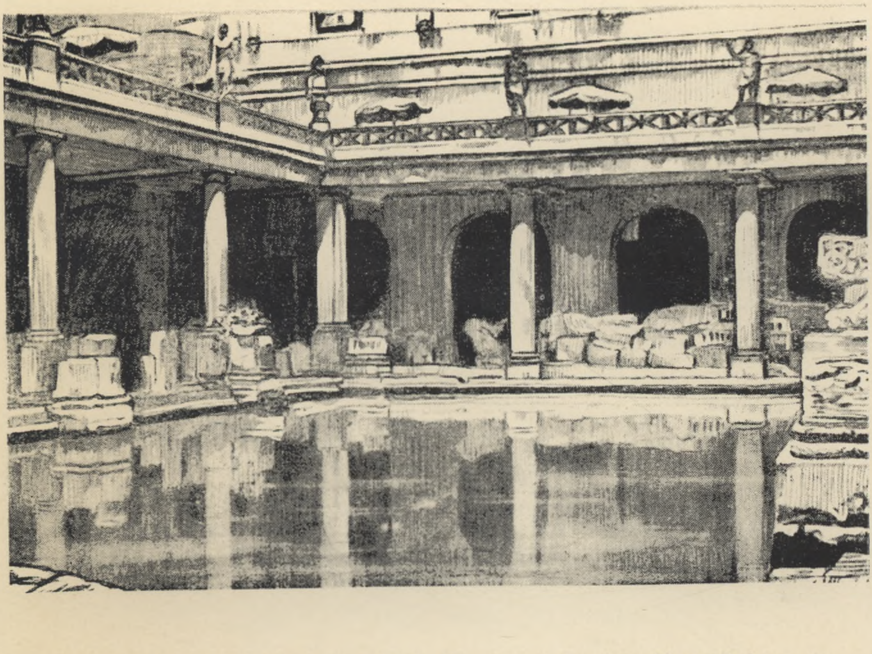

THE ROMAN BATHS in the City of Bath. The existence of geothermal heat at Bath suggests that there may be other more plentiful unexplored sources elsewhere in the country (see p.114). (Courtesy of Messrs. J. Salmon Ltd., Sevenoaks)

DISTRICT HEATING

A Brief Introduction to Planning Requirements

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CONTENTS

Preface 7

1 Introduction 1

2 General considerations 8

3 Control of heat supply 14

4 The heat load 22

5 Transmission network 32

6 The consumer's installation 47

7 Heat production 57

8 Costs 74

9 Measurement of heat consumed 85

10 Charges for heat supply 95

11 Miscellaneous requirements 104

12 Concluding comments 111

Glossary 121

Appendices 123

A Pimlico district heating undertaking Schedule I—District heating operating costs 124

B Pimlico district heating undertaking Schedule II—Weather and adventitious heat aids 128

C Pimlico district heating undertaking. Results of heat loss tests carried out on district heating main at Churchill Gardens Pimlico 132

D Summary of costs during development and on completion 134

E Schedule of estimated electrical loading and duties for a district heating boiler plant, final stage 139

F Summary of items of incidental builders work 141

G Particulars of welder's qualification tests as covered by insurance company's report 142

H Testing of welded pipe joints and flanges 144

I The Pimlico district heating undertaking 145

J Summary of principal planning requirements 148

K Conversion tables 154

Index 159

PREFACE

Modern standards of living and productivity have emphasised the need for a generous and convenient heat supply at a price that all can afford. Throughout the world many town and city dwellers already enjoy such heat services, based on supplies piped from central generating stations. The sources of both home produced and imported fuel are adequate for the provision of the same kind of services in this country, and as the economics, convenience and reliability of district heating become more widely known, the natural outcome will be its greater use in this country.

The information to be found in the following pages is intended for those, who without getting too deeply involved in technicalities, wish to know what may be entailed in the planning of a district heating service, how this may be costed to effect a true comparison with other methods of heat supply and how to ensure its successful financial operation.

A district heating service that is to be economic and completely reliable must conform to definite standards with regard to heat production, transmission and utilisation. For these standards to be assured, it is necessary to have a knowledge of the principal factors involved. This information is supplied for the consideration of those concerned with the economic and other aspects of public utility services and who therefore have a responsibility for choosing from the various forms of heat supply available today for the development of schemes involving such applications. It is also for those who are not familiar with the general design, installing and operating requirements of district heating.

District heating is a large and complex subject, embracing many matters of a financial, technical and general nature, and to deal with all these adequately would require several volumes. The need to present the information briefly here may sometimes have caused some loss of clarity or even neglect of certain problems, and affected the balance of the information presented. In consequence over simplification of some aspects may have occurred and too much detailing of others. The latter however has been intentional at times not only because of their greater importance but also because they involve matters that are generally little known. In the circumstances the reader's indulgence is necessary in considering the information presented.

Acknowledgements are due to the Central Electricity Generating Board for permission to reproduce the illustration on page 62 Fig 11, and the results in Appendices A, B and C, and to the Westminster City Council for the use of information about the Pimlico District Heating Undertaking; also to the National Coal Board concerning the Billingham Scheme; to the Cwmbran Development Corporation about their Town Centre; and to the Northumberland County Council and the Co-ordinating Architect-Planner in connection with the Killingworth Township.

Acknowledgements are also due to Messrs. Kennedy & Donkin for the help received from their staff in the preparation of tables and illustrations.

12, Caxton Street, S.W.1. F. B. T.
November, 1965

Chapter 1

INTRODUCTION

Heat has been one of the basic human necessities since the dawn of civilisation. For centuries a variety of methods were employed for its production; but usually with little or no regard for comfort, convenience, or cost. Thus mediaeval castles had great chimney-less fireplaces in which piles of logs were burned. Earlier, the Romans employed underground hypocausts through which circulated air heated by primitive furnaces. Later on, stoves were used so as to burn the wood, peat and coal more effectively, until eventually the open grate appeared with its extravagant use of fuel for unilateral heating.

Today, because our race is less hardy and more hygienic, more leisurely and more discriminating in culinary processes, we demand that heat be made available more adequately and conveniently for space warming, the supply of hot tap water and for cooking. Modern standards of comfort are such that partial heating of a new dwelling is now seldom tolerated. Adequate heating throughout the building even in the coldest winter, coupled with a constant supply of hot tap water is considered essential. These are now made possible by improved systems of central heating, effected by efficient generation and distribution of heat, and of hot water for domestic, commercial and industrial use.

Because of the many benefits derived from central heating, it was logical to extend the use of this method of serving single buildings so that the central boiler plant could also supply a number of buildings collectively, when conveniently grouped together. Today there are many examples of extensive systems serving industrial and housing estates, hospitals, barracks and office blocks, each covering a considerable area of land. These are often referred to as group-heating systems.

The natural development of group-heating resulted in even greater areas being served, such as part of an existing town, a new town, or a residential district comprising several housing estates. This was the historical evolution of *district heating*, the term used for the system of generating and distributing large heat supplies. It is used in many countries throughout the world.

District heating appears to have been originated by a Mr. Holly, who in 1877 installed an experimental system at Lockport in the City of New York to serve some residences, stores and offices with about three miles of street mains. This installation attracted much attention, and not long afterwards plants were being established in various other parts of the U.S.A. A few years later the American District Steam Company was formed, and did much towards the development of district heating. About the same time the New York Steam Company came into existence, and their activities rapidly expanded to make it the largest and most important company for the distribution and sale of steam. The largest district heating system in existence is operated by this Corporation in New York City for supplying the down-town and up-town sections of Manhattan Island, which includes the Rockefeller Centre and some of the largest buildings in the world.

There are now several thousand district heating systems in the U.S.A., supplying a great variety of buildings, including those in built-up business and residential areas in cities where a high density of load exists, and a good load factor is obtained. Chicago, Detroit, Philadelphia and Baltimore are among the many other cities with a district heat supply to industrial, commercial and suburban areas.

Russia, also, has made good progress in the use of district heating over the last half century, and has gained much impetus from the Five Year Plan of 1938-42 which has since been further developed as part of the planned national economy. Over 30 years ago it was the aim of Russian engineers to bring about the complete 'heatification' of towns and cities as part of the electrification programme, and the effect of this development can be seen today in Moscow, Leningrad and Stalingrad. There are also a number of installations in Siberia and the Far East.

There are over 300 district and group heating systems in West Germany where, like other European countries, the energy needs have compelled the adoption of a national fuel policy and the rapid expansion of district heat supplies. In Hamburg, for example, where the district heat supply started in 1921, the demand has been so great that by 1938 the heat supply had to be increased over 30 times. In Poland the supply increased by 50% between 1957 and 1958, due to the introduction of new schemes.

Other countries where district heating has been adopted are France, Belgium, Holland, Denmark, Norway, Sweden, Finland, Czechoslovakia and Yugoslavia. In Rome the Vatican City is heated entirely by district steam.

The district heating system at St. Pölten in Austria has two features in common with the Pimlico District Heating Undertaking in London. Both systems have now been operating economically successfully for 15 years, and each depends upon a transmission network housed in underground concrete conduits.

New systems are continually coming into existence abroad, such as the one at Toronto. As a result of a feasibility study made for a district heat supply for down-town Toronto, it was decided to proceed with construction. The central plant and sections of the distribution network have already been completed and serve the first phase of development, the final design of the second phase is expected to start shortly.

An interesting feature of the system is the use of a dual-fuel scheme for firing the boilers, so that the amount of oil and gas consumed each year can be varied to obtain the lowest fuel cost as market conditions changed.

Existing district heating systems also continue to be expanded so as to meet increasing heat demands, as in the case of the power plant at Fynsvaerket, Odense, in Denmark. Here an additional turbo-generator has recently been ordered, for commissioning in 1968. Rated at 205 MW, it is understood to be the biggest steam turbine in the world to be used in district heating power plants, with the exception of the Russian 250 MW turbine project. The turbo-generator set is of the contra-rotation cross compound type, comprising one radial flow high-pressure turbine, and one combined radial-axial flow low-pressure turbine, working as one unit.

In Great Britain there is little district heating, despite the excellent opportunities provided for its development by the post-war reconstruction of cities and towns, and notwithstanding the prodigious amount of information on the subject of district heating produced in the country during this time by the activities of research and various

Fig. 1. THE WESTMINSTER CITY COUNCIL'S PIMLICO DISTRICT HEATING UNDERTAKING. The route of the transmission mains is shown from Battersea Power Station across the River to the substation. The distribution mains are also seen extending eastwards to Dolphin Square and in a north westerly direction as far as Abbots Manor estate near Victoria Station. The heat accumulator at the substation is shown in Fig. 13

other committees, the presentation of technical papers, the preparation of reports, and the issue of official publications.

Before the Second World War one small scheme existed in Manchester, serving commercial premises, and another at Dundee supplying a housing estate. Since this time, with the exception of a few housing estates supplied with district heat on a small scale, and one large industrial estate, there have been only two notable developments. One is the Whitehall Scheme which supplies all the government buildings in that area, and the other is the Pimlico Undertaking, seen in Fig. 1 which supplies several housing estates and numerous commercial premises, using exhaust heat from Battersea Power Station. Other schemes are now in the course of development or have recently been completed.

One of the latest schemes to be completed, that at Billingham, in South Durham, is a good example of what can be done by the co-operation of a national board and a local authority in jointly providing and operating a district supply of heat. On full development the scheme will cover 30 acres and will use about 5,000 tons of locally produced coal each year; the metered quantity of heat leaving the boiler house being sold to the council for distribution. The scheme may be regarded as a prototype for other comparable projects throughout the country.

The successful development of district heating, has generally been achieved, but not without difficulties, as might be expected with any new technological venture. In the early stages some schemes proved financially unstable because of inexperience in the operation of this new form of public utility service. Latterly there have been some failures in this country due to the use of unproven methods for the design and installation of the transmission network, but despite setbacks of this kind, the advance of district heating has steadily increased in recent years. This is because improvements in design techniques and in manufacturing processes have made the system more and more economic.

No close pattern has been followed in the design and operation of district heating systems, because the economic conditions in different countries are dissimilar and changeable. Many of the earliest installations made use of the exhaust steam from electrical generating stations, whilst others depended on the use of live steam direct from the boiler plant. Later, there were developments in the use of high pressure hot water. The present trend is in the further development of combined heat and power generation, because of the substantial fuel economies that can result from this method when the generating station is conveniently sited.

The establishment and operation of district heating systems was often originally undertaken by private enterprises that were also concerned with the supply of electricity. As district heating became more widely used and of service to various communities, its installation and administration often became the responsibility of institutions, municipalities or the state. In some countries today, specialist contractors undertake to provide the fuel, operate the plant and maintain it on behalf of the owners. There are also contractors who specialise in providing a heat-metering service. In this country a national board will sometimes provide steam from a power station or the boiler plant and all else that is necessary to supply the heat for sale to others responsible for its distribution.

Experience gained abroad has shown that district heating systems can generally be introduced and operated successfully provided that they are designed on an economic basis. The character of the area served should be appropriate, which sometimes precludes residential districts of insufficiently high housing density. This exemption, however, is less applicable to towns in Great Britain, where climatic conditions provide a better annual load factor, than such cities as New York, Hamburg and Moscow.

A recent feasibility study completed by the author in connection with the district heating of a new town to be built in the north of England, has shown that it is economic to provide a heat supply to both the town centre and all the surrounding housing areas extending over 250 acres.

The chief factors that have contributed to the development of district heating are: its general convenience, saving of fuel, and lower heating costs, and as these become more important in the expanding economy of a country so district heating becomes more extensively used. It is the substantially lower cost of district heat compared with other methods of supply that has been the greatest incentive to its use. It is not, however, generally realised how much lower this cost may be: until this is more widely appreciated and exploited the chief economic advantage of district heating will be lost to the majority of heat consumers. Much of the heat used today costs the consumer up to 4s. 6d. for each useful therm received and usually not less than 3s. 0d. when provided by hot water central heating. District heating plants, efficiently designed and operated, can provide useful heat at a cost as low as 1s. 2d. a therm, a more typical charge being 1s. 6d. a therm. The profits made from heat sales of a single undertaking can approach £500,000 annually.

District heating in this country cannot be expected to be as profitable as that abroad unless its future development is planned for the maximum heat supply, so that its cost may be appropriately less. The size of future schemes should, therefore, be increased considerably to gain full advantage of the economies to be made by the greater heat output. The largest thermal-electric district heating scheme operated in this country, at Pimlico, uses an insignificant fraction of the total generating capacity of the power station, and although the heat supply cost is relatively low, it could be appreciably lower if the heat output were fifty times greater, as with some schemes in use on the continent and elsewhere.

There are many factors affecting the economics of a district heat supply, but none is more significant than its ability to meet the largest demands. This first becomes apparent in the development of a supply undertaking, as phase by phase it is extended to meet the increasing demand for heat which progressively reduces its cost until finally it is at a minimum. With larger installations this lower cost becomes effective at the outset, and is steadily reduced as the expanding heat supply necessitates relatively less and less expenditure on plant, fuel, manpower and the transmission network. Advancement in the technology of large scale production of heat has now lowered its cost sufficiently for it to be distributed effectively over wide areas, but only where equally efficient methods are also used in heat transmission and utilisation. For these reasons it is important to ensure that these three factors are fully co-ordinated in the planning of a successful undertaking.

The figures appearing in the Tables and some of the appendices (for example purposes) have been taken at random from the author's records and show no general correlation. They are not necessarily typical of other projects of similar size.

Chapter 2

GENERAL CONSIDERATIONS

The increasing interest now being shown in the use of district heating in this country derives from a greater appreciation of its benefits to productivity and human comfort. This interest needs to be widened by a fuller understanding of its applications, if it is to provide all that is required by industry, commerce and the individual.

The steady progress made in district heating abroad over the last half century, has demonstrated what can be achieved if advantage is taken of the modern techniques available for the development of this form of public utility service. The facilities in this country for the same development are often similar, and by their investigation it will be found to what extent they may be profitably used. But before much progress can be made in this way it seems necessary to dispel, not only the hazy vision focussed on the subject of district heating, but also the apathetic attitude toward its development. Only a full appreciation of the potentialities of district heating can ensure its successful promotion.

To be completely satisfactory, a district heating service should provide sufficient heat when and where required, and at the right price. This implies that the supply should be: ample in quantity at all times for the service required; variable in output so as to meet individual demands; and available at a cost within the economic price structure of the other available methods of supply. Continuity of supply should also be assured, other than under exceptional circumstances. These requirements first make necessary an examination of the conditions under which the service will be called upon to operate, for these will determine the design of the plant itself and, the way it will be installed and used. To obtain the essential information often entails much investigational work, and unless this is done in some detail before decisions are made, unexpected difficulties may arise later, causing embarrassment to those responsible for the project.

One of the first essentials to be considered is the size of the heat load and the distance this has to travel from the central station to the consumer. For this reason the density of the heat load in the area to be served must be assessed to see if it comes within the economic limit of transmission. The siting of the central station and the density and character of the buildings served, therefore, will show whether or not a district heat supply can be provided economically.

Another factor of importance is the nature of the heat demand according to the class of consumer to be served. This may be entirely residential in character, accommodated in houses, maisonettes or flats, but more often than not there is (in addition) a number of commercial buildings and, less frequently, industrial buildings to be served. According to the number of each class of consumer and the proportion of light, medium and heavy industries, will depend the decision as to whether steam or hot water, or a combination of the two, is the best means of heat transmission. The class of consumer served will also affect the load factor which in turn reacts upon the costs of the heat supply.

The method to be used for the control of the heat supply may also be affected to some extent by the class of consumer to be served. If the heat supplier is to assume full control, as may apply when the area to be served is mainly residential, the supply may be restricted to suit average needs and charged at a flat rate. Alternatively, consumers may be given full control, particularly in an area which includes residential as well as commercial and industrial premises. In this case the supply would be available at all times, and priced according to the amount of heat used by each consumer.

If hot water is used as a medium for transmitting the heat to the consumers, its control needs special consideration for satisfactory results. Here again, if the consumers are mainly residential, a simplified form of control may be used to ensure good stability of water pressures and volumes in the supply circuits. If there are commercial and industrial consumers to be supplied, and they have various types of equipment in their buildings, a more comprehensive arrangement of controls is necessary to ensure good regulation of the supply.

The nature of the terrain through which the transmission network is to pass, particularly in regard to the soil itself, the water table and the contours of the land, has a far-reaching effect on the service. Not only may the cost of the network be much influenced by such conditions, but its reliability may also be seriously impaired unless suitable precautions are taken. The routing of the transmission mains through public streets and roadways may require statutory powers and, if these thoroughfares are already congested with other underground services, careful planning and consultations with the statutory supply undertakings concerned will be necessary.

The magnitude of the heat load forms the basis for supply costing and needs to be accurately assessed if it is to give a reliable indication of the economic value of the service to be provided. Over-estimation of the maximum heat demand must increase the annual costs of the supply, and the actual unit cost of the heat when the service is in operation may then be excessive. Experience indicates that schemes (such as for new towns) requiring several years of development sometimes entail certain preliminary estimates of the demand of those areas to be planned in detail later. In such cases it is better for the annual heat requirements to be estimated on the low side.

A heat supply that is entirely under the control of each consumer must, of course, be provided with some means of measuring and charging for the actual quantity consumed. Factors to be considered here are the capital cost, maintenance and administration of whatever means are being considered, and the final choice is generally dependent upon the quantity of heat supplied to the individual consumer. A combination of conventional heat meters and some form of inferential heat measurement is sometimes found to be most economic.

The charge to be made to the consumer for the heat supply, may be assessed in different ways according to the use made of the supply by the class of the consumer. The charge for the duration of the development period over which it is given, must also cover the interest on working capital and profit required in the sale of the heat. The method chosen for reading meters and collecting payments due, will also have some bearing on the charges made and how they are applied. A study of the annual costs of providing the supply, which determines the charges to be imposed during development and on completion, will show the benefit of using a two-part tariff and how the costs for each part should be apportioned.

Selecting the source of the heat to be used requires a close examination of all the relevant factors, since the success of the undertaking largely depends upon the right choice of generating plant. The situation of the area to be served may clearly indicate the use of direct thermal generation as being most appropriate. Other conditions may favour thermal-electric generation and possibly the use of nuclear power if a station were sited conveniently. Refuse disposal also provides a supplementary source of heat that should not be neglected. When indigenous or oil fuels are being considered, the relative merits of each in particular circumstances require careful investigation. Not the least important factor in this comparison may be the proximity of coal fields or oil refineries to the central station.

The economics of a district heating service depend ultimately upon the income from the sale of heat being sufficient to meet the cost of providing the service. To achieve this, a detailed costing of the plant, fuel and electricity supplies, and everything else necessary for current operation, is essential. Initial investigations may indicate that there are alternative ways for the plant to function in order to provide the required service. Only by costing each is it possible to decide on the least expensive. Then it is necessary to compare the result with other methods of providing and using heat, to see if district heating is competitive and determine the extent of any savings to be made by its use. This entails costing the other methods on a comparable basis, i.e. as to the plant needed and its operating cost. When comparing the cost of a district heating service with other methods of heat supply, it is necessary to take into account any further costs that these other methods involve (See Chapter 8). These are not always reflected in the unit cost of their heat supply.

The final appraisal of the merits of a district heating service will not be entirely dependent upon the financial benefits obtained. There are other advantages provided by a piped heat service which cannot be evaluated on a monetary basis with any certainty. Among these is the greater conveniences of such a supply, and its ability to meet the full demand at all times and for all requirements, as shown in Fig. 2.

Much can be learned about the planning requirements of district heating by a study of the operating results of an efficient system. Some of these are given in Appendices A, B and C for the Pimlico District Heating Undertaking, and apply during the course of development.

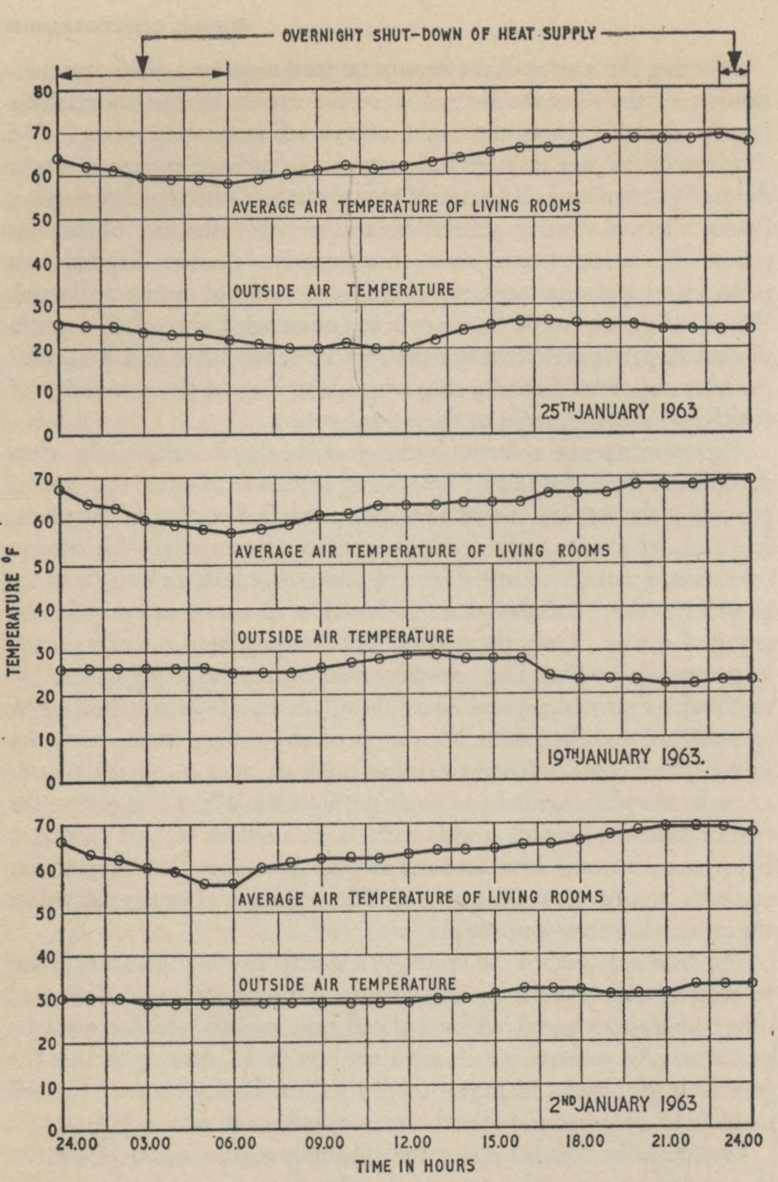

Fig. 2. HOURLY RECORDS OF INTERNAL TEMPERATURES. These were provided by the district heating system at Pimlico during the severe winter of 1962–63. It is significant to note the adequacy of the heat supply when the outside temperature was at or below freezing point. The slow rate of room temperature regain is intentional

Reference is made to these appendices later in connection with different aspects of the subject described in the book. Some more general information about The Undertaking is given in Appendix I.

The chief consideration of a heat service must always be one of economy as determined by the heat-generating and distribution costs. It is, therefore, important for these costs to be carefully computed by adding to the annual expenditure on operation and fuelling the cost from a sinking fund for the amortisation of capital. Dividing this total expenditure by the annual quantity of heat generated and transmitted to consumers will show the unit cost of the heat service and the extent of its economy.

Chapter 3

CONTROL OF HEAT SUPPLY

The successful transmission and distribution of heat to the consumer depends largely upon the method adopted for the control of its supply, for this affects the interests of both supplier and consumer. Thus the supply should not only be used economically, but also be available, preferably, at times and in quantities convenient to the consumer.

Clearly the provision of an unlimited supply is seldom practicable since it would encourage extravagance and wasteful usage, with loss of much of the advantage gained by producing heat at high efficiency in a central station. It is therefore necessary for some restriction to be imposed by the supplier or consumer, such that the heat quantity supplied is reasonably commensurate with the service required.

The heat supply may be provided either under the control of the supplier or the consumer, depending upon the arrangements made for charging for the service. The more positive heating standards expected by the consumer in recent years together with the need for a commensurate charge to be made for the supply, have tended to transfer the control from the supplier to the consumer. The service may then be paid for and used in a way similar to that applying when the heat is provided direct to the premises in the form of electricity or gas.

Whichever way the heat supply is controlled, it is necessary for the quantity to be restricted at times because of changes in the weather, adventitious heat gains, the period of occupancy of the premises, individual preference for warmth, and according to the demands for hot tap water. These needs are difficult to meet by centralised control of the supply without some waste or curtailment of heat which reacts to the disadvantage of both supplier and consumer.

There are examples today of restricted district heating services for dwellings where the supply is provided almost entirely at the discretion of the supplier as regards when and how much heat is available. This simplifies the arrangements necessary for charging the consumer for the heat used. These arrangements allow the charge to be made at a flat rate or fixed price, based on the size of the space heaters installed in the consumer's premises and their period of use, thus affording a means of computing the average amount of heat consumed. To this amount is added the average quantity estimated to be consumed for hot tap water, according to the number of occupants in the building served. The overall total is adjusted periodically for charging purposes as may be found necessary from the current operating cost records.

When the quantity of heat supplied is at the discretion of the supplier (as is necessary when he is responsible for its control), both the maximum heat quantity supplied and the duration of the supply must conform with what is considered by the supplier to be adequate for the needs of the average consumer. This entails programming the length of time of the daily and seasonal space heat supply according to some set pattern, such as 16 hours a day for 30 weeks annually, and to provide enough heat during these periods only when the outside temperature does not fall below some defined minimum.

These arbitrary standards for the heat service (forming necessary impositions in the circumstances), cannot be expected to satisfy all consumers. There are those who would find it more convenient for the supply to continue until say midnight, or even later during Spring, or to be started earlier in the Autumn, so that it may be more in keeping with the weather at those times of the year. It is also not unreasonable for the elderly in particular to be able to have a space temperature above the prescribed maximum, and for this to be provided when the outside temperature is below the prescribed minimum. Charges made for the heat supply when assessed at the flat rate or fixed price cannot be commensurate with the service required by individual consumers, because this must vary according to personal needs. For this reason there has been widespread criticism of heat sold in this way, because it was largely outside the consumers' control and could be available only during specified hours, and only during a particular length of heating season. The fixed charges offered no means of economising, and often bore little relation to the amount of heat actually required.

The advantage of charging by a flat rate is the saving to the supplier made possible by obviating the need to measure the heat quantity supplied to each consumer, thus saving the cost of measuring devices. He is also saved the trouble of making arrangements for their servicing, which includes maintenance and repairs, reading of meters and accountancy. The disadvantage of a flat rate charge is that it necessitates a restricted supply, so that space-heating is not always available at the times and temperatures wanted. There is also considerable waste of heat, since consumers cannot benefit from their individual efforts to economise.

The chief advantage to the supplier in charging by a flat rate is the saving made in capital expenditure for the measuring device, which may amount to many thousands of pounds. The annual cost of operating the system with suitable devices, however, need be no more than without them, because they reduce the amount of heat otherwise supplied. In consequence, if the extra capital investment can be met by the promoter, it may be repaid annually, and according to circumstances, with some interest.

There are many reasons in favour of an unrestricted heat supply in order to provide what has been termed selective heating, so that consumption is governed entirely by the needs of the consumer. The chief advantage is the economic one, but others are of a physiological and sociological nature. All affect consumer satisfaction to some extent.

The effect of giving the consumer full control of the supply, as with a measured service, is to lower the heat demand irrespective of a consumer's specific requirements, because of the saving* made by eliminating the waste that otherwise occurs from the provision of superfluous heat. This reduction in the quantity of heat supplied causes an increase in its unit cost (price per therm), but because of its more economical use the total cost to the consumer (usually residential) is less (See Table 1, cols. 6 and 7). In consequence, part of this and subsequent savings to the consumer can offset the cost of providing some means of measuring the heat supply so that he may further benefit according to his actual requirements. The amount of benefit derived will depend upon how much use the consumer makes of the supply as compared with when it is given under the control of the supplier, as shown in the example in Table 1. It follows that if considerable heat

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* In North-West Germany and in Sweden consumers without meters were using up to 30% more heat than those with meters.

Table I

COST OF HEAT SUPPLY AS AFFECTED BY METERING

I	2	3	4	5	6	7	8
Item	*Method of Control*	*Standard of Heating*		*Estimated Consumption /Dwelling/ an.—Therms average*	*Cost per Therm Pence*	*Cost per Dwelling per annum £*	*Remarks*
		Temperature	*Duration*				
I	By Supplier —unmetered	Full	Full	600	14·4	36	The difference in consumption between Items I & 2 is due to use of incidental space heat gains and avoidance of waste of hot tap water, also shorter duration (I hour). Item I assumed from 6 a.m. to II.30 p.m. Item 2 assumed from 6 a.m. to 10.30 p.m. average. Consumptions include 180 therms for hot water supply.
2	By Consumer —metered	,,	,,	520	14·7	32	
3	By Consumer —metered	,,	¾ Full	480	14·9	30	
4	By Consumer —metered	¾ Full	½ Full	350	16·3	24	
5	By Supplier Compulsory heat (Background)	45°F	Full (Continuous)	280	18·0	2I	

NOTE: The heat demands for Items 2, 3, 4 and 5 assumes no reduction in standard of hot water supply. With supplier control it is necessary to extend duration for the benefit of a minority who stay up late.

wastage can be avoided by its more economical utilisation with a measuring service, its unit cost will be greater. This increased unit cost when combined with a lower overall consumption results in a reduced annual cost, but without loss of adequate temperature.

All consumers benefit with their own control of the supply because, in removing the control from the supplier, there can be an immediate saving in the amount of heat provided, resulting from the effect of adventitious heat and from the more economical supply programme made possible. One example of this is that the daily supply need no longer be given at the full rate for a period longer than necessary for the average consumer. How much further saving is possible for each consumer depends upon his particular habits, such as if he is away at work daily, the time of going to bed, and the level of temperature required.

A measured service provides an incentive for the consumer to benefit from adventitious heat, which is otherwise generally wasted by the opening of windows rather than being used by the closing of heater valves. To get the full benefit from adventitious heat, the measured service should be combined with thermostatic control of the heat supply in the manner referred to on p. 20.

With a measured service it is usual to give industrial and commercial consumers full control of the heat supply, except when this is small, as in the case of residential consumers. In the latter case it is not always practicable to provide a reliable measuring device for both space heating and hot tap water, owing to the prohibitive cost. It is, therefore, sometimes desirable for the hot tap water to be supplied unmeasured and the quantity curtailed by the supplier in a way that can provide for all normal requirements. This may be done by restricting the quantity of hot water provided by the use of individual calorifiers, and by limiting the size of them in each dwelling with regard to both the storage and re-heating capacity according to the amount of accommodation provided.

Rationing the supply of hot tap water for each consumer by the use of individual storage heaters, has been found to be a very effective way of preventing extravagance and wasteful usage. This has been demonstrated by investigations made for a comparison between the quantities consumed when provided from: (a) centralised hot water storage calorifiers, and (b) individual electrical storage heaters. In

Method (b), the quantity consumed was reduced to about one-third of that of Method (a), and although the higher cost of the electrical heating had some bearing on the reduction, the quantity available was found to be adequate for all normal requirements.

When the residential consumer is able to use the heat supply at his own discretion, substantial economies can be made in various ways. One of these results from the modern trend for a larger proportion of dwellings to be unoccupied during the day, and another from the opportunity given to consumers who do not need full heating in order to use lower temperatures than the prescribed standards. Even when heat is desirable, there are always those who, in temporary financial difficulties, are willing to forego some warmth in favour of more compelling bodily comforts! Economising in different ways, as is encouraged with a measured supply, can lead to an appreciably lower cost for a good standard of service with district heating. When this is fully realised by the consumers, it is expected that they will become more generous in their use of heat, with a consequent improvement in the economics of supply.

