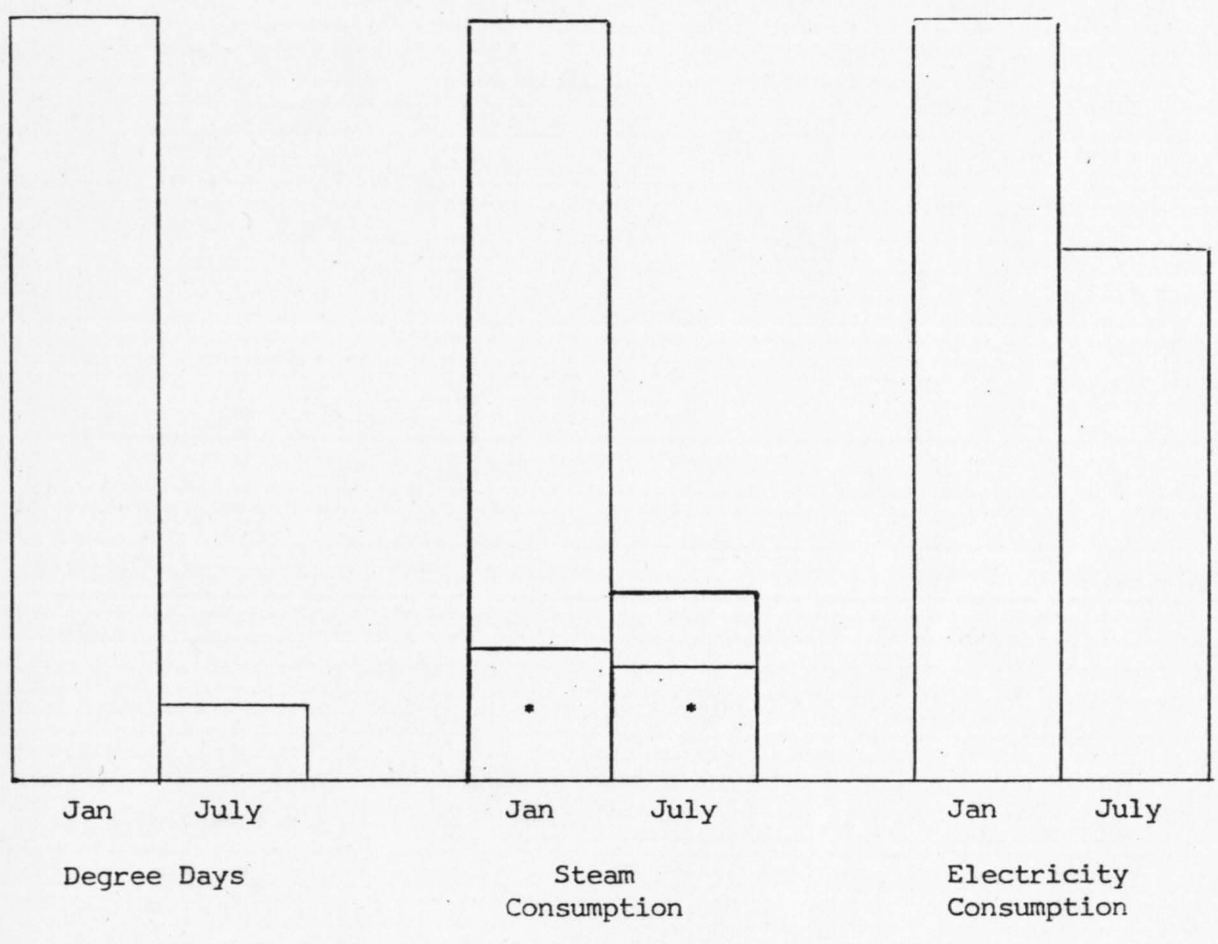
29. Figure V shows the variation between Total Degree-Days and Steam Consumption on a monthly basis, for the period July 1978 through to July 1979. It is noted how closely the two variables follow each other indicating that boiler control is very satisfactory. The actual correlation between D and M is shown in Figure VI indicating (See Appendix I) that the relationship between steam demand M and the number of degree days D recorded is,

$$M = (0.17D + 18)10^6 \text{ lbs steam per month.}$$

Footnote* The degree day convention is explained in Appendix IA

Figure IV

Mid-winter and Mid-summer Comparative Data



* Estimated steam mains losses

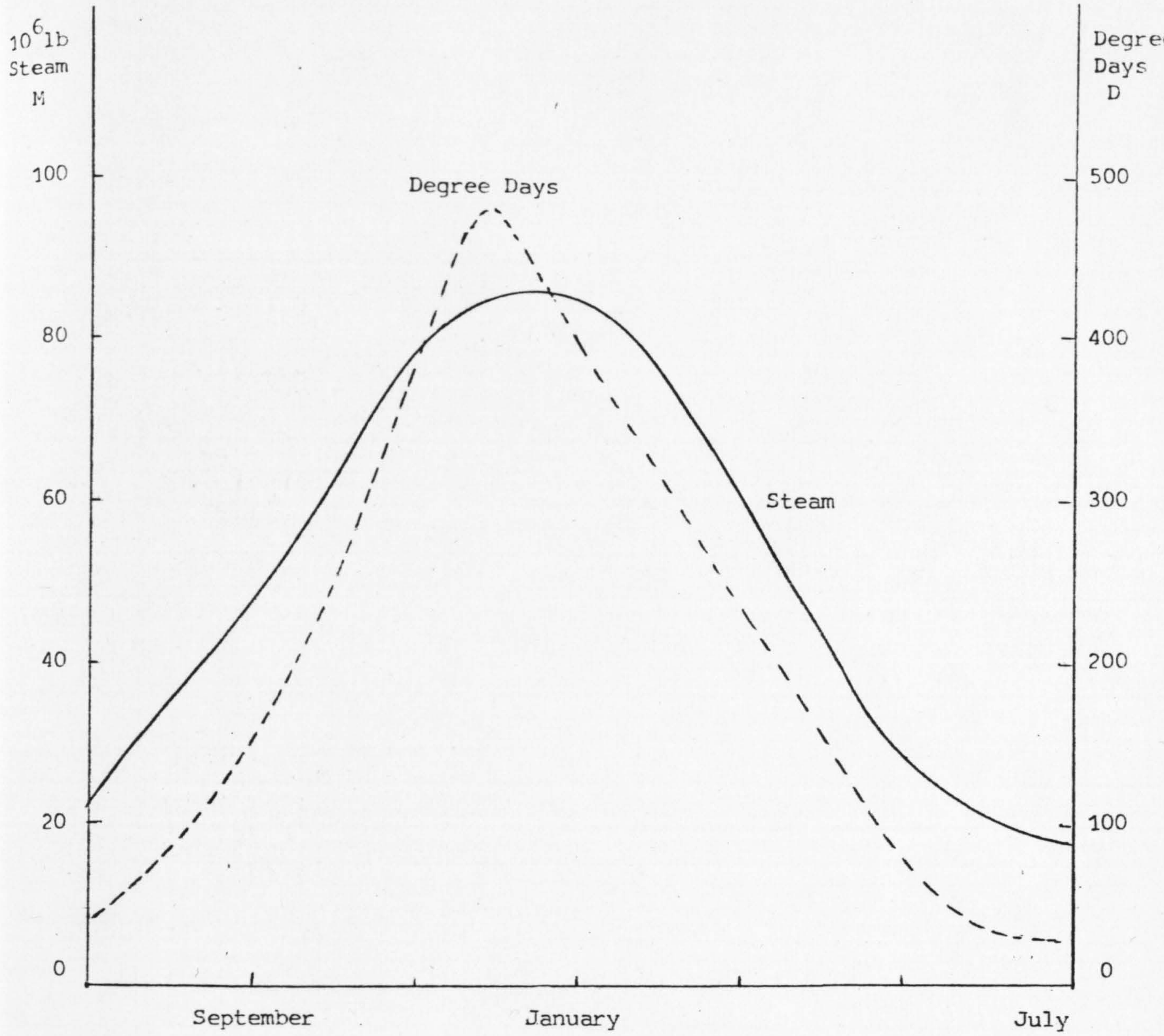


Figure V Degree Days and Steam Consumption/month

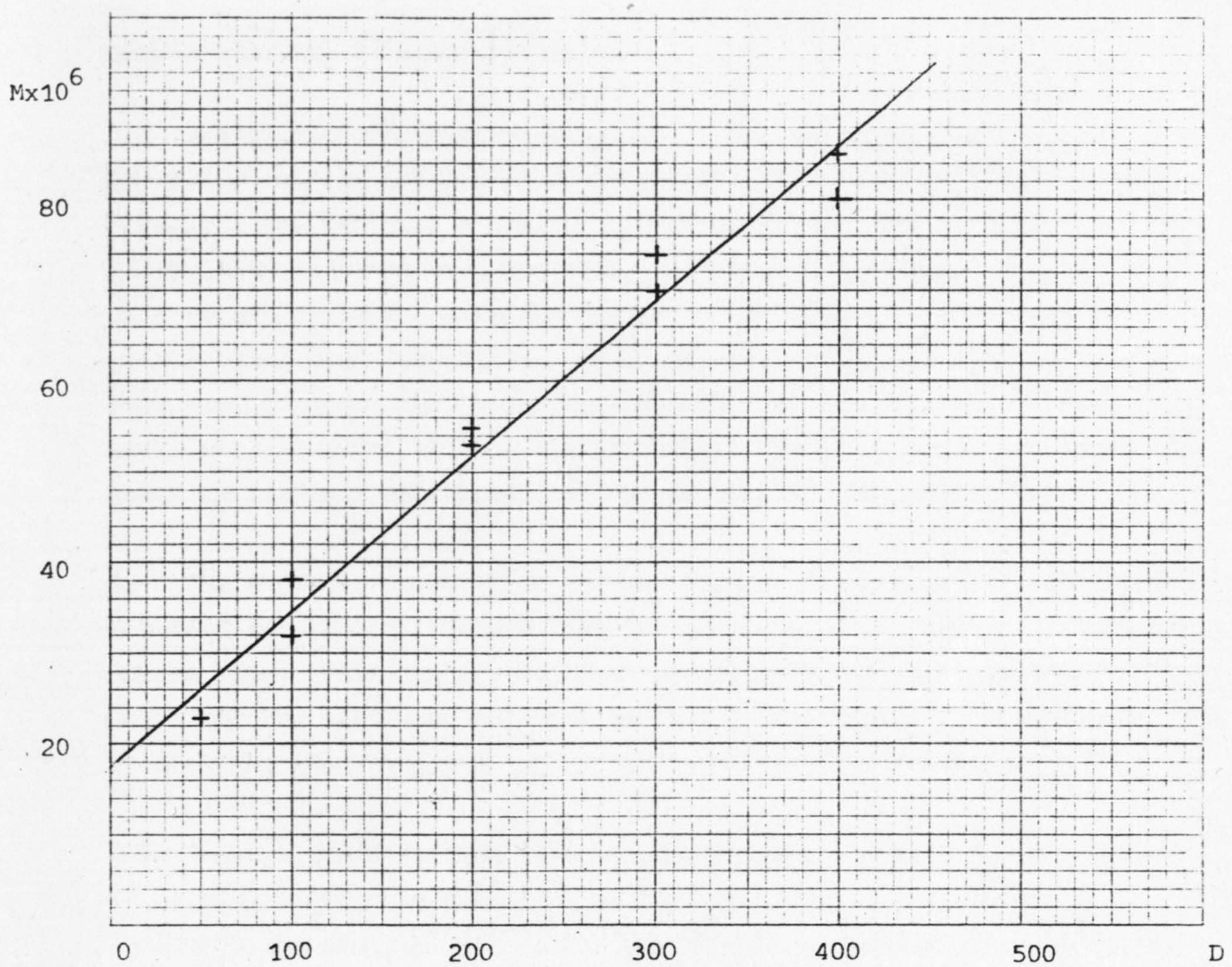


Figure VI Relationship between Degree Days and Steam Consumption

30. The intercept on the M axis, in fact, represents the monthly 'base load' equivalent to the hot water demand and the system losses. The implications of the relationship between heat demand and weather conditions will be discussed in para.70. At this stage it is noted that the results of plotting the variable heat load, represented by the degree days, and the steam consumption are very satisfactory and reflect commendable management of the Boiler House.

Distribution of Heat and Electricity

31. Although the production of steam at the main boiler house is carefully metered and recorded, local metering and recording is limited to only a few centres; a similar situation exists with recording of electricity consumption. Therefore, although the central control figures are reliable, data concerning the distribution are scant and mainly based upon estimation. Nevertheless, reasonable figures have been used to audit the allocation of steam and electricity. A diagrammatic representation of how energy is distributed is given in Figure VII, based on the best estimates that can be made at the present time.

32. The Engineering Division and the Finance Department have established a method for the equitable allocation of energy costs to all buildings on the site. This appears to be a reasonable basis for this present audit and has been used to establish the data on Table IV which aims to show the steam consumption in different types of buildings.

32A. Table V gives similar information covering electricity consumption. It should be borne in mind that without the provision of meters in buildings the data in both tables are subject to confirmation in later reports when physical measurements will, hopefully, be possible. Therefore, it is conceivable that later audits might change the picture presented in Tables IV and V.

33. The study of allocation of energy to individual buildings is very important to any audit because the largest users would generally be the priority buildings for potential savings measures. However, it is

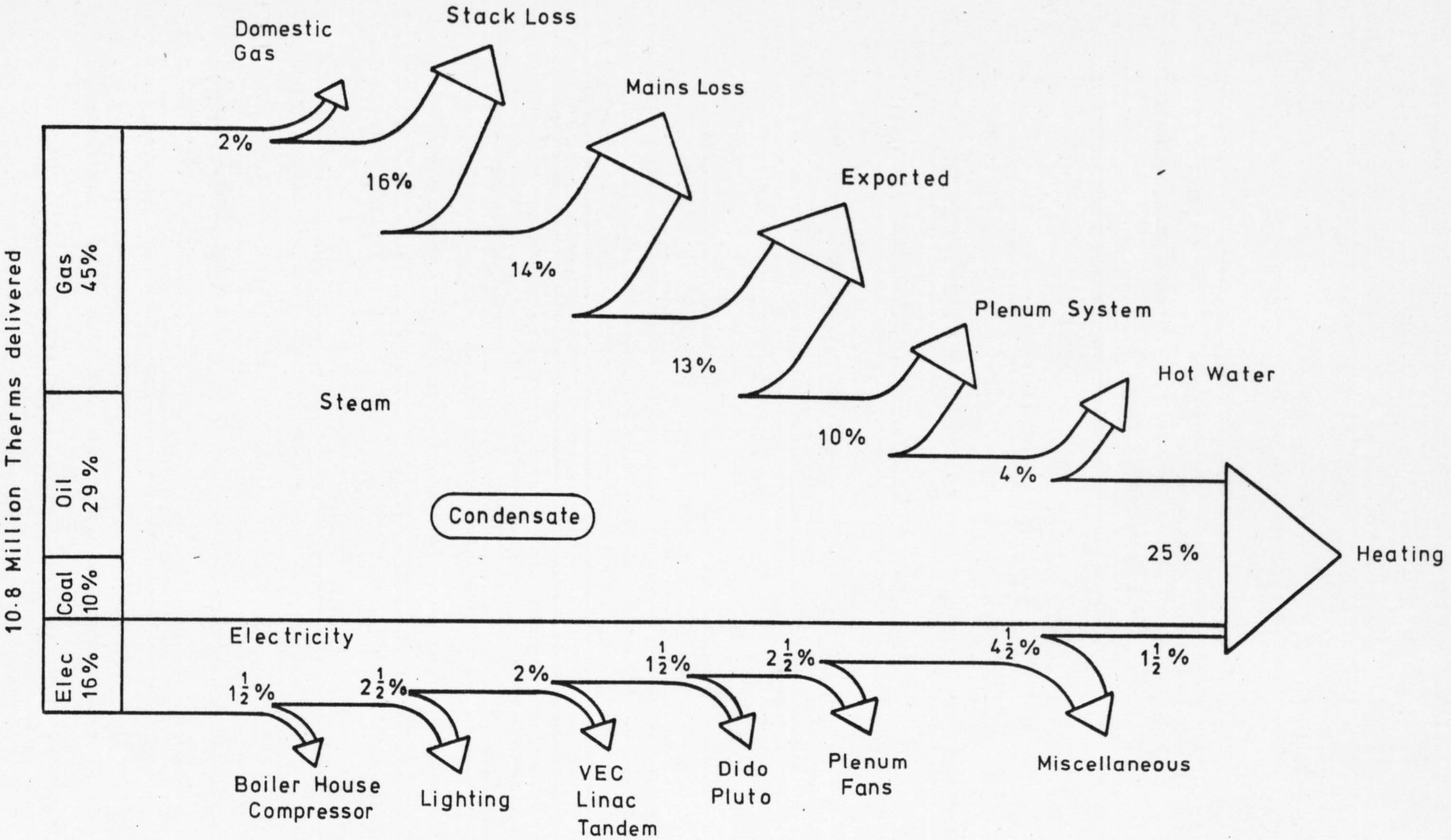


FIG VII ANNUAL ENERGY FLOW DIAGRAM BASED ON FY 1978/79

Total Number of Buildings	Percentage of Site Total Steam Consumption	Average Percentage per Building
5 •	28	6
23	42	2
65	30	½

Table IV Allocation of Steam Demand

• Buildings, 220, 351, 443, 336, 775

Total Number of Buildings	Percentage of Site Total Electricity Consumption	Average Percentage per Building
9*	48	5
8	18	2
11	14	1
39	14	0.5
100	6	0.1

Table V Allocation of Electricity Demand

* Buildings, 418, 220, VEC, 358, 393, 351, DIDO, PLUTO

helpful at this stage to compare the average energy consumption in buildings at Harwell with figures available from other sites (4). Table VI illustrates how Harwell compares in this respect.

34. These examples vary as to type of buildings, exposure to wind and solar input; also some will be fitted with special ventilation or air conditioning systems giving rise to large throughputs of energy. The daily heating periods will vary according to the class of work, eg office hours or shift working. But the Harwell buildings also have many of these differing characteristics, so it is reassuring to find that the average input for Harwell buildings appears to compare very favourably with other establishments.

35. In any detailed audits of the Harwell site it would be useful to look carefully at the energy requirements of particular classes of buildings because it appears probable from the data in Tables IV and V that significant savings could be obtained from special measures in about one third of the buildings, taking electricity and steam demands together. Therefore, it should prove advantageous to study the requirements of major users. Tables IV and V suggest how buildings might be classified prior to any investigation of special conservation measures and the setting of targets.

Aerial Thermography

36. Infra-red thermography of the Harwell site by aerial survey carried out in April 1978 has produced clear pictures indicating areas of relatively high heat emission. They leave little doubt that the steam main itself is a major source of heat loss (ref.para.26). Also, the pictures draw attention to the heat loss associated with buildings and types of roof. Further work is proceeding in MPD to quantify heat losses and also to check the effects of certain conservation measures taken on the site, (ref.para.44). For this purpose a second aerial survey was made on the night of 20th February 1980. At the same time roof and ceiling temperatures were measured with hand instruments on the ground and interpretation of the survey data is now proceeding in MPD. Appendix II gives further details concerning development of the technique and the U-values that have been measured.

Site	$MJ/m^2/y$
A.E.R.E. Harwell	1800
Culham	3000
Government Buildings	600 - 2500
C.E.G.B. Harrogate (Offices)	1500
C.E.G.B. Bedminster (Labs.)	3500
Glasgow Warehouse	3300
Glasgow Warehouse	1100
Cummins Diesel Engine Factory	7800
Stationery Factory Leeds	1900
Sportshall Vimy Barracks	2800

Table VI   Primary Energy Use in Buildings

Building Insulation

37. Retention of the delivered heat is, of course, crucial to the efficiency of heating systems in buildings. Losses take place from the roofs, walls, and floors in proportion to their areas and their overall thermal transmittance "U"values. In this respect new Building Regulations for England and Wales (5) were introduced by the government, which for the first time have been specifically framed for the conservation of energy. Briefly, these regulations require thermal insulation values not exceeding 0.7 w/m^2deg.C for factories and warehouses and 0.6 w/m^2deg.C for offices and other institutional buildings (ref.Table VII). The Building Regulations also severely restrict the area of window openings and roof light openings in new buildings.

38. Although for the most recent buildings, eg Building 424 extension, careful attention has been given to the insulation, most buildings on the Harwell site were constructed to conform with earlier practices which were merely reflections of the thermal properties of the traditional building materials available at that time. The new standards call forth radical changes in materials and types of construction that will characterise all new buildings designed in the future.

39. The policy at Harwell over the last few years has been to carry out improvements to buildings where special need exists. The Harwell buildings have been reviewed and most have been found to have "U" values for walls generally in the range 1.5 - 2 w/m^2C, but there are some very unsatisfactory cases much higher than this.

40. Official publications advise that improvements should be made to reduce heat losses with least expenditure. This usually means insulating roofs and walls, and eliminating draughts. Addition of double glazing and floor insulation involves consideration of higher budget costs.

41. The brick built ex-RAF buildings are, even by modern standards, well designed and some have had improvements by application of additional roof insulation.

Element of Building	(Offices) Purpose Groups ii,iii,iv,v, vii or (if not for storage)viii	(Factories) Purpose Groups vi or (if for storage)viii
1. External wall	0.60 $w/m^2deg.C$	0.70 $w/m^2deg.C$
2. Internal wall exposed to ventilated space	0.60 $w/m^2deg.C$	0.70 $w/m^2deg.C$
3. Floor exposed to external air or a ventilated space	0.60 $w/m^2deg.C$	0.70 $w/m^2deg.C$
4. Roof(other than over a ventilated or partially heated space)	0.60 $w/m^2deg.C$	0.70 $w/m^2deg.C$

Table VII Statutory Requirements for the Structural Insulation of Buildings(1979)

	Buildings	% total
Roof and walls comply	13	12%
Roof only complies	27	25%
Walls only comply	7	7%
Improvements possible	approx.60	56%

(excludes residential houses on the A.E.R.E.site)

Table VIII Insulation of Harwell Buildings

42. The more contemporary buildings with flat roofs cannot so easily be improved, but results from modifications made recently to increase the thermal insulation of the roof and cavity walls of Building 521 are being recorded and studied. The results will assist in formulating proposals for an ongoing programme to improve insulation standards.

43. The general state of the thermal insulation of buildings has been briefly reviewed for this report to determine the extent to which they comply with the new regulations. The results of this review are given in Table VIII. An aggregation of heat losses from the fabric of Harwell buildings, with an estimate of potential savings is illustrated in Figure VIII.

44. Typical costs of improvements to Harwell Buildings to bring "U" values nearer to the new standards are:

- cavity wall insulation	£2 - £3 per square metre
- treatment to flat concrete roofs	£16 per square metre

The present policy of spending £10,000 each year on these measures is gradually raising standards and permitting important evaluation of the results. But as fuel becomes more expensive it may prove justificable to increase annual outlay on thermal improvements to building fabric, particularly for priority buildings (ref.para.35).

45. It can be assumed that there are always measures available to raise the thermal insulation standards of buildings; and such measures will always improve standards of thermal comfort. Cost effectiveness is however more difficult to establish unless additional insulation is part of a comprehensive programme of energy saving measures.

46. But, it should be borne in mind that because of the constraints imposed by the design of existing buildings, it is not always practical to adopt thermal insulation measures that are technically the most attractive schemes. It can be argued, for example, that ideally, insulating material should be applied to the outside surfaces of walls

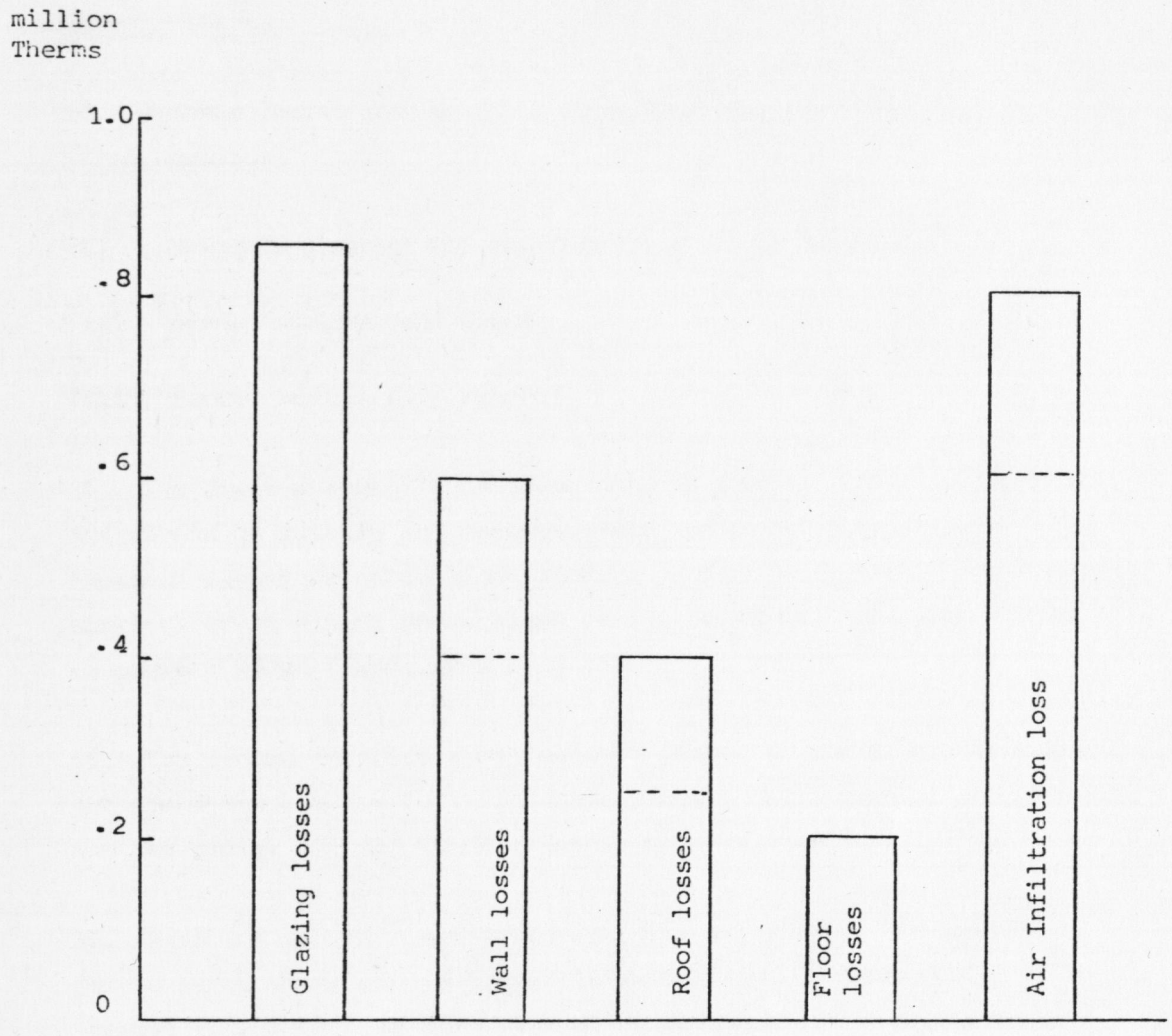


Figure VIII

Aggregate Heat Losses from Buildings on the Harwell Site

(Based on calculations made in April 1980) so that the denser materials, with higher thermal capacities, store heat during the heating periods and re-radiate back into the building. Studies have indicated that overall fuel requirements are lower with these arrangements. This matter is discussed in paras. 58 - 59.

Dynamic Losses

47. Dynamic losses due to air infiltration may be classified under three headings,

(i) draughts through the ill-fitting door and windows

(ii) opened windows and doors

(iii) forced ventilation systems

48. The first are easily detected and reported by building occupants and should be quickly and inexpensively remedied by application of "weather strip" or other minor improvements. In certain situations air-lock or revolving doors might be the required remedial measures to prevent large displacements of air.

49. The second constitute "voluntary" losses at the will of occupants, but doors and windows left open negligently, cause serious heat losses, and can cancel out all other attempts to save energy.

50. Both (i) and (ii) are avoidable losses and every encouragement should be given to reduce them, but ventilating systems represent a special source of high heat loss which on the first analysis appears unavoidable, but this will be discussed in para.83 et seq. Several major buildings have filtered plenum systems that operate continuously for safety reasons. As these cases account for a significant part of the heat load during winter and summer, heat recovery measures as well as improvements to the building fabric should be considered.

51. Heat losses from windows where large areas of wall space are given over to glazing requires special consideration. Two policies

could be adopted but neither is likely to be economically or aesthetically acceptable at the moment. Certain glass panels could be removed and replaced by materials with better "U" values, or double glazing could be installed, at a cost of about £33 per square metre. Minor improvements could be made by applying surface films to the glass; an experiment is in hand in this respect and will be monitored but this measure is more appropriate to the reduction of solar input during summer and can be disadvantageous during winter.

52. Careful study has led to the general conclusion that there is no easy blanket recommendation, but rather that measures for particular buildings should be decided on the merits of each case. Changes to the glazing will of course affect the solar input and this may be an important factor with benefits and disbenefits. (6)

Heating Controls

53. A major criterion of control performance is often the comfort that is enjoyed in buildings. In this respect, common complaints about heating systems are due to:

- insensitivity of the control to changes in outside weather conditions, eg the effects of direct sunlight
- wide fluctuations of temperature due to inadequate control systems
- lack of zoning in heating systems, so that north and south facing rooms are not differentially controlled.