When the supplier is relieved of the responsibility of control, he is no longer subject to criticism of the adequacy of the supply, as this can then be made more than sufficient for all the needs of the consumer. It is, however, essential for the consumer to be provided with the means of automatically controlling the space temperature, so that this may be maintained constantly at the level preferred, irrespective of changes in the weather and other influences.

To ensure an ample heat supply at all times necessitates the outflow water temperature from the boiler plant being constantly maintained at the maximum. By this means the early morning pre-heating period will also be reduced to a minimum, and that of any later pre-heating required, as when domestic consumers turn on their supply on return from the day's work. Maintaining the flow temperature continuously at the maximum level incurs some increase in the transmission heat losses, but these are not significant enough to affect the overall economy of the heat supply.

The hot water may be circulated through the consumers' installations at the maximum temperature when provided with an on-off form of control. Alternatively, the ingoing water temperature may be automatically modulated by a thermostatically actuated mixing device under the control of the consumer, as is more usual with commercial installations. These methods are illustrated in Chapters 5 and 9.

The facilities now available for the automatic control of temperature in the consumers' premises enable accurate regulation of the supply to be provided for securing optimum economy. If it were not for the progress made in automatic temperature control devices over recent years, it would not be possible for the full benefits of a consumer-controlled supply to be obtained.

The accuracy of the heat control in the consumer's premises can depend upon the method of heat measurement used, as when the two are inter-dependent. When this control is by the inferential method that measures the length of time the full supply is given, and not according to the amount of heat metered, the control provides only a common temperature throughout the building acceptable to the occupants in general. Any control of the heat output of individual heaters will not significantly affect the measured time of the supply and, therefore, its cost.

When the quantity of heat is measured more closely by an inferential method of measurement, based on the water quantity circulated at a controlled temperature differential, or more precisely by a conventional heat meter, the control should be as accurate as possible. This means that the amount of heat supplied to each room should be no more or less than that necessary according to the varying heat gains and losses of that particular room. This can be done best by the use of thermostatic valves on each heater to automatically control the quantity of water circulated, or thermostatic switching of the fans of forced draught convectors for control of the air volume circulated.

The use of thermostatic control valves for individual heaters enables the temperature of the space heated to be automatically maintained at the level selected by the occupants, thus ensuring both economy and comfort. It is of considerable economic advantage to give individuals this means of securing the maximum saving in the consumption of heat, as continuous full heating of a room is seldom required.

A further advantage, which is often overlooked, is that during the Spring and Autumn, and sometimes in the Summer when the weather is unseasonable and temperatures sub-normal, sufficient heat will be provided automatically to ensure a comfortable temperature indoors to suit individual preferences.

Individual automatic control of heaters is a method that has been used for commercial buildings for over 30 years, and is now accepted as also being the ideal method for the induction units of air conditioning systems. This method is also being increasingly used for the heaters of residential hot water systems, because of the less expensive range of thermostatic valves now available.

For the greatest accuracy in heat control, those periods of supply required by the consumer should be regulated by a time switch. By this means the supply programme may be devised so as to turn the heat on and off at specific times and, if necessary, also for specific parts of the building when the whole is not to be occupied at all times. This latter arrangement is desirable for residences in particular, so that the heat supply to bedrooms may be restricted during the daytime to prevent its waste. Further information about time switching for commercial buildings is given in Chapter 6.

Chapter 4

THE HEAT LOAD

Before much can be done about the detailed planning of the scheme, it is necessary to estimate the heat load applicable, and to consider whether this is sufficient to justify its transmission over the distance required. The size of the final load may ultimately differ from that expected initially, depending upon how the area subsequently develops, which may be affected by changes in the nature of the areas to be served. Sometimes new areas are subsequently added to those originally planned. Provision for meeting this belated increase in the load may be anticipated initially by allowing space for the possible extension of the central plant which, by a change in operating conditions, may later be made to deal with the greater heat demand.

Some areas, such as those in which new towns are being built, are developed comparatively slowly, and it may be many years before a given scheme is finally completed. In these circumstances it is necessary to phase the period of development to suit the expected rate of building construction, and to estimate the heat load in stages convenient to the increasing heat demand. In this way it is possible to relate the heat demand for each stage to the cost of meeting it, and so determine the cost of the heat supply progressively. This can vary over fairly wide limits, as is seen in Table 2, until the most favourable cost is finally reached on full development of the scheme.

The information given later about the production and transmission of heat shows how the cost of this to the consumer is substantially reduced by the greater load. It is therefore expedient to consider, whether or not the load can be increased by including in the supply any existing buildings in the vicinity of the area to be developed. In some localities such opportunities exist for extending the supply by serving buildings such as blocks of flats, offices, churches and shops, the heat demand of which can much improve the economics of the supply, especially if this extra load is carried at the outset.

Table 2

DISTRICT HEATING DEVELOPMENT PROGRAMME SHOWING FLUCTUATION IN COST OF HEAT SUPPLY ACCORDING TO VARIATION IN ANNUAL COSTS

Item No.	*District Heating Development Period*	1	2	3	4
1	Number of years in Period	2	3	4	5
2	Maximum Capacity of Plant, Therms/hr.	1,200	3,200	5,200	8,400
3	Fixed Annual Charges £	77,534	170,064	237,876	355,699
4	Variable Annual Charges £	75,980	197,500	290,200	416,500
5	Total Annual Costs £	153,514	367,564	528,076	772,199
6	Heat Demand per annum Therms	2,100,000	5,600,000	8,400,000	12,500,000
7	Cost of heat supply at end of period. Pence/Therm (Item 5÷Item 6)	17·5	16·0	15·1	14·8

NOTE: The annual totals given above apply to the last year of the development period.

The size of the heat load and the distance traversed, when later reviewed on a cost basis, will show if these are economically related to each other. The apportionment of the costs of heat production and transmission must, therefore, eventually be ascertained to know how these compare and to decide if they are appropriate. This can be done in the way shown in Table 6 of Chapter 8.

With this information available, it can be seen to what extent the cost of heat production is increased by its transmission from the central station to the consumer. The actual incremental cost permissible will depend to some extent upon the size of the heat load, as the greater this is the smaller will be the proportionate cost of its production and, in consequence, the greater will be the margin available for its transmission.

In general, it may be assumed that the transmission capital cost would be in the region of 50-100% of that of generation on full development of the scheme. The actual percentage cost, however, depends upon the method of heat production used and also the nature of the region served, as this may entail a more costly transmission service especially if it is a built up area.

The suitability of the heat load for a district service must depend largely upon the kind of service to be provided. If the load is highly concentrated, with a good diversity factor and low transmission losses, as in some of the new towns where the town centre is planned as one compact unit, the circumstances are ideal for district heating. Alternatively, the areas to be served may be dispersed over country that is difficult to traverse with supply mains because of obstructions of different kinds, or simply because of the distance to be covered. Such conditions raise doubts about the suitability of a district heat supply.

The heat requirements of industrial and commercial consumers may be estimated within reasonably close limits according to the particular needs of each consumer, as these should conform to definite standards of heat quantity and supply duration. The requirements of the domestic consumer, however, may vary considerably, depending to some extent upon how the supply is to be controlled. It is necessary to decide about this control before attempting to estimate the heat load, as mentioned in Chapter 3.

Investigations made into the suitability of applying district heating for various projects have shown a wide diversity in the conditions under which the schemes would be installed and have to operate. The specific nature of the conditions applicable often becomes apparent only after a careful study of all the circumstances involved, indicating the need for a thorough examination of the different factors applicable to a particular scheme.

There is not likely to be much variation in the demand to meet structural heat losses of the average building today, as these usually comply with recognised standards of thermal insulation and which are to some extent obligatory for new industrial buildings. But the standard of air temperature and hot tap water maintained with a consumer controlled supply may differ considerably between one dwelling and another, depending upon the importance attached to comfort and hygiene, and on how much the consumer is willing to spend on this aspect of the household expenditure. These are the circumstances which mainly affect the annual heat demand.

When estimating the maximum hourly heat demand, it is necessary to allow for a full standard of the service provided, on the assumption that this may be required by any consumer. For space heating this can be approximated without much difficulty by the use of a factor varying from 3 to 5 Btu/h/ft^3 of space heated, according to the type of building concerned. But for hot tap water what is a full standard for some is inadequate or more than enough for others, and there is always the wastage factor to be covered. In consequence, it is desirable with an unmetered supply to provide a method of hot water supply that will meet all normal requirements and, at the same time, prevent waste, as described in Chapter 3, page 18.

The recognised standards of thermal insulation can be improved when it can be shown that this is economically justified. The use of double and triple glazing, for example, should be given careful consideration now that its cost is becoming less owing to improved manufacturing techniques, because of the construction of higher buildings, and the tendency for the price of heat to rise. Calculations of the savings in the cost of fuel and of the heating system itself by use of multiple glazing, will show if an adequate return on the capital investment can be assured.

The recommended standards for space air temperatures and hot tap water as prescribed in official publications and adjusted as necessary to comply with the requirements of local authorities, should be used in the estimation of the maximum hourly demand. Any lowering of these standards, will, for the reasons given, reduce the annual heat demand and increase the unit cost of the supply.

The total calculated maximum hourly demand should be adjusted to allow for the diversity factor, applied to the heat load according to the classes of consumer served and found by dividing the expected peak load by the total load. The period during which the maximum heat demands for each class of consumer coincide will show what the actual peak load is likely to be at any one time, and to know this it is necessary to compare the demands of each class of consumer when these are at their maximum. It will be found that when the demand of one class of consumer is at a maximum, that of another is not, and that the full demands of all consumers do not occur simultaneously.

A careful analysis of the heat demands of industrial, commercial and domestic consumers should be made therefore, according to the estimated requirements of each throughout the day to show when the maximum demand occurs, and its size. In this way it is possible to take full advantage of the diversity in demand and thereby often effect an appreciable reduction in the size of the boiler plant and its cost. The amount of diversity varies to some extent with each scheme, and under favourable conditions can produce a factor as low as 0·75, indicating that the peak load represents only 75% of the total load.

The building density applying to the development of land can have a considerable effect on the load, and for residential areas may vary according to locality from about 15 dwellings per acre to 80 or more per acre in large towns; and with an average occupancy of 3·5 persons per dwelling, the corresponding number of persons per acre would be 52 and 280. Because of a preponderance of single- and two-room dwellings in a particular development, the average number of persons per dwelling may not be more than 2·5, and at this density the maximum hourly heat demand per person would be in the region of 0·04 therms for hot tap water, and 0·06 therms for space heating. It is seen, therefore, that there would be some divergence in heat demand for a given area on account of both the density of buildings and occupancy, particulars of which should be known in making an assessment of heat requirements.

To complete the heat load figures, losses in transmission and also from heat storage, if used, must be included when it is known what kind of transmssion network is to be used. This latter will depend upon whether steam or whether high or low temperature water is used, or a combination of the three; upon the distance covered by the mains and what proportion is under and over ground. The mains losses of a well designed and insulated network are small, the percentage loss varying inversely as the amount of heat supplied. When a single pair of low temperature hot water underground mains is used, the heat loss should not exceed 5% of the load in Winter and about 12% in Summer, for a medium size system on full development (See Appendix A, Item 24).

Much investigatory work has been undertaken in connection with heat losses under conditions closely approximating to those occurring during normal operation. The 'Rate of Cooling' method of testing, with results verified by a Heat Loss Meter, has shown that the losses are generally small compared with the heat carrying capacity of the system. In the case of a hot water heat accumulator of medium storage capacity, the hourly loss at normal working temperature would be of the order of 0·1% of its average heat capacity. The hourly loss per

100 ft run of hot water underground mains could vary between 0·020% and 0·035% of their heat carrying capacity according to the diameter of the pipes and how they are installed.

Appendix C gives the results of heat loss tests carried out on underground mains in conduits and the thermal conductivity figures may be used for calculating transmission losses of a system installed under similar conditions. The inner surface temperature of the insulation given in Item 11 will be equal to the water temperature in the pipe for all practical purposes. The pipes were covered with 1½ in thick preformed cork.

In estimating the annual heat demand, which determines the load factor obtainable and the unit cost of the heat, a careful examination is necessary of the conditions under which the service is likely to function throughout the year. The occupancy period of the various buildings supplied, and therefore the duration of the heat supply, is a significant factor. This again varies widely according to the class of building served, as for example, that of industrial premises where single, double or continuous shift work may apply. The duration of the supply for commercial buildings, should also be estimated according to the kind of building served. Hotels, hospitals, police and fire stations, are occupied for longer each day than offices, shops and municipal buildings, which in turn, are longer occupied than schools, theatres and public houses.

The occupancy period of dwellings is difficult to ascertain closely, because it cannot be predicted what proportion of consumers will be away at work each day, when little or no heat would be required. This proportion, in medium income group housing estates, can amount to as much as 50%. The standards of heating actually attained in dwellings, unlike that in commercial and industrial buildings, will therefore vary appreciably, according to the habits of individual consumers, and so affect the annual heat demand. This is normally in the region of 600 therms per annum for an average size of semi-detached dwelling where the supply is under the control of the supplier, giving an annual load factor of about 30%. Under especially good conditions the load factor can be as high as 50%, the actual percentage obtained depending upon a number of factors, including: the facilities provided for measurement of the quantity of heat supplied for charging purposes, and upon the means adopted to prevent the waste of hot tap water when this is not included in the measurement.

The annual heat demand will also be affected by adventitious heat gains, especially when these are fully utilised by thermostatic control of the heat supply. These gains from the consumption of electricity and gas, from solar radiation and from occupancy, have been estimated to amount to 160 therms during the heating season for blocks of flats in Southern England each flat being occupied on average by four persons (See Appendix B).

It is important to assess the heat demands carefully, so that the estimated cost of the heat supply shall be as accurate as possible. The maximum hourly heat demand, by indicating the capacity of the plant required, will govern its capital cost and amortisation, and represent the great part of the standing of fixed supply charge applicable. The annual heat demand, by indicating the fuel, electricity and other costs of operating the service, determines the unit cost charge applicable for the heat supply. Because of this it is prudent to under- rather than over-estimate this demand, so that the cost may be slightly inflated to cover contingencies. Any subsequent increase in the demand will tend to lower the cost of the supply and vice versa.

It is unnecessary to be precise in estimating the annual heat demand, and indeed, precision is not always possible because the necessary detail is sometimes not available during such investigations. On the supposition that the demand can be estimated within ±10% of the actual demand, the cost of the heat supply should not vary by more than 3d. per therm.

Estimation of the annual heat demand must necessarily be somewhat of an empirical nature because, being mainly dependent on predictions, it cannot be based on any very sound theoretical calculations. As district heat becomes more widely used and more operating data becomes available, the task will be simplified. Until then it is necessary to compute requirements from a knowledge of present records and of the consumer's general habits as may be disclosed from a study of the present day regime.

The requirements of industrial consumers can often be ascertained within reasonably close limits because, as in the case of factories, the processes undertaken will usually follow a set pattern for most of the time and may therefore be pre-determined without much error. The supply to commercial buildings will also follow a definite routine, according to the administrative programme of each organisation. It is the domestic consumer who creates uncertainty about the annual heat demand, because of the many variables that can affect consumption. These may cause considerable deviation from the maximum, as is to be expected when the needs of each household are dependent upon its particular mode of living. Until more is known about load duration curves for district heating systems as derived from operational records, an indication of the demand may be obtained by using factors of heat utilisation to represent the consumption in therms per dwellings per day.

The factors applicable with supplier heat control, after careful investigation of the working of a particular system providing a full

Table 3

SUMMARY OF ESTIMATED MAXIMUM HOURLY HEAT DEMANDS IN THERMS

	Development Period	*Dwellings*	*Commercial and Industrial Buildings*	*Total Demand Therms*
Space and Process Heating	Phase 1	420	320	740
	,, 2	830	620	1,450
	,, 3	480	690	1,170
	,, 4	960	950	1,910
	Total Space and Process Heating Demand = 5,270			
Hot Water Supply	Phase 1	210	120	330
	,, 2	420	240	660
	,, 3	240	270	510
	,, 4	480	290	770
	Total Hot Water Supply Demand = 2,270			

Total Space Heating, Hot Water & Process Demand = 7,540
Total demand with allowance for diversity, say 0·8 = 6,030
Total station load including mains losses, say 5% = 6,330

Table 4

SUMMARY OF ESTIMATED ANNUAL HEAT DEMANDS IN THERMS

	Development Period	*Dwellings*	*Commercial and Industrial Buildings*	*Total Demand Therms*
Space and Process Heating	Phase 1	873,000	429,600	1,302,600
	,, 2	1,748,000	848,300	2,596,300
	,, 3	1,017,000	953,000	1,970,000
	,, 4	1,673,000	665,000	2,338,000
	Total Space and Process Heating Demand = 8,206,900			
Hot Water Supply	Phase 1	270,900	128,600	399,500
	,, 2	541,000	259,820	800,820
	,, 3	315,000	288,140	603,140
	,, 4	519,000	427,900	946,900
	Total Hot Water Supply Demand = 2,750,360			

Total Space Heating, Hot Water & Process Demand = 10,957,260
Total demand with allowance for adventitious heat gains, say 10%* of space heating demand = 10,150,000
Total station load including mains losses, say 8%† = 10,962,000

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*Full 10% applicable only with automatic temperature control of individual space heaters.
†To cover average loss during winter and summer.

standard of heating amounted daily to 1·8 therms for space heating, 0·45 therms for hot tap water, and 0·25 therms for towel rails and linen cupboard coils for each dwelling. (See Appendix A, Items 38 and 39). The hot water consumption per person per day was 20 gallons. With this information available, adjustment of the factors can be made if, for example, linen cupboard coils are not provided, or the allowance of hot water is restricted to some figure below 20 gallons. It is also necessary to allow for the diversity in demand as between one dwelling and another, if the supply is consumer-controlled, and this may reduce the annual total by as much as 20%.

The metered analysis of the heat utilisation of the particular system investigated showed that of the total annual heat supplied: space heating accounted for 60%; hot tap water for 25%; and heating, for towel rails and linen cupboards 15%.

Tables 3 and 4 show examples of how the heat demands may be summarised for all classes of consumer according to the requirements for space heating, hot tap water and other services.

Chapter 5

TRANSMISSION NETWORK

The economy of heat transmission will be much influenced by the size of the load in the same way as is the production of heat. The bigger the load therefore, the less will be the relative cost of transmitting it. This is not only because the size of the mains becomes proportionately less as their heat carrying capacity increases reducing their overall cost, but because the percentage of heat lost in transmission is also reduced. This becomes more readily apparent when considering the relative economy of hot water transmission mains later in this chapter.

To ascertain the best way to transmit heat economically and reliably over a distance of many miles, as is required for a district heating service, it is necessary to consider the alternative methods available, and to apply them to the particular circumstances of any given area in order to find out which is the more appropriate method. When the heat source is some distance away from the area of distribution, it may, for instance, be more economic to transmit the heat to one or more sub-stations conveniently situated to the centre of the load. By this means better facilities can often be provided for extending the circuitry as the project develops, and also for heat storage if required.

It is essential to employ an economic heat transmission system. This implies that not only must the constructional work involved in routing the mains and the heat lost in transmission be kept at a minimum, together with that of the motive power necessary to move the heat over the required distance, but the amount of subsequent maintenance work must also be minimised. The functional performance of the network must therefore be influenced by its capital cost, as upon this will depend how effective will be the transmission services, and careful correlation of these two factors necessarily becomes implicit in its design.

It is not always possible to achieve the ideal design, because of cost limitations, and in consequence a compromise must be sought that will ensure sufficiently good safeguards for an efficient, reliable and durable service. Unless such safeguards are provided, an otherwise efficient heat service can be seriously impaired. For this reason, careful consideration needs to be given to several factors such as: the kind of transmission media; operating pressures and temperatures; the type and thickness of pipe insulation; and, the number and type of pipe fittings, supports, anchors, guides and expansion devices. Equally important is the protection to be afforded to underground mains, such as by concrete conduits, or by one of the alternative methods using preformed pipe casings, aerated concrete or loose fill insulants and moisture repellents. According to the provisions made in regard to all these features will depend how far the heat can be transmitted from the central station to the consumer without making its cost prohibitive.

It will be seen on reference to Chapter 8 concerning costs how the expense of transmitting the heat may be added to that of its production so that the overall cost may be appropriate. For every foot of distance the mains are extended from the central station there will be a corresponding fractional increase in the cost of the delivered heat supply until this cost reaches the economic maximum and determines the limit of extension. Because of this restriction, a preliminary design of the transmission system can be costed for comparison with recognised costs of heat production, to see if the two are compatible and justify proceeding with a more detailed investigation.

Amongst the alternative design methods to be considered, one of the most important is the transmitting media to be used, which may be steam or, high, medium or low temperature hot water. To meet the need of some industrial consumers for process work, a supply of steam is necessary, which initially, may be in the region of 250 lb/in^2 and 600°F. This might be provided economically from the central station if the steam load represents a fair proportion of the total heat demand, and if it can also be used conveniently at sub-stations for the further transmission of heat by hot water to commercial and domestic consumers. When the industrial steam load is known to be light and variable, a cheaper supply may be possible by the use of individual steam generators in those factories requiring a supply, thus dispensing with steam for heat transmission altogether.

The use of steam as a transmitting medium provides certain advantages for specific purposes which cannot be claimed for hot water. One of the chief of these is its rapid response to demands for heat as a result of its higher rate of travel and higher heat content per unit of weight. These features make steam more suitable for industrial use when demands are often widely variable in time and quantity which permits of little delay in its supply. There are also many processes carried out by plant designed expressly for steam consumption only, although others will function equally well with high temperature water.

There is little difference in the capital cost of providing a steam and hot water service, but because of the latter's better reliability, maintenance costs are reduced and the overall costs are less. For this and other reasons to follow, it is now generally accepted that hot water is preferable for district heating when steam is not required by the consumers.

Hot water is regarded as superior to steam for heat transmission to public and residential buildings, owing to its greater flexibility and reliability, and because of its higher overall efficiency. The actual water temperatures used have a significant effect on the economics of the system and should be selected accordingly. The aim in general should be to use mains of a size commensurate with a medium flow temperature, such as 250°F, and a temperature differential of about 100°F, as this range is usually more economic than either high temperatures such as 330-230°F or low temperatures of 200-160°F.

High temperature water is most advantageous for the larger scheme when transmission distances are appreciable, and it can be used at its circulatory temperatures directly in space heaters, and when artificial pressurisation is unnecessary. It may also be used when a supply of low pressure steam is required by some consumers, by the installation of local generators. High temperature water may be of little or no benefit for a less extensive service and when used mainly for commercial and domestic consumers. Comparisons of the cost of high and medium temperature systems can show that the latter is cheaper, because the more costly equipment required for high temperatures can be eliminated. The lower mean temperatures, however, could affect the cost of the consumer's installations in industrial buildings, because of the larger heaters required.

The amount of circulating head required for the quantity of water

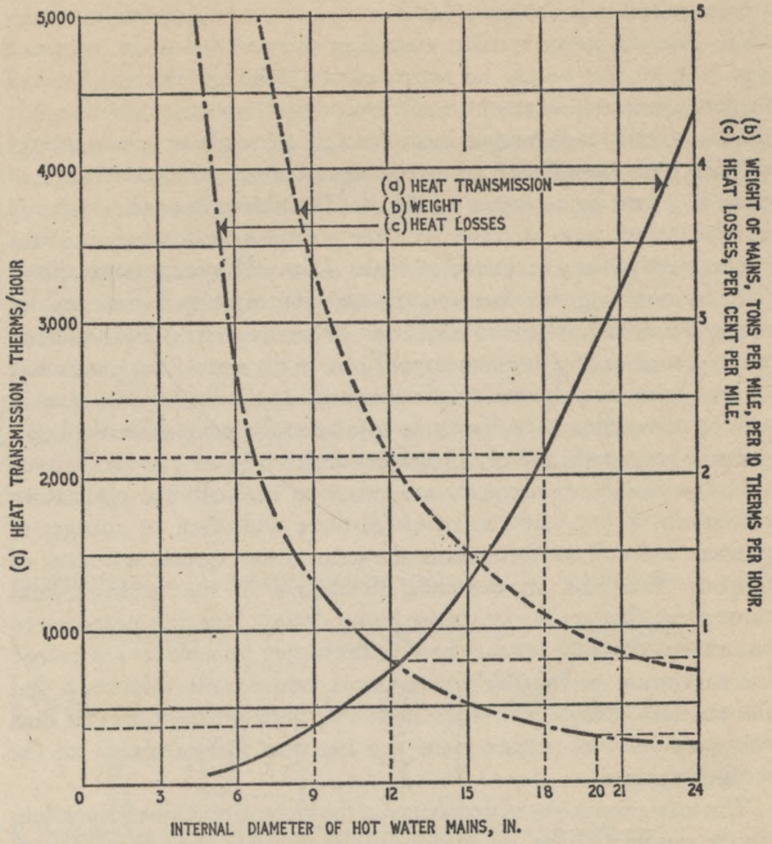


Fig. 3. *RELATIVE ECONOMY OF HOT WATER TRANSMISSION MAINS. Length of flow and return* = 1 *mile. Pressure drop* = 5 *in per* 100 *ft. Temperature drop:* 220°F − 120°F = 100°F. *Insulation thickness* = 2 *in. Conductivity of insulation* = 0·323 *Btu/hr/ft²/°F/in.*

necessary under the desired temperature conditions, depends upon: the size of the system; the limitations of commercial pump capacities; and the relative costs of pumping, and of the mains themselves. In this latter respect it will be found that there is an economic minimum size of mains below which any advantage gained by a saving in their cost is nullified by a disproportionate rise in pumping costs. For the smaller system, where the transmission distance is no more than a mile or two, a pressure loss in the region of 10 in w.g. per 100 ft of travel is permissible. For the larger system, extending over several miles, a loss of 5 in w.g. or less would be appropriate. Although this smaller loss might appear to indicate the need for unduly large mains, the fact that the load carried is that much more for a more extensive system, brings the carrying capacity of the mains into a more economic range of sizes, as is seen by reference to Fig. 3. This shows how the economy of heat transmission increases with the greater heat demand, as in the example given for 9 in dia and 18 in dia mains. This comparison shows that, by doubling the diameter, the carrying capacity is increased by nearly 6 times that of the smaller size. The increase is 66 times as much when comparing a 4 in dia main with a 20 in dia main. The percentage of heat losses also diminishes progressively as the load increases, as is seen by comparing 12 in dia mains with 20 in dia mains when the losses per mile are 0·77% and 0·32% respectively.

Unless suitable precautions are taken to maintain the circulatory conditions of hot water as required, there will often be changes of pressure and volume throughout the transmission system as a result of frequent variations in demands, extensions of the network, and subsequent changes in circulating pump duties. It is thus necessary to ensure that the total pressure head at the supply points does not exceed the maximum permissible for radiators, and equally important that the volumes at these points are correlated with demands, so that each consumer receives neither more nor less than that necessary for the service required.

The total pressure head necessary for the water circulation, depending on the distance of the building most remote from the central station, results in the production of excessive pressure at intermediate service points. The effect of this higher pressure may be reduced by the use of hand regulating valves, but not to within very close limits of accuracy, and they will need further adjustment as the scheme develops. This becomes a tedious and time consuming job for an extensive installation.

The pressures and volumes of the water in transmission, therefore, need to be controlled automatically for these to be stabilised correctly and at all times provide the right conditions for the consumers' installations. When the characteristics of these installations are known at the time the transmission network is being designed, the requirements may be simplified; but more often than not the extent and the details of such installations are not known until later. This makes it necessary to ensure that the pressure and volume control is fully co-ordinated at the outset.

Figs. 4 and 5 show two methods of providing equalised flow conditions for commercial and industrial consumers. Other methods include the use of heat exchangers for space heat supplies, and also for hot tap water, when they may be of the non-storage type as is seen in Fig. 20.

The experience gained with continental district heating systems has shown the advantages of a close regulation of water pressure and volumes in the transmission mains. This has resulted in the development and production of a wide range of controllers for pressure, volume and temperature in order to secure the right operating conditions both during development and on completion of the system. The controllers may serve a group of consumers or alternatively, when convenient, a differential pressure controller may be provided in the

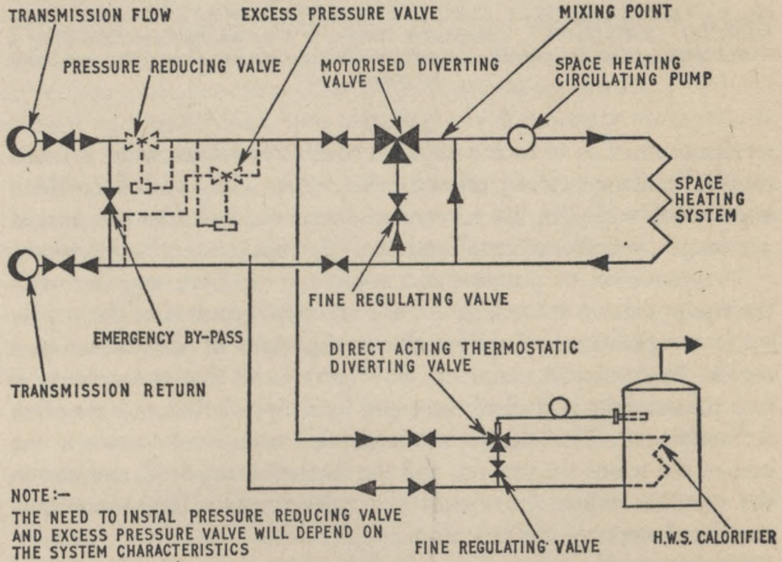


Fig. 4. TYPICAL SERVICE CONNECTIONS TO INDUSTRIAL AND COMMERCIAL CONSUMERS. Temperature modulation is by diverting valve to ensure equalised flow conditions in the mains. Pressure controllers may also be necessary to safeguard radiators

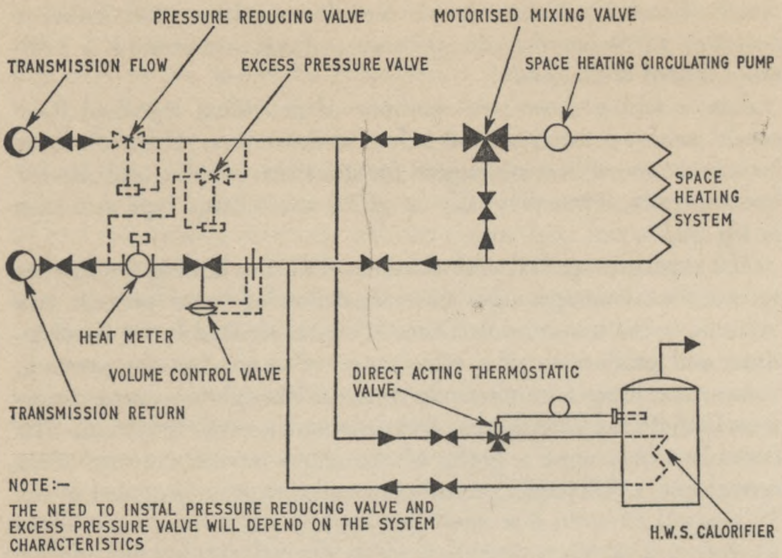


Fig. 5. TYPICAL SERVICE CONNECTIONS TO INDUSTRIAL AND COMMERCIAL CONSUMERS. Temperature modulation is by mixing valve necessitating a volume controller and also controllers for pressure when this can exceed maximum permissible for radiators

service connection to each consumer, to ensure that the water volume supplied is always closely related to his needs. This controller, which is provided with ½ in dia screwed connections, and does not exceed 4 in length, is simple to install and needs the minimum of maintenance.

The provision of pressure and volume controllers, together with the equipment now available for the automatic control of the supply water temperatures, simplifies the arrangement of the transmission mains. Transmission mains can now provide all that is necessary, as two pipe circuits instead of three and four pipe circuits as were often formerly used. This enables a considerable saving to be made in the cost of the mains themselves, and the insulation required, and also in the conduits when the mains are underground. This more than justifies the cost of the control equipment.

The size of the mains, although dependent on the maximum load carried, may ultimately be influenced by how the scheme develops, and thus how the circulating pumps are to be arranged in regard to the number and duties of each, to give the best efficiency. It is usually necessary, with district heating service schemes, to allow for the requirements at each stage as well as after complete development. The operational characteristics of the pumps, should therefore, when used singly and in parallel, and with impeller changes, match as near as possible the varying water pressure and volume conditions corresponding to the heat load during each stage of development. It is sometimes possible to do this more effectively by sizing some sections of the mains to suit the final pressure characteristics of the pumps rather than vice versa. The use of variable speed pumps should also be considered.

The size of the mains necessary for a particular project may be calculated in the usual way, but their arrangement in the central station should include provision for metering the supply accurately, and without complications in handling the fluctuating heat demand. Because of the wide variation in demand during Winter and Summer, the corresponding heat quantities are often outside the meters' normal operating range. This necessitates separate meters for the two periods of the year. When the meters are connected to the supplies to Winter and Summer pumps respectively for alternating operation, the change over from one meter to another is synchronised automatically with the change in seasonal load, thus avoiding any dependence upon the use of hand valves at the time of the change over.

Effective disposition of the mains relative to the area served can do much to avoid possible interruptions to the heat supply, due to future extensions etc., and hence reduce the cost entailed for their provision. When the mains radiate in different directions from a generating- or sub-station that is centrally sited, separate circuits can be used for a number of areas so that each circuit may be independently isolated when necessary. If this arrangement is not possible, such as when a station is situated at one side of the area served, it is necessary for each main branch circuit, and also the secondary circuits (if the network is extensive) to have isolating valves.