54. However, although it is important to control the comfort environment for occupants, it is also essential to select control systems that are designed to minimise the amount of energy required because the method of control alone determines the quantity of fuel that is used.

55. It is important to note that 30 - 50% fuel savings can be achieved by installing heating controls that take account of the hours of occupancy and such factors as the thermal characteristics of the building fabric. (7)

56. Control devices that take account of temperature, weather conditions, working hours, and thermal characteristics of the building, are known as optimisers. These instruments, new to the heating and ventilating market, should eventually replace traditional thermostats and time switches.

57. BSRIA, who have quantified the percentage savings mentioned above, point out how important control systems are to energy savings measures and there is general acceptance of this approach. Many experts argue that control systems should receive priority attention in any energy management programme. Figure IX indicates the relative savings due to heating control systems.

58. Although the above argument has emphasised the importance of optimising heating regimes in buildings, research by the Gas Council (8) has shown that simply lowering thermostats by 3°C is in some situations more effective in saving fuel than adopting intermittent operation by optimisers or time switches.

59. These issues bring out the importance of considering the merits of each case rather than applying blanket recommendations. Another important issue concerns the serious effects that sudden changes in steam demand due to intermittent heating cycles might have for the site boiler house. Therefore it follows that the spreading use of local controls must be associated with improvements in central control of the system. At the present time progress has been made with installation of optimised controls for 23 buildings, but the large number of heating loops (approximately 300) associated with the site distribution system, requires that progress should be gradual and logical.

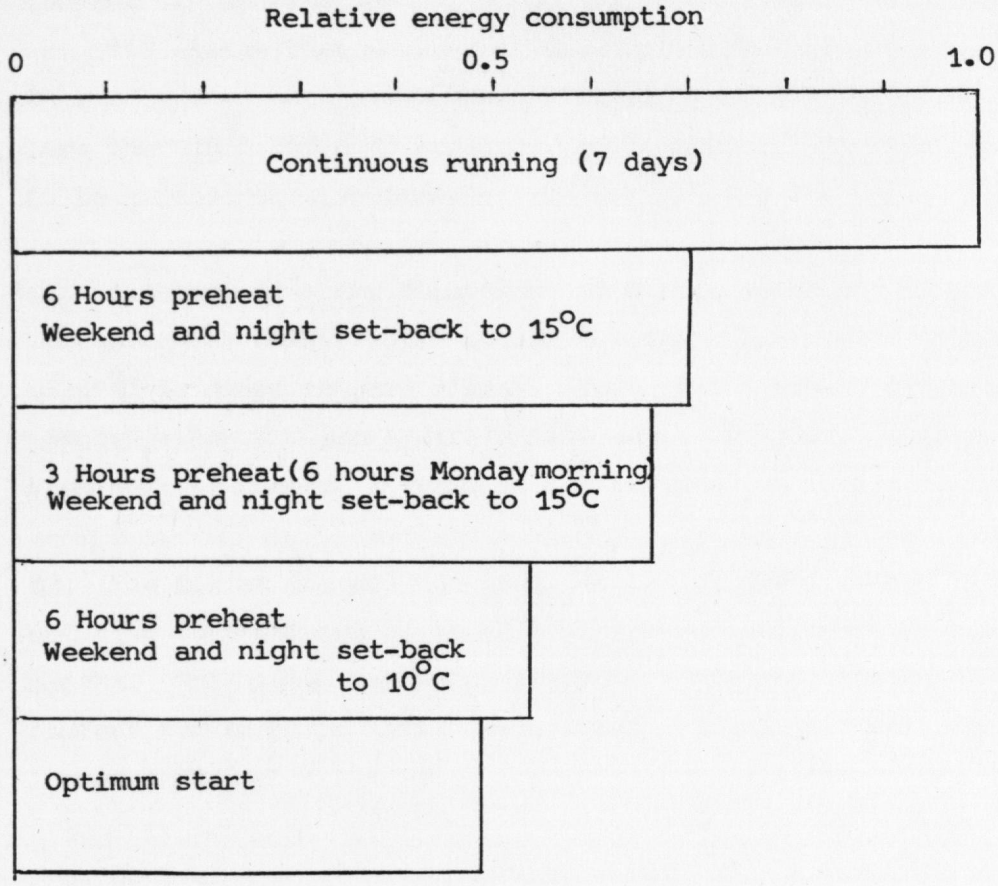


Figure IX

Relative Savings due to Control Systems

60. The heating levels for most buildings on the Harwell site are generally covered by Statutory Orders. The Energy Act (1976) prohibits the use of fuel or electricity to heat premises above a temperature of 20°C (68°F), while the Shops, Offices and Premises Act 1963 states that where a substantial proportion of the work done in a room does not involve severe physical effort, a temperature of less than 16°C (60.8°F) shall not be regarded, after the first hour, to be a reasonable temperature while work is going on.

61. A letter from the Department of Energy addressed to industry, including the UKAEA, implies that the upper limit will soon be lowered to 19°C in order to save energy. This will allow an operational tolerance of 3°C and indicates the sensitivity that will be required from heating control systems in the future.

62. The aim at Harwell has been, as far as practicable, to keep building temperatures up to 18°C during working hours of the winter months. This level generally provides acceptable standards of thermal comfort for people sitting down, wearing clothing equivalent to a lounge suit.

Zone Control

63. Although optimisers or set back controls are easily fitted in any system it must be borne in mind that to be completely effective, modernisation of heating control must also include a capability for zone control. That is, it should be possible to vary the circulation of heat to different parts of a building. Introduction of zone control would necessarily involve far reaching alterations to existing pipework and could only generally be envisaged for new buildings or major rebuilding programmes.

64. Research by the Electricity Council and Gas Council (8, 9) has drawn attention to thermal comfort and energy control criteria associated with different types of heat emitters or appliances. For example, thermal environment throughout a building will not be uniform, even when zone control is possible. In practice the degree

of uniformity will depend on type and siting of heating appliances. It is certain that such factors will govern the amount of energy that is required to secure comfort, and that certain appliances will consume more energy than others.

65. For example, panel radiators have been found to require less energy than natural convectors, and even more so when siting is under windows to offset draughts and cold radiation.

66. Research (9) also indicates that radiator efficiency is increased when a ventilated screen with a high emissivity surface facing the radiator panel, and a low emissivity surface facing the wall, is placed behind heating panels. A reduction in heat loss of 10 per cent has been claimed, and even higher figures when such measures are combined with improved wall insulation. (9)

67. From the discussion above, it is clear that there are a number of overall energy control strategies that might be adopted; but the choice for retrofitting existing buildings is essentially limited to installation of heating controls.

Heat Stratification

68. In the notably tall buildings, for example the Hangars, air temperature gradients from ceiling to the lower occupied zones cause additional heat losses because the air at roof level is higher than that needed for comfort at floor level. Although this is always found to be the case, certain types of heating appliances minimise the gravitational effects. Temperature gradients of between 0.3 and 0.6°F per foot incremental height above working level associated with different types of heating appliances for a 26 feet high workshop have been measured. (10)

69. The aerial thermo-photographs of the Harwell site indicate the relatively higher roof temperatures of the hangar buildings but it is gratifying to note the better state of the Main Workshops roof, due to the 'false ceiling' that was fitted in 1959. It seems important

therefore to give special attention to stratification effects with a view to saving energy in the very large, high buildings by careful selection and positioning of the most appropriate type of heating appliances. Where it is practical to install false ceilings heat requirements will be lower due to the reduction of the building volume and due to the improved insulation.

Steam Mains Operation

70. The vast majority of the heating needs on the site are supplied from the Boiler House via the distribution pipe mains. Although this policy has several important advantages characteristic of most large centralised services, two important questions arise concerning efficiency of the system:

(a) the mains annual heat loss (reference Figure VII)

(b) the disproportionately large heat loss during the summer season (reference Figure IV)

71. The site mains serves very effectively the many calorifier rooms and heating appliances in Harwell Buildings with regard to the quality of the steam delivered and there are no serious problems concerning pressure drop due to condensation. However, the heat loss due to condensation is significant (ref.Figure VII) and the question of the adequacy of pipe insulation should be carefully reviewed, using the concept of optimal thickness of lagging. In this approach the incremental capital costs of applying lagging to the pipework is compared with the total cost of energy to maintain the mains at the required pressure. (11)

72. From this the most cost effective pipe lagging is determined. The mains pipe might be covered with additional insulation or it is conceivable that pipe ducts might be in-filled with insulating material, greatly attenuating the heat transmittance to ground and atmosphere.

Local Appliances

73. Another approach, specifically, to avoid the relatively high summer heat losses from the steam mains when minimal heat is being carried to buildings, would be to isolate sections of the site mains, or to shut it down completely from April through to September each year. The savings from this innovation could be considerable because boiler stack losses as well as pipe losses are avoided.

74. In this situation the mains supply would be substituted by local appliances installed, where necessary, in laboratories, medical department, restaurant, and cloakrooms. It would be important to consider, for each situation, the most appropriate and economic heating appliance, either gas or electric, selected from the range of equipment that is commercially available.

75. Before arriving at a policy decision in this direction, it would first be necessary to ascertain the actual requirements for hot water services in each building; in some situations there may be no justifiable need for a continuous supply during the summer. Secondly, the installation and running costs of appliances required to service local needs must be evaluated and deducted from the mains savings.

76. At this stage, with the summer fuel costs of operating the site steam mains running at about £300,000, it seems likely that significant cost savings would accrue from switching to local heating appliances. Engineering Division have commissioned (April 1980) consulting engineers to investigate the possibility of providing local domestic hot water to buildings to shut down significant sections of the site steam main.

Reactor Heat Recovery

77. Heat in the cooling air of BEPO reactor was recovered in the 1950's. By means of a 2 MW heat exchanger installed in the pile cooling duct it was possible to heat water to 70°C and circulate it to several large buildings for their radiator heating systems (12). Today there is

interest in harnessing the much larger waste heat recovery potential from the Dido and Pluto reactors. However, because it is not practical to fit a heat exchanger in the reactor primary circuits it would be necessary to accept the lower temperature of 40°C available from the secondary circuits.

78. Studies have now shown that it would be technically feasible and cost effective to circulate water at 40°C through a 6 inch diameter mains to individual buildings and to raise the temperature to a utilisable level of 70°C by means of heat pumps installed in calorifier rooms. (13)

79. Once a Pilot unit has demonstrated the success of this concept, it could be progressively adopted building by building. Table IX gives the estimated energy flows and the economic evaluation for a 500 KW module, suitable for Building 521.

80. The above evaluation indicates that a reactor waste heat recovery scheme servicing the space heating requirement for Building 521 on the reactor site would reduce steam consumption by 4½ million lbs/y, equivalent to offloading the site boilers by about 0.75 per cent. The scheme would pay for itself in 5½ years.

81. Additional maintenance costs for electric heat pumps would detract from energy cost savings but it is argued that cost effectiveness will improve over time once such systems are installed due to fuel price inflation.

82. Due to the large amount of reactor waste heat that could be harnessed, progressive adoption of similar heat pumps in individual buildings offers a large potential savings, if extended over the reactor site and beyond. The general concept is shown in Figure X.

<u>Plenum System Heat Recovery</u>

83. Substantial quantities of energy are being wasted from our large

Electric heat pump 500 KW rating	
Primary power	420 KW
Input to motor	125 KW
Input from reactor waste heat	390 KW(T)
Output from condenser	500 KW(T)
Performance ratio	4
Primary energy gain ratio	1.2
Capital outlay	£50,000
Net energy savings at current prices	£ 9,000/y

Table IX Modular Reactor Waste Heat Recovery

Heat Pump Energy Flows

1. Electric System

Primary power	420 kW
Input to motor	125 kW
Shaft power to compressor	110 kW
From reactor coolant	390 kW
Output from condenser	500 kW

Heat Pump C O P = 500/110 = 4.5

Overall C O P = 500/125 = 4

Primary Energy Ratio = 500/420 = 1.2

2. Gas System

Primary power	260 kW
Shaft power to compressor	75 kW
From reactor coolant	260 kW
Output from condenser	340 kW
Recovered heat	160 kW

Heat Pump C O P = 340/75 = 4.5

Overall C O P = 500/260 = 2

Primary Energy Ratio " = 2

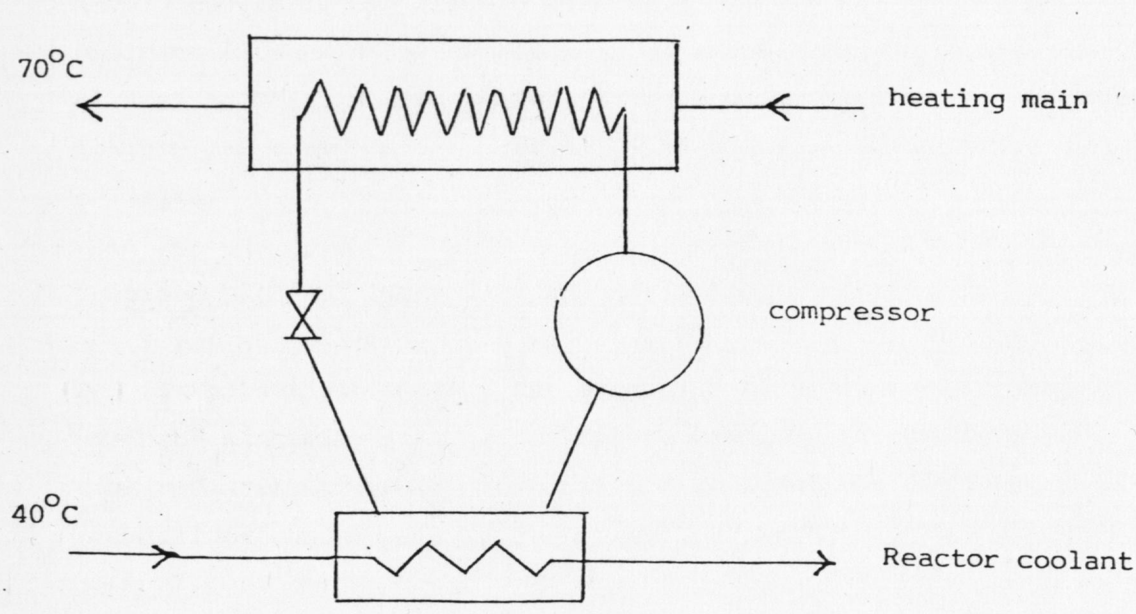


Figure X

Reactor Heat Recovery General Concept

plenum systems (ref. Figure VII). This fact has also been recognised in industry where large air conditioning systems, similar in scale to the B.220 plant, are operated. Developments with the heat-wheel concept have been one approach to the problem of recovering heat from the extracted air and feeding it back into the inlet air stream. However, this innovation necessarily exposes the inlet air to the same surfaces seen by the outlet air stream. Thus the heat wheel would be unsuitable for buildings where contamination control is of crucial importance. (14)

84. This problem is avoided by adopting a two-coil heat recovery system, in which a suitable fluid eg glycol, transfers the heat from the outlet duct to the inlet duct. In this approach the two air streams remain totally isolated from each other. (15)

85. Unfortunately very large heating coils are required and capital costs are correspondingly high. A system based on this concept was considered by Engineering Division for the Cardiff Isotope Building but rejected on grounds of capital costs.

86. Nevertheless commercial development is proceeding with these ideas, mainly to find the optimal air flow rates to reduce capital costs. Providing easy, low cost installation in existing ducts can be developed, it is conceivable that such systems will be suitable for Building 220 and other situations. Meanwhile the large throughputs of heat associated with plenum systems should be viewed with serious concern and every effort made to adopt the most conservative operating policies.

Combined Heat and Power Generation

87. In situations where there is a need for a continuous supply of heat and electricity it is logical to consider the economics of a combined heat and power plant.(16) To this end the Engineering Division commissioned an investigation by the CEGB Generation Development Division.

88. Broad calculations indicated that a gas turbine scheme using high cost distillate fuel was unlikely to be economic so the CEGB offered to prepare outline proposals for a diesel, residual oil fired scheme. This has now been completed in sufficient detail to enable technical performance and budget costs to be estimated. Figure XI illustrates the general concept.

89. The system is designed to generate 3½ MW electrical power and to recover and utilise as much diesel engine waste heat as practicable with minimum interruption to electrical generation.

90. Heat is recovered by means of a 12½ MW waste heat boiler fitted to the engine exhaust, and by a heat exchanger fitted to the engine cooling system. The latter is used to preheat the boiler feed water, while the waste heat boiler with supplementary burner produces steam at 100 psig 340°F compatible with the site steam main requirement.

91. Capital costs, including installation and connection to the site steam and electricity mains would amount to about £1.4 million.

92. The plant would run for 6,000 hours each year based on a regime of shift operation and planned maintenance for which two craftsmen and one supervisory technician would require special training.

93. The output of heat and power would off-load the site boilers by 33 per cent and reduce the supply taken from the grid by 45 per cent. Capital costs, fuel requirements and savings are shown in Table X.

94. It appears from these figures that the main advantage comes from savings in electricity purchases from the SEB. The site fuel bill would be increased by £200,000 but there would be a reduction of £600,000 in the electricity bill, yielding a net savings in site energy costs of £400,000 each year based on current prices.

95. The main uncertainties are the plant maintenance costs and any grid demand penalties associated with plant outages at periods of

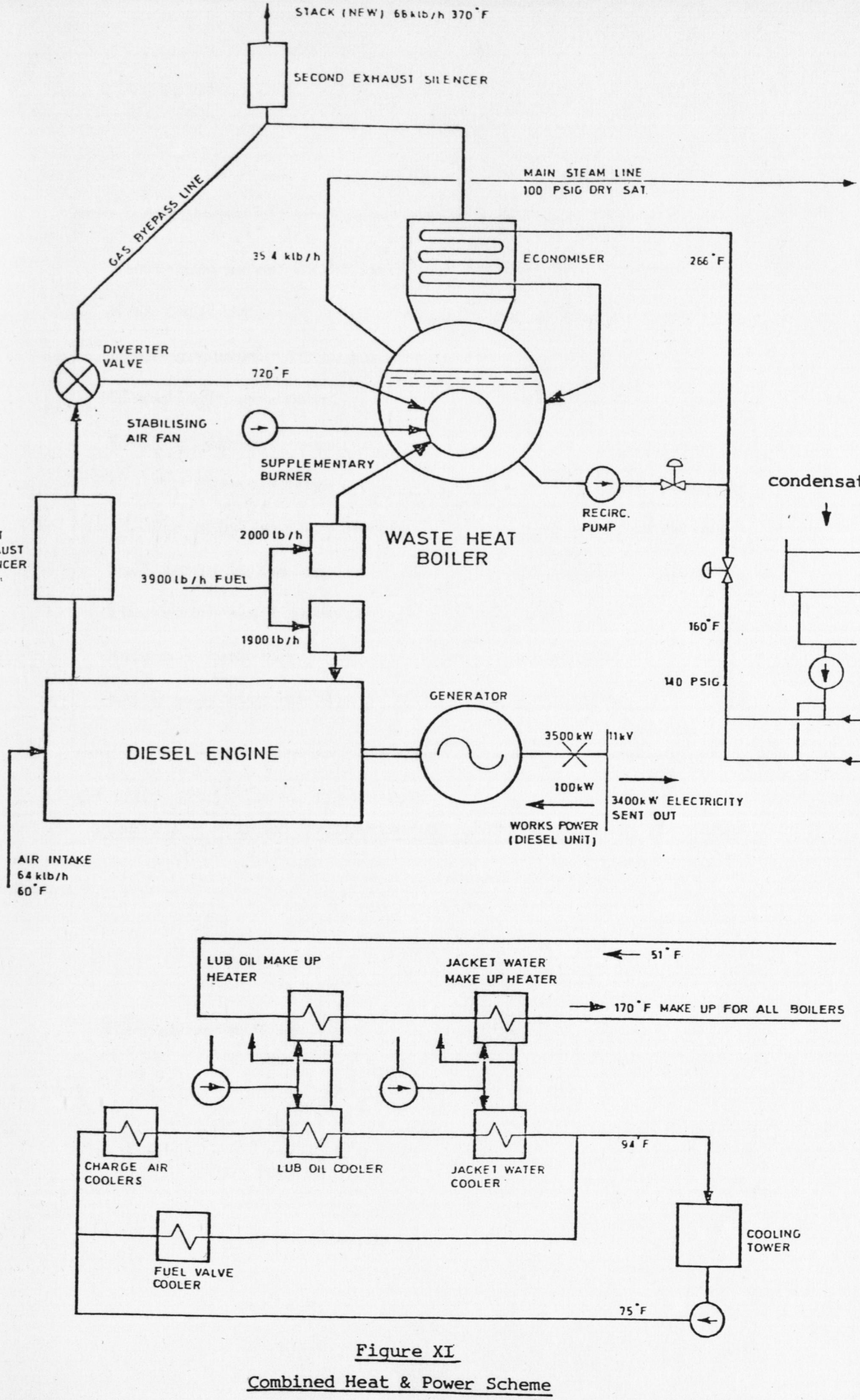


Figure XI

Combined Heat & Power Scheme

Electrical Power Capacity	$3\frac{1}{2}$ MW
Heat Capacity	$12\frac{1}{2}$ MW(T)
Steam produced	225 million lb/y
Electricity generated	23.5 GWh/y
Fuel required:	
For diesel engine	2.25 million Therms/y
For supplementary burner	2.41 million Therms/y
Fuel saved in boilers	3.3 million Therms/y
Electricity cost savings	£600,000/y
Marginal fuel cost	£200,000/y
Net energy cost savings	£400,000/y

Table X Broad Evaluation of C.H.P. Scheme

(Costed at 1979 prices)

maximum demand. These costs are likely to reduce the net savings to about £330,000 each year giving a simple pay back period of about 4 years.

96. Adoption of a CHP plant would increase the site's dependence on fuel oil supplies. This could not be avoided even if all the remaining steam requirement was produced from coal or gas fired boilers. Also, as there would be no standby unit for the diesel engine generator the site would be always dependent on the SEB grid. The thermal efficiency of the CHP plant would be 71 per cent, which is somewhat lower than the present boiler house efficiency. Therefore, overall thermal efficiency of the site would be marginally reduced. (Ref.para.123A)

97. On this view of the pros and cons of Combined Heat and Power, it appears that any decision to adopt the diesel engine scheme studied by the CEGB would depend mainly on judgements about the future price of fuel oil vis-a-vis the price of electricity supplied by the SEB.

98. If electricity prices rise more than residual oil prices, then the economic case for the Diesel CHP scheme is strengthened. If, on the other hand, oil becomes scarce and very expensive, cost effectiveness of the scheme would diminish year by year.

Lighting

99. Data in Figure VII indicate that lighting consumes only 2½ per cent of the total site energy, but this is about 7 per cent of the total energy costs and represents about 16 per cent of all electricity used on the site. Therefore, every effort should be devoted to achieving good lighting practices in buildings and externally.

100. Fuel Efficiency Booklets suggest that it is generally found in practice that illuminances are above the recommended levels of 500 lux for offices and 1500 lux for fine assembly work. (17)

In view of the dramatic savings that have been claimed from attention to lighting systems (eg in Marks & Spencer's buildings and elsewhere) it is worth identifying the key points, summarised below:

- taking into account effects of decorations and furnishings
- choice of light source (filament or discharge)
- choice of fittings (reflectors, diffusers)
- position and height of luminaires
- localised task lighting and general ambient lighting
- time control switching and manual switching
- photo electric control switching
- cleaning and replacement life

101. It is claimed that even in clean locations the output from lights is reduced by 20 per cent due to accumulation and deposit of dust. Many of the light fittings in Harwell buildings are of old type and replacement is possibly justified as well as the adoption of a cleaning and maintenance programme. Positioning is very important from the point of view of access for maintenance, particularly in the Hangar buildings.

102. Selection and position of luminaires is also important because of the vast difference between the output from filament and discharge lamps, for example, 12 lumens per watt compared with 55-80 lumens per watt. The concepts of task/ambient lighting has important relevance in large hangar buildings where the density of occupation of the space is relatively low. It has been found (18) that a reduction of 44 per cent in lighting load can be obtained by using local lights at each task centre (bench, desk, machine) and installing an acceptably lower level of general ambient illumination.

103. External luminaires, particularly those that are kept on for security reasons should also receive attention from the energy conservation point of view. Time switches and photo electric control are relevant to these situations as well as to buildings with fixed times of occupancy.

104. In daytime, daylight will be the principal source of light because except in special types of buildings the window area is usually not less than 20 per cent of the external wall surface. As the glazed area is increased, depending on the length of working hours, the electricity consumed in lighting decreases. But this issue must be considered in relation to the effects of glazing on building heat losses referred to in paras 51 - 52.

105. Research (19) in connection with the design of a new office building indicated that for a southern aspect, total energy consumption, ie lighting, heating and air-conditioning, was least with 45 per cent glazing. For a northern aspect the optimum window area was 30 per cent. Generally it has been found that above 40 per cent window area the total energy consumption rises significantly, while below 20 per cent there is little overall savings in annual consumption. As noted in para.52 the effects of the solar heat input are important in making these assessments of the overall requirements of lighting, heating and, where appropriate, cooling.

106. Studies (20) by the Building Research Establishment have indicated that at present prices, automatic dimming systems are likely to be cost effective for controlling the use of lighting in new buildings where there is a 5 days (09.00 - 17.30 hrs) working week. These conclusions were based on studies of the number of working hours when the daylight illuminance exceeded specified values.

107. It is clear from these arguments that measures taken to save energy dedicated to artificial lighting must be considered in relation to window design and the overall energy audit of buildings.

Electric Heating and Other Appliances

108. A practice has grown up of using electric space-heating in several portable buildings on the site. It should always be borne in mind that electricity compares unfavourably with the site steam mains for space heating applications (reference para.20). Also, there are additional costs due to the increased maximum demand associated with electrical appliances.

109. If electric heating is unavoidable then careful consideration should be given to the use of off-peak storage heaters. The cost of night time electrical energy at Harwell is about one quarter of daytime costs, and this advantage should be exploited whenever possible.

110. Similar consideration should also be given to battery charging - particularly of electric vehicles used on site. It should prove possible to programme charging periods, using time switches, to be in phase with periods of minimum demand and the low tariff costs. Where it is appropriate, this approach to electricity economies should be taken in the use of other appliances, eg furnaces or other heavy current equipment.

111. In certain laboratories there is a significant dissipation of heat from electrical furnaces. During the summer it is essential to extract the heat from the working areas, but during winter such a source of waste heat could be utilised for space heating requirements. Existing ventilation systems do not take account of this potential agency and expensive electrical heat is removed while steam is used for heating the plenum air. Attention should therefore be given to the redesign of laboratory ventilation systems in these situations to utilise any waste process heat.

Electrical Motors

112. Motors associated with machine tools, pumps, fans and other equipment can often be found running idle. Unnecessary use of electricity in these situations not only wastes energy and adds to

maximum demand, but also contributes to a lower power factor because of the importance of the magnetising currents when motors are only lightly loaded.

113. It has been found profitable elsewhere to turn off idle plant, and to introduce measures to reduce maximum demand and improve power factors. Due to the large number of electric drives used on the Harwell site it may prove profitable to review operational procedures. Discussion of this topic has already been initiated with the Self Financing Productivity Saving Scheme in the Main Workshops.

Site Air Compressor

114. The site air compressors consume about one per cent of total energy, (ref. Figure VII). Because of the cost importance of electrical energy it is worthwhile considering the potential for savings, particularly as the major part of the energy expended by the electric motor is extracted by coolers to improve performance and to remove moisture. All this energy cannot be recovered but a significant savings potential is claimed in Fuel Efficiency Booklets. This source of waste heat can possibly be utilised for local space heating, providing the capital costs can be recovered by the reduced heating costs. (21)

115. Consultants who were commissioned by Engineering Division to study this particular opportunity have reported (April 1980) that a scheme would not be economically viable. However, they suggest that the costs of a heat pump or a direct heat exchanger scheme be re-appraised in the light of future fuel price escallation.

Electricity Demand

116. It has been noted in para.19 that in the last financial year, FY 1979 - 80, electricity consumption accounted for 42 per cent of the total site energy bill. This is a figure that is representative also of earlier years and indicates the importance of measures designed to economise in the use of electrical appliances and lighting.

117. In this respect there are two cost elements to bear in mind:

- the demand charges
- the tariff charges for units consumed.

118. The AERE site has a base load of around 5 MW and a peak load during working hours that builds up to 10 MW. The demand charge is based on the maximum load that is recorded during October through to March for which the figure was £15.20 per KW in FY 1979 - 80, accounting for 15 per cent of the electricity bill.

119. The actual pattern of daily demand is shown in Figure XII. The steep rise in load, beginning at 6 a.m. and reaching a peak by 10 a.m. is clearly the time when appliances and luminaires are switched on as staff arrive and start work, commencing with the early morning shift team.

120. Electricity costs might be reduced by planning the operation of certain appliances during periods of least tariff cost, for example, during the months April through to October, and during the hours 20.00 through midnight to 08.00 on all days of the year. Also, by minimising demand charges through load levelling arrangements to avoid the peak load 'penalty'. An analysis of electricity costs on a percentage basis for FY 1979 - 80 is shown in Table XI. This indicates the proportion of costs attributed to demand charges and charges for units used during different periods of the day and year.