The routing of the mains, and their levels relative to new and existing buildings, public highways and private roads, railways, canals and bridges may sometimes appear as a formidable task until, by the gradual process of elimination, a clear way eventually emerges past the various obstacles. In some cases it may be necessary to procure

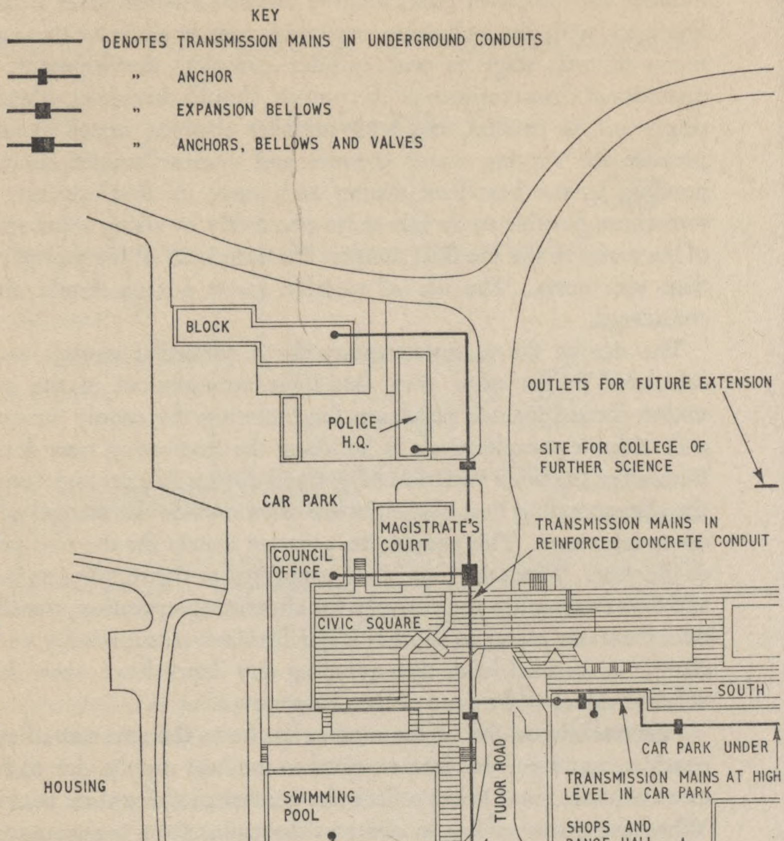
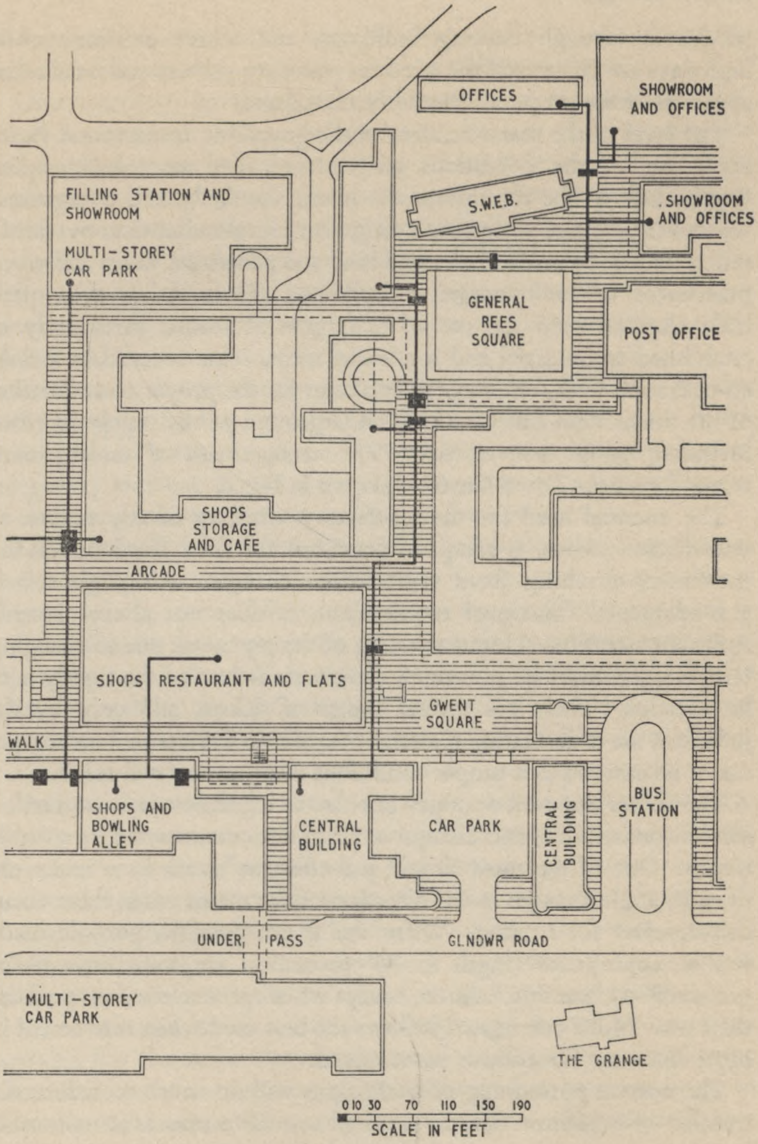


Fig. 6. THE TRANSMISSION SYSTEM OF THE CWMBRAN NEW TOWN CENTRE. *The route is shown of the underground mains to be later extended, and also the positions of chambers for valves and expansion bellows*


OFFICES
SHOWROOM AND OFFICES
FILLING STATION AND SHOWROOM
MULTI-STOREY CAR PARK
S.W.E.B.
SHOWROOM AND OFFICES
GENERAL REES SQUARE
POST OFFICE
SHOPS STORAGE AND CAFE
ARCADE
SHOPS RESTAURANT AND FLATS
GWENT SQUARE
WALK
SHOPS AND BOWLING ALLEY
CENTRAL BUILDING
CAR PARK
CENTRAL BUILDING
BUS STATION
UNDER PASS
GLNDWR ROAD
MULTI-STOREY CAR PARK
THE GRANGE
0 10 30 70 110 150 190
SCALE IN FEET

wayleaves through existing buildings, and where existing public highways are concerned the need for statutory powers and ministerial approval of the proposals should be considered.

The level of the mains relative to the ground to be traversed varies according to the conditions encountered, and to reduce capital expenditure to the minimum, the mains should be run overground whenever possible, preferably near ground level rather than overhead, unless use can be made of elevated road and pedestrian ways, and when practicable, of the basements to buildings. There is, however, often little alternative to the use of underground mains, particularly in established commercial and residential areas. This necessitates a close co-operation with statutory undertakings for the proper co-ordination of the mains with other existing underground public supply services, including public conveniences. The arrangement of underground mains for a new Town Centre is shown in Fig. 6.

The essential need for the satisfactory working of any system of transmission mains, is adequate provision for their freedom for the movement resulting from temperature changes. Although this is a fundamental functional requirement, it does not always receive sufficient attention. Undue stressing of the pipework due to changing temperature, must be prevented if ultimate failure of the supply is to be avoided. There are several causes of failure, and only by the judicious use of insulating materials, expansion devices and anchorages can it be ensured that proper conditions of operation will result.

The forces imposed on pipework due to expansion and contraction can be considerable, and disruptive when not counteracted by suitable means. One of the most simple and effective means is to make use of right-angle changes in the direction of the mains when these occur conveniently for routing. When this is not possible, purpose made sets of appropriate length in 'U' formation are sometimes to be preferred to expansion bellows, except when space restrictions prohibit their use. Multi-corrugated bellows are best used when movement in more than one direction is encountered.

The correct positioning of anchorages will do much to reduce the number of expansion devices required to relieve stresses at vulnerable points in the system, and when the anchorages are situated at intersections in the mains, there is no danger of welds or fittings at these points being adversely affected. The structure for the anchorage must be substantial enough for the heavy loading to be imposed and securely embedded in concrete, or fixed to main building structures.

Other necessary provisions, which sometimes receive scant attention, are those for mains venting and drainage. Because of the greater size and length necessary of district heating mains, there must be adequate facilities for these purposes. The accumulation of air at the high points of the system can be the cause of much trouble unless it can be speedily removed, as can also be the accumulation of sludge at the lower levels. The provision of isolating valves and ample drainage points is also necessary to facilitate the testing of sections of the pipework as completed, and for future extensions.

Satisfactory conditions for the welding of the pipework require sufficient space for the welder to properly do his work. As it is not practicable to rotate the pipe for every butt weld, the provision of temporary welding bays at suitable points en route is necessary so as to facilitate access for bottom welding at final connections.

Much depends upon the workmanship for this part of the installation, and unless rigid standards are employed in its execution, there is always the risk of subsequent failures of the heat supply (See Appendices G and H). For the same reason it is important for completed sections of pipework to be thoroughly tested, both by appropriate hydraulic pressures, and by the application of heat at the maximum working temperature. Not before the test conditions have been fulfilled is it possible for insulation to be applied and the final cover made.

Defects in pipework do not always appear during hydraulic testing, because the maximum stresses occur only at working temperatures. Heat tests must therefore be made, and these are sometimes required before the boiler plant is ready for service when mains are underground, to enable roadways to be completed. This calls for the use of a mobile heating and pumping unit to produce a circulation of hot water in positions convenient to the sections of mains to be heat tested.

Mains that are to be installed underground should be assured a working life of not less than 60 years and considerably more in some circumstances, if a repetition of the failures that have occurred in several installations in this country is to be avoided. The cause of these failures is well known and understood.

Design and workmanship standards must be high if mains are not to leak and corrode in consequence of the pressures and temperatures

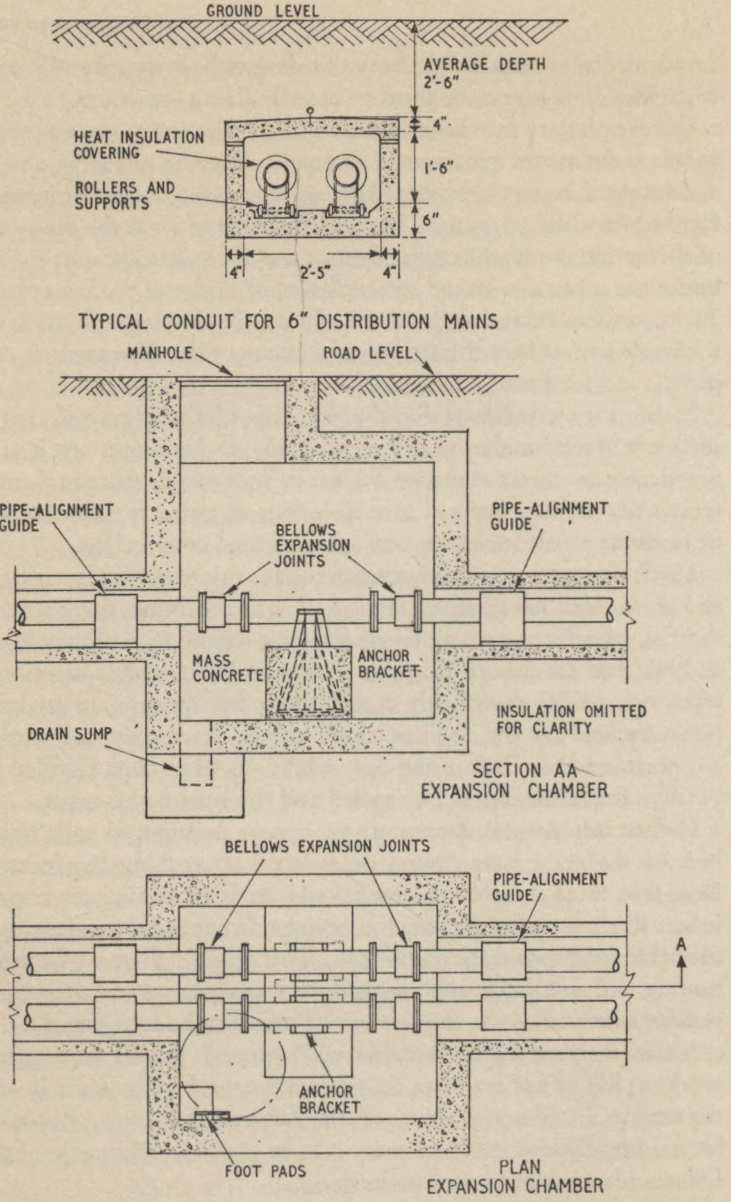


Fig. 7. TYPICAL UNDERGROUND REINFORCED CONCRETE EXPANSION CHAMBER. The chamber may also accommodate isolating, drainage and air valves. A conduit for 6 in dia mains is also shown

applied. This will obviate the need for access for repairs and maintenance other than for valves, expansion bellows, vent and drainage cocks. It is also essential to afford the mains ample protection from the effects of surface and subterranean water.

The life of underground mains depends upon how effective are the measures to avoid the corrosion of the steelwork that results from moisture penetration. One small leak in the mains that continues undetected for some time can eventually cause much damage. It is of little use, however, to ensure by sound design and workmanship that leakage of the mains does not occur if water is allowed to penetrate to the pipework from the soil through lack of adequate protection.

Most of the troubles experienced by the corrosion of underground pipework have been caused not by pipework leakage, but through the use of unsuitable methods to protect the pipes from the effects of ground surface and subterranean water. The effectiveness of any method must depend upon the condition of the ground, and when this is known to become saturated with water a strong moisture barrier must be provided between it and the pipes in the form of a conduit. Untreated brickwork, for example, cannot be used for this purpose, despite the attempts of the uninformed to prove otherwise by costly practical demonstrations of its unsuitability!

The form of protection and heat insulation used must therefore depend upon the nature of the soil and the water table, and where these are unfavourable it is desirable for the mains to be installed in reinforced water-proofed concrete conduit. Under more favourable conditions, methods that rely for thermal and moisture protection upon the use of such materials as aerated concrete, loose mineral fills and pre-formed casings, may be considered and, if used, should be applied with extreme caution if they are to be satisfactory.

The effectiveness of the different methods of insulation, especially those using prefabricated sheathed pipes for laying directly in the ground, will depend very much upon the site workmanship conforming rigidly to the specified requirements. Unless constant and careful supervision is given as the work progresses, supposedly minor defects in assembly can later develop into major causes of failure. It is important, therefore, when considering a prefabricated method of construction for this to ensure that the casing can be air pressure tested after lengths are joined together on site. It is also desirable to provide a permanent monitoring system for casing leakage detection.

Fig. 7 shows the arrangement of an R.C. Conduit and expansion chamber with its associated pipework, which is typical of many in use today.

Accessible underground chambers of the kind shown in Fig. 7 are necessary at a number of points in the transmission network for operating isolating, vent and drain valves, and for the maintenance of expansion bellows. The chambers also serve as collecting points for any water that may accumulate over the years, and are provided with sumps for its easy removal by a mobile pumping unit.

The cost of pipes, fixings, insulation and concrete conduits will depend to some extent upon the ground conditions encountered, as these will affect the amount of work for excavation, shoring, the removal of water, and any re-surfacing of roadways required. With the exception of the last three items, the range of costs applicable per foot run extends from about £5 for 2×2 in dia pipes to £10 for 2×8 in dia pipes, and extra cost will be entailed for valves and expansion chambers.

Chapter 6

THE CONSUMER'S INSTALLATION

The best use of a district heat supply in the consumer's premises necessitates its distribution in a way that will ensure a close balance of supply and demand in order to effect the greatest heat economy, and at the same time provide the right conditions for process work and, the comfort and convenience of the occupants themselves in the buildings served.

The comfort of consumers can be assured if the supply is not used wastefully, because the comparatively low cost of district heat enables the temperature of the whole building to be maintained at an adequate level. This cannot be said of many heating systems in use today in residential buildings, because the higher price of the heat enables only partial or background warmth to be provided except, perhaps, in the living room.

Recent surveys of the methods for heat utilisation in buildings indicate that great economies can be effected by the use of the latest techniques in this field. It is no longer practicable to provide a copious heat supply to the consumer in the hope that it will be efficaciously used unless the means are provided to this end. This is particularly significant with district heating systems using exhaust heat from power stations, which many consumers believe to be waste heat and, therefore, need not be conserved, since it is a superfluous by-product in the generation of power.

When district heat is provided by direct thermal generation, the economics of supply are even more dependent upon its efficient employment at the points of utilisation, and this can be ensured only if the supply is distributed in such a way that the specific uses of modern appliances and controls are exploited to their fullest extent.

The increasing price of fuels in recent years has emphasised the need for economy in their use, and this has led to the development and production of a variety of relatively inexpensive devices to automatically control the heat supply according to the consumer's needs. Previously it was often customary to depend upon hand regulation of the supply, and although this method could be fairly satisfactory when diligently applied, more often than not it was neglected, thus causing heat wastage, inferior process work and uncomfortable working and living conditions for those concerned with its use.

The rising cost of fuel has also given impetus to the adoption of methods of heat usage showing the greatest economy, convenience and cleanliness. The trend now is towards dispensing with numerous separately fuelled heating appliances, by using one central appliance with its facilities for the close control of heat output, thus saving on the capital and operating cost of the installation. The small bore hot water central heating system is one example of this modern trend, as it now provides some of the advantages of district heating in being able to make better use of the heat to be distributed throughout the building.

The automatic control equipment now available can be used to good advantage at the district heat supply point to the consumer's premises, by enabling the constant supply temperature of the transmission network to be modulated in accordance with that actually required at any particular time. Automatic control is also essential with steam supplies to process plant, since a small deviation from the required temperature can slow down production and impair the quality of the product.

Of much importance is the need for accurate control of the heat supply to space heating and hot tap water systems because of the wide variations in demand that can apply over a short time period. The economic significance of this in regard to space heating is appreciated when it is realised that each degree Fahrenheit deviation from normal air temperature can effect a change in fuel demand of about 5% and a corresponding wastage when overheating occurs.

Heat supply to hot water systems can be conserved by reducing circulation of losses which may represent a high proportion of the total heat demand, as losses usually also occur in towel rails and linen cupboard coils. In some classes of buildings such as flats and hotels it is not essential for circulation to be continued throughout the night, and may be interrupted for some hours by automatically switching off the circulating pump, or by the use of a time controlled motorised valve in the secondary circulating pipework.

Control of the steam supply by means of on-off valves and pressure or thermostatic actuators, suitably positioned, will usually provide all that is required with this form of heat supply. When the supply is hot water, and it is used for space heating, it is necessary to modulate the temperature continuously, or shut off the supply entirely, to closely compensate for changes in the weather. This can be done by the use of mixing and diverting valves under central or zone control. An exception to this arrangement can be made for industrial and commercial buildings, when using natural or forced draught convector heaters having individual thermostatic control, and also for the heaters in dwellings when they are fitted with thermostatic control valves. The less expensive, but not so effective alternative to these valves is the thermostatically controlled diverting valve in the supply circuit, as shown in Fig. 4. Automatic control of storage calorifier temperatures by diverting valves is also to be preferred to on-off valves in order to assist in stabilising pressures in the transmission mains.

The zone control of buildings, to compensate for changes in heat demand resulting from the prevailing ambient temperature, solar radiation and wind velocity, requires special treatment when applied to multi-storeyed buildings containing up to 30 floors or more. This entails zoning the building according to both its directional and elevational exposures to make the control fully effective. The amount of vertical zoning necessary will depend upon the altitude and contours of the adjoining land, and the proximity of nearby buildings. Separate zones may be required for every 5 floors above the first 10. This need results in a complexity of controls, and a less expensive and more effective alternative could be to provide automatic temperature control valves on each heating unit throughout the building, as has been done for many years in large office blocks.

To ensure the greatest economy and comfort at all times in the use of space heating systems requires the use of additional automatic control equipment to start and stop the heat supply daily. The modern building, having structures of low thermal capacity, is heated more economically when the overnight supply is shut off, rather than when the temperature is merely lowered. It is therefore necessary for the daily pre-heating of the building to be neither more nor less than adequate. The pre-heating period will vary from day to day according to the overnight heat loss as influenced by the weather and other factors, and to compensate for this the starting-up time, each day, needs to be thermally co-ordinated with the prevailing conditions. The best results would come from the type of control that is adjustable with regard to both switch-on time and the range of temperature rise, so that these may be set according to the thermal characteristics of the building structure and of the heating system.

Unnecessary pre-heating can also be avoided when the supply is provided by a centralised warm air system, if full re-circulation of the air is provided during the pre-heating period. This can be arranged by using the time switch to also control the motor operating the fresh air intake dampers, so that these are not opened until the time the building is first occupied each morning.

There is now such a wide range of heaters for use in buildings of different kinds that the choice of the one which will give the best service under particular conditions is not easy. Although there is no restriction in the type of heater or distribution system to be used with a district heat supply, it is necessary for this to be used efficiently by providing good heat transference to the space to be warmed and direct to individuals.

The choice of the type of heater to be used in a building is influenced by many features. Amongst these are: its appearance and compactness, ease of installation and cost, and less frequently, its thermal efficiency! Heaters requiring a low initial outlay are, sometimes, also, thermally inefficient, because they do not provide the heat where it can be most effective; whereas others concentrate the output of heat within a small area to the discomfort of individuals in its vicinity.

Experience of the conditioning of space in buildings (or of 'environmental engineering' to use the latest term) has shown that, satisfactory space warming cannot be achieved by merely introducing enough heat to offset the losses by conduction and air infiltration without regard to the comfort of the occupants in the particular conditions created. Provision must be made for a reasonably good balance in the transfer of heat by conduction, convection and radiation to produce an acceptable 'equivalent' temperature where it can be most beneficial. This implies that the heaters used should not produce pronounced air temperature gradients, or abnormal temperatures of structural surfaces that may be near, or come in contact with individuals, or yield insufficient radiation to counteract the cooling effect of glazing.

Reliance cannot, therefore, be placed entirely on air temperature alone to provide a satisfactory thermal environment since this also calls for the dissipation of heat by conduction and radiation. The ideally warmed space would be provided by a combination of low temperature flooring and medium temperature walling, with the addition of some convective heat for air movement. Such a combination as this would be costly to provide, and a compromise is necessary to obtain something approaching the ideal.

A satisfactory compromise is obtained when the mean radiant temperature of a space is near the optimum, and this may be achieved by the use of panel type radiators if these can be suitably positioned. If not, supplementary radiant heating is desirable, which may be provided from the floor or wall surface by embedded or interposed pipe coils. Skirting panel heaters may also be used to advantage when they are not likely to be much obscured by furniture.

The type of building to be heated will determine the kind of system selected. Modern buildings with large glazed areas, like offices and hotels, and others used for certain manufacturing processes, may require a full air conditioning system to provide a satisfactory environment. Some factories can be adequately heated and ventilated by forced draught convector heaters, and supplemented, if necessary, with radiant panels, especially when supplied with high temperature water. Low temperature radiation in the form of heaters embedded in the building structure, or superimposed on its surface are alternatives which may be used for commercial buildings and some residential buildings, particularly when concealment of heaters is desirable.

A good distribution of both radiant and convective heating is obtained by using continuous cased heating elements or linear type air diffusers on the inside of external walls below windows, especially when the latter occupy a high proportion of the wall area. This method is convenient for modular unit construction, and when demountable partitions are used, in enabling the floor area to be sub-divided to suit individual tenants without disturbing the heating installation. When hot water is used, this circulates through a concealed heating element, the warm air being discharged through the top of the casing at or below window sill level. Alternatively, warm air may be circulated from a central plant through a continuous duct below the windows and discharged through the diffusers in the sill as seen in Fig. 8. This method, in also providing mechanical ventilation, can be used for full air conditioning to compensate for some of the shortcomings of modern building construction.

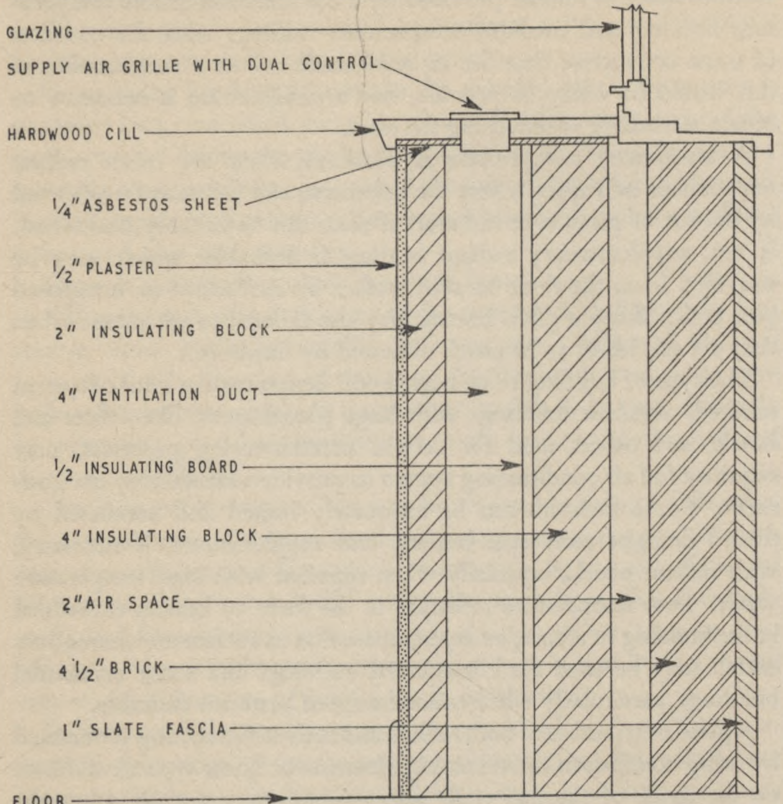


Fig. 8. *A METHOD OF HEATING AND COOLING AN OFFICE BUILDING. An inconspicuous arrangement for supplying conditioned air discharged through grilles in the window sill*

The method used for heating residential buildings in general also depends to some extent upon how the accommodation is arranged. Multi-storey blocks of flats are most conveniently provided with hot water heaters of the panel type, arranged as shown in Fig. 9, or with natural flow convector heaters positioned below windows, especially when supplied with the higher water temperatures. The same method is applicable to maisonettes, terrace houses, and those which are semi- or fully-detached, with the alternative of ducted warm air from central heaters in each dwelling, when provision can be made to conveniently accommodate the air ducts in the building structure.

Ducted warm air systems are able to provide a quicker supply of heat than hot water heaters, but in depending more on the movement of warm air than those systems where lower air temperatures are combined with radiant heat, necessitates more frequent redecoration of the house. For heating open-plan houses ducted warm air is less convenient when overall heating is not required continuously. These systems in producing more pronounced vertical temperature gradients will also require higher thermostatic settings (70-80°F) to provide comfortable conditions at sitting level.

The heating of residential buildings is improved when some continuous background warmth is provided, so that the temperature of dwellings unoccupied for some time does not fall low enough to cause condensation, and also not to increase too much the heat losses from adjoining dwellings maintained at normal temperature.

Whatever type of heater is decided upon, it should, of course, have a heat output adequate enough to provide the temperature required under the given conditions. Such factors as the position of the heater in the space to be warmed, the position of the space relative to the height of the building and its orientation, and any pre-heating required will all affect the size of the heater and its supply circuitry.

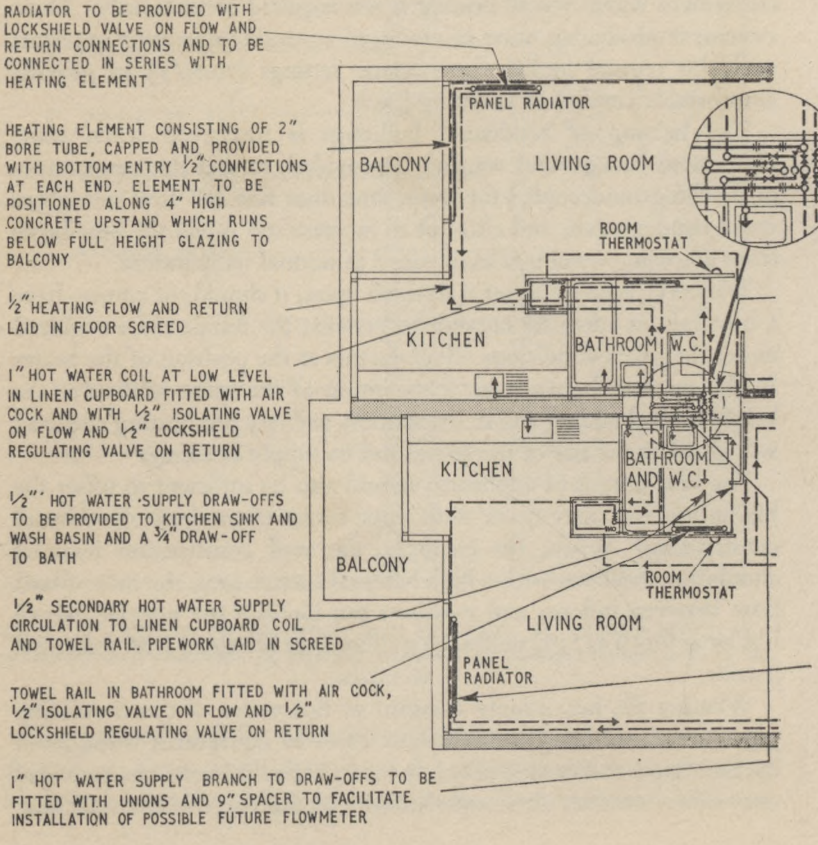
The heat output of appliances should also be sufficient to offset the higher loss that may occur with some forms of modern curtain-wall construction. When, for example, the wall construction includes aluminium mullions with a high external surface area, the rate of heat flow between indoors and outdoors can increase the normal overall loss by as much as 15% unless the mullions are provided with a thermal barrier.

Whether the heat supply is steam or hot water, if the circulating pipework distributing it to various types of equipment throughout the building is to function properly the right facilities must be provided to avoid the troubles often experienced with this part of the installation.

When steam is used, adequate initial and index circuit supply pressures are essential, as is also the venting, trapping, draining and grading of the pipework. With hot water the correct balance of circulating pressures is even more important if short circuiting is to be avoided, as this cannot be entirely prevented by the hand adjustment of regulating valves.

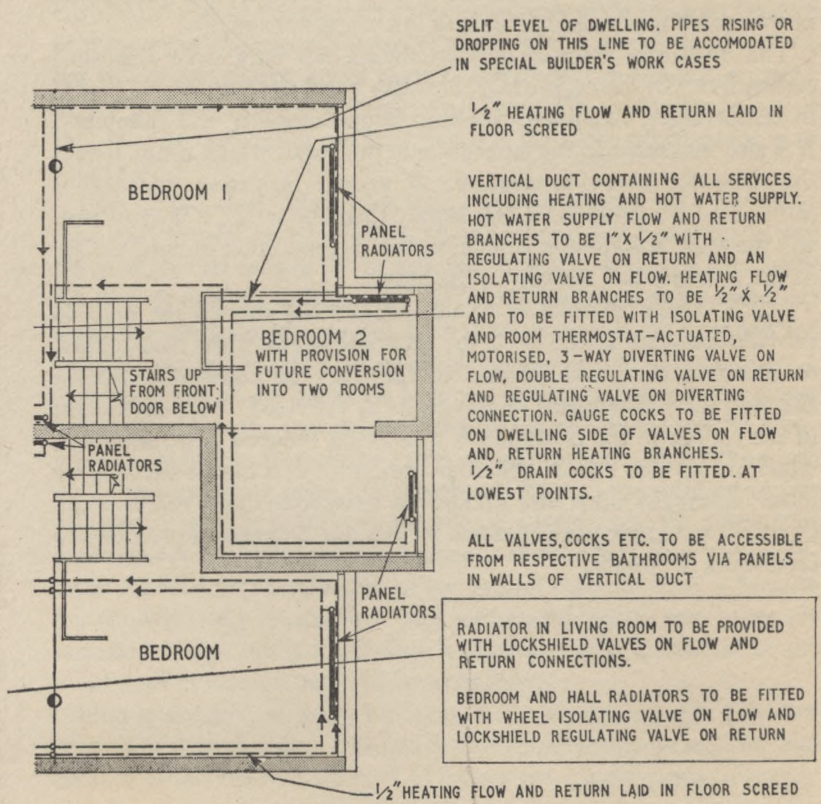
The provision made for the expansion and contraction of the pipework, to ensure its freedom of movement, should also be adequate, not only to avoid heavy stresses, but also to prevent the creaking and

Fig. 9. SPACE HEATING AND HOT WATER SUPPLY SERVICES. The arrangement of heaters and pipework is shown for flats in a multi-storey block of a housing development of 800 *dwellings*



cracking noises which can be disturbing sounds in residential buildings. These noises, which are caused by rapid rises in temperature resulting from the action of automatic controls, can be avoided by treatment that allows pipe movement to be unrestrained by adjoining structures. This treatment also applies to radiator lugs and brackets where metal to metal contact occurs between moving and stationary surfaces.

The present trend towards the complete concealment of circuit pipes in the building structure emphasises the need for precautions to avoid restricting the movement of the pipes. This can easily occur, for



instance, when the pipes are buried in the floor screed unless they are suitably encased to prevent any restraining action by the screeding. The encasement should also be of insulating material to avoid local floor surface overheating and excessive heat transmission downwards. Concealment of pipes also necessitates providing proper access for the operation and maintenance of valves, cocks, air eliminators and expansion bellows.

Much can be done to improve the efficiency of heat distribution by the proper use of thermal insulation for pipework and other equipment, especially in places where heat losses can be considerable. The need for making provision to reduce these losses, which is often neglected, is emphasised when the circulation losses represent a high proportion of the usable heat demand, as with hot tap water supplies.