Modernisation of Boiler Plant

121. Current policy for modernising the site boiler house is based on the concept of the CHP system discussed at para 87 et seq, together with replacement of time expired oil and coal fired boilers by modern gas/oil units. However, fluidised bed combustor development has reached a stage where it will clearly have an important future commercial use in coal fired plants, making the latter comparable in size with oil/gas fired boilers.

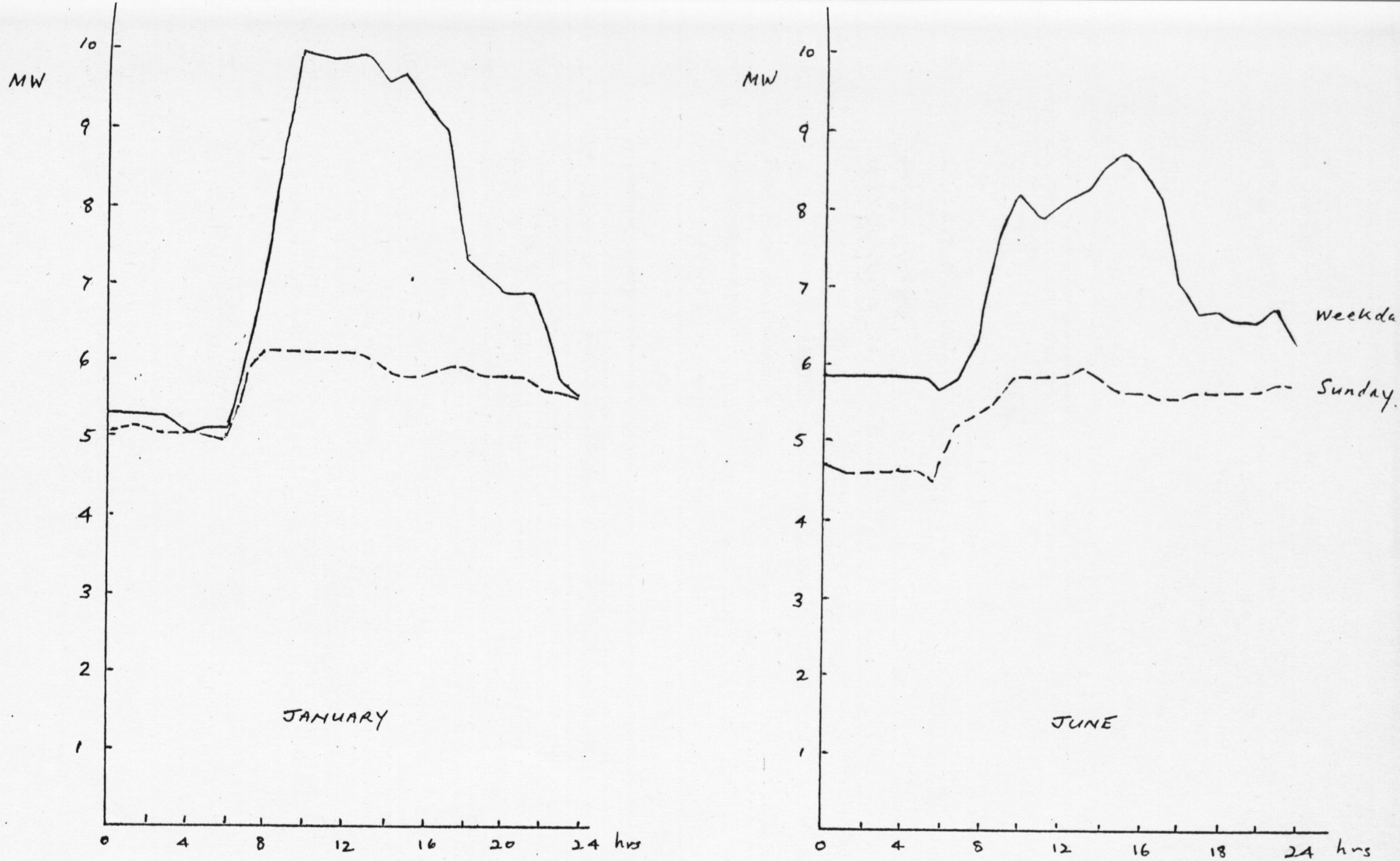


Figure XII Daily Pattern of Electricity Demand

Item	Percentage of total	
	Costs	Units
Demand Charges	14	
Unit charges: 24.00 - 08.00 h, All year	9	30
08.00 - 24.00 h, Apr.-Oct.	30	45
08.00 - 24.00 h, Nov.-Dec.	26	25
Fuel Cost Adjustments	19	
Service charge	2	
	100	100

Table XI Make up of Electricity Costs

122. In view of predictions that oil and gas may become scarce and increasingly expensive, modernisation plans should be reviewed. The advantages and disadvantages of retaining some coal burning capacity should be carefully considered including questions of high capital cost and the availability of proven equipment.

123. Heat will be recovered from a new non-active waste incinerator currently being commissioned. This will be used to pre-heat the boiler house feed water, giving a useful but small contribution to overall energy savings.

123A. Boiler house efficiency depends on the type, number, condition, combustion or stoking performance and operational policy, eg use of reserve boilers and control of individual boiler loads vis-a-vis total load factor. National figures for overall performance of steam boilers indicate that the overall efficiencies of gas and oil type boilers are in the range 67 to 85 per cent, while coal boilers are in the range 57 to 80 per cent. The overall thermal efficiency of the Harwell Boiler House is around 77 per cent. The coal boilers, because of extended service life operate near the lower end of the national range but the new dual fired oil/gas boilers have high efficiencies. Completion of modernisation plans can be expected to raise the overall efficiency to around 82 per cent. If CHP is adopted the overall thermal efficiency of steam production on the site would be somewhat lower around 78 per cent (reference para.96).

General Conclusions

124. In para.30 attention was focussed on the commendable relationship that exists between steam production and degree day data, indicating that the centralised steam main is held in satisfactory control.

125. The graph Figure VI of steam demand against degree days is very important to energy auditing because the slope shows the variable heat demand and the intercept shows the size of the base load. Experience elsewhere has proved that the graph can be used to estimate and monitor the effectiveness of on-going energy conservation measures. The slope and intercept of the graph have been reduced year by year, as energy saving policies have been adopted progressively by a number of organisations. (22)

126. Through a similar strategy, our aim should be to reduce both variable demand and base load on the Harwell site. The main measures that have been identified in the report, summarised in Table XII would achieve this objective.

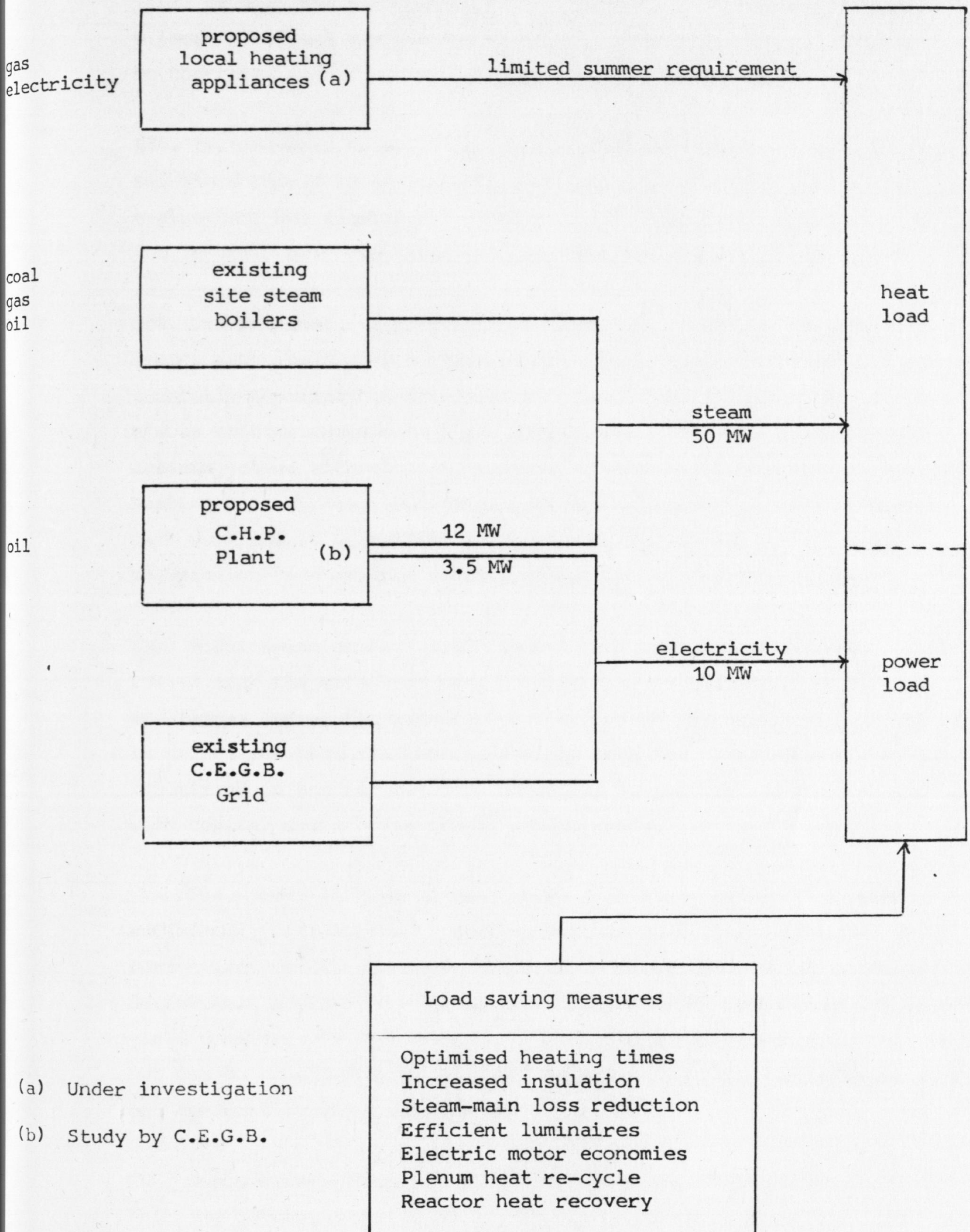
127. Cost effectiveness of savings measures will largely depend on the capital costs of implementing various schemes vis-a-vis energy prices that are rising steadily in real terms. For example, during the last year the price of oil has risen by about 60 per cent, gas by 45 per cent, coal by 20 per cent and electricity by 30 per cent.

128. As such rates of increase are well above the general inflation rate it is argued (ref.para.81) that cost effectiveness of measures, that are only marginally economic now, will increase with time. However, each measure should be carefully evaluated for its contribution to cost savings based on the best judgements about future energy supplies (ref.para.97).

129. It is logical to view saving measures in the context of an overall system of energy management (Figure XIII) and to formulate a list of priorities for implementation. Certain measures are simple to introduce on a progressive basis, e.g. building by building adoption of optimised heating controls and improvements to insulation. In aggregate they would

Main para. reference	Measure	Target Savings percentages, reference Fig.VII
15	Optimising the use of fuels year by year	
44	Improvements to building insulation standards	Reduce heating requirement by 2.5%
57	Adoption of heating controls in all buildings	Reduce heating requirement by 7.5%
72	On-going improvements to main insulation and operation	Reduce losses by 3.5%
73	Curtailing use of site steam main during summer by adoption of local appliances	Reduce losses by 3.5%
80	Recovery of reactor heat, small pilot scheme to establish feasibility	Reduce heating requirement by 1%
86	Investigating and reducing the dynamic losses due to plenum systems,e.g. heat recovery loops and systems reduction	Reduce plenum losses by 2%
87	Introduction of $3\frac{1}{2}$ MW(E) C.H.P. Scheme	£1.4M outlay, £0.3M/y savings
99	Investigation of special measures e.g. lighting compressors, motors, furnaces	Reduce total by 1%
123	Motivation and accountability	
	Total savings potential target	21 per cent

Table XII Summary of Energy Savings Measures



(a) Under investigation

(b) Study by C.E.G.B.

Figure XIII

Overall Energy Supply System

yield significant economies. Other measures, e.g. CHP scheme, offer a large potential savings but involve a major departure from tradition on the site.

130. Improvements to wall and roof insulation yield important savings and there should be an on-going programme, based on monitoring and evaluation, but significant reductions in heat losses from building fabric could also come from measures to reduce window losses.

131. Unfortunately, cost effective measures are not yet available to remedy heat leakage from large single-glazed areas. Therefore it is crucially important to eliminate the large losses associated with continous heating regimes in these situations. This can be achieved by pressing ahead with plans to install modern instrumentation to control heating time-cycles. Buildings that are occupied for only 40 hours each week should be subject to froststat control with sufficient pre-heating to guarantee thermal comfort during working hours.

132. Significant savings would accrue from measures to minimise heat losses from the site heat main particularly by switching to local appliances during the summer when sections of the main could be isolated. In total, the potential energy savings from the remedial measures identified in the review would amount to 21 per cent of current use with capital costs being repaid economically.

133. The potential from CHP and other heat recovery opportunities are sufficiently attractive to justify further study but judgements about future fuel prices vis-a-vis electricity costs are crucial to these decisions. A diesel engine generating plant with waste-heat boiler would yield considerable cash savings in electricity purchases from the SEB but due to considerations of capacity and reliability the site would still be dependent on the grid supply.

134. Reactor waste heat recovery offers an attractive potential for building heating and a pilot scheme incorporating a commercial heat-pump is recommended. If successful, there is a large potential in this direction.

135. Priority should continue with completing the modernisation of the site boiler house because of plant deterioration, but the advantages and disadvantages of retaining coal as a main fuel should be carefully re-examined in the light of medium and long term issues, e.g. innovation with fluidised bed combustors; availability and prices of fuels, and the high capital costs of coal type plants.

136. In addition to technological measures involving capital outlay, exhortation by management and the motivation and accountability of staff are of the uppermost importance. The CBI issued a special Bulletin (23) to its members stating that much can be achieved through giving attention to simple matters of good housekeeping. It refers to the obvious need for managers to set high personal examples in their own use of heat, light and power.

137. The CBI Bulletin contains a check-list of eighty-three items that are relevant to the on-going energy saving programme on the Harwell site. However, although exhortation as a means of motivating people is important, more sustained results can come through incentives. In this respect, there might be considerable cost benefits to be obtained from installing local electricity and steam meters in local centres so that divisions could be credited with the savings that are secured from successful attempts to economise in their use of energy. The benefits, and incentives that may be achieved from continuous monitoring of consumption, on a building or cost-centre basis, have been reported by industry and local authorities, (24,25).