The insulating material selected should not only have a thermal conductivity of the right order, but, also good serviceability in regard to temperature, dampness, vermin, incombustibility and durability. It is also necessary to use an economic thickness, which is not always the same for every installation. A greater insulation thickness is justified with a continuous heat supply than one which is intermittent, and the exact thickness of insulation will depend upon its cost, the life of the material and the cost of the heat.

Much of the information in this chapter has stressed the need to provide adequate facilities for the economical use of the heat supply, so that the maximum amount of fuel may be conserved without affecting the full standard of service to be provided. The annual cost of the supply to the consumer is thus being reduced to a minimum, which means that a more generous amount of heat can be afforded by those consumers otherwise obliged to have something below a full standard, the consequent increase in the heat demand improving the economics of supply.

Chapter 7

HEAT PRODUCTION

The bulk generation of heat, as with other mass-produced commodities, enables the cost of the product to the consumer to be reduced because of the greater and more efficient output. As the output increases, the less will be the relative cost of plant, fuel, transport and labour, required in the production of a thermal unit. From this economic truism it follows that the greater the heat demand the more profitable it is to supply it.

One of the chief reasons for being able to supply the larger heat quantities at relatively lower cost is the saving made possible in the purchase of fuel which, as the amount increases, becomes less costly *pro rata*. It is often possible, also, to reduce the fuel cost by using less expensive grades made possible by boiler plant specially designed for this purpose, and which is not available for the smaller heat output.

Another reason for the lower heat cost is that the larger boiler plants are able to burn the fuel more efficiently because of the precise combustion conditions that can be provided and maintained, by the more costly and extensive range of controls and instruments justified for this purpose. Also, when heat is produced on a large scale, the amount of attention for operation and maintenance of the plant does not necessarily increase proportionately to the greater output. This is because the modern fully mechanised and automated plants can be much increased in size without entailing a corresponding increment in the number of personnel required for attendance.

Heat generation in itself, however, is not always the sole criterion of successful production. The heat has to be conveniently utilised, and because of this there is the need to equate the requirements of supply and demand to accord with the particular circumstances. This applies particularly, for instance, with combined heat and power generation.

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This method of heat supply, with electricity as a by-product, has been shown to produce heat with optimum economy in countries abroad, but in this country has made little progress. The fact that economic, social and political conditions in the countries abroad are similar to our own, implies that here certain influences, including insufficient co-ordination of the country's heat and power requirements have reacted to the disadvantage of the heat consumer.

It is necessary to have a reasonable coincidence in the heat and power demands, so that the latter may be made available at times of peak demand to increase its value. This entails the use of back pressure turbines, or pass-out and condensing turbines combined with heat storage to produce an economic scheme. The use of either type of turbine appears to offer good prospects of developing economic supplies of heat and power, and this is now being closely investigated by a committee of expert engineers to find out more about the practical implications.

Heat production direct from a thermal generating plant, having an efficiency of 80-85%, is an alternative to the dual generation of heat and electricity that is able to substantially reduce the cost of heat compared with the more conventional methods of supply. Because of this financial advantage, straight thermal generation combined with a district heat supply, can often provide a service that is also superior in other ways. This explains the greater interest now being shown in this method of production.

The production of heat independently of electricity generation has been used for many years to provide district heating services. At the present time there are several schemes in this country under construction, or recently completed, which will be able to supply low cost heat to consumers in conveniently planned communities. Most of these projects are of medium size; nevertheless the heat demand is sufficient to merit the supply being provided from centralised boiler plant.

The use of nuclear energy, as a means of producing heat for district supplies, has not yet become an economic proposition, mainly because of the present high capital cost of plant. Another reason is the restriction governing the siting of nuclear stations, which results in their being situated away from built-up areas, and thus uneconomic because of the transmission costs of heat over the intervening distances. But the development of new areas for industry and commerce, together with a relaxing of siting restrictions, and the attainment of parity between the costs of nuclear and conventional condensing generations may do much to make the use of nuclear power more favourable for district heating.

There is at present one scheme in operation in Sweden at Farsta, a suburb of Stockholm, using nuclear plant for district heating. The reactor is of the heavy water type, using natural uranium as fuel and supplies nearly 2,000 therms an hour from a back pressure turbine. This plant may be regarded mainly as a development project, able to provide useful experience in connection with future schemes.

It is not possible in the space available here to deal with heat production in other than general terms. A more detailed study may be made by consulting the various publications on the subject. The following information is given, therefore, to outline what may be involved in heat production by both thermal-electric and direct thermal generation.

The amount of heat rejected and lost by generating plant in a power station is a high proportion of the heat input, as is seen by reference to Fig. 10. The amount discarded by one modern generating unit alone is sufficient to heat the medium size of town. If all this heat is not to be wasted, by using that required for district heating, there is much to be gained by reducing the large quantities of heat lost to rivers and to the atmosphere with future generating plant. Part of this plant could be designed to operate with appropriate turbine exhaust steam and pass-out pressures, and be usefully employed at the outset by the existence of a district heat demand. Circumstances such as these require the construction of conveniently situated generating stations to proceed concurrently with the development of new towns and associated industrial areas so that supplies of electricity and heat may be provided at the time required. This could involve a reduction in the size of some of the central station generating units, together with a small increase in the overall generating capacity. There will also be some change in the operating regime later as stations become confined to daily peak hour generation, and a resultant compromise in the overall generating efficiency.

It has long been realised that there is scope for improvement in the efficiency of thermal power stations to make better use of the fuel consumed. During recent years there has been a steady improvement in efficiency due to the advance in steam pressure, steam temperature,

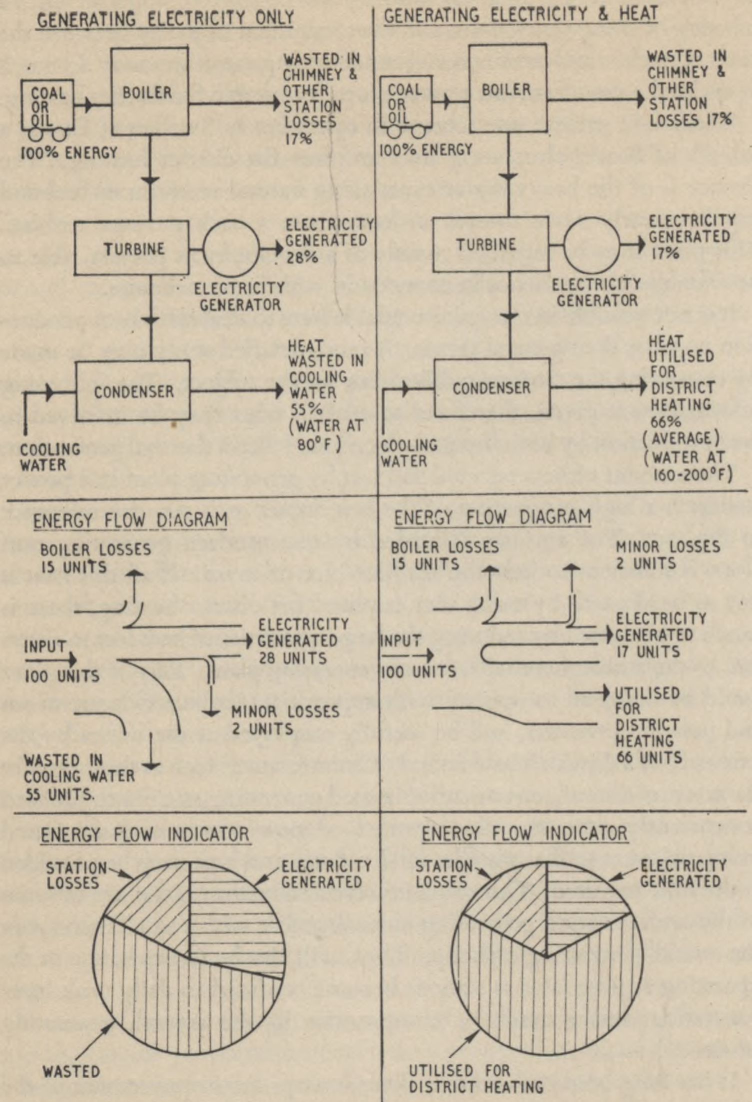


Fig. 10. RELATIVE ENERGY UTILISATION VALUES. The comparison shows the amount of heat utilised when generating electricity: 1. *independently and* 2. *combined with heat supply*

and size of plant. The maximum efficiency of a supercritical pressure station now in construction will probably reach 40%, and in the U.S.A. one such station is in operation at 42%. Nevertheless, the average efficiency of generation today in this country is still less than 30%, and the maximum is unlikely to be much more than 40% with a conventional prime mover.

Most of the 60–65% of the heat input which is eventually rejected at a modern power station passes out at the turbine exhaust, and the ultimate temperature of the steam is not more than 90° F, which is of no value for district heating. To provide useful heat from steam turbine plant necessitates increasing the pressure of the steam to provide the higher temperature, as may be done by the use of condensing machines arranged to allow part of the total steam throughput to pass out for heating purposes, or alternatively by back pressure turbines.

The present mode of electricity generation, exclusively at optimum efficiency, is seldom in the interests of the general public, who have an interest also in the efficient generation of heat and its availability at the lowest possible price. This realisation by private enterprise has enabled substantial economies to be made in the supply of heat for commercial purposes by combined heat and power generation.

Fig. 11 gives an indication of the heat economy possible for district heating with combined heat and electricity production in showing the percentage saving in fuel over that required for the production of electricity and heat separately.

The important feature of any combined heat electric scheme is the ratio of the electrical energy to the heat sent out. The commercial value of heat as such is much less than the value of the equivalent quantity of electricity, and it will be appreciated that the higher the ratio of electricity to heat the more valuable is the combined revenue from both sources of energy. These requirements can be met by using dual purpose steam turbines and thermal storage.

The coincidence of the heat and power demands will vary according to the use made of these supplies, which depends upon the class of consumer connected. The extent of demand variation is affected according to whether or not the supply is given jointly to industrial, commercial and domestic consumers, or one or two of the three, and the particular requirements of each consumer. These circumstances not only affect the variation in demand throughout the day, but also

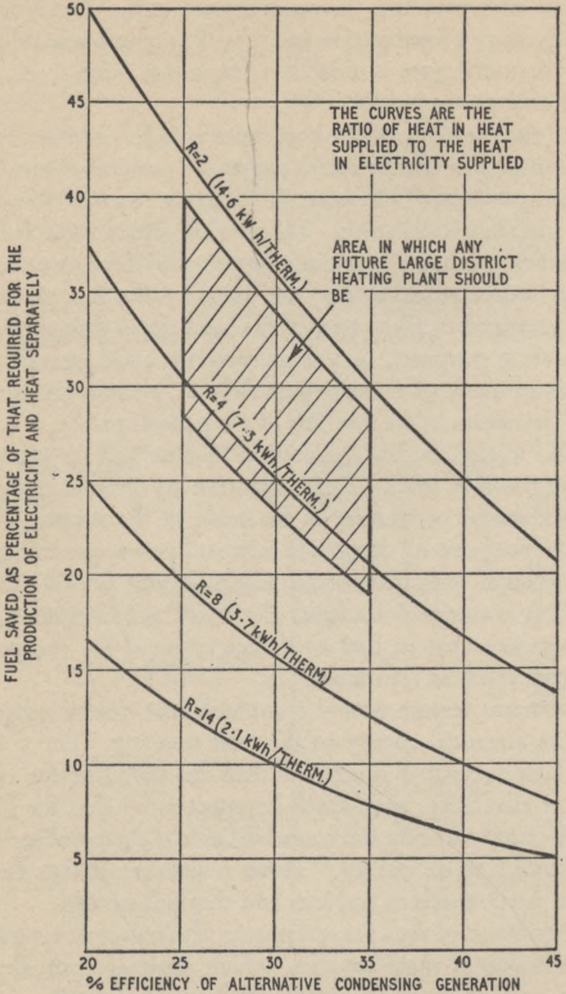


Fig. 11. *HEAT ECONOMY PROSPECTS OF DISTRICT HEATING. Fuel saved expressed as a percentage of the amount required for the separate production of heat at a thermal efficiency of* 80% *and the separate production of electricity by condensing generation at a thermal efficiency shown by the abscissæ, assuming that the thermal efficiency of the district heating plant is also* 80%

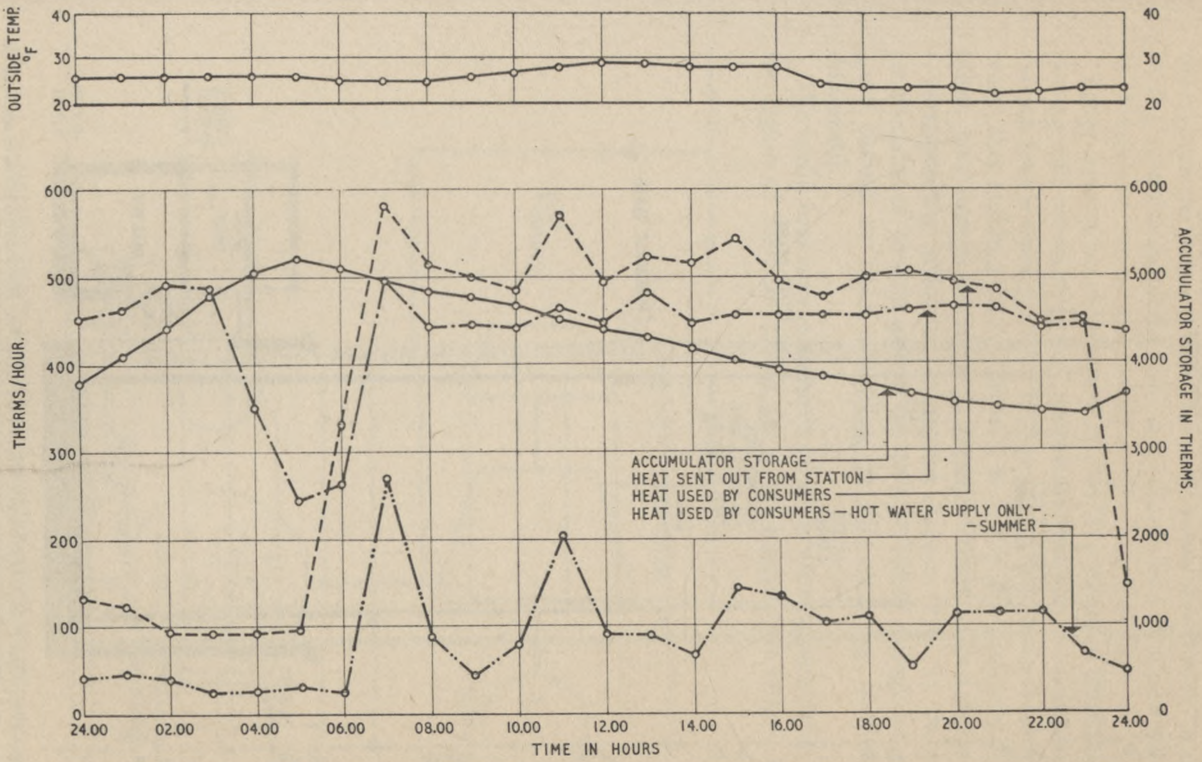


Fig. 12. HOURLY VARIATIONS IN SUPPLY AND DEMAND AND ACCUMULATOR STORAGE. The conditions apply to the Pimlico system when the outside temperature is below freezing point. It is seen how discrepancies in supply and demand are met by the heat reserve in storage which is sufficient to deal with greater peak demands on future development

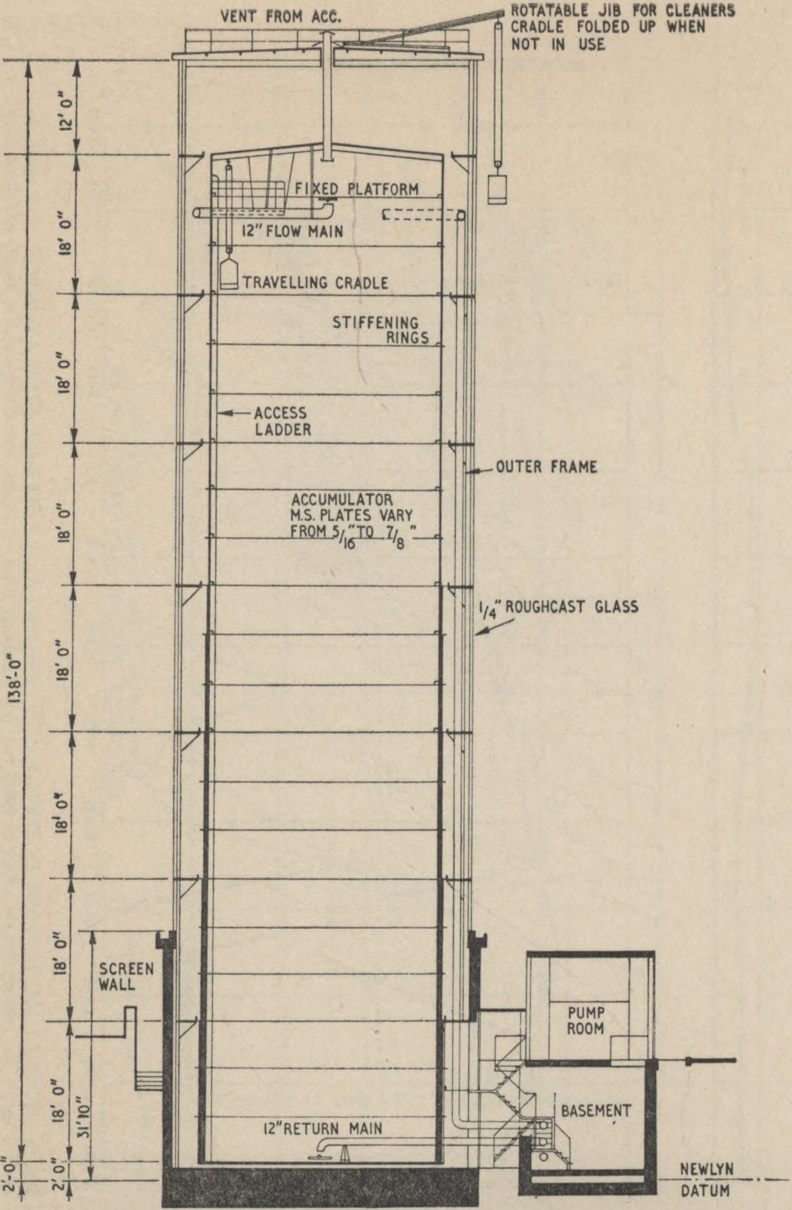


Fig. 13. THE HEAT ACCUMULATOR AT PIMLICO. *Hot water is stored at atmospheric pressure, and the vessel is charged and discharged automatically according to supply and demand conditions*

throughout the year as from Winter to Summer. This is illustrated by Fig. 12 which shows the daily supply loads for a district heat supply in Winter and Summer to mainly residential buildings.

Large capacity hot water accumulators are a means of balancing the heating and electricity loads, so that any surplus or deficiency of exhaust heat is made good by storage of the heat in the form of hot water, thus enabling the two services to be run independently of each other. Heat storage also serves to improve the annual load factor with a corresponding reduction of capital charges. Fig. 13 shows an accumulator of 500,000 gallons capacity providing storage for about 5,000 therms or more according to the operating temperature differential.

The useful heat storage capacity of a hot water accumulator is in the region of 5,000 Btu/ft^3 for the lower temperature range. With

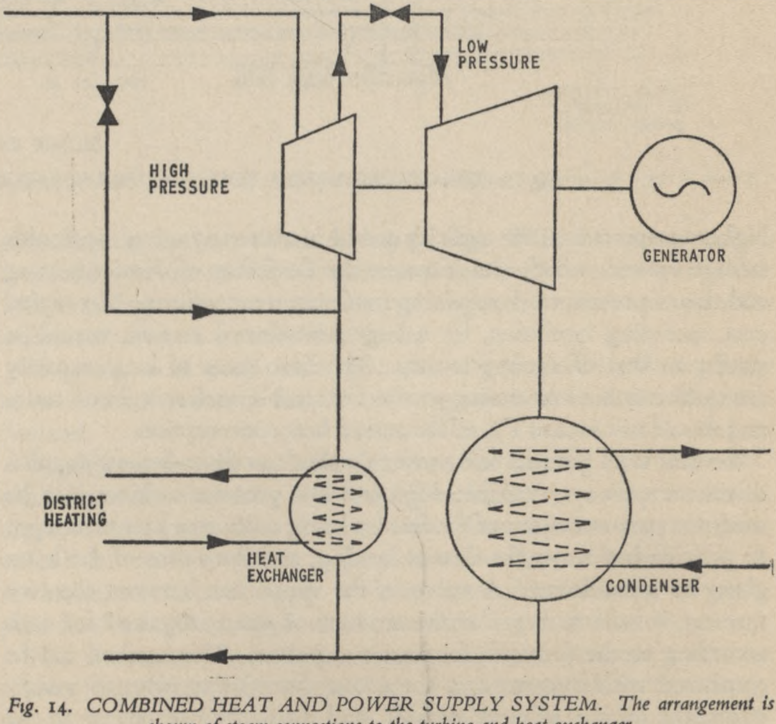


Fig. 14. COMBINED HEAT AND POWER SUPPLY SYSTEM. The arrangement is shown of steam connections to the turbine and heat exchanger

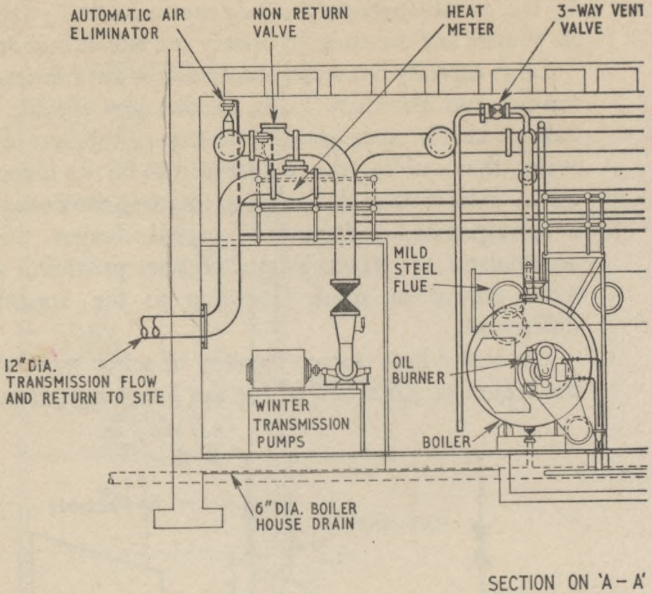
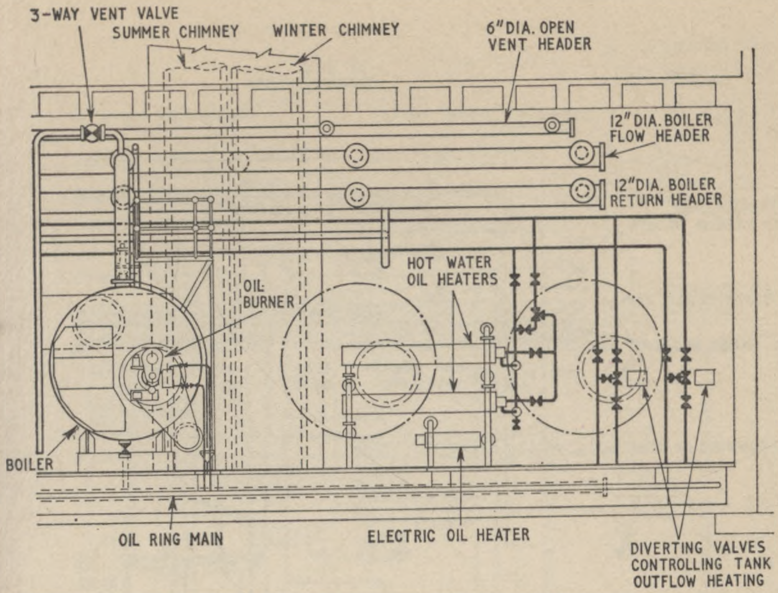


Fig. 15. *THE CWMBRAN NEW TOWN CENTRE BOILER PLANT*

higher temperatures, the capacity can be increased by using the double storage system, which also increases the flexibility of district heating and also of process work requiring moderate temperatures. The capital cost, including insulation, for a large heat-electric station, would be similar to that of cooling towers. The heat losses of large capacity accumulators are low owing to the favourable surface/volume ratio, and should not exceed 1% of the annual heat consumption.

To deal with the heat and power demands so that adequate supplies of each are always available, high and low pressure turbines may be used, the pass-out steam of the former being taken to a heat exchanger to provide hot water for district heating, and the steam of the latter going to a condenser. A valve in the steam line between the two turbines is used to regulate the amount of steam required for each according to the demands for heat and power. This method can be combined with heat storage, the accumulator being charged mainly overnight during off-peak periods, and discharged according to the



The arrangement of the oil fired plant shows the first stage of installation (*continued on pages* 68 *and* 69)

prevailing demand conditions during the day. With this arrangement, the maximum amount of heat generated can be reduced considerably with a corresponding saving in the cost of plant. Such an arrangement is shown in Fig. 14 in simplified form.

The purpose of using two stage turbines is to enable both stages to be used simultaneously for electricity generation at times of peak demand.

Conditions may be such that at times the heating load does not compensate the electricity supply load, necessitating a supplementary supply of live steam direct to the heat exchanger when requirements exceed the capacity of the high pressure turbine. Alternatively, as mentioned, a reserve supply of heat accumulated during off-peak periods of electricity supply can be provided by thermal storage.

The alternative method, by the use of back pressure turbines, enables the exhaust steam temperature to be increased to that necessary for district heating. To assist with the balancing of the demands with

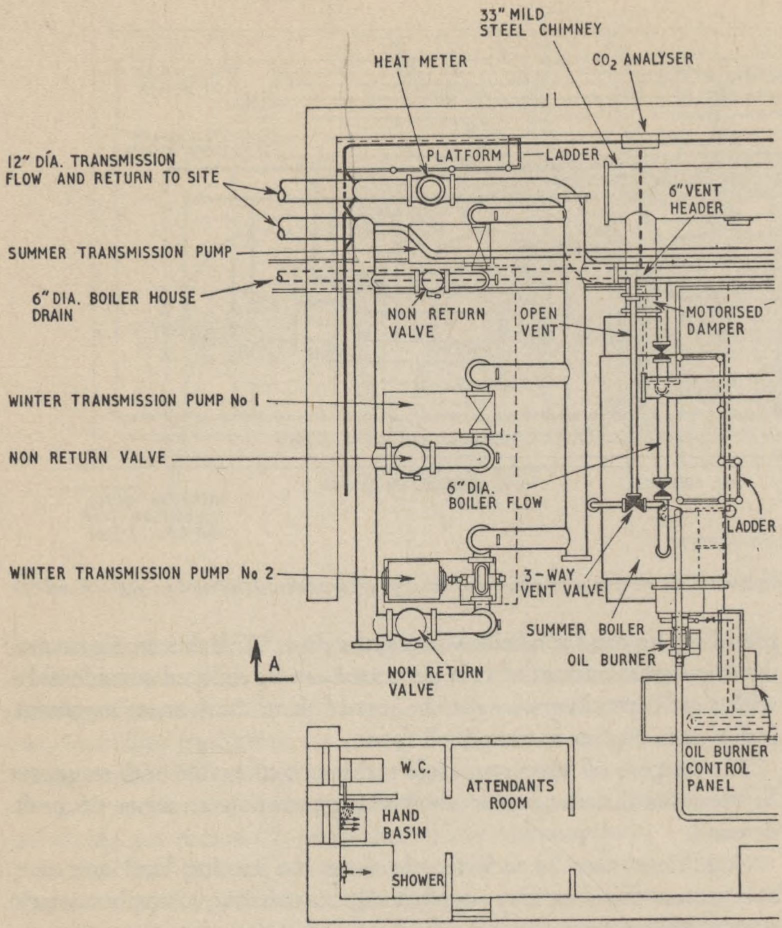
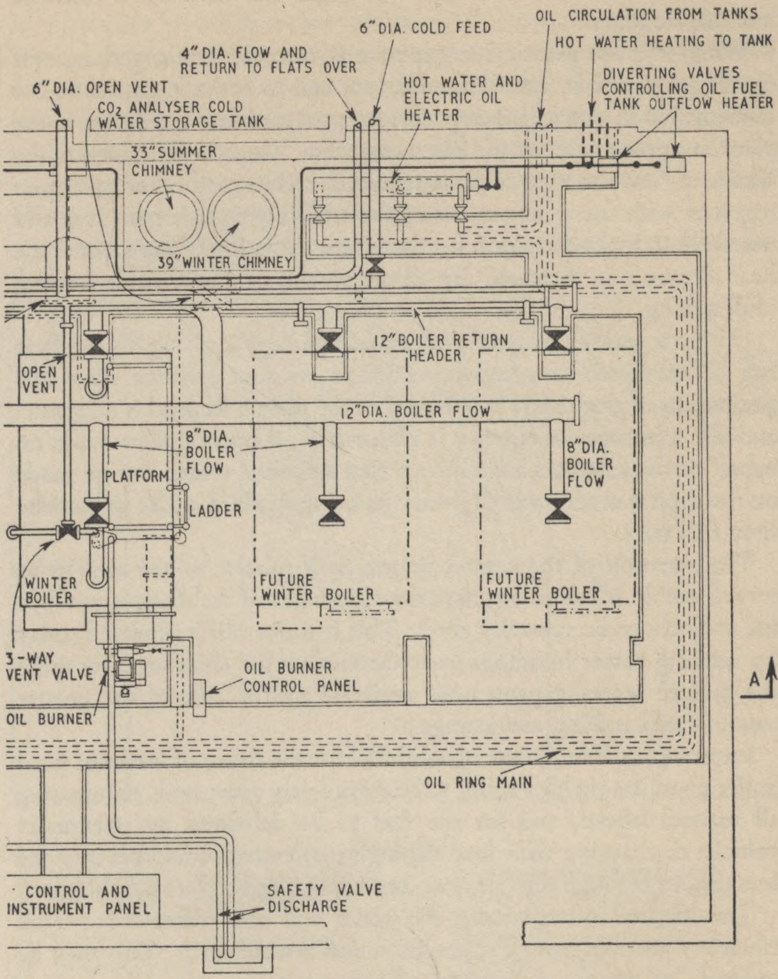


Fig. 15 (*continued*)


OIL CIRCULATION FROM TANKS
6" DIA. COLD FEED
HOT WATER HEATING TO TANK
4" DIA. FLOW AND RETURN TO FLATS OVER
DIVERTING VALVES CONTROLLING OIL FUEL TANK OUTFLOW HEATER
6" DIA. OPEN VENT
HOT WATER AND ELECTRIC OIL HEATER
CO_2 ANALYSER COLD WATER STORAGE TANK
33" SUMMER CHIMNEY
39" WINTER CHIMNEY
12" BOILER RETURN HEADER
OPEN VENT
12" DIA. BOILER FLOW
8" DIA. BOILER FLOW
8" DIA. BOILER FLOW
PLATFORM
LADDER
WINTER BOILER
FUTURE WINTER BOILER
FUTURE WINTER BOILER
3-WAY VENT VALVE
OIL BURNER CONTROL PANEL
A
OIL BURNER
OIL RING MAIN
CONTROL AND INSTRUMENT PANEL
SAFETY VALVE DISCHARGE

PLAN

this method, it may be necessary to arrange with the local Electricity Area Board for the sale and purchase of power when this is more or less than required.

When it is not practical to generate power and heat together, heat can be produced by itself efficiently enough to make it economic for transmission in district heating services, provided that the design of the plant is appropriate to the circumstances. These will influence the choice of fuel, the type of plant required, and its method of operation together with the arrangement of the auxiliary equipment. It is also necessary to make provision for the future extension of the plant as the heat demand is increased by development of the district heating undertaking.

It is now realised by solid and liquid fuel suppliers that district heat can be marketed at competitive prices without reliance upon the generation of electricity, provided that the size of the load is adequate, and the transmission distance is reasonable. Recent studies made on behalf of the suppliers have shown that sufficient return can be made on the capital investment to justify its being made in order to increase their fuel sales.

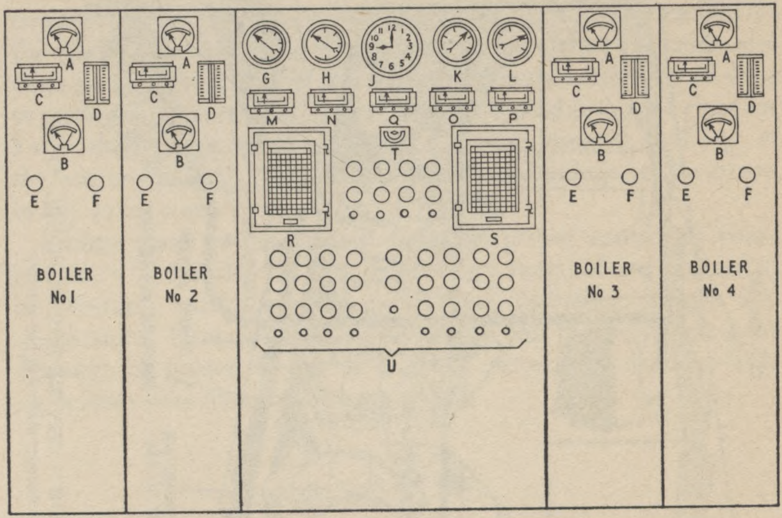
The situation of the central station itself relative to the area to be served can do much to improve the economics of the scheme, as when the station can be centrally sited. This is more easily achieved today by utilising tower buildings to accommodate the chimneys; by using the quieter working plant now available and because of the greater ease of fuel handling and storage.

Improvements in the use of solid fuel for the firing of medium sized boiler plant has enabled firing to be completely automatic, eliminating all manual labour, and for the fuel to be delivered by pneumatic vehicles discharging their load through permanent standpipes into the bunkers, or through flexible hose direct into overhead storage hoppers.

The method of operating the plant will also affect the overall efficiency and the cost of supervision and maintenance. This may be reduced by using a full range of automatic controls and adequate instrumentation, with provision for remote control of the plant when this is desirable.

The modern design of medium sized multi-pass smoke tube and water tube boilers, constructed as self-contained, compact units, complete with firing equipment now available, not only improve the efficiency and reliability of operation, but also saves materials and labour for their installation, and space for their accommodation, each of which can be costly to provide in certain circumstances. It is such features as these, combined with automatic operation, that have enabled district heating services to be linked effectively with the more economic heat production desirable for their provision. Further developments in this particular range of boiler plant and auxiliary equipment should help to extend the scope of district heating, so that its usefulness and efficiency may be more fully exploited.

A well designed boiler plant that is automatically controlled and



REFERENCE

A	Smoke density recorder and indicator
B	CO_2 flue gas temperature recorder and indicator
C	Boiler flow temperature indicator
D	Draught gauges
E	Green light oil burner 'on'
F	Red light oil burner lock out
G	System flow pressure gauge
H	System return pressure gauge
J	Electric clock
K	Oil storage tank contents gauge
L	Oil storage tank contents gauge
M	System flow temperature gauge
N	System return temperature
O	Rate of flow indicator Btu meter
P	Btu meter integrator
Q	Klaxon
R	System flow system return and external air temperature recorder
S	Btu recorder
T	Lamp and Klaxon test
U	Push button and indicator lamps

Fig. 16. THE PANEL OF INSTRUMENTS. For the plant shown in Fig. 15

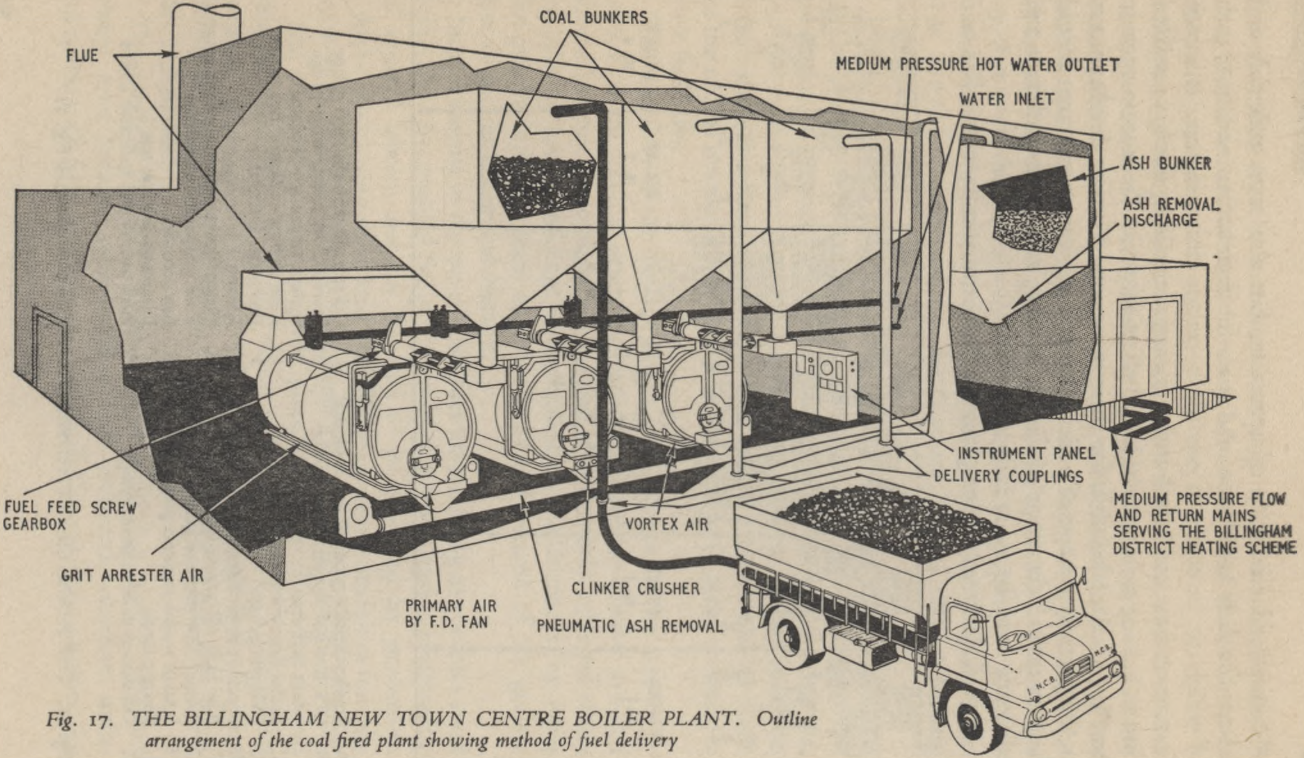


Fig. 17. THE BILLINGHAM NEW TOWN CENTRE BOILER PLANT. Outline arrangement of the coal fired plant showing method of fuel delivery

fully instrumented can operate at an average thermal efficiency approaching 85%, and maintain this figure consistently with regular servicing of components. Much of the improvement in efficiency during recent years has resulted from the progress made in combustion control technique which, depending less upon the human element for regulating firing conditions, enables these to be adjusted at shorter intervals and with greater accuracy.

The layout of the plant for a direct thermal central station should conform to the statutory and other requirements essential for its correct operation. These will include compliance with the *Clean Air Act;* reserve equipment to ensure continuity of operation for maintenance and emergency purposes; indicating and recording instruments for efficient operation, and signals and audible alarms for safety and other purposes. Fuel, water and heat meters are also required to assist in costing the heat service. Fig. 15 shows a typical layout of plant for a new town centre, using oil fuel of 3,500 secs viscosity, and Fig. 16 the instrument panel. The arrangement of plant to burn coal is shown in Fig. 17 for a new town centre.

Because good instrumentation facilitates proper control of combustion, it is desirable for a comprehensive range of instruments to be provided, particularly for gas analysis, including draught and temperature. Plant operators should also be able to readily detect the discharge of smoke, so that it does not exceed the darkness scale applicable to the *Clean Air Act.*

Chapter 8

COSTS

Much of the work entailed in investigating the suitability of a district heating service is concerned with the preparation of cost estimates, as upon these will depend whether or not the consumer can be charged an economic price for the heat supply. It is therefore necessary, for cost estimating purposes, to plan in some detail the extent and proposed arrangement of the necessary plant and ancillary equipment required, as well as estimating the current expenses incurred in its operation. These may then be evaluated reasonably accurately to show the annual costs entailed in providing the service.

In considering the cost example figures, given in the Tables of this and other chapters, it should be remembered that they refer to undertakings and projects in this country, seldom representing a very economical size of scheme compared with many of those abroad. Because of the difference in heat output, the former do not, therefore, produce the more favourable costs per therm of the larger schemes.

It is necessary for a full preliminary design to be made of the proposed scheme in order to obtain sufficient information for costing purposes. The design will show the extent of the civil, mechanical and electrical engineering work involved, so that this may be adequately covered in the estimates.

The chief factors affecting the capital cost of the scheme are its thermal output and the distance this has to travel to the consumers. The size of the plant to be provided, must therefore, be ample for the service required in the particular circumstances. An approximation of the plant size and that of the transmission network in some detail is time well spent, as upon its accuracy will also depend the cost of the civil and electrical engineering parts of the works.

In addition to the current cost of materials and labour there will be further expenditure incurred to meet increases in the cost of these items during the contract period extending over several years. The inclusion of a provisional sum to cover contingencies is usual, but further sums to cover water, gas and electrical supplies to the site may be necessary. The cost of engaging an insurance company for inspection and testing services, especially in connection with any underground mains, must be met, also the fees of the consulting engineers responsible for the investigational, design and supervisory services.

When the estimated total annual costs have been made and divided by the estimated annual heat demand, the result will be the net unit cost of heat production and transmission. This cost is then increased to cover contingencies and reserves, and any profit required, the final figure being the sale price of the heat to the consumer after allowance for transmission losses. During the development period the annual costs must also include the payment of interest on the loan to cover development losses later recouped.

As with most other commodities, the net production and distribution cost of heat is dependent upon the demand and, therefore, on the quantity sold over a specific period of time. The greater the output of heat and the shorter the time over which it occurs, the smaller will be the cost of the heat because the standing charges become proportionately less. That is why the annual costs given in Table 2 do not increase proportionately to the increase in the capacity of the plant as a result of the incremental rate of fixed charges being smaller.

The reasons for the slower increase rate of the fixed charges are: (a) As the size of the plant increases, a corresponding increase in the number of staff for operation and maintenance is unnecessary; (b) The space available in the central station also becomes more fully utilised as additional plant is installed, as also does the capacity of the chimneys, for it is not economic to increase the size of the station for each new phase of development, and not always practical to provide an extra chimney at these times.

How much the heat will eventually cost the consumer to use is dependent upon the type and annual cost of the equipment required in the consumer's premises to utilise the heat supply, and this expense is added to the supply cost to show the overall expenditure entailed. Until this is known, it is not possible for the cost of the various methods of heat supply and utilisation to be compared realistically for the same standards of heating in each case—a need which is often overlooked in endeavouring to obtain good value in the purchase of heat.

This comparison of the overall cost of district heating with other methods of supply on a similar basis will show if it is economically favourable when each is considered on the same useful heat quantitative basis. For this reason it is important to assess carefully the heat utilisation efficiency of the alternative methods of supply as distributed in the consumer's premises. This depends upon the particular methods and appliances used.

Before the consumer can use the heat supply to his premises, heaters must therefore be installed and connected to the supply. This is an additional expense to be met when using district heat, electricity, gas, oil or solid fuel, although for the latter two fuels supply connections to the heaters are not always necessary. To find out what this extra expense amounts to entails further estimation of the costs of the various methods for using the different supplies. The capital and operating costs will differ for each form of supply according to the purchase price of the heaters, the cost of the connections and the amount of useful heat obtained from the quantity supplied.

When making cost comparisons for heat supply by different methods it is essential, if these are to be valid, to ensure that each method provides the same amount of useful heat for the services required. Some methods are able to produce heat from the source of supply at higher efficiency than others, but may lose much of this advantage when using certain methods of transferring the heat to the space to be warmed.

The incremental cost of the heat supply to the consumer for its utilisation in his premises will thus vary to some extent according to the form of supply and to the type and cost of the equipment that it is necessary to install. With some forms of heat supply, this equipment cost is comparatively low, but because of the higher cost of the supply associated with the less expensive equipment, there is little, if anything, gained by this lower cost. The extra cost to be borne by the consumer is derived from the amortisation of the capital expended on the equipment installed and its operating cost, and when this annual expenditure is related to the consumer's annual heat demand, the supplementary cost per therm may be ascertained.

The extra cost of making use of the supply is least when this is provided by gas and electricity because the expense of the necessary appliances is less. For this reason householders wishing to minimise capital expenditure choose one of these two supplies, preferring to pay more for the heat as it is used rather than invest more capital in a method assuring greater overall economy.

It is desirable to be reasonably accurate in estimating the capital expenditure involved, as the final cost of the heat supply must vary from that estimated according to the difference between the actual and estimated amount of expenditure. If, for example, capital costs are under-estimated, and are exceeded in actual expenditure by 10%, the resultant increase in the heat supply cost would amount to about 5%. The total expenditure for civil and mechanical engineering works—the latter of which will also include electrical services—needs to be shown separately so that the relevant amortisation periods may be applied.

The estimation of operating costs being largely dependent upon the amount and cost of the fuel used, the heat generation efficiency, and the operating personnel required, requires care to be exercised in the quantities used for these four items if the results are not to be misleading. The same applies to the consumption of electricity for auxiliary equipment, the cost of which may also be influenced by the Electricity Board's tariff selected. To complete the estimate of the annual operating cost, an amount to cover wages and stores, repairs and maintenance and rates, insurance and administration should be included.

The costing of the fuel requires special attention, as it is a heavy item of expenditure in the operation of the plant, and a small variation in its purchase price can have a significant effect on the cost of the heat supply. The ultimate cost of using the fuel being governed by its quality, the quantity bought, distance delivered and the unloading, storage, and feeding requirements, calls for a close examination of these factors before deciding about the economic value of a fuel when used under specific circumstances.

In order to secure the best terms in the purchase of fuel, it may be desirable to enter into an agreement with the supplier for some years. This enables special rebates to be offered by most suppliers who undertake to maintain them throughout the agreement period. At the same time an 'escape' clause in the agreement permits the purchaser to cancel the agreement if it can be shown at any time that more favourable terms can be obtained elsewhere.

The cost of the electricity consumed can also be appreciable, and the estimated quantity allowed should be based upon a close assessment of the running times of auxiliary plant and other power requirements (See Appendix E.) For the maximum saving of electricity, automatic speed reduction of the motors may be a worthwhile feature, together with time switching, and this might include changing daily to off peak supply periods to make use of the lower tariff applicable.

The wages to cover the attendance of a plant for its current operation should be costed on the assumption that it will be continuously manned on a 3 shift working basis, with an extra man to stand in when workers have their weekly days off duty during a 40 hour working week. One man per shift is normally sufficient when the plant is fully mechanised and under complete automatic control. Of the four men employed one should be fully skilled and the others semi-skilled workers able to carry out routine inspection and maintenance duties. In some circumstances it may be sufficient to man the plant only during the day time.

The relevant particulars of the main items of cost are detailed in the example shown in Table 2 of Chapter 4, according to the development periods applicable, to illustrate how these items affect expenditure and the cost of heat supply for each phase of development, when related to the respective annual heat demands. The total annual costs are divided into fixed and variable amounts, as these will subsequently need to be applied separately in fixing the tariff for the heat supply.

It is important to regulate the capital expenditure for plant according to the rate of development of the project so that the outlay incurred is restricted, as far as possible, to the amount necessary for each phase of development. In this way only sufficient main plant is used to meet the current heat demand to ensure obtaining the best load factor, and this has the effect of reducing the higher average charge for the heat supply that it is necessary to impose during the development period. Despite this arrangement all of the initial plant cannot be made appropriate for the first phase only, and is common to the requirements of full development, and this is one reason for the higher cost of the initial heat supply. Another is because it is not practical to extend the size of the central station building at the start of each new

Table 5

ESTIMATED ANNUAL EXPENDITURE AND REVENUE ON FULL DEVELOPMENT OF UNDERTAKING WITH 5% VARIATION OF INTEREST ON CAPITAL EXPENDITURE FOR CENTRAL BUILDINGS AND PLANT

Expenditure	*Amount per annum*		*Revenue*	*Amount per annum*	
	Minimum Interest £	*Maximum Interest* £		*Minimum Interest* £	*Maximum Interest* £
Capital Charges on Generation and Transmission	21,760	28,550	Sale of 963,170 therms at 15d/therm	60,220	
Working costs on generation and transmission for 1,011,320 therms sent out*	36,380	36,380	Sale of 963,170 therms at 16·7d/therm		67,010
Balance in hand for Contingencies and/or Reserve	2,080	2,080			
	£60,220	67,010		£60,220	67,010

*The difference in the number of therms sent out and the number sold represents the loss in transmission.

The above example shows the variation to be expected in the sale price of heat with interest rates of 10 and 15% for th ecapital cost of central buildings and plant and 6% on remainder of installation.

development phase which results in space and chimneys not being fully utilised initially. A third reason is that the station staff may be under-employed until the project is fully developed.

The division of the total annual costs into two parts to represent the fixed and variable amounts of expenditure is apportioned according to their share of the full costs entailed. The ratio of fixed to variable costs will fluctuate during each development period as the heat demand changes, and when this is increased to the maximum at the end of the period the proportion of fixed costs becomes less. Covering the fixed costs by a separate standing charge to the consumer ensures that these are met irrespective of the number of heat units sold under the running charge, which is made sufficient to balance the cost of fuel, electricity, repairs and maintenance.

Appendix D shows an example of how the principal items of cost may be set out to arrive at the annual expenditure incurred.

With known total annual costs, a statement can be made of the estimated annual expenditure and revenue on the full development of the undertaking, according to the amount of heat supplied, in the way set out in Table 5. This shows a small addition to the capital charges and working costs, to provide a balance in hand for contingencies and/or reserve, and includes transmission losses, to give the total expenditure to be covered by revenue. The sale price of the heat is therefore that much more than the supply cost, and this price is increased as required for a profit-making undertaking within the economic price structure for other methods of heat supply.

It is convenient with a district heat supply to separate the cost of generation from that of transmission to ascertain that the apportionment of the total cost between them is realistic, and also for administrative purposes. The cost ratio will show if the expenditure on transmission is appropriately relevant, and may also indicate some error in the costing of the transmission network. It may also be desirable to know what cost is to be borne by the producer and by the distributor when responsibility for the heat supply is to be divided between two different Authorities.

Because the economics of a scheme depend so much upon the cost of the transmission mains, it is prudent to make a preliminary appraisal of this expenditure before estimating the cost of the boiler plant to see if it is likely to represent a reasonable increase of the heat production costs in current use, so that the total costs may be appropriate. This can be done by approximating the cost of the transmission network on the basis of the cost per therm transmitted according to the annual heat demand, so that when this cost is added to the production cost per therm the total cost is known. Table 6 gives an example of this procedure. If the heat production cost is low, as with thermal-electric generation, the greater will be the margin available for heat distribution.

Table 6

PRELIMINARY ESTIMATED COST OF HEAT TRANSMISSION WITH MAINS IN UNDERGROUND R.C. CONDUITS

1.	Total length of transmission mains	5 miles
2.	Average diameter of transmission mains	6 in
3.	Capital cost of pumps and mains with all fittings and insulation	£132,000
4.	Capital cost of underground concrete conduits including valve and expansion chambers	£105,000
5.	Total capital cost	£237,000
6.	Annual cost of mains and conduits, amortised at 6·18% for 60 years	14,600
7.	Annual cost of electricity for pumping, and maintenance	2,800
8.	Transmission heat loss, 8% if at 10d. per therm	£6,600
9.	Total annual cost	£24,000
10.	Total annual heat supply, therms	2,000,000
11.	Cost of transmitting heat per therm (Item 9 ÷ Item 10)	2·88d
12.	Cost of heat production per therm, say	10·00d
13.	Total cost of production and transmission, per therm	12·88d

Table 7 serves as an example of the approximate comparative costs of combined heat and electricity generation, and direct heat generation, and shows the three separate unit prices applicable to each method of supply. The actual costs may vary from those shown according to the particular circumstances involved, and the particulars given are, therefore, intended to illustrate the method of presenting the information required for comparison purposes, and not to show the difference in the costs themselves. The extra cost represented by the difference between Items 2 and 3 of the Table is an indirect charge to the consumer, normally included in the rental value of the premises, or otherwise covered by the annual cost of the property to be met by the owner. It is not, therefore, an element of cost in fixing the price to be charged to the consumer for the supply of heat, but is used for comparative purposes as previously mentioned.

Comparisons in the cost of using different forms of heat supply cannot be very exact because of the many variable factors that apply to each method. The comparisons, however, will show if the difference in cost is more than sufficient to cover marginal inaccuracies, and adequate enough to merit the use of district heating, and also allow for any profit making that may be required. The figures will also make apparent the wide difference in cost of the most and least expensive forms, which is not generally appreciated in considering the economics of a heat service.

Table 7

APPROXIMATE COMPARATIVE COSTS OF COMBINED HEAT-ELECTRIC AND DIRECT HEAT SUPPLY METHODS

Item No.	*Cost Division*	*Cost of useful heat in pence/therm for the method of supply:*	
		Heat-electric	*Direct Heat*
1	Generation (Producer)	6—9	10—13
2	Generation and Transmission (Distributor)	10—12	14—16
3	Generation, Transmission and Utilisation (Consumer)	16—18	20—22

The actual cost of the heat depends upon such variables as the size and type of installation, its thermal efficiency, the district served and the fuel price rebates applicable.
Item 3 in representing the ultimate cost to the consumer should be used in making comparisons of the costs of other methods of supply. These may range from about 30d. to 50d. per therm.

Considerable care is necessary in assessing the thermal efficiency of each method of heat supply, as upon this will depend how much useful heat will be obtained from the fuel consumed and therefore the cost of the effective thermal unit purchased. The more expensive heat sources need to be provided with accurate means of automatic time and temperature control, so that they may be used without waste, and the saving thus made usually justifies the cost of the necessary control equipment. This should be included in estimating the capital cost of the heating installation to give comparable results.

The heat cost comparisons, such as those shown in Table 7 do not reveal the full financial and other benefits accruing from a district heating service. One of these benefits is a further saving in cost, often made possible by the avoidance of heat wastage by consumers; by the more precise automatic control facilities that can be included in the capital cost of the installation. Another is the saving in the cost of space in buildings for plant, fuel storage and chimneys, when independent boiler systems are dispensed with. A third is the elimination of a serious fire risk. There is also the advantage, with a district heating service, of a full and continuous supply during the worst Winter conditions, obviating the need to use alternative forms of heat at these times. These four incidental items of cost are considered in some detail in the following paragraphs.

Because of the lower cost of district heating, it is possible for the charges made for the supply to cover the cost of providing suitable equipment to ensure a standard of automatic control above that normally given by other methods of heat supply. By this means not only is the optimum economy secured in the use of the heat, but also ideal conditions of comfort are assured.

When costing, for comparative use, independent methods of heat supply such as with separate central heating plants in each building, it is necessary to include the extra expense of providing the structural additions for the boiler house, fuel stores and chimneys, and also of the space requirements of these items. The rising cost of land, especially in towns and cities, has much increased the rentable value of the floor area of buildings, and when this is reduced by the requirements of boiler plant, allowance should be made for the corresponding loss of income in assessing the annual costs applicable.

One of the intangible costs involved with a heat supply is that concerned with the risk of fire, which is of some significance with certain methods of supply. The losses incurred by fire may be considerable, as they are seldom fully covered by insurance, and any means available for their prevention merits careful consideration. Heat that is procured by combustion on the premises of solid, liquid and gaseous fuel, whether in boiler houses or in individual room appliances that provide an incandescent form of heat, including those using electricity, are never free from some danger of fire, despite any safety precautions that may be taken. Because this risk can be avoided by district heating, there is an intrinsic monetary gain by its use which cannot be evaluated.

During prolonged severe Winter weather conditions, it is often impossible to maintain normal supplies of the various fuels to individual consumers because of the sudden rise in demand exceeding the resources available for supply and delivery. On occasions such as these it is frequently necessary to boost the normal supply by other means of heating to restore the customary temperature level. This can involve the use of supplementary heaters and eventually meeting of a heavy bill for the alternative fuel consumed. A district heating system cannot be overloaded by sudden rises in heat demand because it is designed to provide sufficient heat output for the maximum needs of each consumer when the outdoor temperature is at freezing point.

Chapter 9

MEASUREMENT OF HEAT CONSUMED

The information given in Chapter 3 concerning the control of the heat supply shows the advantage gained if control facilities are extended to small consumers, such as private dwellings, shops and offices, so that they may benefit from metering just as larger consumers do. The reduction in the total amount of heat consumed has been shown to be enough to justify the expense of providing both the measuring device and that entailed in its current operation.

The meter, being the alternative to the imposition of standard charges for the heat supply, is a sound reason why the different measuring methods should be closely examined to find one that is able to satisfy the needs of both the supplier and the consumer. In the past there has been no moderately priced and efficient heat meter available to measure comparatively small heat quantities, but recent developments in metering techniques have produced devices that are both relatively inexpensive and sufficiently reliable to provide the information required for charging purposes.

Individual control of the supply, made possible by metering, affords the means of curtailing the amount of heat that would otherwise be given under the control of the supplier, so that all consumers benefit when using a full standard of heating. The amount of benefit, however, is correspondingly increased for those consumers who do not require a full standard because they are satisfied with lower temperatures and/or a shorter duration of supply, such as when their premises are not occupied throughout the day.

With an unmetered supply the supplier is obliged to provide heating for a period long enough to satisfy the majority of consumers, which is often more than enough for the average consumer. This difference in heat quantity can be saved by metering, so that the average consumer no longer subsidises the minority who require a longer period of heating both daily and from Autumn to Spring time, and who consequently pays that much more for the service.

How much money can be spent in providing a metering service for the smaller consumer will depend upon his annual heat demand. The greater this is, the greater will be the saving of heat when metered, and thus a larger amount of money will be available for the metering service. The amount of heat consumed in the average dwelling allows for the use of only a moderately priced meter, in the region of £15 to £20, unless the unit heat cost of a particular scheme is low enough to permit the use of a more accurate and costly meter. Until a reliable meter is obtainable within this price range, it is necessary, therefore, to simplify the measuring device for some of the smaller consumers. This can be done by using an inferential method of measurement that does not register actual heat units, but records the near equivalent of the quantity of heat consumed on a time or water volume basis.

Some of the inferential methods to be described depend upon the maintenance of a constant flow water temperature in order to simplify measurement, by reliance either on a time or water quantity basis for computing the amount of heat used, whilst others depend on a controlled return water temperature. A constant flow temperature also allows the use of a less expensive heat meter when this is provided with a single temperature sensing element.

An effective inferential method can be provided for space heating by measuring the length of time the heat supply is used by means of an hour meter (or elapsed-time counter, as it is sometimes called). This device is connected in the electrical supply circuit to the motor of the hot water circulating pump, or to a diverting valve when used, as shown in Fig. 18. For a ducted warm air system, the meter is connected in the circuit to the delivery fan. The meter, therefore, simply measures the total number of hours the system is switched on by the air thermostat for the delivery of heat, and it cannot take full account of the consumer's control of the individual heaters. It will thus be realised that the meter indirectly indicates the amount of heat used throughout the whole building according to the temperature selected on the thermostat, which can also be used to switch the whole supply on and off as the consumer desires.

Recording the length of time that a constant flow water temperature is supplied to heaters of a specific output is a method that can provide a fair measure of the heat supplied when all the heaters are in use and is the least costly form of heat measurement when this need not be of the highest accuracy. The cost of an hour meter is about £3.

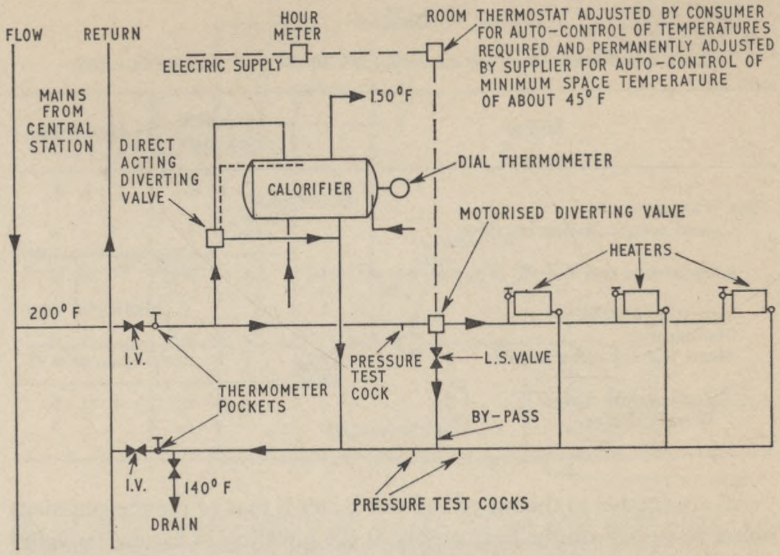


Fig. 18. *HEAT MEASUREMENT BY HOUR METER AND DIVERTING VALVE. Diagram of consumers installation showing arrangement of circuits and valves*

An hour meter may also be used in conjunction with a diverting valve to show the period of time that heat is supplied for hot tap water when an individual calorifier is provided for each consumer. Alternatively, the heat consumption may be assessed according to the storage and re-heat capacity of the calorifier, or a water meter in the cold water feed to the calorifier may be used for measurement, although this will take no account of fluctuations in storage water temperature.

Hour meters should be positioned within the thickness of a conveniently situated external wall of the building, so that they may be easily seen by the reader. This saves his time and avoids delays that could be experienced in obtaining access to the buildings. When hour meters cannot be positioned so that they can be read from both inside and outside each building, they may be grouped together at some central position in the block, and housed in a lockable cabinet for easy viewing by the meter reader. Some hundreds of meters can be contained in a space of a few cubic feet.

Table 8

COST OF METERING WITH MECHANICAL HEAT METER AND WITH HOUR METER

Method	*Mechanical Heat Meter*			*Hour Meter*		
	£	s.	d.	£	s.	d.
PER DWELLING						
Capital cost, including installing	40	0	0	6	0	0
Amortisation cost at 8·7% (6% p.a. over 20 years)	3	10	0		10	6
Operating Cost:						
Maintenance	1	0	0		5	0
Meter reading and accounts	1	0	0	1	0	0
Total annual charge	5	10	0	1	15	6
Weekly charge		2	1			8

An alternative to the use of an hour meter is that of the pre-payment meter to switch on the heat supply at the insertion of a coin, its value determining the amount of heat provided. This method of paying for the service eliminates the accountancy otherwise entailed, the services of the weekly meter reader being replaced by those of a collector to empty the coin box. In the coldest weather it would be necessary to insert several of the largest coins accepted by the meter in order to meet the heat demand of the larger dwellings. Some consumers may regard this as an inconvenient way of paying for the service.

Table 8 shows a comparison in the cost of using a heat meter and an hour meter on a housing estate of 700 dwellings. It will be seen that the weekly charge for the metering service is appreciably less when an hour meter is used, and represents only a small proportion of the total weekly charge for the heat supply.

An alternative and more accurate method of inferential heat measurement for space heating and for hot tap water supplies is by the use of a water flow meter, and thermostatic control valves in the return circuit from the heaters. The thermostatic valve automatically maintains a set return temperature which enables the water volume to be reduced as its temperature tends to rise with diminishing heat output, and this is reflected in the quantity of water metered. This method is shown in Fig. 19.

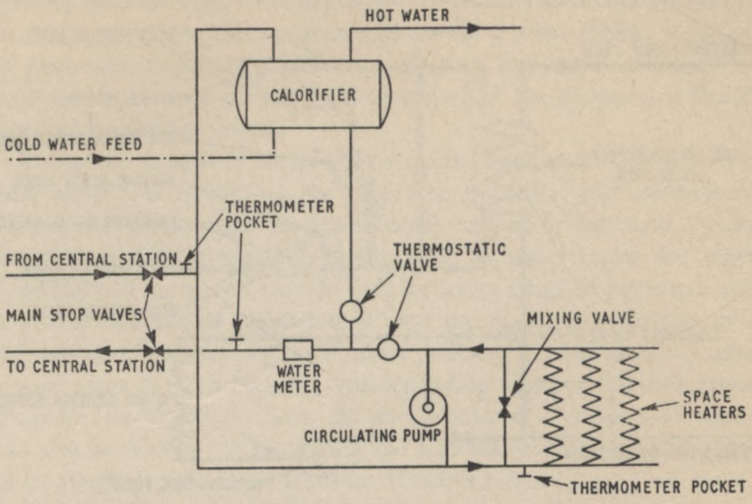


Fig. 19. *HEAT MEASUREMENT BY WATER METER AND THERMOSTATIC VALVES. Diagram of consumers installation showing arrangement of circuits and valves*

When each room heater is provided with its own adjustable thermostatic valve, this can be used, instead of a single thermostatic valve in the return mains, for controlling the water quantity circulated to meet the prevailing heat demand, but the results will not be quite so accurate.

Another arrangement to facilitate metering is to provide hot tap water from a non-storage calorifier connected in series with the high temperature circuit for space heating. The temperature of the hot water supply is maintained nearly constant by intermixing this with some of the cold water supplied to the calorifier passing through a thermostatic blending valve. During the hot water supply peak periods there is a temporary loss of heat for space heating, but this has no detrimental effect if the capacity of the equipment is adequate. This instantaneous method of heating the cold water supply, in providing a constant flow temperature, enables a water meter to be used for measuring the hot water supplied to each consumer when space heat is charged at a flat rate, and, in general, is an arrangement less costly in plant and space than the more conventional methods. A diagram of the circuits is shown in Fig. 20. Using a supply connection that is common to both space heating and hot water supply might, under some conditions, enable both services to share a heat meter when its range is wide enough to handle both Winter and Summer duties without loss of accuracy.

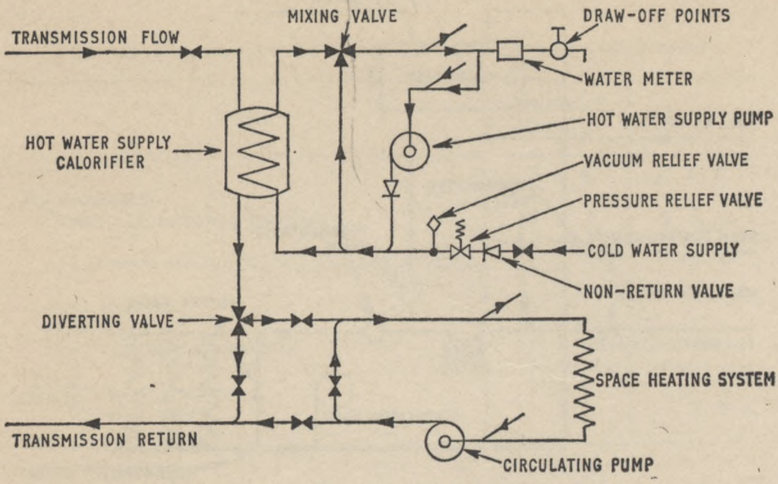


Fig. 20. *HEAT MEASUREMENT OF HOT WATER SUPPLY BY WATER METER. Diagram of consumer's installation showing arrangement of circuits and valves*

Space heat supplies may also be measured on an inferential basis by the use of a device fitted to each radiator and working on the evaporation principle. For measuring hot tap water the distillation principle is used. The 'meters' are normally read annually when the ampoules registering the amount of heat used are changed. This system of measurement is of continental origin and, if necessary, may be installed and operated by the suppliers on behalf of the heat supply undertaking.