138. In summary of this audit, steam consumption on a weather corrected basis has decreased by about 6 per cent over the last two years. These savings are attributable to economies in the periods when buildings are heated and the attention that has been given to thermostat settings on plants. Electricity consumption was also lower by about 2 per cent last year. It is concluded therefore that energy demand is being held down but further reductions will mainly come from the general targets that have been identified. The next step should cover a series of audit of major buildings to identify the energy saving measures that are appropriate to each.

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Appendix IA

Degree Day Convention - based on Fuel Efficiency Booklet 7

Relation of Degree Days to Fuel Consumption for heating buildings

Degree day data may be used to establish whether fuel used for heating buildings is being consumed efficiently. A direct comparison may be made between fuel used over a period with the number of degree days in the same period. Month to month variations in fuels used may be explained by proportional changes in degree days or, perhaps more effectively, the factor of 'fuel used per degree day' can be derived.

Definition of Degree Days

The generally accepted definition of a degree day is the daily difference in °C between a base temperature of 15.5°C and the 24-hour mean outside temperature, when it falls below the base temperature. This is based on the following argument.

Although, experience in Britain shows that 18.3°C is generally considered comfortable for normal purposes, tests based on careful observation have indicated that heat requirements (ie fuel consumption) of buildings which maintain an inside temperature of 18.3°C are more closely related to the amount by which the outside temperature falls below 15.5°C. The explanation of this difference,(ie 18.3°C - 15.5°C = 2.8°C) lies in the fact that not all the heat requirements of a building are supplied from its heating plant. It has been found that other sources such as people, lift-motors, appliances, lights, etc. supply sufficient heat to raise the internal temperature on average by some 2.8°C. This figure may vary with occupancy and standards of thermal insulation, but for normal use a difference of 2.8°C is acceptable.

Heat consumption in any given period depends upon temperature and time. If it is assumed that an outside temperature of 14.5°C prevails for one day then heating requirements are proportional to (15.5 - 14.5)°C, ie $1^{o}C$ for that day. This condition of one degree difference between outside temperature and $15.5^{o}C$ maintained for one day of 24 hours is called 'one degree day'.

If the outside temperature remained at $14.5^{o}C$ for each day of a week a total of seven degree days would be accumulated. In the same way an outside temperature of $13.5^{o}C$ for one week would accumulate two degree days each day, making 14 degree days for the week. We could then infer that fuel consumption for the second week would be roughly twice the fuel consumption for the first week.

Unfortunately temperature does not remain constant during the day so that it is necessary to calculate degree days from temperature readings in a less straightforward manner, which is explained as follows.

Calculation of Degree Days

The Meteorological Office currently calculates degree day figures and supplies them to the Department of Energy. They advise that a set of three alternative formulae for the calculation provide acceptable accuracy. The graph of temperature for any one day determines which formula is used.

The 'generally accepted' definition of a degree day quoted corresponds roughly to the first formula (Case 1), which is used for any day when the outside air temperature does not exceed the base temperature. The full definition for this case is as follows:

A degree day is the product of one day (24 hours) and $1^{o}C$ difference of temperature between the base temperature and the 'average outside air temperature' $\frac{(t\ max + t\ min)}{2}$

When the outside air temperature has exceeded the base temperature during the day, Case 2 or Case 3 is used. The reason for having alternative formulae may be illustrated as follows. If, for example, the maximum temperature was 16.5°C and the minimum temperature was 14.5°C, the average would equal the base temperature of 15.5°C and according to the simple definition no degree days would be recorded although it is certain that some fuel would be used in such circumstances during that part of the day when temperature fell to 14.5°C. To allow for varying conditions when temperatures exceed and fall below base temperature during the same day the Meteorological Office provided the alternative formulae 2 and 3.

Case 1

When daily maximum and minimum temperatures are both below 15.5°C, ie t max is less than 15.5°C and t min is less than 15.5°C. Accumulated temperature in degree days = $15.5 - \frac{(t\ max + t\ min)}{2}$

Case 2

When the daily maximum temperature is above 15.5°C but by a lesser amount than the daily minimum temperature is below 15.5°C, ie (t max - 15.5) is $\frac{1}{2}$(15.5 - t min) - $\frac{1}{4}$(t max - 15.5).

Case 3

When the daily maximum temperature is above 15.5°C but by a greater amount than the daily minimum temperature is below 15.5°C, ie (t max - 15.5) is greater than (15.5 - t min). Accumulated temperature in degree days = $\frac{1}{4}$(15.5 - t min).

Correlation between Monthly Steam Production and Weather Conditions

The data plotted in Figure V indicate that monthly steam production is closely related to the weather conditions represented by the number of degree days recorded during the month. Since the bulk of the steam required on the site is used for building heating it is natural that there should be a close relationship between steam used and the weather conditions.

It is possible to see from the scatter of the data when Steam production M is plotted against Degree Days D in Figure VI that a linear relationship exists between the variables. The slope represents the variable demand depending on weather conditions and the intercept represents the base load of the process heating and water heating requirement.

Using the regression curve model based on the method of least squares (reference Chatfield, C., Statistics for Technology, Penguin Books), an estimate of the mean value of the relationship can be calculated,

Reading	$M \times 10^6$	D	D^2	$DM \times 10^6$
1	23	50	2500	1150
2	32	100	10000	3200
3	38	100	10000	3800
4	53	200	40000	10600
5	55	200	40000	11000
6	74	300	90000	22200
7	70	300	90000	21000
8	80	400	160000	32000
9	85	400	160000	34000
Totals	510	2050	602500	138950
Means	57	228		

$$\text{slope} = \frac{9 \times 138950 - 510 \times 2050}{9 \times 602500 - 2050 \times 2050} \times 10^6$$

$$= \underline{0.17 \times 10^6}$$

$$\text{intercept} = (57 - 0.17 \times 228) \times 10^6$$

$$= \underline{18 \times 10^6}$$

Therefore, the estimated relationship between monthly steam production (M) and weather conditions represented by the number of degree days (D) is:

$$M = (0.17D + 18)10^6 \text{ lbs steam}$$

(ref.para.29)

Aerial Thermography

1. Thermography of the walls of buildings using portable infra-red cameras is an established method of promoting energy conservation by providing visual evidence of heat loss. The use of aerial thermographic surveys for examining roofs is a more recent development that has been supported by the Department of Energy. The supply of aerial infra-red imagery of industrial and factory sites enables energy managers and architects to identify heat losses from roofs and other important sources, eg process plants, heat mains and services.

2. Qualitative thermal imagery of sites clearly shows the position of heat emitting objects in detail, similar to that of a low grade black and white photograph. Buildings are clearly recognised but the appearance of other recognisable heat sources, eg steam mains, enable all the major thermal emitters on a site to be identified. In addition to black and white imagery, colour imagery can also be supplied which makes it easier to make comparisons of heat emission from different parts of the same site.

3. Quantification of heat losses is important for the cost analysis of improvements to thermal insulation of buildings and plants. For poorly insulated non-metallic surfaces, eg single skin asbestos roofs, reasonably accurate assessments of thermal conductance may be expected. Heat losses from roofs with low emissivities, eg metallic, are more difficult to assess and the imagery would normally simply reveal areas or points of gross defects in the quality of insulation.

4. Quantitative analysis of actual heat loss from the building fabric requires that the convective and radiative losses be estimated and added together. If the internal temperature of the building close to the roof is known a measured U-value is derived.

5. The design U-values for various constructional materials are not necessarily an accurate measure of the performance of a roof in real

conditions. The actual performance can only be determined by direct measurements, for example by infra red thermography. Conventional design estimates can be low in cases of buildings that need insulation, for example, when the U-value of the roof is greater than 1 $w/m^2\ ^oC$ (ie a roof in need of insulation), the surface resistances constitute a large proportion of the total thermal resistance. These factors are normally the least accurate components of design calculations. Comparison of design and measured U-values obtained for this study indicated that the measured values are all greater than the design figures, by up to twice in some instances.

PART III

INDUSTRIAL MOTIVE POWER

Introduction

1. Attention has often been drawn to the disadvantages of the constant speed electric induction motor as the agent for driving industrial machinery where speed reduction or adjustment is an essential requirement met by geared systems of various kinds. It has been suggested (1) that the adoption of centrally powered hydraulic systems of industrial motive power would offer significant advantages. It is worthwhile therefore to consider this potential opportunity by comparing electrical and hydraulic drives.

Fluid Power Technology

2. A striking characteristic of modern oil-hydraulic motors is their vastly greater power output in relation to their size and weight compared with any other type of driving unit. For this reason hydrostatic control and operation finds favour for mobile construction plant and transportation, agricultural machinery, aircraft, marine and industrial machinery where compactness is an attractive feature.

3. Hydrostatic systems are usually a first choice of designers if the cost can be justified. The increased performance demanded from all of the above and other sectors has increased the complexity of accomplishing power transmission and control by other methods to the point where hydraulic systems have become competitive and are now becoming more economical.

4. A further reason for the growth of fluid power systems is the increasing willingness of designers and operators to accept more sophisticated techniques. Thus fluid power control methods that met with resistance a decade or so ago are now readily accepted in some industries.

5. The National Engineering Laboratory specialises in the development of fluid power technology and cooperates with British firms to bring about innovation and commercial exploitation of new hydrostatic systems in various sectors of industry.

6. Apart from compactness other important characteristics of fluid drives include:

- The pressure developed depends on the magnitude of the load. If the load is zero, input pressure in the motor is zero.

- After the pressurised, or energised, fluid leaves the pump it flows directly through the pipework and control device to the motor.

- Energy transfer at the motor end is made directly to a mechanical load.

- The energy transfer cycle from pump to motor can drive the load smoothly and with continuous variable speed control, without the need for additional gear-box equipment.

- The return pipework can operate at atmospheric pressure.

7. The ability to store energy hydrostatically is a particular advantage of centrally powered hydraulic systems. The output from hydraulic pumps does not have to be used instantaneously but can be stored in a hydraulic accumulator and eventually fed to hydraulic motors as required.

8. Major manufacturers have units up to 75 kw with some reaching 375 kw and 750 kw. In general, efficiencies range from 75 to 90 per cent with piston type equipment on the high side. By suitable selection of units it is possible to obtain any required drive characteristic;

- constant torque

- constant horsepower

- constant torque and horsepower

9. Adjustable speed control capability is a significant factor in all except the most simple applications. Flow control devices are used, which work either by throttling or diverting the fluid. Either method causes a pressure loss which is converted into heat. Direction control is also obtainable by devices which start, stop, accelerate, decelerate and control direction of motion of the load. Electro-hydraulic servo-valves are obtainable to provide accurate control of velocity, acceleration or position. Control by variable displacement is the most efficient of all the systems. (2,3).

10. Since hydraulic systems cannot be fully efficient, heat is produced as a by-product. If this heat is allowed to accumulate, the temperature of the fluid rises with undesirable consequences for the seals, also the viscosity changes, adversely affecting the system performance. Heat exchangers are used to cool the hydraulic fluid.

Roles of Hydraulic Drives

11. In the machine tool sector fluid power has up to the present time been used only for main drives where there is a reciprocating motion, e.g. broaching machines. It has been widely used on all types of machines for feed control due to the advantages of shockless motion and ease of quick approach and return.

12. There are no technical constraints against the use of fluid power for main rotary drives for lathes, mills, etc., and due to the growing need for sophisticated and accurate controls on NC machines, hydro-static spindle as well as table drives are now being used on the more advanced machine tools, (e.g. 'Hydrocut' and 'Hydrotape' machines by Brown and Sharpe).

13. Hydrostatic power dominates in the plastic injection, die-casting, laminate-pressing, machinery sectors. In view of the increasing cost

competitiveness of fluid power units, their small dimensions, reliability and most important, the accuracy with which their speed can be controlled and adjusted, it seems inevitable that hydrostatic power systems will penetrate most of the machine tool and similar markets. At the present time all the indications are that the growth in application of fluid power throughout industry will continue to be in the self-contained unit machine mode. There is no evidence of a revival of the centralised system, - except in marine applications where there is a strong tend towards ship-board hydraulic ring mains powering pumps, capstans, hoists, steering gear and other machinery.

14. In choosing fluid power drives, energy saving over competing methods does not appear to be a significant factor in the minds of designers. The attractiveness of hydrostatic units lies in their technical merits described above with no special claims with regard to superior efficiency vis-a-vis electric motors and mechanical gear-box drives.

15. Electric induction motors coupled to loads via variable speed gear-boxes are usually selected large enough to deal with the highest loading likely to be placed on machines. As a consequence electric motors run partly loaded for the majority of their operational lives which has adverse implications for their efficiencies and power factors. In the case of machines likely to meet very high peak loads, designers often rely upon the ability of electric motors to run overloaded for short periods without harmful effects. This however also represents inefficient operation in terms of electrical energy.

16. British Standard Specifications give guidance on the selection of size of motors for given types of load factors, in order to optimise performance and efficiencies. However,it is clear that the way in which machines are used in the factory situation depends upon a range of unpredictable factors, for example; the habits of the operators and the style of management, the level of maintenance, the types of materials cut or processed, and the level of business of the firm at any time. Such factors will bear directly upon the efficiency of use of machines.

Power Transmission

17. The transmission of power by hydrostatic means is accomplished by the flow of fluid at a high pressure. The energy stored in the fluid due to the pressure is small and the power is mostly transmitted by the displacement of the fluid under a state of stress. Because line losses increase as the square of the flow velocity, the latter is kept relatively low. Therefore, the kinetic energy stored in the working fluid is also very small. In practice both kinetic energy and strain energy are regarded as negligible quantities. The major problems associated with the transmission of fluid power are related to the mechanical or physical characteristics of the circuit and to the fluid flow characteristics within the passages of the components. Because high pressures are used (up to 690 bar) and because the consequences of failure of pipes or components could be serious, mechanical strength is an important factor. For this reason safety factors of 3 to 5 are usually employed in design. Fatigue is also an important matter because of the cyclic variation of the fluid pressure which occurs in hydrostatic circuits. Alloy steels are used for pipes and components because of their superior endurance limits.

18. In practice it is essential to avoid misalignment of components and to ensure that power lines are anchored at key points otherwise they will respond to sources of vibration with serious results.

Size of Equipment

19. A particularly useful figure of merit for any power unit is the power per unit weight or volume. Contrasted with electric motors or generators which embody relatively large amounts of magnetic and electrical conducting and insulating materials which work at relatively low stress levels, hydraulic pumps and motors use alloy steels which work at high stress levels. This results in a remarkable difference between electric and hydraulic motors in terms of power to weight ratios. The magnitude of this difference in terms of weight can reach a factor of 10 in favour of hydraulic units. At power levels above 0.75 kW

the power weight ratio for a variable displacement axial piston unit is about 2 kg/kW. This notable virtue of smallness can however present a problem of obtaining a drive shaft with commensurate torsional stiffness. Appendices I & II give details of relative sizes and costs.