Evaporative meters for measuring space heat are usually provided on each radiator, although one type may be installed for each room. The liquid level in the meter, as affected by evaporation when read against a vertical scale, indicates the intensity and duration of heating, and thus the relative quantity of heat used. Some types of evaporative meters may be subject to interference by consumers, whilst others are fitted with a patent lock and sealing device requiring a special key for reading and servicing. Hot tap water distillation meters fitted on the incoming supply to each consumer use a venturi tube, restrictor flange, or pitot tube to obtain a fixed proportion of the water consumed to indicate the amount of heat used according to the quantity of liquid distilled by various means.

There are various types of conventional mechanical and electrical heat meters for measuring the supply to industrial and commercial consumers, when quantities are sufficient to justify their cost. They function within acceptable tolerances of accuracy under the right conditions of use which include both a correct range of operation and a proper amount of maintenance. For steam measurement, a self-contained, self-operated type of meter provides a better accuracy over a wide range of flows than the type depending on an orifice differential pressure and electrical drive. As an alternative, a condensate meter can also be reliable for measuring the amount of steam used, because of its simplicity of design and ease of maintenance.

Electrical heat meters, which are all broadly similar in construction and depend upon electrical or electronic integration for measurement direct in heat units, consist of a system of several separate components. These comprise a flow transmitter meter and indicator, a Btu integrator, a Btu recorder, electrical resistance thermometers and a venturi or orifice plate with pressure connections. Additional components, if required, include a flow recorder for use with a roll-chart. The cost of these meters ranges between about £400 and £600.

Heat measurement with hot water, when the best accuracy is required, as with large heat quantities, is best done with an electrical type of heat meter, but for average requirements the less expensive mechanical type should give the better all round service.

Mechanical meters, in dispensing with electrical means to effect the integration of the two variables, require less components, and are consequently less expensive than electrical meters, and, sometimes, more reliable. They are connected direct in the pipe line and consist essentially of three main parts; the temperature sensing elements, flow meter and Btu computer. The range of sizes varies according to make,

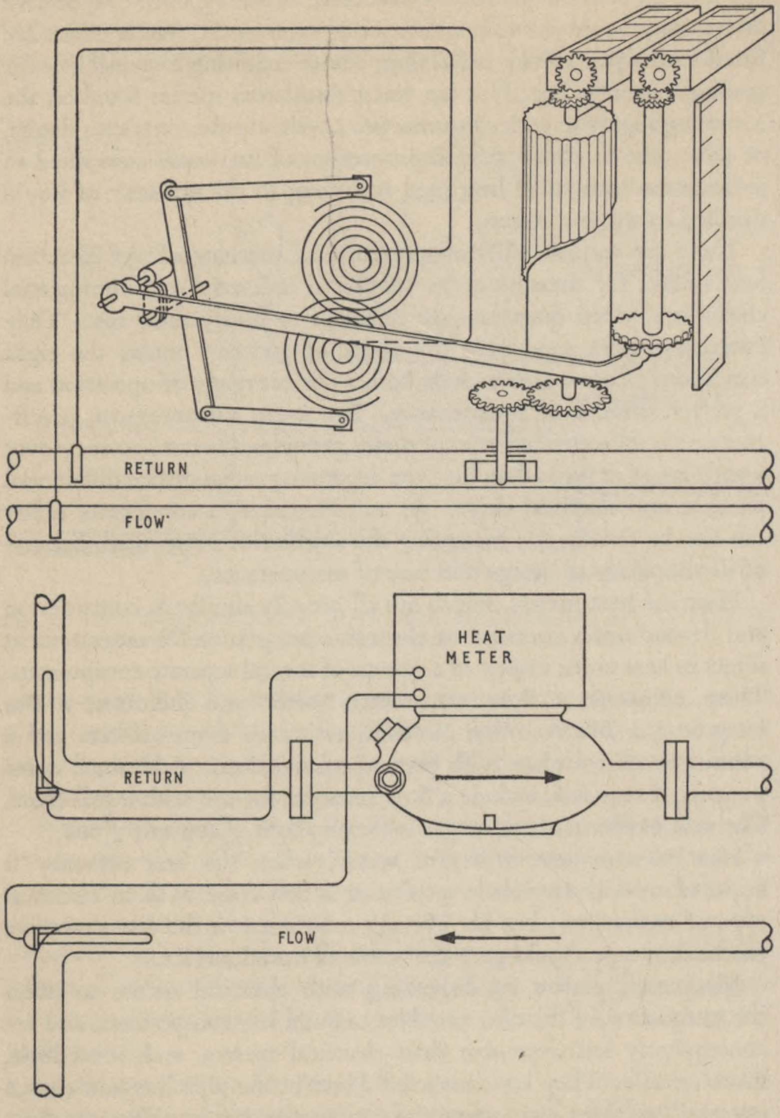


Fig. 21. MECHANICAL TYPE OF HEAT METER. *(Above) Arrangement of measurement and indicating mechanism. (Below) Assembly of meter and probes in pipe lines*

and the cost from about £30 to £300. This kind of meter, which has undergone much research and development in recent years to reduce its cost and improve its reliability to meet the increasing demands for its use, is produced in a number of variants, one of which is shown in Fig. 21.

A new design of heat meter eliminating the use of a water flowmeter and mechanical integrator, has been developed by the British Coal Utilisation Research Association, and is now undergoing final trials in the field. The relatively simple and inexpensive mechanism appears to give a close integration of water flow and temperature difference as recorded by a watt-hour meter. The design of the meter enables the product of flow and temperature to be measured directly by by-passing a small proportion of the return water and re-heating it to the inlet flow temperature by a small immersion element, automatically controlled by a bellows-operated switch. The bellows are connected by capillaries between two vapour pressure phials—one in the by-pass tube and the other in the flow main. The electricity used by the element is a measure of the heat taken from the flow by the consumer.

Another new type of heat meter for both space heating and hot water consumption has been developed in Denmark, and is claimed to measure heat quantities accurately. It operates on the thermo-electric principle by the use of thermo-couple elements fitted to the radiator and the adjacent wall, the amount of heat given off being expressed by the temperature difference of the two elements, their number of thermo-junctions and by time. The total current generated by all the thermo-couples is measured by an electrolyte meter, the sight glass of which is calibrated in thermal units to give a direct reading of the heat used after multiplication by a single digit factor.

In prescribing the standing charge to apply to each consumer, which is done on the basis of the fixed cost of the heat supply, the expense of administering the metering service has to be taken into account. This comprises the following items:

1. Inspection and maintenance of the meters
2. Periodical meter reading
3. Collecting charges and crediting any repayments.

The amount of time necessary for 1. will depend upon the method of measurement used. An hour meter will require comparatively little attention, whereas a hot water flow meter may require recalibration and replacements every few years if it is to continue to give accurate results.

The expense involved for the inspection and maintenance of the meters is consequently least for an hour meter, as this should give many years of reliable service without attention. Allowance should be made, however, for the replacement of a small number of these meters during the first few years of use, when they are liable to become defective.

The amount of maintenance required for hot water flow meters varies according to the make used and how they are serviced. Users' experience of these meters over several years suggests that good results are obtained providing pre-installation inspection and testing is adequate, and if routine maintenance is carried out at regular intervals. Little breakdown maintenance was required for the different types of faults which developed, as these were few and infrequent. This also applied to mechanical heat meters.

Meter reading can become an expensive item of a metered service, unless it is done at infrequent intervals, because of the time spent in gaining access to internal meters owing to the large proportion of consumers who are away at work all day. When the meters can be read externally, when for example they are situated outside for ease of access, or are all centralised in some convenient position, the time required for reading is much reduced and can be done more frequently.

Meter reading at six-monthly intervals is considered to be adequate for the purpose of making any adjustments to the charge when paid weekly by residential consumers by the method shown in Table 11. The same frequency for commercial and industrial consumers would enable any adjustments to be made to the alternate charges paid quarterly and based on an estimated consumption.

The accountancy work entailed in billing charges, collecting the money and making any repayments due, will depend upon the method of charging adopted. The least expensive one is for the charge to be paid weekly as a supplement to the tenants' normal rent.

Chapter 10

CHARGES FOR HEAT SUPPLY

To remain solvent, a heat supply undertaking must ensure that income balances expenditure, both during the period of development of the service and upon its completion. To achieve this, the methods adopted for charging the consumer and for collecting the amounts due must be carefully considered. The tariffs to be applied however are, in general, similar in basic principle to those of the electricity and gas supply boards.

Charging for a restricted heat supply which is under the control of the supplier presents little difficulty, as the charge is a standard one calculated on the basis of the maximim amount of heat that can be used by each consumer. The tendency to impose overcharging when fixed rates are used in order to cover excesses in heat demand can, however, be reduced by restricting the amount of hot water included in the rate to a maximum quantity. Unlike space heating, the quantity of hot tap water used can much exceed what is considered to be the normal maximum amount required because of the extravagant or wasteful habits of some consumers. This excess consumption when recorded by a water meter can thereby be paid for as a supplementary charge to the fixed rate covering the normal quantity.

With a consumer-controlled supply, the circumstances are entirely different, both in regard to the charge to be made and the way in which this is collected. This involves matters such as how much use each class of consumer makes of the supply, their ability to pay for what they use and, in consequence, the frequency of collecting the dues.

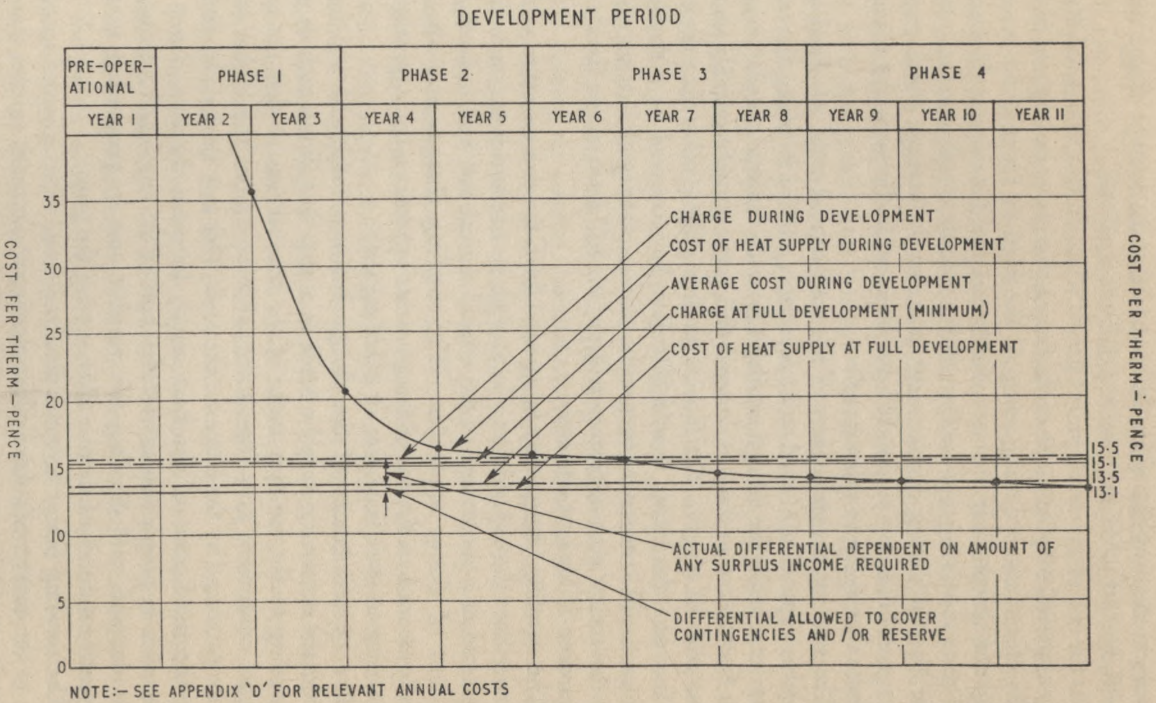
Dealing first with the net total charge per therm applicable, it was seen from the example given in Table 2 how this is derived from the total annual cost and the annual heat demand during the various periods of development. In order to keep the charges for the heat at a reasonable level throughout the development period, the capital expenditure is apportioned, as far as practical, according to the requirements of each stage of development. This will not, however, prevent some inflation of the supply cost during the earlier part of the development period on account of the relatively higher capital and operating expenditure at that time; and to avoid unduly high charges to the consumer at this time it is necessary to allow a deficit in revenue to accumulate and for this to be recouped during the later development period. By this means the charges may be stabilised at a fixed amount throughout development, with each consumer contributing fairly to the development costs irrespective of the time of first taking the supply.

As is to be expected, the cost of the heat diminishes as the demand increases until the end of the development period, when it reaches a minimum. The difference between the initial and the final cost is affected mainly by how much the load varies from start to finish, and how closely the load can be matched by the plant installed for each development period to minimise capital expenditure. The greater loss in revenue occurs during the early part of each development period when the plant is not fully loaded, and a full return on the capital invested is unobtainable.

Table 2 has shown that in the particular example given the maximum capacity of the plant during the 4 development periods increased 7 times that of the initial capacity, but the corresponding increase in total annual annual costs was only a little over 5 times. This gives an indication as to how much the total charge for the supply can be reduced as the size of the system is increased.

To determine the proper charge applicable throughout development it is necessary to aggregate the annual cost of the supply year by year over this period, according to the variation in capital outlay (and including extra interest payment during loss period), operating costs and in heat demand, and relate the total sum to the corresponding total amount of heat supplied. The resultant cost per therm will represent the average charge to produce sufficient income to meet expenditure.

The sum total of the costs to be incurred each year for the heat thus shows the true amount of expenditure to be met during the entire development period for the relevant quantity of heat supplied, and it



NOTE:– SEE APPENDIX 'D' FOR RELEVANT ANNUAL COSTS

Fig. 22. HEAT COSTS AND CHARGES. *Graph showing variations in cost per therm during phases of development*

is only in this way that it can be ensured that the average charge made is sufficient to cover the total expenditure involved.

At the end of the development period when the heat cost is stabilised, a re-appraisal may be made of the future charges to be imposed in the light of current operating costs, or the need to increase the reserve fund and also possibly operate in future as a profit making undertaking.

Fig. 22 shows in graphical form how much the supply costs may vary year by year during development, and also the average development charge and that applying to full development in the particular circumstances that apply to this example.

The two main components of the total annual costs, i.e. fixed and variable expenditure, need to be separately applied in fixing the tariff in order to make the charges equitable for each consumer, and to ensure that fluctuations in the heat demand will not react unfavourably on the economics of supply. The fixed costs, being those other than the cost of fuel and electricity, should therefore be recovered by a standing charge to the consumer irrespective of the quantity of heat supplied. By this means each consumer will pay his full share of the fixed cost regardless of his heat demands.

The standing charge may be assessed from the cost estimates which should show the expenditure allocated to the relevant items, and when expressed as a percentage of the overall annual cost will indicate the amount of charge applicable. The standing charges may also be finally assessed on the size of the consumer's premises, and apportioned according to their floor area or cubic capacity.

The apportionment of the charge between residential and non-residential consumers may be made in a way that allows each to pay according to the use they make of the heat service, so that the residential consumers may have some advantage from the higher load factor produced by the domestic demand. This may be done by dividing the fixed costs of the heat supply between the two classes of consumer in proportion to their fraction of the combined maximum heat demand, and dividing the variable cost in proportion to the respective number of therms taken during the year.

The standing charge to cover the fixed costs, when adjusted according to the consumer's share of the maximum demand, ensures that he contributes fairly towards the cost of the plant necessary for his particular requirements. In this way industrial consumers, for instance, who require appreciable quantities of heat for relatively short periods will pay more of the fixed costs than other consumers because of the peak nature of the demand.

Some adjustment of the charge made to residential consumers may also be considered desirable to compensate for inequalities in heat demand because of the type and situation of the building occupied. This applies to multi-storied blocks of flats where, for instance, the heat loss of a corner flat on the top floor can be appreciably more than one situated more centrally near ground level. It may be said that the flat with the greater heat loss provides the superior accommodation because of its elevated position and the tenant should be expected to pay more for this privilege. On the other hand the tenant may have been given no choice when the flats were allocated, and may have preferred one that was thermally more economic.

Today consumers have little choice in the amount of the charge made if they occupy a building of the latest design. Modern architecture in building high and embodying such features of construction as curtain walling and excessive glazing increases the capital cost of both heating or cooling installations and their costs of operation. These differences in the thermal characteristics of buildings erected today and those of conventional design formerly built react to the disadvantage of the occupier, who now pays considerably more for much the same air conditions as before.

The economic and other advantages gained by the consumer with a district-heat supply, as compared with the usual alternative independent methods of supply would permit the charge for district heat to be fixed not much below that expected for the alternative methods, and consequently more than the actual cost of the district heat supply. This method of charging would have the effect of producing a surplus of income if this was desired.

It is reasonable to suppose that commercial consumers in particular when supplied with district heat could afford to pay almost the same as for the next more expensive conventional method of supply in view of the greater advantages accruing from the use of district heat. On this assumption, the cost per therm supplied could be increased by up to 20% to show a substantial profit on the sales of heat.

The three alternative methods of charging, which indicate the range of price that might apply, are shown in the example in Table 9.

Table 9

ALTERNATIVE CHARGES FOR HEAT SUPPLY TO RESIDENTIAL AND NON-RESIDENTIAL CONSUMERS ON FULL DEVELOPMENT

Item No.	*Method of Charge*	*Charges per therm d.**		*Surplus Income/p.a.*
		Non-Residential Consumers	*Residential Consumers*	
1	When fixed and variable costs are equally divided between consumers	15·0	15·0	Nil
2	When fixed and variable costs are apportioned relevant to the two consumers demands (See penultimate para, page 98)	15·4	12·8	Nil
3	As for Item 2 above when consumers are charged as for the method† of heating next lowest in cost, less say 10%	18·0	18·0	£14,000

With an annual heat demand of 1,000,000 therms.
*Excluding annual charges for equipment in consumers premises.
†Oil or coal fired central heating.

Table 10

QUARTERLY CONSUMPTION BLOCK RATE CHARGES

Therms	*Price per Therm d.*
For the first 100 i.e. from 1 to 100	14·0
,, ,, next 200 ,, ,, 101 to 300	13·5
,, ,, ,, 500 ,, ,, 301 to 800	13·0
,, ,, ,, 800 ,, ,, 801 to 1,600	12·8
,, ,, ,, 1,200 ,, ,, 1,601 to 2,800	12·5
,, all over 2,000	12·2

Because the cost of producing a thermal unit is reduced as the demand increases, thus cheapening the supply as the result of the improved load factor, it is logical to offer consumers some inducement to use more heat by charging less for the greater amount consumed.

This may be done by using a block rate tariff that allows the charge to diminish progressively when the amount of heat consumed exceeds the minimum quantities scheduled during quarterly periods, as shown in the example in Table 10. Some variations may be made in the charges to commercial and industrial consumers on account of the different conditions under which the supply is given.

This method of charging is not only an incentive for the average consumer to benefit from the more liberal use of heat at a lower price, but it also serves as an inducement for the large potential heat consumer to be connected to a district-heat supply.

It is not, of course, possible to foresee how the cost of the heat supply may be affected later by different circumstances, and although the estimated cost should include a small margin for contingencies, this may not be sufficient to cover all eventualities. Some small revision of the scale of charges may therefore be necessary to meet such items as increases in the rate of interest at which money can be borrowed; increases in the cost of fuel and electricity together with those of constructional materials and labour during the course of development; and delays in the building programme causing a greater accumulated deficit before the undertaking could be self-supporting. Under some circumstances it may not be necessary to recoup all the accumulated deficit during the development period, and losses may be allowed to continue for several years longer before the account is balanced and thus enable a reduction to be made in the charges.

The arrangements made for reading meters and collecting payments vary according to the different classes of consumer. The heat demands of industrial consumers and most of the commercial consumers are large enough to justify the use of a conventional heat meter which may be read at the usual quarterly or half yearly intervals, and charged accordingly.

The requirements of residential consumers are somewhat different and need special treatment. Many of the residential consumers would be in the lower income group and accustomed to arranging their finances on a weekly basis, making it desirable for them to pay for the heat supply weekly. If dues are allowed to accumulate, many would have difficulty in finding the money, owing to other commitments such as hire purchase. In order, therefore, to keep both bad debts and administration costs to a minimum, the method of determining and collecting the charges should provide for as little meter reading as possible, and facilities for consumers to pay for the heat with their weekly rent.

Although the cost of the heat supply is greater during the Winter than the Summer (because of the much higher demand), it is a convenience for the lower income group tenant to be able to pay for the heat received throughout the year by equal weekly instalments. This is another reason why the pre-payment meter method of collecting charges may be considered undesirable.

The amount of the weekly payment to be made should be assessed

Table 11

PROPOSED WEEKLY CHARGES FOR CONSUMERS ACCORDING TO HEAT DEMAND

1\. Supply cost per therm = 14·6d.
Sale price per therm = 15·0d.

2\. Let estimated annual heat demand for average consumer = 500 therms

$$\therefore \left\{\frac{500\times 15}{52\times 12}\right\}\text{ s.} = \text{12s. 0d. per week}$$

3\. Total annual costs on full development:
Fixed £6,864 = 35% } of total costs
Running £12,620 = 65% } of total costs
£19,484

4\. Standing charge = 12s. 0d. × 0·35 = 4s. 3d. per week
Running charge = 12s 0d. × 0·65 = 7s. 9d. ,, ,,
Running charge proposed to cover excess over estimated consumption say = 8s. 6d. ,, ,,
Add standing charge as above = 4s. 3d. ,, ,,
Total charge to consumer, initial = 12s. 9d. ,, ,,

5\. Cost per therm to cover running charges only, for purpose of adjusting weekly payments every 6 months:
15·0d. × 0·65 = 9·75d. per therm

6\. On the assumption that the metered quantity is only two-thirds of the estimated consumption during 6 months, the running charge over this period amounts to:

$$\left\{\frac{500\times 0{\cdot}67}{2}\right\} = \text{168 therms at } 9{\cdot}75\text{d.} = \text{£6 16s 6d.}$$

Amount actually paid by consumer over 6 months = 8s. 6d. per week × 26 = £11 1s. 0d.
Amount of half yearly refund = £4 5s. 6d.

so as to cover the highest average heat demand expected from any one consumer. This would subsequently be adjusted in accordance with the actual measured quantity of heat supplied by means of a half-yearly or yearly refund. Table 11 shows a method of calculating the initial weekly charges with heat at a sale price of 15d. per therm, and the amount of refund that might be applicable.

It is seen in the example of assessing the weekly charge that a standing charge of 4s. 3d. per week is included to cover the fixed costs, which represent 35% of the total costs of the heat supply. The half-yearly refund would not normally be paid in cash, but credited to the consumer by adjusting the subsequent weekly charges.

The amount of the weekly charge will depend upon whether or not the supply is metered and, if metered, upon the method used. The charge also varies according to the size of the building. Table 12 serves as an example to show the charges applicable for space heating and hot tap water, and how these compare with those for rent, rates and water included in the total weekly payments. The charges apply to an unmetered heat service provided by thermal-electric generation.

Table 12

WEEKLY RENTS, RATES AND HEATING CHARGES

Type of Flat	*Maximum Rent*	*Rates and Water*	*District Heating and Hot Water*	*Total Weekly Payment*
	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Bed-sitting room	1 14 0	4 0	6 9	2 4 9
2-room	2 5 0	4 9	12 5	3 2 4
3-room	2 16 0	6 7	15 1	3 17 8
4-room	3 7 0	7 8	17 10	4 12 6
5-room	3 18 0	8 10	1 0 3	5 7 1

Chapter 11

MISCELLANEOUS REQUIREMENTS

In planning and costing a district heating system it is important not to overlook items of expenditure ancillary to the main work. In relation to the boiler plant, for example, it is necessary to include all the civil engineering work necessary for its accommodation and operation. The extent of this work will vary with the design of each installation, with the class of fuel to be used, the facilities to be provided for its unloading and storage, and the type of chimneys deemed necessary. The installation of the transmission mains may necessitate the building of sub-stations, underground pipe conduits, and their associated structures. Foundations for heat accumulators and oil storage tanks may also be necessary.

The boiler house dimensions should be adequate to house not only the plant but also an office and, washing and changing facilities. The height of the building depends upon the type of boilers used and the fuelling arrangements, which vary over fairly wide limits. The floor structure may require heat insulation if it is to be in direct contact with the boiler bases, and generous openings should be provided in the wall or roof for the entry of combustion air. Permanent or semi-permanent openings are also necessary for the moving in and out of plant.

The proximity of the central station to adjacent buildings will determine if it needs any special acoustical treatment. This may entail the provision of special insulators for plant mountings to eliminate vibration, and sound absorbing materials for walls and roofs. Other incidental items of work include cable and pipe ducts, sumps, bases for boilers, when required, and for pumps.

The level of the central station may be influenced by the nature of the sub-soil, and the consequent cost of excavation. When solid fuel is to be used, for example, it may be economical to lower the floor below the surrounding ground level in order to minimise both the capital cost of plant and the mechanical power required for elevating the fuel. The fuel bunkers should be large enough to store not less than two days' supply at full load, and the overhead ash hopper to have sufficient capacity for about a week's storage. An access roadway for fuel delivery vehicles, with ample turning space, is also required.

When the situation of the central station does not permit oil storage tanks to be exposed to view, these will require screening or housing above or below ground level. In the latter case the brick or concrete chambers should be provided with enough space on all sides of the tanks for welding of the plates, for interior access, and for draining facilities below. As an alternative to the use of tank chambers below ground level, and one that may prove to be more economic in annual costs, the tanks may be constructed of suitably lined concrete in direct contact with the soil, and provided with the necessary access and service manholes at ground level.

The opportunity may be taken here, in connection with oil fuel storage, to show by example the advantage of making a close examination of the costs entailed in using alternative auxiliary plant for different purposes. Despite the higher capital cost of the plant, because of the way it is installed and the materials used, the total annual costs are sometimes found to be lower than the alternative of lower capital cost, when the operating and maintenance expenditure also is taken fully into account. This becomes apparent, for instance, when comparing the relative costs of providing storage for the oil in steel tanks exposed above ground with those of concrete tanks cast *in situ* underground. It is seen that although the capital cost of the tanks underground is more than of those above ground, because of the former's longer life expectancy, there is little difference in the amortised costs. They also entail lower operating costs owing to the negligible oil heat loss and less maintenance (because there is no paintwork to deteriorate), making the total annual costs that much less. These may be further reduced when there is no loss in land value by using the extra ground area made available to obtain income from ground rents or car parking charges. This is made clear in the comparison shown in Table 13.

The number of chimneys required for a boiler plant, their dimensions especially height, and the form of construction, vary considerably according to circumstances. Under some conditions the chimneys may form an integral part of a tower building, and in other cases they may be erected as independent structures containing one or more flues such as shown in Fig. 23.

The provision of a chimney of the appropriate height is important in order to avoid the nuisance of smoke, including large particles of oily acidic carbon, and also, grit and dust not removed by the arrestment plant. The approximate height, which depends upon such factors as the amount of sulphur dioxide emitted, and the efflux velocity, can be calculated by a relatively simple method described in an official publication connected with the *Clean Air Act*.

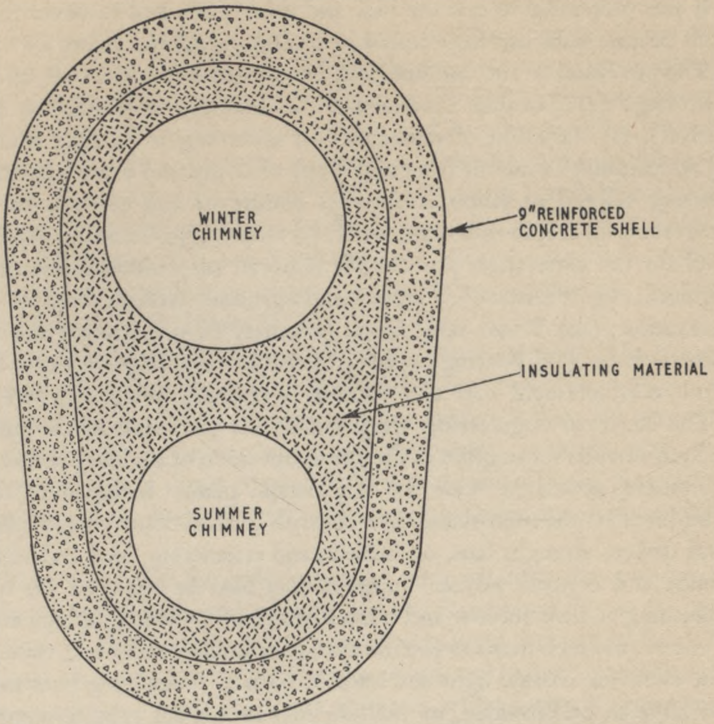
The provisions necessary for underground pipes will mainly depend upon the method adopted for their insulation and where they are situated. Some methods require excavation only, others both excavation and some refill. Each will need extra excavation to form welding bays at suitable intervals and also accessible valve chambers, which may also accommodate expansion bellows. Substantial concrete blocks for anchorage fittings are required at regular intervals.

When mains are to be installed in underground conduits, they should preferably be constructed of waterproofed concrete with rod or steel-mesh reinforcement as required for the loads to be imposed.

Table 13

RELATIVE COSTS OF FUEL OIL STORAGE TANKS WHEN INSTALLED OVER AND UNDERGROUND

Cost Item	*Position and Material of Tanks*	
	Overground, Mild Steel	*Underground, Concrete*
Capital Cost	£8,500	£9,500
Amortisation Cost:		
over 20 years	740	
over 60 years		590
Operating Cost	300	30
Maintenance Cost	80	Nil
Loss in ground value, say	500	Nil
Total annual Cost	£1,620	£620



APPROXIMATE SURFACE TEMPERATURE CONDITIONS BASED ON SURROUNDING AIR TEMPERATURE OF 50°F AND INTERNAL CHIMNEY TEMPERATURE OF 550°F

Insulation Construction	*Interface Temperature i.e. Inside Face of Shell*	*External Shell Surface Temperature*
4½ in Insulating brickwork	170°F	70°F
6 in Insulating brickwork	135°F	65°F
6 in Insulating concrete	175°F	75°F
9 in Insulating concrete	145°F	70°F

Fig. 23. *TWO FLUE CONCRETE CHIMNEY.* ***Sectional plan view of chimney of independent construction***

It is also preferable to cast the base and sides *in situ* and to cover these with precast slabs carefully sealed in position at all the joints.

The provision of the conduits will be affected by factors such as the followng: (1) Locality (availability of building materials in the district); (2) Variation of materials cost according to haulage limits; (3) Availability of labour force; (4) Type of bonus and other incentive schemes offered to labour force; (5) Nature of soil or rock to be excavated; (6) Depth to be excavated; (7) Suitability of existing ground level for the excavation process; (8) Amount of protective hoarding required; (9) Presence of other underground services hampering excavation; (10) Water table levels (necessity of de-watering during construction); (11) Bearing capacity of the ground; (12) Necessity for extra reinforcement of the conduit if passing under roadways.

The electrical engineering work entails the provision of the main and sub-circuits for supplies to the numerous items of ancillary electrical equipment associated with the mechanical plant. Included in this equipment are the motors and their controls for fuel conveyors, mechanical stokers, draught fans, oil burners and circulating, feed and sump pumps and control valves. Supplies may also be required for oil-preheating at tank outflow and burner heaters, for tracing oil lines and, of course, for such items as thermostats, instruments, recorders, meters, time switches, clocks, light and audible signals. Telephone lines may also have to be provided, or G.P.O. lines rented for remote control and indication. An example of the loadings that may be required for an oil-fired boiler plant is given in Appendix E.

Some of the electrical equipment may be situated remotely from the central station, as when it is used in sub-stations; or it may be in the plant rooms of consumers' premises to transmit information about operating conditions there. Items such as temperature compensators may be supplied as complete units, pre-wired at the factory, thus requiring only connection to the supply terminals. The preparation of a schematic wiring diagram is necessary to show the circuits to be provided for the various items of equipment.

The equipment to be installed throughout will also entail the use of various building trades such as bricklayers, concreters, carpenters, painters and plumbers. A brief summary of the items applicable is given in Appendix F. This is usually referred to as 'incidental builders' work'.

The satisfactory completion of the entire plant also requires the inspection and testing of materials, and workmanship, to ensure that proper standards are maintained throughout the course of construction. The services of an insurance company and the fees applicable should also be covered by the cost estimates, and an adequate sum allowed especially for the inspection and testing of welds in the transmission mains. Particulars of a welder's test are given in a typical insurance company's report in Appendix G. The mains should also be heat tested by the use of a mobile heating unit before insulation is applied. Examples of specification clauses applicable to welding test requirements are given in Appendix H.