Variable Control

20. It is possible to vary the fluid displacement of pumps and motors by external controls through a shaft or actuating device so that the rate of transmission of energy can be varied. In the case of a pump running at constant speed, increasing the displacement causes increase in the flow delivered by the pump and hence increase in hydraulic power transmitted. In the case of a hydraulic motor running with constant flow input from a pump, increasing the displacement of the motor results in decreasing the shaft speed and increasing the torque. By suitable combination of such variable controls almost any required characteristics can be obtained. (4) The variables have the following relationships:

Flow	Q
Displacement per revolution	D
Speed	W
Torque	T
Pressure	B
Power	P

$W = \frac{Q}{D}$ $\qquad$ $P = TW$

$T = BD$ $\qquad$ $P = BQ$

21. When a power unit is to be employed in systems requiring rapid acceleration or deceleration the moment of inertia of the rotating parts at the output shaft is often an important factor in relation to the maximum torque available to accelerate these rotating masses. The torque-inertia ratio of hydraulic pumps and motors is usually at least a thousandfold greater than the ratios for electric generators and motors of the same power ratings. Although some systems require the largest torque-inertia ratio obtainable it must be recognised that in some applications the lack of flywheel effect in a hydraulic motor is disadvantageous.

Efficiency of Hydraulic Systems

22. The efficiency of hydraulic pumps and motors depends upon friction and leakage losses.

Pump torque T_p = Torque + Friction torque

Pump flow Q_p = Flow - leakage

Motor torque T_m = Torque - Friction torque

Motor flow Q_m = Flow + leakage

Friction losses comprise:

- pressure dependent friction
- speed dependent friction
- friction which is independent of pressure or speed usually present in seals and bearings.

Leakage losses comprise:

- leakage dependent upon pressure
- cavitation loss which is speed dependent.

23. Friction torque is also known to vary with excessive rise of temperature of the fluid in the small clearances and spaces between parts. Misalignment of shafts, improper mountings and poorly designed bearings can also lead to unexpected high friction losses. Breakaway friction is also an important quantity in pumps or motors which are started and stopped frequently. It can exceed low-speed friction losses by a factor of two or more. Leakage, in addition to internal routes can occur also between external and internal areas.

24. The overall efficiency of hydraulic pumps or motors is dependent upon:

- the volumetric efficiency
- the mechanical efficiency

Volumetric efficiency is determined by the amount of leakage in relation to the theoretical flow (based upon the geometry of the pump) Q.

Volumetric efficiency of pump $E_{vp} = \frac{Q - \text{leakage}}{Q} = 1 - \frac{\text{leakage}}{D_W}$

Volumetric efficiency of motor $E_{vm} = \frac{Q}{Q + \text{leakage}} = \frac{1}{1 + \frac{\text{leakage}}{D_W}}$

Mechanical efficiency is determined by the amount of friction (torque) in relation to hydraulic torque T.

Mechanical efficiency of pump $E_{mp} = \frac{T}{T + \text{friction}} = \frac{1}{1 + \frac{\text{friction}}{DB}}$

Mechanical efficiency of motor $E_{mm} = \frac{T - \text{friction}}{T} = 1 - \frac{\text{friction}}{DB}$

Overall efficiency of pumps or motors is determined by the amount of power lost due to leakage and friction, in relation to the external power supplied P.

for pump, $E_p = \frac{P\ in - P\ loss}{P\ in} = \frac{P\ out}{P\ in}$

$$\therefore \quad E_p = \frac{BE_{vp}\,Q}{\frac{T}{E_{mp}}\,W} = \frac{BQ}{TW} E_{vp}\,E_{mp} = E_{vp}\,E_{mp}$$

for motor, $E_m = \frac{P\ out}{P\ in} = \frac{E_{mm}\,TW}{\frac{BQ}{E_{vm}}} = E_{mm}\,E_{vm}$

25. Data on actual efficiencies of pumps and motors are difficult to obtain from manufacturers. This is probably due to the very wide range of operating conditions obtainable.

26. The performance characteristics of variable displacement units are similar to those of fixed displacement units especially when the former are operating at maximum displacement. In general pumps and motors have, from makers' information, efficiencies between 80 to 95 per cent over a wide range of their capacities. Efficiency curves shift upwards at lower speeds and downwards at higher speeds, but in general peak efficiencies cluster around 90-95 per cent. (5) The efficiencies of all units drop sharply at low loads where losses due to friction and leakage form an increasing proportion of the power. This is particularly emphasised with variable displacement units because leakage and friction do not vary to any appreciable extent when the displacement is varied.

27. The total efficiency of any hydrostatic transmission system is lower than the figures given above because the interactive efficiencies of both pump and motor have to be taken into account as well as the prime mover. The performance characteristics of integrated hydrostatic transmission systems comprising electric motor, variable displacement pump, circuit pipework, control devices and variable displacement motor are extremely complex because of the wide range of variables, but the total efficiency will be many points lower than the individual efficiencies indicated for pumps or motors.

28. British Standard 4617: 1970 sets out the "Methods of Testing Hydraulic Pumps and Motors for Hydraulic Power Transmissions." Tests carried out according to this specification indicate that the maximum efficiency of an integrated system (excluding the efficiency of the prime mover) is about 85 per cent at medium speeds and less than 80 at higher speeds. When the efficiency of the electric motor is taken into account these figures will drop to within a range of about 50 to 78 per cent. It is reported that some variable displacement units have sustained high friction at very low speeds thus limiting their usefulness, without a mechanical reduction gear box, for continous operation below 50 RPM. This further reduces the total efficiency of a hydraulic power transmission.

Efficiency of Electric Motors

29. The efficiencies shown in the follow data for squirrel cage induction motors are typical of commercial machines. Motors of ratings above 200 kW have efficiencies rising to a maximum of 97 per cent at 5000 kW rating and above. (6, 7)

Performance data for 3 phase TEFC electric motors

Efficiencies %

kW	HP	RPM	FULL LOAD	¾ LOAD	½ LOAD	¼ LOAD
0.37	0.5	710	62	60	52	44
0.75	1.0	930	70	69	67	57
1.5	2.0	1425	76	76	73	62
3.0	4.0	1440	80	79	77	65
7.5	10.0	1440	86	86	85	72
15	20.0	1450	88	88	87	80
30	40	1475	90	90	88	81
55	75	1475	91	91	90	83
75	100	1475	92	91	90	83
150	200	1480	92	91	90	83
200	270	1475	92	91	90	83

30. The efficiencies of AC motors of the wound rotor and synchronous types up to 200 kW rating are similar, within a few per cent, to the squirrel cage types. Variable speed commutator machines for operation on alternating current have efficiencies in the range 30 to 92 per cent depending upon the size, type and speed selected. When a semi-conductor type of variable speed control is used in conjunction with a squirrel cage motor the overall efficiency will be reduced, for example, by up to 6 per cent for motors in the range 2 to 7.5 kW. Direct current motors of the series, shunt or compound types have efficiencies similar within a few per cent to the values given for squirrel cage machines of comparable ratings. A specification for the methods of verifying the efficiency of electrical machinery is given in British Standard 266: 1927 amended 1961, "Methods of Declaring Efficiency of Electrical Machinery".

Efficiency of Machinery

31. In general, the efficiencies of machines will vary considerably between makes and types of machinery; also different gearing and bearing arrangements will produce a wide variation in power consumption between machines of a similar type. Firms appreciate that a machine having a higher efficiency is more economical to run in terms of power costs but this factor has been of secondary importance compared to other crucial considerations such as robustness, accuracy, reliability and the capability to operate at high production rates when required; and last but by no means least, considerations of capital costs.

32. Technical data on the efficiencies and losses of motors are available from suppliers, e.g. the close comparison between electric motor and hydraulic motor efficiencies is indicated in Appendix III, but such information on machinery is sparse - probably because as suggested above interest in overall energy efficiency has been of minor importance. However, rising power costs, and a trend towards energy conservation will in future direct more attention upon power losses in manufacturing processes and efficiency data will become of more central interest in the design and operation of machinery.

33. The mechanical efficiency of a machine mainly depends upon the frictional forces resisting the motion between mating parts. It is impossible to produce perfectly smooth surfaces which would be frictionless, so due to the roughness of surfaces, tangential forces are induced between them which resist relative motion. These frictional resistances represent power losses, dissipated in the form of heat, which account for a significant proportion of the total energy consumed in industrial and manufacturing processes.

34. Within machines the losses are due to either sliding or rolling friction. Generally a greater force is required to initiate motion than to maintain it because static friction is greater than dynamic friction, by up to thirty times depending upon the size of the load and type of lubricant. In practice the sliding coefficients are much higher than the values for rolling coefficients for the same materials. For lubricated surfaces on typical industrial machines the coefficients of friction fall as the high spots are reduced by wear or by an initial running-in under gradually increasing load. The coefficient of rolling friction between metal surfaces will be as low as 0.001 for hard smooth accurate surfaces; and it will seldom exceed 0.01. At slip conditions, however slight, rolling friction is superseded by sliding friction. Therefore roller and ball journals must be carefully designed and loaded so that slip cannot occur. Friction losses are generally lower with ball or roller bearings than with plain bearings.

35. Hydrostatic bearings have the lowest friction losses. They have no static friction and running friction is remarkably low. Starting torque and power losses are much reduced. Also these bearings are characterised by their high rigidity making possible the achievement of high accuracy spindles and slideways for advanced precision machine tools (e.g. Brown and Sharpe Hydrocut and Hydrocentre machines).

36. In spur, helical and bevel gears the amount of relative sliding of the contacting teeth surfaces is small compared with the corresponding circumferential displacement of the teeth, consequently the power loss is small. With smooth and accuratefly finished tooth profiles, correct alignment and adequate lubrication, the power loss due to

sliding friction is usually less than 1% of the power transmitted; with large pinions this may drop to about 0.5%. When circumferential speeds of gear wheels are above 200 rpm the power losses due to churning the lubricating oil will probably exceed the tooth friction losses. At very high speeds (2500 rpm) it becomes economic to pump oil onto the gear wheels at their points of contact and avoid the comparatively large oil churning losses in splash lubricated gear box units. Bearings, already discussed, also contribute significantly to losses in gear box units; plain bearings having losses of 3-4% roller 2% and ball bearings 1%.

37. Taking all factors into account the full load losses of a single pair of high quality gears including shaft, bearing and oil losses would be in the range 2-5 per cent of transmitted power depending upon the speed. Actual losses are both speed and load dependent but speed is the most crucial factor. Tests indicate that the large difference between power losses at high and low output speeds is mainly due to losses in main spindle bearings; but in general the number of lay shafts, gears, bearings and main spindle bearings together with the oil churning losses determine the aggregate loss and this loss in terms of power varies directly with the output speed,(8)

38. Chain and sprocket drives have losses of about 1-2 per cent; vee belts about two per cent of power transmitted. Worn gears have losses varying from about 5 to 30 per cent plus bearing and oil losses which are speed and load dependent. Worn gears act as static brakes when their lead angles do not exceed 8^{o}.

39. In summary this appraisal of friction losses accruing in different forms of mechanical drives indicates that significant power losses are involved. Generally these losses increase markedly with speed and at the highest machine speeds they can account for about half the rated power of the driving motor. Therefore, they represent a large fraction of the energy consumed by industrial machinery. Every machine contains a prime mover and a multiplicity of gears, shafts, bearings, slides and other elements each of which contributes to the total power loss. Different types of bearing design and lubrication also affect the size

of power losses. Machines incorporating hydrostatic bearings will have greatly reduced losses compared to film lubricated bearings.

Comparative efficiencies

40. The following figures are indicative of the efficiencies of self contained machines:

Hydraulic drives

	Prime mover Electric motor	x	Hydraulic pump	x	Hydraulic motor	=	overall efficiency per cent
Efficiency range:	70 to 92 depending upon size		89 to 92 depending upon speed		89 to 92 depending upon speed	=	55 to 78

Geared Electric drives

	Electric motor	x	Gear box	=	overall efficiency
Efficiency range:	70 to 92 depending upon size		72 to 92 depending upon type of gears, bearings, lubrication and output speed		50 to 85

41. Types of Driven Machines - Fixed Industrial Plant (ref:BSS 1400,3790)

Light duty:
- Agitators for liquids, Reaction vessels
- Blowers
- Exhausters
- Centrifugal pumps and compressors
- Fans
- Light load conveyors

Medium duty: Belt conveyors for sand, grain etc.
Dough mixers
Large mixers
Large fans
Laundry machines
Machine tools
Presses, punches, shears
Printing machinery
Vibratory screens

Heavy duty: Brick making machinery
Bucket elevators
Conveyors
Hammer Mills
Pulverisers
Sawmill and wood working machines
Textile machines
Crushers
Mills, Extruders
Hoists
Cranes

Types of Prime Movers and Transmissions:

AC motors Synchronous, Squirrel Cage, Slip Ring
DC motors Shunt, series, compound, wound
IC Engines. Steam turbines, gas turbines
Clutches, brakes
Gear boxes. Worm, spur bevel, spiral
Chain and sprockets
Vee belt
Flat belt

The load characteristics of machines will vary considerably with, for example, uniform loading, intermittent, shock loading, fixed and variable speed.

Evaluation of energy losses

42. The efficiency of a machine is the ratio of the output energy to the useful input. The difference between the two is an absolute quantity which when aggregated for all industrial machinery gives the total energy dissipated in the form of useless heat due to friction in the machines, but friction heat dissipated in factory buildings can help the space heating load. In the past it has been usual to emphasise the harmful effects of friction in terms of 'wear and tear' in machines, a major concern being that high friction leads to rapid wear with loss of accuracy and short machine life. Tribology was conceived as a new branch of science and technology with the objective of overcoming these problems. In future, friction will also be regarded with increasing emphasis in the energy conservation context.

43. Efficiencies are highest when machines are run near full rated loads. Below this load, or above it, efficiency drops but it remains within about 10 per cent of maximum full load value over a fairly wide range of loads. This is particularly true of medium and heavy duty machinery but the efficiencies of light duty machines are more sensitive to load factor. However, it must be recognised that as 'FULL LOAD' comprises USEFUL LOAD plus LOSSES in motor and driven machines, it is necessary to carefully evaluate and understand the latter.

$$\text{Efficiency} = \frac{\text{useful output}}{\text{input}} = \frac{\text{input - losses}}{\text{input}}$$

$$= 1 - \frac{\text{losses}}{\text{input}}$$

44. Losses in complex gear change drives can constitute up to 50 per cent of rated input power at high machine speeds and 25 at low speeds. In more simplified forms of industrial machinery drives, the losses will be lower and depending upon the prime mover, number and type of bearings, gears, and system of lubrication, will be in the general range 45 per cent at high speeds to 15 per cent at low speeds. Losses in machines vary directly with speed but they are largely independent of the load.

They are approximately determined by the amount of input power when machines are running light or on zero load.

45. In evaluating the energy efficiency of machines therefore, two characteristics are definable:

- Full load efficiency

- No-load loss

No-load loss may be expressed in relation to the rated power of the machine, giving the:

- Normalised no-load loss = $\frac{\text{No-load loss}}{\text{Rated power}}$

Vis-a-vis full load efficiency, the normalised no-load loss is an indication of the no-load deficiency of a machine. These two criteria are helpful in understanding the economy of the use of energy in industrial machinery, and given reliable data, should assist in the best selection of machines in the energy context.

Losses in self-contained and centralised systems

46. Self-contained machines

Consider a group of self contained machines

Utilisation of Machines	= u
Total rated power of machines	= P_R
Total power input	= P
Normalised no-load loss	= y

The total power input will be the sum of the utilised power plus the no-load losses when machines are running light.

$$P = uP_R + y(1 - u)P_R$$

$$P = P_R(u + y(1 - u))$$

Centralised Systems - comprising same machines as above

47. The power unit of a centralised system will be selected according to the connected load and the utilisation factor; and it will therefore operate at full load.

Total power input $P_1 = uP_R$

Savings of power due to a centralised system $= P - P_1$

$$\text{Savings} = P_R(u + y(1 - u)) - P_R u$$

$$= y(1 - u)P_R$$

In practice the savings will be higher than this because P_R for the self-contained system will have a higher value than for the centralised system, for two important reasons:

- the centralised system permits the selection of large size motors with higher efficiencies than are possible with the multiplicity of small motors installed in the self-contained systems.

- the total rated power of a self-contained system is usually higher than required because of the tendency to select oversized motors

$$\text{Savings} = P_R(u + y(1 - u)) - P_{R_1} u$$

where $P_{R_1} \leq P_R$ (P_{R_1} is rated power of centralised system)

48. Consideration of these derived expressions for savings of energy due to a centralised hydraulic system indicate that savings will accrue in the approximate range of 3 to 27 per cent with generalised values of y in the range 0.15 to 0.45 and u in the range 0.4 to 0.8. In practice, such values will depend upon the types of machines and products and the scale of operations. For example, a group of plastic

injection moulding presses will have peak-power characteristics and a low utilisation factor, while a group of conventional machine tools will have more even-power characteristics and a higher u value. Therefore the savings due to centralisation would probably be higher for the plastic moulding machines than for the metal cutting machines when each is compared with their alternative self-contained systems.

49. The costs of transmitting 500 kW by hydrostatic or electrical mains over a distance of 100 metres have been studied for the purpose of comparison. By equating the size of each type of mains to a power loss of approximately 1.5 per cent (as in industrial practice) it turns out that the capital costs of economically sized mains of either type are not significantly different. The flexibility of the electrical mains system implies that replanning of machine layouts may be less costly than for the centrally powered hydraulic mains system. However, the life of hydraulic mains are likely to be longer than electrical power cables.

Primary Power Supply for Central System

50. A centralised hydraulic system could be energised via a number of routes, each having its own characteristic efficiency in the conversion of primary fuel to driving torque at the shaft of the central hydraulic pump. Examples are:

(1) electric motor supplied from the national supply grid
(2) electric motor supplied from firm's generator
(3) IC engine drive (Diesel or gas engine)
(4) Steam turbine drive
(5) options (2), (3) and (4) operating as combined power and heat schemes.

Examples of Overall Efficiencies of Central Systems:

	CEGB		Ind Motor		Hyd Pump		Hyd Motors		o/a efficiency
Option (1)	.29	x	.9	x	.9	x	.9	=	.21

Option (3)	Diesel Eng		Hyd Pump		Hyd Motors		o/a efficiency
	.38	x	.9	x	.9	=	.31

Conclusions

51. It has been shown above that fluid power units transmitting both linear and rotary power are chiefly characterised by their very small size in relation to their power capacities, their ease of control and cost competitiveness.

52. The 'power-packs' of modern hydraulic machines have compounded peak efficiencies between about 55 to 78 per cent depending upon power rating. Thus they offer little or no direct efficiency advantage over the general range of "geared electric motor" drives. Some manufacturers of high quality gear units claim efficiencies as high as 96% ie 85% compounded with induction motors. However fluid systems possess certain merits which lead indirectly to the conservation of energy.

- hydraulic drives are much smaller than their counterparts, thus yielding a savings of materials

- hydraulic drives provide the means for hydrostatically lubricated bearings on machines, thereby virtually eliminating friction in main spindles and slideways. This if widely adopted would produce a notable net reduction in power losses. Also wear and tear is reduced in hydrostatic bearings giving prolonged machine life and sustained high accuracy, yielding savings of materials

- hydraulic powered feeds and controls on machine tools decrease cycle times almost reducing them to the cutting time, thereby increasing productivity and efficiency in the manufacturing process. Also, operator fatigue is reduced.

The centralised hydraulic power system offers power savings probably between 3 and 27 per cent depending upon machinery connected and utilisation factor when compared with the self-contained hydraulic and non-hydraulic alternative systems. Its full potential for conservation of energy would be realised when the prime mover is part of a combined power and heating system within the factory complex; but such advantages must be compared with:

- capital and running costs
- reliability and availability factors
- implications for CEGB load
- technical problems in the application of hydrostatic drives to various types of machinery

54. After considering the pros and cons for the different forms of motive power transmission in industrial machinery, particularly their technical, operational and efficiency factors, it is concluded that there will always be a need for each type of drive, electrical-geared and hydraulic. Machinery of the future will embody the best features of each system particularly as the full potential of each is realised. There will continue to be a wide market for heavy electrical-geared fixed ratio drives where variable speed range is not a requirement fluid power systems have attractions where variable speed control is essential.

55. Central hydraulic systems should have much lower no-load losses, therefore this form of motive power might be advantageous with groups of intermittently loaded machines. However, substantial operational experience is lacking and results with any centralised pilot scheme must be carefully evaluated.

56. It should be borne in mind that advances are being made in the design and operating efficiencies of electrical-mechanical drives and modern electronic controls are being applied to variable speed drives. Therefore it will be necessary to evaluate the performance of hydraulic systems against advances in the other technologies for industrial motive power.

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BSS's covering Gears and Gearings are as follows:

BS	721	Worm Gears
BS	545	Bevel
BS	978	For Pitch
BS	235	For Traction
BS	1807	For Turbines
BS	3696	Spur Gears
BS	436	Helical Gears

Power to Weight Ratios

Radial Piston Hydrostatic Motors

Constant volume type	0.97 kg/kW	1.02 kW/kg
Variable volume type	3.22 kg/kW	0.31 kW/kg

Axial Piston Hydrostatic Motors

Constant volume type	0.85 kg/kW	1.17 kW/kg
Variable volume type	1.94 kg/kW	0.51 kW/kg

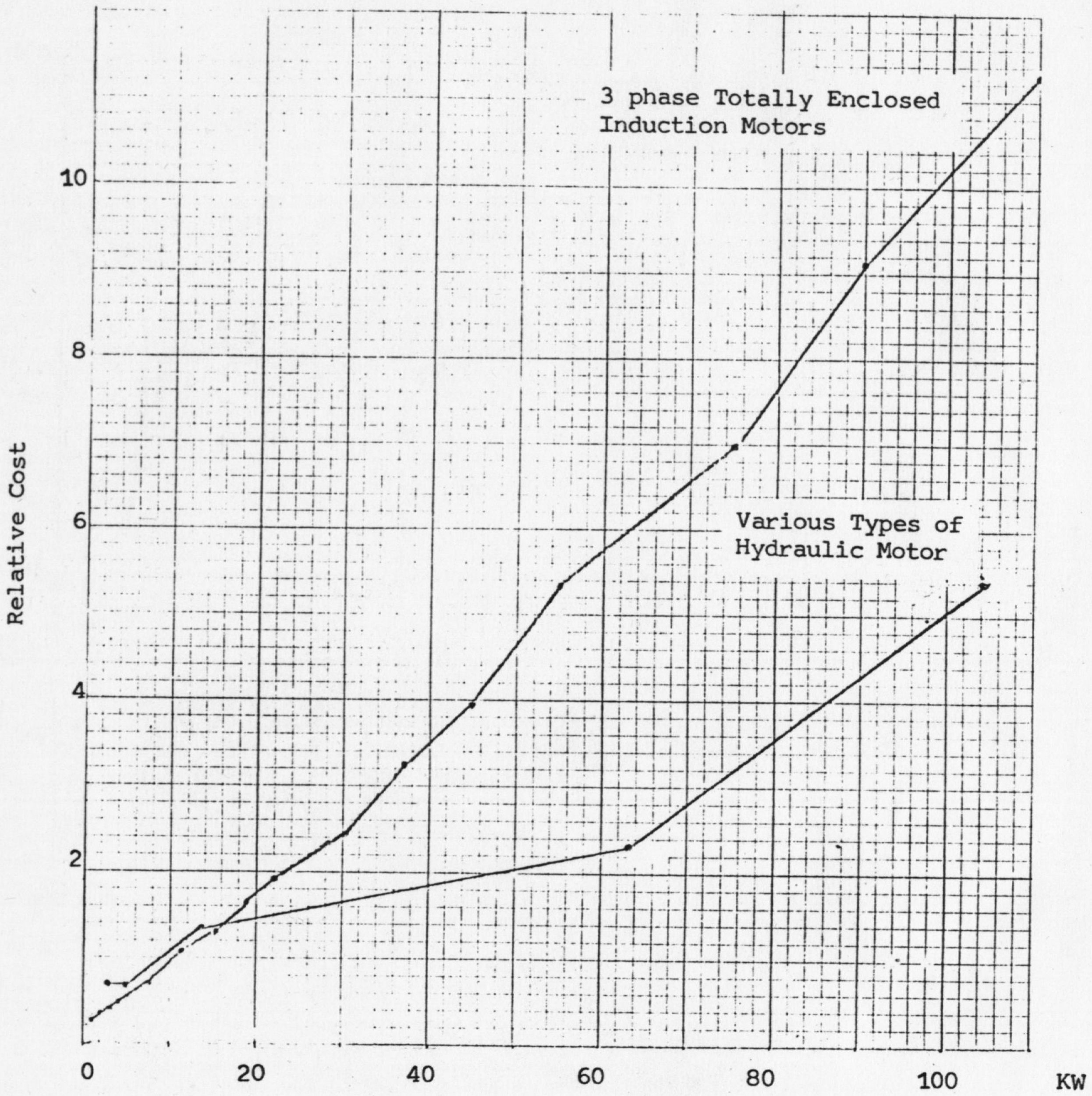
Hydraulic Pumps

2.02 to 6.08 kg/kW   0.49 to 0.16 kW/kg

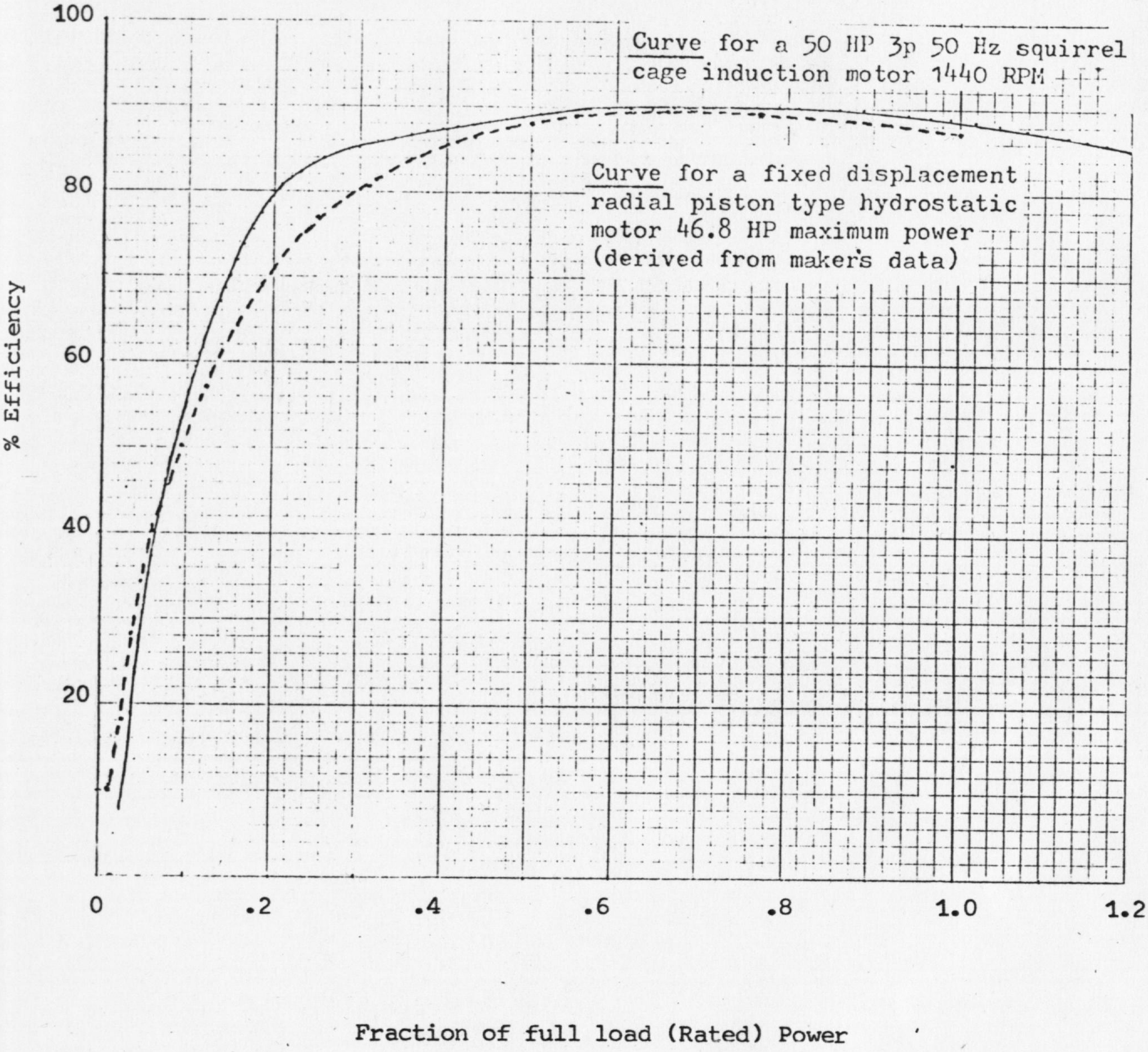
Totally enclosed fan cooled induction motors

650V maximum 3 phase, 50 HZ, 1500 RPM
(British metric/IEC 72)

8 to 21 kg/kW   0.12 to 0.05 kW/kg



Comparative Costs of Electric & Hydraulic Motors



Comparative Efficiencies of Electric & Hydraulic Motors