Provision should also be included for water treatment. The coloration of the circulating water is desirable for detecting leakage in heat exchangers, and also in underground conduits where it is necessary to differentiate between system and soil water. A small dose of a fluorescein dye of about 50 ppm. (1 lb per 10 tons of water) is sufficient treatment of the water for the colour to be revealed by an ultra-violet lamp.

Water treatment for scale formation depends upon the quantity of make-up water used, and when this is less than about 1% of the total content of the system, scale formation should be negligible. To prevent corrosion it may be desirable to use a chemical to remove the oxygen and to ensure that the condition of the water is maintained correctly, frequent samples need to be tested by a *p*H value indicator. Bacterial contamination of the water can produce a black sulphide sludge, and this may be troublesome if allowed to accumulate. The bacteria cannot exist unless the water temperature is below about 200°F, and district-heating systems would therefore be immune and not require chemical treatment other than for secondary circuits.

The kind of water treatment for steam systems will depend upon the quantity of feed water used and its chemical analysis.

To comply with statutory requirements and be acceptable to the local authorities, whose approval is necessary before erection commences, certain matters must be taken into account. The *Clean Air Act 1956*, for example, makes it an offence for new furnaces to be installed if they are incapable of operating without emitting smoke when burning the fuel for which they were designed. The regulations prescribe the requirements to be observed in regard to boilers, fuels, flues, dampers and instruments, and include reference to apparatus for indicating and/or recording the density or darkness of smoke emitted from any furnace. 'The Notice of Intention to install Furnaces' calls for a number of technical details of the plant to be provided before the approval of the local authority can be obtained. The design of heating, ventilating and air-conditioning equipment in the consumers' premises may also be affected by the current *Factories Acts 1937 and 1948; The Offices, Shops and Railway Premises Act 1963*, and the Construction of Industrial Buildings by the *Thermal Insulation* (*Industrial Buildings*) *Act 1957*.

The establishment of a heating authority to provide a public supply in an existing urban area may necessitate obtaining special statutory powers to facilitate putting the scheme into effect. One example of this is the *London County Council* (*General Powers*) *Act 1949*, which provides that the heating authority shall give to the appropriate ministers and to the relevant statutory undertakers notice of their proposals, and supply any such information to them as may be reasonably required.

Chapter 12

CONCLUDING COMMENTS

The last chapter finished with a reference to the heating authority that must be responsible for the establishment and working of a district heating undertaking, and some comments can now be made about the authority's constitution and functions. In the past the body that initiated a district heating scheme also often undertook the administration of the service; whilst in other cases the developers had only a partial interest in the inception of a scheme, and delegated to others the responsibility for administering the service.

There are several different ways in which a district heating service may be promoted and operated, each of which depends to some extent upon the kind of service provided, and for whom it is intended. When the service, for instance, is intended exclusively for use in government property, it is usual for it to be provided and operated by a government ministry. For local government buildings, municipalities generally assume responsibility for the entire project, except when private premises are also supplied. In this case responsibility terminates at the consumer's supply connection. In other circumstances the local authority may undertake only to distribute the heat from a central station provided by a separate organisation which generates the heat only and guarantees its supply under agreed terms of use.

Many more district heating schemes will, no doubt, continue to be established and operated in much the same way as before, and although the schemes have been generally satisfactory in the past, there may be some doubt as to whether they will continue to serve the public's best interest, owing to the more stringent economic conditions which must prevail in the future, and thus the need to make the best use of the country's energy resources.

Circumstances such as these suggest that a heating authority might function best as an entirely independent private body, with power to develop projects in different areas in close collaboration with other public utility undertakings such as gas and electricity. This could secure a fully co-ordinated plan and avoid unnecessary competition, overlapping and duplication in the provision of heat services. Policy decisions would have to be made on whether or not consumers should be given the choice of alternative methods of heat supply, other than for cooking, on the standards of heating applicable, and on the metering of supplies and fixing of tariffs. Such a consortium type of organisation as this, with a status similar to a development corporation and empowered to act on equal terms with statutory supply undertakings, could not only plan new schemes with the optimum overall economy, but also act as a fuel utilisation efficiency controller to maintain heat production and transmission at an economic level in the current operation of the service.

It is a curious anomaly that we should have national boards to look after the supply of electricity, gas and coal for conversion into heat by various means when, the supply of cheap ready made heat in the form of steam and hot water, is left to others to provide as best they may. A heat authority that could also carry out research, development and capital investment on a national scale, could do much to enhance the value of district-heating services with the improvements that must ensue.

Further deliberation on this subject might enlarge the terms of reference of the authority to enable it to allow a project to develop according to requirements. One consideration here is the need to ensure that the contractural procedure adopted is in accordance with the overall planning requirements of a scheme and does not, therefore, allow estimates of the capital costs of a project to be grossly exceeded by the acceptance of excessively high tenders. Restrictive practices have been known to produce tenders for even a moderately sized installation which were many tens of thousands of pounds in excess of current market values, and it was only by adopting special remedial measures that such prices were brought down to a commensurate level that was about half the amount of the original tenders. It is clear that if the economics of a scheme are not to be jeopardised in this way, the awarding of contracts needs careful and informed consideration. The re-introduction of bills of quantities might be one way of abolishing 'price fixing', much of which has arisen to obviate the high costs entailed in competitive tendering, due to the large amount of unproductive work undertaken by contractors. The contract work would need to be covered by a full set of working drawings for the preparation of accurate bills of quantities for realistic pricing by a quantity surveyor, the rates used being supported by a schedule of basic prices. Selective tendering may also prove to be one form of precautionary measure, and a negotiated price another, the latter, perhaps, being subject to the 'target cost' system of payment. The alternatives of fixed and variable price contracts should also be considered to procure the best results.

Another function of a heating authority would be to develop the greater use of district heating by extending the service in several different ways, and thus improve the economics of a scheme. The greater diversity in heat demand resulting, for example, from roadway heating for over- and under-passes, which require the greater heat supply overnight to prevent ice formation, and for snow clearance, improves the load factor and, incidentally, effects considerable economy compared to present methods. The heating of terraced pedestrian ways and shopping arcades and precincts in new town centres, bus shelters, swimming pools, sports stadiums and horticultural and poultry houses are other examples of how a district heating service could be profitably extended. Agriculture could also benefit from district heat by improved crop growth and its drying.

Investigations into new ways of providing and installing the heat transmission mains from the central station to consumers could result in a reduction in this part of the cost of providing the heat supply. In theory it would appear economic for all underground services to share a common conduit, but in practice there are several objections to this arrangement, and supply undertakers are consequently reluctant to co-operate on this basis. Because of the critical importance of heat transmission costs, a new concept of integrated design is required to facilitate the construction, siting and erection of the mains with a proper regard to economic and aesthetic needs. We have become accustomed to the sight of electricity pylons and overhead transmission lines throughout the countryside, which suggests that the appearance of district heating transmission mains on roadway verges or railway embankments and elsewhere would soon become accepted as part of the landscape. Mains in built-up areas which are normally run underground would be less costly to provide if they were erected alongside walls; on roof flats or in roof spaces, passing from one building to another at high level, and with suitable architectural treatment to harmonise with the surroundings.

It has been suggested that new towns of the near future, provided with a monorail service, offer a good opportunity for transmission mains to be accommodated conveniently as part of the monorail supporting structure. In this way the mains could be used to heat rail points to prevent freezing, and also the stations en route.

The increasing output of factory-produced building units to speed the erection of houses and other buildings, offers still further scope for connecting them to centralised heat supplies. In the process of prefabrication, the wall and floor components could quite cheaply include pipes for the circulation of hot water, or ducts for the circulation of warm air, instead of these being embodied sometimes on the site, so that these components might themselves serve as heaters. They could also be made of materials, including multiple glazing or metal coated heat reflecting glass, for improving standards of heat insulation generally. It has been estimated that at little extra cost the thermal insulation could be improved sufficiently to reduce heat requirements by some 20%, which represents an appreciable reduction in the heat load of a central station.

A further question is whether the heat load of the future can be met in other ways than by energy derived from fossil fuels, residual oil or nuclear power. At one time it appeared feasible that an alternative source might be the underground gasification of coal, but extensive field trials of this method have proved it to be impractical. Natural gas also appears to be non-existent in this country. Nevertheless, there are underground heat sources in the form of hot water and steam that have been used for some time to provide a heat supply for towns. One example is at Reykjavik, the capital of Iceland, where the supply is piped for some miles from geothermal springs. Power generation from geothermal heat has been provided on a substantial scale for some time in Italy and also at Wairakei in New Zealand. In Britain an apparently everlasting supply of hot water exists at the Spa of Bath, where the yield of volume and temperature is constant at 500,000 gal. every 24 hours at a maximum temperature of 120°F. It has been calculated that by the use of a heat pump this hot water would be able to supply space heating for about 5,000,000 ft^3 of office or living accommodation.

Oil and natural gas prospecting now is progress in the North Sea, and using the latest techniques of seismic geophysics, may reveal an abundance of these fuels and also steam or hot water. The latter may eventually be found offshore or inland, and thus provide a convenient source for district heating.

Terrestrial heat is the only other known natural source of supply, and although solar radiation has been used in a small way for heating water, it cannot yet be regarded as a practical method for large heat supplies, because the rate of heat collection would be inadequate. The temperature climate of this country, lying so far north of the equator, would not provide sufficient heat to justify capital outlay for the solar energy absorber equipment required.

Whatever new sources of heat may emerge in the future, there is much that can be done at present to ensure that better use will be made of those now available, especially as is possible with combined heat and power generation.

In this latter connection it has been pertinently remarked that an engineer may well question a system that involves the loss at the power station in flue gases and cooling water of two-thirds of the heat in the fuel. This lack of efficiency in conventional electricity generating plant is still little realised by the public nor its significance appreciated by the ordinary householder. It does, however, emphasise the importance of achieving a greater conservation of fuel especially of an indigenous nature, and of the benefits that would ensue both for the nation and the individual.

To absorb most of the heat that could be made available by the future generation of electricity as a by-product would be a very gradual process indeed, and could extend over the better part of a century. During this time it is envisaged that the greater part of most towns would be rebuilt, and if this were done from the start in conformity with a co-ordinated plan for the economic provision of public utility services, district heating could be fully utilised as part of the electricity generation. Much earlier results in a smaller way would be obtained in connection with the many new towns to be built within the next decade or two to accommodate the steady rise in population.

The planning of new towns is known to provide the means for the economic use of district heat, and some progress is already being made for this reason, but a great deal more would result from a fuller realisation of the relative merits of the various forms of heat supply.

The sources of heat at present available have enabled the exploitation of district heating to meet the needs of consumers whose chief concern is to have a heat supply that provides the maximum of comfort and convenience at an economic cost. For comfort the level of space temperature must be adequate even in the coldest weather and at the same time the supply must also be reliable and continuous and, therefore, not subject to interruption of any kind. Convenience means the service must possess entirely automatic features for its operation so that there is no need to manipulate switches, valves or air dampers, handle fuel, clean and adjust combustion appliances, or call the fire brigade! An economic cost implies that all the above requisites are obtained with the least expenditure, not only by the individual consumer, but also by the general public who are indirectly affected by the use of a particular supply method. Examples of some of these indirect expenses are atmospheric pollution, renovations caused by dampness in insufficiently heated buildings, and loss of time by traffic congestion in the delivery and unloading of fuel to buildings.

As the advantages of district heating become better known, it is more widely used, and for other than economic reasons. A method of heat supply, for instance, that is intrinsically safe in use, removing the hazards associated with other methods, such as electrocution, asphyxia, poisoning, fire and even hypothermia. Although many of the deaths from hypothermia have been accidental and resulting from the inadequate scale of clinical thermometers, it is not a little surprising that they should occur at all in an affluent society, from exposure to cold that is not outside but inside of buildings due to a shortage of heat.

If consumers are to have all the heat they want, it must be provided and used under the right conditions, otherwise its cost becomes prohibitive. To ensure that a given method of supply is economic as well as able to provide the full quantity required, the ultimate cost of its utilisation by the consumer must be competitive with other methods for the same heat demand. The heat demand in this context is the usefully consumed amount, and not the quantity supplied, which depends upon the thermal efficiency of the method used. The cost per therm of useful heat may also differ because of the expense of the consumer's installation and its maintenance, and for these three reasons the final cost per therm for one method may be found to be two and three times as much, or more, than for another. Much of this cost differential is due to variation in the purchase price per unit of heat of the different fuels. This makes the supply less costly with coal and oil than with gas and electricity at present prices. Each of these forms of heat supply will be found to have certain advantages in particular circumstances, and upon these will depend which method provides the most advantages at the least cost.

Because there are so many variable factors involved in the purchase of heat, it is prudent to make a careful appraisal of each supply method to ascertain how much of the heat supplied may be effectively used by the consumer, and at what price. There are many methods of heat supply in use today that fail to measure up to the standard required by consumers, either because they are obliged to use a method not of their own choice, or because they have chosen one with insufficient knowledge of its limitations.

Decisions as to the form in which heat is to be supplied and used are affected by factors which may be political, social or economic. This has resulted in recent years in a variety of methods being adopted throughout the country according to the relative importance attached to each of these factors. What is considered a suitable method for one locality may be regarded as inappropriate for another of apparently similar circumstances, and the reasons for this are often obscure. One explanation may be that those responsible for selecting the method to be used have experienced difficulty in obtaining reliable and complete information on the other systems and appliances available. These are becoming increasingly complex.

Even today, in the construction of many large buildings, we persist in using space heating methods that we know should be prohibited by law in the interests of national economy because they are grossly extravagant in the use of fuel and thus inflate the price of heat.

The relatively slow development of district heating in this country has been attributed to various causes, but on a close examination of these there appears to emerge only one of any validity. This is the failure

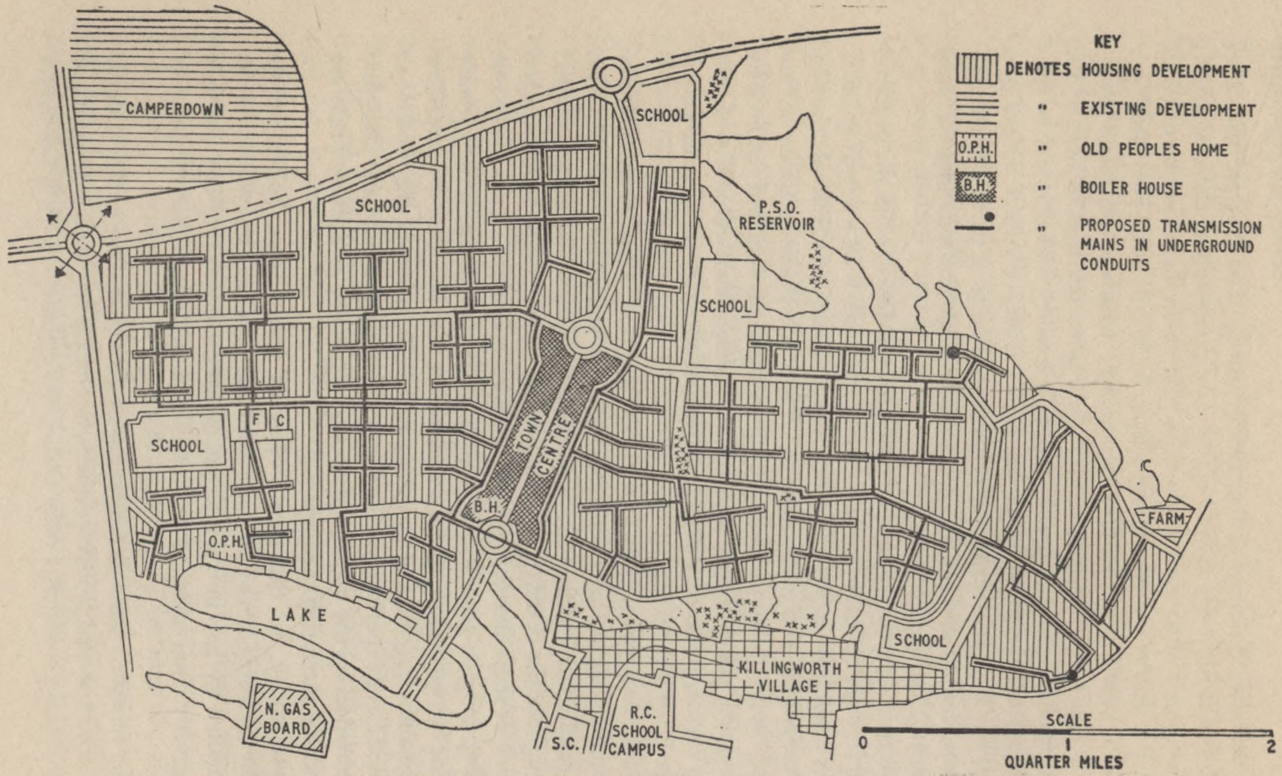


Fig. 24. SCHEMATIC PLAN OF KILLINGWORTH TOWNSHIP. *The inclusion in a district heating scheme of housing areas surrounding a town centre, can improve the economy of the heat service*

to fully exploit the best means available today to satisfy the rapidly increasing demand for heat.

In the past, the demands upon our fuel resources have been moderated by the working and living standards accepted by people generally. Today these standards are much improved by statutory regulations and individual demands, necessitating a considerable increase in heat supplies. These have been met in various ways without much regard to their effect upon the national economy or the individual, who is thus often deprived of a full measure of heat for the money he pays. Because of these circumstances the proper organisation of heat supplies is now acquiring increasing significance, and also because the rapidly developing progress in technology is changing the somewhat rigid attitudes previously held towards the implementation of new proposals.

The impact of these conditions has evoked a noteworthy response from discriminating developers. Being concerned with securing both the highest utility value from a completed project and capital investment with an assured adequate return, they have been responsible for providing district heating for a small minority in this country. Others now equally well informed in such matters have recently completed, or are proceeding with, district heating schemes, because of their ability to meet the most exacting demands of consumers at a highly economic price, as is shown by the almost universal demand for their use. A project under consideration is seen in Fig. 24.

The money spent on a well designed, installed and economic district heating scheme is a sound investment and one that we can no longer afford to ignore in the interests of national economy. For this reason it is an obligation of those responsible for the provision of public utility services to assure themselves of the economics, convenience and reliability of the heat service contemplated for a given project so that it may be certain to provide the greatest benefits for the greatest number of people.

The few thousand residential consumers in this country who have lived for many years with efficient district heating are unanimous in their praise of the convenience and reliability of the service, and particularly of its economy, which they claim is much superior to any of the other methods that they had previously.

GLOSSARY

BACKGROUND HEATING The maintenance of a continuous minimum temperature usually below that required for sedentary occupation.

BOARD OF TRADE UNIT See 'Unit'.

BRITISH THERMAL UNIT (Btu) A heat unit representing the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

CALORIFIC VALUE A measure of the heat content of fuel expressed in Btu/lb.

CALORIFIER An appliance for the transfer of heat in steam or water to water without intermixing.

CO_2 Chemical formula denoting carbon dioxide.

CONDUCTION The transfer of heat between two bodies in contact with each other.

CONVECTION The transfer of heat by the circulation of a liquid or a gas such as air.

CORRECTED EFFECTIVE TEMPERATURE The effective temperature with allowance for radiant heat.

DEGREE DAY (BRITISH) The product of one day (24 hours) and 1°F difference of temperature between the base temperature and the average outside air temperature during the day when this is below the base temperature.

DRY BULB TEMPERATURE The temperature of air indicated by an ordinary thermometer.

EFFECTIVE TEMPERATURE An index of the effect produced by a combination of temperature, humidity, and air movement.

EQUIVALENT TEMPERATURE An index of the effect produced by a combination of temperature, radiation, and air movement.

HEAT A form of energy associated with matter and characterised by temperature.

HUMIDITY An admixture of water vapour, and dry air.

KILOWATT-HOUR (kWh) =1,000 Watt-hours=3,415 British Thermal Units.

LOAD FACTOR The ratio of the average load to the maximum load during a prescribed period of time, usually expressed as a percentage.

MEAN RADIANT TEMPERATURE The sum of the products of surface temperature and surface area surrounding a space divided by the surface area.

*p*H VALUE A number expressing the active acidity or alkalinity of an aqueous liquid.

PLENUM A space under pressure used as a chamber from whence air is distributed in ducts.

RADIATION (THERMAL) The transfer of heat through space by wave motion.

RELATIVE HUMIDITY The ratio of the actual vapour pressure in air to the vapour pressure of saturated air at the same temperature, expressed as a percentage.

TEMPERATURE A measure of the degree of heat having no relation by itself to quantity.

TEMPERATURE GRADIENT Variation in the air temperature of a heated space on a vertical or horizontal line.

THERM (Th) A unit of heat measurement equivalent to 100,000 Btu.

THERMAL CONDUCTIVITY (*K*) Quantity of heat expressed in Btu which will pass through one square foot of material one inch in thickness in one hour for one degree Fahrenheit difference of surface temperature.

THERMAL TRANSMITTANCE (U) Quantity of heat expressed in Btu's which will pass through one square foot of material in one hour for one degree Fahrenheit difference of air temperature.

THERMOSTAT A heat regulating instrument, actuated by temperature changes, and used for automatic control purposes.

TOPPING-UP HEAT The extra heat required for a comfortable temperature in a room when occupied.

WET BULB DEPRESSION The difference between dry and wet bulb temperatures.

WET BULB TEMPERATURE The temperature indicated by a thermometer having its bulb covered by a wet wick.

UNIT (BOARD OF TRADE) An electrical unit of measurement equal to one kilowatt maintained for one hour. Equivalent in heat to 3,415 Btu.

VENTILATION The supply or removal of air to or from a space by natural or mechanical means.

APPENDICES

Appendix A

PIMLICO DISTRICT HEATING UNDERTAKING
SCHEDULE I—DISTRICT HEATING OPERATING RESULTS

Item		*Units*	*Derivation*	
1	Beginning of operating period			1st Oct.
2	Termination of operating period			30th Sept.
3	Maximum rate of heat supply	Therms/Hour	Meter readings	480
4	Quantity of heat sent out from supply point	Therms	Meter readings	1,489,146
5	Number of hours in period	Hours	–	8,784
6	Length of time heat was supplied	Hours	Log Sheets	5,298½
7	Heat lost between supply point and pump house during running hours	Therms	(6)× 2·989*	15,837
8	Heat lost between supply point and pump house while shut down	Therms	See Note 6	12,254
9	Total heat loss between supply point and pump house	Therms	(7)+(8)	28,091
10	Above heat loss as percent of heat supplied	%	(9)× 100÷(4)	1·886
11	(a) Heat received at Churchill Gardens pump house	Therms	(4)−(9)	1,461,055
	(b) Heat received at pump house, from meter reading	Therms	Meter Reading	1,474,154
12	Change in heat contents of accumulator	Therms	Log Sheets	+400
13	Heat loss from heat accumulator	Therms	(5)× 1·73*	15,197
14	Heat loss from accumulator as percent of heat supplied	%	(13)× 100÷(4)	1·021
15	Heat sent out from pump house	Therms	(11a)−(12)−(13)	1,445,458
16	Heat sent out to Dolphin Square	Therms	(19)+(17)	734,001
17	Heat lost by Dolphin Square transmission mains	Therms	(5)× 0·858*	7,535
18	Heat lost by Dolphin Square mains as percent of heat supplied	%	(17)× 100÷(4)	0·506
19	Heat received at Dolphin Square	Therms	Meter Readings	726,466
20	(a) Heat sent out to Churchill Gardens Estate	Therms	(15)−(16)	711,457
	(b) Heat sent out to Churchill Gardens Estate from meter	Therms	Meter Readings	651,245
21	Heat lost from Churchill Gardens distribution system	Therms	See Note 7	44,203
22	Heat lost from distribution as percent of heat supplied	%	(21)× 100÷(4)	2·968
23	Heat received in Churchill Gardens Flats	Therms	(20a)−(21)	667,254
24	Total transmission and distribution losses as percent of heat supplied	%	(10)+(14)+(18)+(22)	6·381

Item		*Units*	*Derivation*	
	DOLPHIN SQUARE			
25	Total heat received from district-heating supply	Therms	Item (19)	726,466
26	Number of flats occupied	Flats	–	1,220
27	District-heating supplied per flat	Th/Flat	(25)÷(26)	595·465
28	Average daily heat supply per flat	Th/Flat/Day	(27)÷Days	1·627
29	Average daily district-heat supply for hot water	Th/Flat/Day	See Note 8	0·902
30	Average daily district-heat supply for heating	Th/Flat/Day	(28)–(29)	1·246†
31	Average outside temperature at Pimlico	°F	Log Sheets	44·65†
32	Difference between indoor and outdoor temperatures	°F	64°F–(31)	19·35†
33	Daily district-heat supply for heating per °F difference	Th/Flat/Day/°F	(30)÷(32)	0·0644†
	CHURCHILL GARDENS ESTATE			
34	Total heat received from district-heating supply	Therms	Item (23)	667,254
35	Number of flats occupied (Average for month)‡	Flats	–	1,045–1,184
36	District heating supplied per flat	Th/Flat	(34)÷(35)	622·721
37	Average daily heat supply per flat	Th/Flat/Day	(36)÷Days	1·701
38	Average daily district heat supply for hot water	Th/Flat/Day	See Note 8	0·676
39	Average daily district heat supply for heating	Th/Flat/Day	(37)–(38)	1·762†
40	Average outside temperature at Churchill Gardens	°F	Log Sheets	44·65†
41	Average difference between indoor and outdoor temp.	°F	66°F–(31)	21·35†
42	Daily district heat supply for heating per °F difference	Th/Flat/Day/°F	(39)÷(41)	0·0825†

‡These are mean monthly figures for September and include 12 shops which are considered to be the equivalent of 3 flats.

NOTE: The Heat Consumptions given in Item 36 and subsequent items are somewhat low due to heat metering errors.

*Average heat loss from test results.
†Applicable to heating season only.

See overleaf for Notes 6, 7, and 8 referred to under *Derivation*.

The results were recorded over a period of five years but space permits the inclusion of those for the last year only.

Appendix A—*continued*

NOTES ON SCHEDULE I

Referred to under *Derivation*

Note 6. Several cooling curves for the river crossing mains have been obtained and heat loss curves on this basis have been constructed, so that the total loss of heat for any length of time after shutting down can be read off from the curves. Dividing the total time out of commission by the number of generating periods gives the average length of shut down; the heat loss appropriate to the average length of shut down is then read off from the curve and multiplied by the number of generating periods to give the heat loss while shut down.

Note 7. For the four years 1951 to 1955 the heat loss from the distribution mains at Pimlico was based as a rough estimate of 3·7 therms per hour. After the experiments on the electrically heated distribution mains this heat loss could be calculated more accurately and the figure for the schedule is based on this test data.

Note 8. During the summer months the district heating scheme supplies hot water service only, hence, if there is no seasonal variation in hot water consumption, the Summer figures can be assumed to apply to the Winter months.

Appendix B

PIMLICO DISTRICT HEATING UNDERTAKING
SCHEDULE II—WEATHER AND ADVENTITIOUS HEAT GAINS

Item		*Units*	*Derivation*	
1	Beginning of Operating Period			1st Oct.
2	Termination of Operating Period			30th Sept.
	WEATHER			
3a	Average outside temperature at Churchill Gardens	°F	Log Sheets	44·65*
3b	Mean dry bulb temperature at Kew	°F	Kew Observatory	42·48*
4	Mean depression of wet bulb at Kew	°F	Kew Observatory	2·7*
5	Mean relative humidity at Kew	%	Kew Observatory	79·20*
6	Solar radiation at Kew	$cal/cm^2/day$	Kew Observatory	131·76*
	ADVENTITIOUS HEAT GAINS DOLPHIN SQUARE			
7	District-Heating received per flat for hot water	Th/Flat	(29) (Sched. I) × Days	330·138
8	District-Heating received per flat for space heating	Th/Flat	(30) (Sched. I) × Days	265·327
9	Adventitious heat gain due to occupancy per flat	Th/Flat	See Note 9	30·000†
10	Adventitious heat gain due to solar radiation per flat	Th/Flat	See Note 10	80·000†
11	Tenants' gas supply	Therms	See Note 11	11·196†
12	Landlord's gas supply	Therms	See Note 11	12,998†
13	Tenants' electricity supply	kWh	See Note 12	2,134,458
14	Landlord's electricity supply	kWh	See Note 12	1,706,882
15	Adventitious heat gain due to tenants' gas supply	Therms	70% of (11)	7,838†
16	Adventitious heat gain due to landlord's gas supply	Therms	25% of (12)	3,250†
17	Adventitious heat gain due to tenants' electricity supply	Therms	90% of (13)	43,213†
18	Adventitious heat gain due to landlord's electricity supply	Therms	25% of (14)	9,202†
19	Total adventitious heat gain from gas and electricity	Therms	(15)+(16)+(17)+(18)	63,503†
20	Number of flats occupied	Flats	See Sched. I	1,220
21	Adventitious heat gain from gas and electricity per flat	Th/Flat	(19)÷(20)	52·051†
22	Total useful heat input per flat for heating	Th/Flat	(8)+(9)+(10)+(21)	427·378†
23	Mean temperature difference between indoors and outdoors	°F	64°F−(3a)	19·35*
24	Heat per flat per day per °F temperature difference	Th/Fl/dy/F	(22)÷[(23)× Days]	0·1037*

Item		Units	Derivation	
	CHURCHILL GARDENS ESTATE			
25	District heating received per flat for hot water	Th/Flat	(38) (Sched. I)× Days	247·461
26	District heating received per flat for space heating	Th/Flat	(39) (Sched. I)× Days	375·260
27	Adventitious heat gain due to occupancy per flat	Th/Flat	See Note 9	30·000†
28	Adventitious heat gain due to solar radiation per flat	Th/Flat	See Note 10	80·000†
29	Tenants' gas supply	Therms	See Note 11	41,398†
30	Tenants' electricity supply	kWh	See Note 12	909,506
31	Landlord's electricity supply	kWh	See Note 12	330, 253
32	Electricity supply to district heating pump house	kWh	L.E.B.	147,741
33	Adventitious heat gain due to tenants' gas supply	Therms	70% of (29)	28,979†
34	Adventitious heat gain due to tenants' electricity supply	Therms	90% of (30)	18,130†
35	Adventitious heat gain due to landlord's electricity supply	Therms	10% of (31)	690†
36	Total adventitious heat gain from gas and electricity	Therms	(33)+(34)+(35)	47,799†
37	Number of flats occupied	Flats	See Sched. I	1,045 to 1,183
38	Adventitious heat gain from gas and electricity per flat	Th/Flat	(36)÷(37)	45·129†
39	Total useful heat input per flat for heating	Th/Flat	(26)+(27)+(28)+(38)	530·389†
40	Mean temperature difference between indoors and outdoors	°F	66F°−(3a)	21·35*
41	Heat per flat per day per °F temperature difference	Th/Fl/dy/°F	(39)÷[(40)× Days)]	0·1166*

*Weighted Averages for Heating Seasons only i.e. Oct.—April inclusive.

See overleaf for Notes 9 to 12 referred to under *Derivation*.

†Applicable to Heating Season only.

NOTE: The Heat Consumption for Items 25 and 26 and subsequent items are somewhat low due to heat metering errors.

Appendix B—*continued*

NOTES ON SCHEDULE II

Referred to under *Derivation*

Note 9. According to Dr. Weston's estimate the body heat due to a family of two adults and two children for a house of 900 ft^2 floor area is 30 therms during the heating season. This has been divided between the 7 months of the heating season, in proportion to the number of days in each month.

Note 10. Dr. Weston's estimate of the heat gain due to solar radiation was 80 therms during the heating season. This has been sub-divided between the 7 months of the heating season in proportion to the solar radiation figures recorded at Kew, and the number of days in each month.

Note 11. These figures were supplied by the North Thames Gas Board who obtained them from quarterly meter readings and then sub-divided them into monthly gas consumptions.

Note 12. The units of electricity used during each month both by the landlord and tenants were calculated by the London Electricity Board from quarterly meter readings. The sub-division into monthly electricity consumption was done in proportion to the electrical demands on the transformer chambers supplying Dolphin Square and Churchill Gardens respectively.

Appendix C

PIMLICO DISTRICT HEATING UNDERTAKING

RESULTS OF HEAT LOSS TESTS CARRIED OUT ON DISTRICT HEATING MAIN AT CHURCHILL GARDENS, PIMLICO

General Formula for obtaining the Thermal Conductivity of Cork Insulation.
(For Units see third column in table below.)

$$k = \frac{q.\log_e[d_2/d_1]}{2\pi\,(t_1 - t_2)}\ \text{Btu/h/ft}^2/^\circ\text{F/ft}$$

6 in Nominal Bore Flow and Return Mains laid side by side in Concrete Duct of 97 ft 0 in. Length Extending East from Block No. 21.

	Item	*Symbol in Formula*	*Units*	*Period from 15th November to 1st June*	
				Flow Main	*Return Main*
1.	Duration of Test	–	Hours	4,728	4,728
2.	Length of Test Pipes	–	Feet	97	97
3.	Outside Diameter of Pipe	d_1	Inches	6·424	6·424
4.	Outside Diameter over Lagging	d_2	Inches	9·424	9·424
5.	Ratio of Outside to Inside Diameter of Lagging	d_2/d_1	–	1·467	1·467
6.	Hyperbolic Logarithm of Item 5	$\log_e [d_2/d_1]$	–	0·3834	0·3834
7.	Total Electrical Input	–	kWh	7,642	5,531
8.	Average Hourly Electrical Input	–	kW	1·616	1·170
9.	Hourly Heat Equivalent of Electrical Input	–	Btu/h	5,515	3,993
10.	Heat Input per foot run	q	Btu/h/ft	56·86	41·17

Item	Symbol in Formula	Units	Period from 15th November to 1st June	
			Flow Main	*Return Main*
11. Average Temperature of Inner Lagging Surface	t_1	°F	166·7	142·9
12. Average Temperature of Outer Lagging Surface	t_2	°F	77·9	76·8
13. Temperature Gradient Across Lagging	$t_1 - t_2$	°F	88·8	66·1
14. Numerator in General Equation	$q.\log_e [d_2/d_1]$	–	21·80	15·78
15. Denominator in General Equation	$2\pi (t_1 - t_2)$	–	558·0	415·4
16. Thermal Conductivity per Foot Thickness	k	Btu/h/ft^2/°F/ft	0·03907	0·03799
17. Thermal Conductivity per Inch Thickness	–	Btu/h/ft^2/°F/in	0·4688	0·4559

NOTE: **The appearance of four significant figures in the above quantities is merely computational, it does not imply a corresponding degree of accuracy. It is considered that Item 17 is reliable to two significant figures only.**

Appendix D

SUMMARY OF COSTS DURING DEVELOPMENT AND ON COMPLETION

1. CAPITAL COSTS

Item		*Year 1 Pre-Commissioning*	*Phase 1*		*Phase 2*		*Phase 3*			*Phase 4*		
			Year 2	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Year 8*	*Year 9*	*Year 10*	*Year 11*
		£	£	£	£	£	£	£	£	£	£	£
A	Boiler House & Chimney	114,268	–	–	–	48,972	–	–	–	–	–	–
B	Boiler Plant	72,292	–	64,130	–	64,130	–	–	32,648	–	–	–
C	Transmission Mains	70,800	66,600	84,900	55,150	48,350	72,100	30,600	36,110	28,390	21,710	–
D	Total Capital Costs	267,360	66,600	149,030	55,150	161,452	72,100	30,600	68,758	28,390	21,710	–
E	Cumulative Total Capital Costs	267,360	333,960	482,990	538,140	699,592	771,692	802,292	871,050	899,440	921,150	–

2. ANNUAL LOAN REPAYMENTS

Item		*Year 1 Pre-Commissioning*	*Phase 1*		*Phase 2*		*Phase 3*			*Phase 4*		
			Year 2	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Year 8*	*Year 9*	*Year 10*	*Year 11*
		£	£	£	£	£	£	£	£	£	£	£
F	Boiler House & Chimney	7,600	7,600	7,600	7,600	10,850	10,850	10,850	10,850	10,850	10,850	10,850
G	Boiler Plant	6,500	6,500	12,300	12,300	18,100	18,100	18,100	21,030	21,030	21,030	21,030
H	Transmission Mains	4,700	9,120	14,750	18,410	21,630	26,410	28,440	30,840	32,730	34,170	34,170
J	Total Annual Repayments	18,800	23,220	34,650	38,310	50,580	55,360	57,390	62,720	64,610	66,050	66,050
K	Cumulative Total Annual Repayments	18,800	42,020	76,670	114,980	165,560	220,920	278,310	341,030	405,640	471,690	537,740

(Based on money being borrowed at 6½% interest.)

Appendix D—*continued*

3. CUMULATIVE TOTAL ANNUAL COSTS

Item		*Year 1 Pre-Commissioning*	*Phase 1*		*Phase 2*		*Phase 3*			*Phase 4*		
			Year 2	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Year 8*	*Year 9*	*Year 10*	*Year 1*
		£	£	£	£	£	£	£	£	£	£	£
L	Annual Repayments	18,800	23,220	34,650	38,310	50,580	55,360	57,390	62,720	64,610	66,050	66,050
M	Annual Operating Costs* Boiler Plant	–	16,434	33,910	53,070	65,930	83,420	96,310	109,220	117,120	124,930	132,770
N	Annual Operating Costs* Transmission Mains	–	2,044	3,724	6,233	7,964	9,654	11,486	13,070	13,987	14,908	15,787
O	Total Annual Costs	18,800	41,698	72,284	97,613	124,474	148,434	165,186	185,010	195,717	205,888	214,607

*For individual items see those numbered 1 to 12 under Sections 6 and 7.

4. COST OF HEAT SUPPLY

Item		*Year 1 Pre-Commissioning*	*Phase 1*		*Phase 2*		*Phase 3*			*Phase 4*		
			Year 2	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Year 8*	*Year 9*	*Year 10*	*Year 11*
P	Total Annual Costs £	18,800	41,698	72,284	97,613	124,474	148,434	165,186	185,010	195,717	205,888	214,607
Q	Heat Sold Therms/An.	–	280,000	865,000	1,470,000	1,885,000	2,320,000	2,750,000	3,190,000	3,430,000	3,680,000	3,940,000
R	Cost of Heat Pence/Therm	–	35·7	20·2	16·0	15·8	15·3	14·4	13·9	13·7	13·4	13·1

From Table 4 the Average Cost of Heat Supply during Development=**14·8143d**/Therm

Appendix D—*continued*

5. LOAN REPAYMENTS TO COVER DEVELOPMENT AND PRE-OPERATIONAL LOSSES

Item		*Year* 1 *Pre-Commissioning*	*Phase* 1		*Phase* 2		*Phase* 3			*Phase* 4		
			Year 2	*Year* 3	*Year* 4	*Year* 5	*Year* 6	*Year* 7	*Year* 8	*Year* 9	*Year* 10	*Year* 11
S	Heat Demand Th. Sold	–	280,000	865,000	1,470,000	1,885,000	2,320,000	2,750,000	3,190,000	3,430,000	3,680,000	3,940,000
T	Expenditure £	18,800	41,698	72,284	97,613	124,474	148,434	165,186	185,010	195,717	205,888	214,607
U	Income @ 14·81d/Therm £	–	17,283	53,392	90,737	116,353	143,204	169,746	196,905	211,720	227,151	243,200
V	Loss £	18,800	24,415	18,892	6,876	8,121	5,230	–	–	–	–	–
W	Gain £	–	–	–	–	–	–	4,560	11,895	16,023	21,263	28,593
X	Cumulative Loss £	–	43,215	62,107	68,983	77,104	82,334	–	–	–	–	–
Y	Cumulative Gain £	–	–	–	–	–	–	4,560	16,455	32,478	53,741	82,334
Z	Loan Repayments £	2,440	3,400	2,840	1,125	1,480	1,080	–	–	–	–	–
AA	Total Annual Repayments* Less Gains £	2,440	5,840	8,680	9,805	11,285	12,365	7,805	470	–	–	–
BB	Cumulative Total Annual Repayments* less Gains £	2,440	8,280	16,960	26,765	38,050	50,415	58,220	58,690	55,032	46,134	29,906

*The actual amounts to be repaid annually after year 6 are those shown plus the deductions made for gains.

Expenditure over Entire Development Period, *Item* T	£1,469,711
Total Development Expenditure (including *Item* BB for *Year* 11)	£1,499,617

Total Heat Supply over Development Period	23,810,000 Therms
Cost per Therm over Development Period	15·1 pence

Appendix D—*continued*

DETAILS OF ANNUAL OPERATING COSTS
(EXCLUDING CAPITAL CHARGES)

6. BOILER PLANT ANNUAL OPERATING COSTS

Item		*Phase 1*		*Phase 2*		*Phase 3*			*Phase 4*		
		Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Year 8*	*Year 9*	*Year 10 & Subsequent Years*
1	Heat Demand Per Annum Gross Therms Generated	305,000	939,000	1,586,000	2,054,000	2,529,000	2,994,000	3,460,000	3,734,000	4,005,000	4,278,000
2	Fuel	£	£	£	£	£	£	£	£	£	£
	Grade: Northumberland Washed Singles Calorific Value :12,900 Btu/lb. Purchase Price: 110s. 9d. per Ton Boiler Efficiency: 80%	7,550	23,200	39,300	50,800	62,500	74,000	85,500	92,000	99,000	106,000
3	Electricity North Eastern Electricity Board Tariff M	640	1,950	3,300	4,270	5,270	6,240	7,220	7,800	8,340	8,930
4	Water	50	10	40	20	40	30	30	40	40	40
5	Wages and Wages Charges	3,900	3,900	3,900	3,900	5,500	5,500	5,500	5,500	5,500	5,500
6	Maintenance	1,044	1,550	2,080	2,440	3,620	4,000	4,380	4,580	4,800	5,000
7	Rates	2,400	2,400	3,225	3,225	4,680	4,680	4,680	5,100	5,100	5,100
8	Insurance	800	800	1,075	1,075	1,560	1,560	1,560	1,700	1,700	1,700
9	Administration	50	100	150	200	250	300	350	400	450	500
	Total Annual Operating Costs	16,434	33,910	53,070	65,930	83,420	96,310	109,220	117,120	124,930	132,770

Appendix D—*continued*

7. TRANSMISSION MAINS ANNUAL OPERATING COSTS

Item No.		*Phase 1*		*Phase 2*		*Phase 3*			*Phase 4*		
		Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*	*Year 6*	*Year 7*	*Year 8*	*Year 9*	*Year 10 & Subsequent Years*
		£	£	£	£	£	£	£	£	£	£
10	Maintenance	870	937	1,022	1,077	1,125	1,197	1,228	1,264	1,293	1,314
11	Insurance	354	687	1,111	1,387	1,629	1,989	2,142	2,323	2,465	2,573
12	Administration	820	2,100	4,100	5,500	6,900	8,300	9,700	10,400	11,150	11,900
	Total Annual Operating Costs	2,044	3,724	6,233	7,964	9,654	11,486	13,070	13,987	14,908	15,787

NOTE: The costs for Adminstration include the Heat Metering Service.

Appendix E

SCHEDULE OF ESTIMATED ELECTRICAL LOADING AND DUTIES FOR A DISTRICT HEATING BOILER PLANT, FINAL STAGE

Item No.	*Equipment*	*3-Phase Circuits Amps/ Phase*	*1-Phase Circuits Amps/Phase*			*Hours/ Day*	*Days/ Year*	*Hours/ Year*
			Red	*Yellow*	*Blue*			
1	Winter Pump No. 1	39	–	–	–	17	210	3,570
2	Winter Pump No. 2	39	–	–	–	17	210	3,570
3	Summer Pump	7	–	–	–	17	155	2,635
4	Summer Boiler	3	–	12·5	–	17	155	2,635
5	Winter Boiler No. 1	7	17	–	12·5	17	210	3,570
6	Winter Boiler No. 2	7	17	12·5	–	17	210	3,570
7	Winter Boiler No. 3	7	17	–	12·5	17	210	3,570
8	Oil Pump No. 1	3	–	–	–	17	365	6,205
9	Oil Pump No. 2	3	–	–	–	Stand by	—	—
10	Oil Line Heater	–	–	–	25	1	365	365
11	Oil Tank No. 1 Heater	–	25	–	–	1	365	365
12	Oil Tank No. 2 Heater	–	–	25	–	1	365	365
13	Instruments	–	–	–	15	17	365	6,205
14	Lighting	–	–	15	–	17	365	6,205
15	Sockets	–	–	20	–	17	365	6,205
16	Pipe Tracing	–	–	–	22	17	365	6,205
17	Spare	60	–	–	–	–	—	—
	TOTAL	175	76	85	87			
	Less item Nos. 3 and 4 (Summer Duty only) and item No. 9 (stand-by duty only)	13	–	12·5	–			
		162	76	72·5	87			
	Max Amps/Phase	162+87=249						

Stage I	*Stage II*	*Stage III*	*Final Stage*	
Item 3	Item 1	Item 1	Item 1	Item 12
,, 4	,, 3	,, 3	,, 2	,, 13
,, 8	,, 4	,, 4	,, 3	,, 14
,, 10	,, 5	,, 5	,, 4	,, 15
,, 11	,, 6	,, 8	,, 5	,, 16
,, 12	,, 10	,, 10	,, 6	
,, 13	,, 11	,, 11	,, 7	
,, 14	,, 12	,, 12	,, 8	
,, 15	,, 13	,, 13	,, 9	
,, 16	,, 14	,, 14	,, 10	
	,, 15	,, 15	,, 11	
	,, 16	,, 16		

Appendix F

SUMMARY OF ITEMS OF INCIDENTAL BUILDERS WORK

(Some items are alternatives to others)

BRICKLAYERS: Substations, calorifier and tank chambers, fuel bunkers, horizontal and vertical boiler flues and chimneys, supports for fuel and water tanks and calorifiers. Ducts and chases for pipework. Ducting for ventilation.

CONCRETER: Substations, calorifier and tank chambers, fuel bunkers, horizontal and vertical boiler flues and chimneys, bases for boilers, pumps, fans, tanks and calorifiers. Underground pipe conduits, valve and expansion chambers. Ducts and chases for pipework. Ducting for ventilation.

PAINTER: Painting of boilers, fans, pumps, fuel and water tanks. Thermal insulation. Radiator and other heaters. Pipes and fittings. Air ducts. Clips, stays, hangers, brackets and other engineers' metalwork normally finished with paintwork.

PLUMBER: Cold water supply to feed and expansion tanks, storage calorifiers, air washers. Connections to sanitary fittings from hot water supply systems.

GAS FITTER: Gas supply for ignition of oil burners when required.

PLASTERER: Finish over embedded warming panels in ceiling, walls and other structures with plaster to specified requirements.

TILER, MARBLER AND FLOORER: Finish over interposed warming panels with tiling, marble, terrazzo or wood blocks to specified requirements.

CARPENTER: Provision of casings for pipes, deflector shelves for radiators. Insulating casings for feed and expansion tanks in exposed positions. Boxes and access covers to concealed regulating valves. Hardwood frames for propeller fans, ventilating grilles, louvres and registers.

INSULATOR: Insulation of feed and expansion tanks in exposed positions, flat roofs above ceiling warming panels, inside face of external wall surfaces behind warming panels, and pitched roofs and walls when necessary.

ELECTRICIAN: (Other than for main plant.) Wiring up of switchgrear and motors for circulating pumps and fans. Forced draught convectors. Temperature compensators. Motorised valves, hour meters, heat meters, thermostats and time switches. Remote temperature indicators. Telephones.

GENERAL: Formation, or cutting away and making good, of openings in walls, floors and roof for passage of pipes and air ducts. Cutting away for and building in supports, stays and brackets for heaters, radiant panels, piping, ducting, and other sundry items of equipment. Provision and fitting of rebated frames and cover plates for trenches, sumps and manholes for underground chambers. Sweeping and soot doors and dampers in flues. Air intake and discharge louvres. Water, heat and electricity for testing.

Appendix G

Particulars of welder's qualification tests as covered by insurance company's report

Location of Site:	New Town Centre, Blankshire.
Description of Plant:	District heating underground transmission mains. Phase 1.
Contractor:	Universal Tube Erectors Co. Ltd.
Welder's Name and Identification Mark:	L. O. Fusewell, Mark K.
Description of Material:	Mild steel pipe to *BSS 806 C*, 12½ in and 6½ in o/d and ¼ in wall thickness. Two pipe lengths of each size were prepared on ends with correct angle and root face, and tacked together with correct welding gap. Welding commenced with each specimen fixed at an angle of 45°. The 6½ in o/d specimen was completed, then the 12½ in o/d. No preheating applied. Electrodes used—Multiweld, ⅛ in and $\frac{5}{32}$ in dia with current of 94 and 120 amp dc.
Description of examination and test:	On completion of each specimen, the welding was examined and found visually satisfactory. No heat treatment was applied after welding. Four strips were then cut down the 6½ in specimen, ⅝ in width, and crossing the weld. Also four strips were cut down the 12½ in specimen, ⅞ in width, and crossing the weld. All eight strips were rounded lightly on edges, and the weld on surface smoothed off. All eight strips were then bent fully round a former ⅝ in dia, in each case with the weld against the former, inner surface in tension. A macro-etch was prepared on side of one strip from each specimen, at weld.

Remarks: The weld of each strip from both specimens proved satisfactory on bending, no undue defect appearing.
The macro-etch of the weld of the two strips, showed the welds to be sound with good fusion.
The welding of above two specimens is satisfactory and it is in order for this welder to proceed on this class of work.

Date of examination: 7/6/65.

Inspector: R. A. Stickler.

Countersigned: F. L. Wright.

Appendix H

TESTING OF WELDED PIPE JOINTS AND FLANGES

Selected welders only with long and proved experience in pipe welding shall be employed and each welder shall, before commencing work on site, satisfy the engineer as to his ability to weld to the required standard. The welder will be required to weld together two short lengths of pipe of at least three representative diameters, and fixed in such a manner as to simulate the average and the worst conditions under which the welder will have to work.

From these specimens three samples shall be cut, the width being approximately equal to the thickness of the pipe wall, and cut from the top, bottom and side of the specimen weld. The samples should have the internal and external surfaces ground flush with the internal and external surfaces of the pipe; corners to be radiused to $\frac{1}{32}$ in. The samples shall then be bent to an angle of 90° with the inner pipe surface in tension (i.e. a reverse bend test) round a former whose diameter is equal to three times the wall thickness of the pipe. Each of the samples are to bend to 90° without signs of cracks or failure. Slight premature cracks or failure at the edges of the sample are not necessarily to be considered as a cause for rejection.

If the reverse bend acceptance test does not reach the required standard, two further weld specimens shall be prepared by the same welder. If neither of these welds reach the required standard, the welder will be unacceptable and the Contractor shall immediately supply another welder for the acceptance tests.

Check tests by representative sample on 2% of all pipe welds shall be carried out generally as above, but welds may be called for to be cut out of the pipe line at the Engineer's discretion. In doubtful cases, where good results are not obtained from any one sample test piece, reverse bend tests should be made on samples from the same weld adjacent to the doubtful sample.

If the reverse bend test does not reach the required standard, two further welds made by the same welder shall be prepared or cut out and treated in the same way. If either of these two welds does not also reach the required standard the cutting out of all welds made by the same welder may be required subject to the Engineer's decision, and the welder shall be taken off the work.

A welder who has failed either acceptance or check test may be re-submitted for testing after suitable training, on the Contractor's assurance that he stands a reasonable chance of passing the test.

Appendix I

THE PIMLICO DISTRICT HEATING UNDERTAKING

The Undertaking, which is owned and operated by the Westminster City Council, was originally planned to serve Churchill Gardens, an Estate of 33 acres on the north bank of the Thames. As the scheme developed other buildings were supplied including Russell House, a 9-storey block of 74 flats which had been in existence for some years; Dolphin Square, which is reputed to be the largest single block of flats in the world, and Abbots Manor, a new housing estate near Victoria Station. The connection of Dolphin Square to the system was a valuable acquisition for the undertaking at a time when consumers were few during the early stages of development. The scheme, when completed, will supply over 3,000 dwellings and other buildings serving about 10,000 people.

As this was to be the first thermal-electric district heating scheme in the country to serve residential estates, it was decided to provide a standard of space heating and hot water supply that would be sure to satisfy all the reasonable needs of the majority of consumers. Where necessary, equipment has been duplicated to ensure continuity of operation. Operational records of the past 15 years have confirmed that the service more than fulfils all the normal demands of the consumers, and the Council is to be highly commended for their foresight in providing a heat service that today is still unequalled elsewhere in the country.

In each dwelling a temperature of 65°F is provided in the living rooms and 60°F in the bedrooms, and these temperatures can be maintained when the outside temperature is at or below freezing point. Some dwellings are also provided with radiators in the dining-kitchens and entrance halls. The heat supply is turned on at 6 a.m. and shut off at about 11 p.m. During the night the air temperature in the dwellings falls only a few degrees because of the good standard of insulation provided for the building structure.

A continuous and unlimited supply of hot water is provided for the kitchens and bathrooms, the latter being fitted with a heated towel rail. The linen cupboards are also heated. Hot water is also supplied to the common laundries in the basement of some of the larger blocks of flats. The consumption of hot water at 130°F averages out at 15-20 gallons for each person every day. For the total heat and hot water service the tenant pays a weekly charge ranging from 7s. 0d. to 20s. 6d. according to the size of the dwelling occupied.

To provide the heat required at Pimlico for the services given, exhaust steam from two small turbines in Battersea Power Station is used. Heat in the steam is transferred to water and this is circulated between the Power Station and a Substation, on the other side of the Thames, and from there to the consumers. The output of the two turbines represents an infinitesimal proportion of the total generating capacity of the Power Station.

The system has been in successful operation without any interruption for 15 years and during this period consistent results have been obtained showing that the designed quantities of heat and electricity have been obtained with an overall thermal efficiency of more than 80%. It has been established that the heat sent out in the form of electricity is almost exactly 17% of the heat delivered for heating purposes. The transmission and distribution efficiency is over 95%.

To conduct the hot water to the north side of the Thames a tunnel, that has existed for many years under the bed of the river and which belongs to the Metropolitan Water Board, is used for the transmission mains. Before these were installed the tunnel was a damp and dreary place with its array of stalactites stretching from end to end. The only sound audible was the occasional drone of ships' propellers overhead. Today the tunnel is dry, warm, well ventilated and lit, and served by telephone.

It is possible to walk beside the hot water transmission mains all the way from Battersea on the south to the Substation at Pimlico on the north side of the river. From the north end of the old tunnel under the river a new one continues below Grosvenor Road and through the old Belgrave Dock to the Substation. Here the operators control the quantities and temperatures of the outgoing water to the consumers, and regulate the space heating in each building separately by remotely controlled valves, when the heat is not required in full. Numerous instruments, signal lights, and visual and audible alarms are provided to assist the operators in their duties, and to give warning of emergency conditions should they occur in the under-river tunnel; the Substation, or in the accumulator. The instruments include recorders to show the temperature at any time of day or night in a number of living rooms in the dwellings. By this means the operators are able to control the heat supply to the dwellings according to the air temperatures prevailing generally throughout the buildings.

The glass encased heat accumulator at the Substation near All Saints Church in Grosvenor Road (also supplied with heat from the system) is a vessel 29 ft dia and 128 ft high, holding nearly 500,000 gallons. It is insulated with cork 3 in thick. The use of the heat accumulator is essential to the economy of a combined heat-electric system, as it serves the important function of enabling the heat that is generated according to the demand for electricity to be consumed according to the demand for heat. The accumulator is charged automatically when the supply of heat from the Power Station exceeds the demand; it is discharged automatically when the supply is insufficient for the demand and the balance has to be taken from the storage.

Engineering a district heating project of the kind at Pimlico is not without its difficulties, both administrative and technical, as is only to be expected with a prototype scheme. To carry it into effect it was necessary to obtain special statutory powers, which were granted by Parliament in the *London County Council* (*General Powers*) *Act*, 1947. The scheme provoked opposition from suppliers of heat as well as criticism from Government Departments, and to meet these the powers granted to the Westminster City Council were subjected to certain restrictions. Negotiations were also necessary with more than a dozen Ministries, Public Utility Boards, and other Authorities, including the Port of London Authority, in order to smooth the way for this new venture.

It was not always easy to find space for routing the underground mains without first removing a certain amount of impedimenta such as large blocks of concrete, old service mains, disused petrol storage tanks and the footings of brick walls. Evasive action was also necessary for water and gas mains, sewers, electrical transmission mains and telephone lines. Occasionally it was necessary for the hot water mains to pass through existing basements, and when these were occupied this necessitated securing wayleaves. Sometimes streets had to be closed and traffic diverted by arrangement with the Commissioner of Police.

On the 20th February, 1951 the heat supply was turned on to the 104 dwellings comprising Chaucer House, the first block to be completed of over 40 eventually built. The opening ceremony took place in July, 1951, when the estate was officially named 'Churchill Gardens' in honour of and as a tribute to the (then) Prime Minister. In September, 1951 Dolphin Square was connected up, and a year later Russell House also.

Associated as it is with the illustrious name of Sir Winston Churchill it is apposite that the district heating system has itself proved to be of outstanding service to the community in its own way: it has reduced atmospheric pollution, saved fuel and labour, provided a cheap supply of heat and safer and better living conditions generally. Because of these and other features the scheme has aroused world-wide interest, and has been examined by many visitors from abroad including delegates from the Soviet Union, a country that has for many years been a user of district heating.

* * *

The author was one of the engineers responsible for the design and installing of the Pimlico System during its development over the past 20 years.

Appendix J

SUMMARY OF PRINCIPAL PLANNING REQUIREMENTS

The information given below serves to indicate the more important matters to be considered under the different headings applicable to the planning of a project.

DESIGN. To formulate a comprehensive design necessitates consideration of the following items to ensure satisfactory operation of the scheme.

1 General
  (a) Extent of service desired, i.e. supplies to residential, commercial and industrial buildings.
  (b) Method of heat production.
  (c) Balancing of supply and demand.
  (d) Siting and arrangement of central and sub-station plant.
  (e) Routing, accommodation and insulation of transmission mains.
  (f) Method of measuring heat supply.
  (g) Compliance with Regulations and Acts.

2 Thermal Capacity
  (a) Space heating and hot tap water temperatures required.
  (b) Process heat required.
  (c) Maximum hourly heat demand with diversity allowance.
  (d) Annual heat demand with adventitious heat allowance.
  (e) Heat storage.
  (f) Fuel storage.

3 Operational
  (a) Class of fuel.
  (b) Steam or water pressure and temperature conditions.
  (c) Circulating pressure loss in transmission network.
  (d) Pressurisation method.
  (e) Chimney area and height.
  (f) Automatic controls, signals and alarms.
  (g) Indicating and recording instruments.

4 Reliability
  (a) Compliance with British and other Standards.
  (b) Duplicate plant including heat exchangers and pumps.
  (c) Accessibility for inspection and maintenance.

- (d) Spare parts stock.
- (e) Water treatment.
- (f) Leak detection.
- (g) Servicing agreements.

5 Costs

- (a) Capital expenditure for buildings and plant.
- (b) Phasing of capital expenditure according to development rate of project.
- (c) Repayment of loans according to term and interest rate.
- (d) Fuel, electricity, gas and water purchase prices and bringing in supply.
- (e) Attendance on plant and maintenance.
- (f) Rates and insurance.
- (g) Administration.
- (h) Charges for heat supply during development and on completion.

SPECIFICATION. This should state clearly what is required and be in accordance with the best practice and the most economic standards available. It should ensure compliance with these two requirements without possibility of evasion.

1 Conditions of Contract

- (a) Direct or sub-contract.
- (b) Form of general conditions to be used.
- (c) Inclusion of Forms of Agreement and Guarantee.
- (d) Variations necessary to general conditions.

2 General Clauses

- (a) General particulars of work.
- (b) Work excluded from contract.
- (c) Miscellaneous.
- (d) Prices and payments.
- (e) Labour.
- (f) Manufacture and design.
- (g) Work on site.

3 Plant Clauses

- (a) Main plant including boilers and firing equipment with controls, fuel storage tanks and hoppers with conveyors. Turbo-alternators, condensers, heat exchangers, drain coolers, feed heaters. Heat accumulators, pumps, water treatment plant and all necessary switchgear and cabling.

  - (b) Instrument panel with instruments and signal lamps and all associated piping and wiring.
  - (c) Tube and fittings including expansion bellows, anchorages, isolating, air and drain valves.
  - (d) Insulation of boilers, heat exchangers, accumulators and transmission mains.
  - (e) Automatic controls.
  - (f) Electrical installation for items (a), (b) and (e).

4 Appendices
  - (a) Quantitative particulars of plant.
  - (b) Dates of readiness for delivery and completion of contract work.
  - (c) Names of manufacturers of plant to be supplied and alternative makes proposed by tenderer.
  - (d) General particulars and guarantees to be given by tenderer.
  - (e) Drawings accompanying specification.
  - (f) Inspection and tests.
  - (g) Summary of prices, prices for measured work at schedule rates and schedule of basic rates.

DRAWINGS. These form part of the contract documents to supplement the specified requirements.

1 Schematic plans and diagrams
  - (a) Site plan showing position of central plant, sub-stations and route of transmission network indicating phases of development.
  - (b) Schematic diagram of automatic controls.
  - (c) Wiring diagram of electrical installation.

2 General arrangement drawings
  - (a) Layout of central and sub-station plant.
  - (b) Layout of fuel storage.
  - (c) Layout of instrument panel.

3 Detail drawings
  - (a) Dimensional drawing of transmission network.
  - (b) Dimensional drawing of transmission mains, underground showing conduit or other method of accommodation.
  - (c) Typical pipe supports and anchors.

TENDERS. It is necessary for each of these to comply with the specification and drawings to ensure that prices are comparable. Alternative proposals by the tenderers may be considered.

1 Conditions of tendering
    - (a) Open or selected tenders.
    - (b) Negotiated price contract.
    - (c) Fixed or variable price contract.
    - (d) Bills of quantities.

2 Deviations (alternative proposals by tenderers)
    - (a) Schematic arrangement.
    - (b) Manufacturers of plant.
    - (c) Compliance with other standards.

3 Consideration of tenders
    - (a) Comparison of prices and scheduled particulars.
    - (b) Prices relationship to current market values.
    - (c) Examination of any alternative proposals and difference in prices.
    - (d) Time required for start and completion of work.
    - (e) Any qualifying statements or reservations accompanying tenders.

ERECTION Close supervision of all work is necessary for the following: adherence to programme schedules: quality of materials and workmanship used; verification of the specified make and sizes of plant and auxiliaries installed; compliance with contract drawings; variations to contract; testing and commissioning.

1 Inspection
    - (a) General inspection of materials and workmanship at works.
    - (b) General inspection of materials and workmanship at site.
    - (c) Special inspection by insurance company of manufacture at works and welding on site.

2 Installing
    - (a) Co-ordination of mechanical, electrical and civil engineering work to comply with space allocation and time schedules.
    - (b) Compliance with specified makes and sizes of plant and auxiliaries.
    - (c) Compliance with general and detailed particulars shown on drawings.
    - (d) Variations to contract (additions and omissions) and sanction of overtime if required.
    - (e) Certification of interim payments.

3 Testing

- (a) Material tests for compliance with British and other standards.
- (b) Hydraulic tests above working pressures.
- (c) Heat tests at circulating temperatures.
- (d) Circulating pressure control tests.
- (e) High voltage tests at twice normal voltage plus 1,000 V.
- (f) General performance tests of main plant and auxiliaries.

4 Commissioning and acceptance of plant

- (a) Witnessing acceptance tests.
- (b) Trials attendance period of contractor's and sub-contractor's engineers.
- (c) Agreement to taking-over date.
- (d) Servicing agreements.
- (e) Expiry of maintenance period.
- (f) Provision of record drawings of plant as installed.
- (g) Provision of operating and maintenance instructions.
- (h) Agreement to interim final or final payment.

Appendix K

CONVERSION TABLES

Metric equivalents of British Units

The following Tables are reproduced from *A Guide to Current Practice* by permission of the Institution of Heating and Ventilating Engineers.

DEGREES FAHRENHEIT TO DEGREES CENTIGRADE

Figures in parenthesis represent negative values on the Centigrade Scale

F	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
	°C	°C	°C	°C	°C	°C	°C	°C	°C	°C
0°	(17·8)	(17·2)	(16·7)	(16·1)	(15·6)	(15·0)	(14·4)	(13·9)	(13·3)	(12·8)
10°	(12·2)	(11·7)	(11·1)	(10·6)	(10·0)	(9·4)	(8·9)	(8·3)	(7·8)	(7·2)
20°	(6·7)	(6·1)	(5·6)	(5·0)	(4·4)	(3·9)	(3·3)	(2·8)	(2·2)	(1·7)
30°	(1·1)	(0·6)	—	—	—	—	—	—	—	—
30°	—	—	0	0·6	1·1	1·7	2·2	2·8	3·3	3·9
40°	4·4	5·0	5·6	6·1	6·7	7·2	7·8	8·3	8·9	9·4
50°	10·0	10·6	11·1	11·7	12·2	12·8	13·3	13·9	14·4	15·0
60°	15·6	16·1	16·7	17·2	17·8	18·3	18·9	19·4	20·0	20·6
70°	21·1	21·7	22·2	22·8	23·3	23·9	24·4	25·0	25·6	26·1
80°	26·7	27·2	27·8	28·3	28·9	29·4	30·0	30·6	31·1	31·7
90°	32·2	32·8	33·3	33·9	34·4	35·0	35·6	36·1	36·7	37·2
100°	37·8	38·3	38·9	39·4	40·0	40·6	41·1	41·7	42·2	42·8
110°	43·3	43·9	44·4	45·0	45·6	46·1	46·7	47·2	47·8	48·3
120°	48·9	49·4	50·0	50·6	51·1	51·7	52·2	52·8	53·3	53·9
130°	54·4	55·0	55·6	56·1	56·7	57·2	58·7	58·3	58·9	59·4
140°	60·0	60·6	61·1	61·7	62·2	62·8	64·3	63·9	64·4	65·0
150°	65·6	66·1	66·7	67·2	67·8	68·3	68·9	69·4	70·0	70·6
160°	71·1	71·7	72·2	72·8	73·3	73·9	74·4	75·0	75·6	76·1
170°	76·7	77·2	77·8	78·3	78·9	79·4	80·0	80·6	81·1	81·7
180°	82·2	82·8	83·3	83·9	84·4	85·0	85·6	86·1	86·7	87·2
190°	87·8	88·3	88·9	89·4	90·0	90·6	91·1	91·7	92·2	92·8
200°	93·3	93·9	94·4	95·0	95·6	96·1	96·7	97·2	97·8	98·3

F	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
210°	98·9	99·4	100·0	100·6	101·1	101·7	102·2	102·8	103·3	103·9
220°	104·4	105·0	105·6	106·1	106·7	107·2	107·8	108·3	108·9	109·4
230°	110·0	110·6	111·1	111·7	112·2	112·8	113·3	113·9	114·4	115·0
240°	115·6	116·1	116·7	117·2	117·8	118·3	118·9	119·4	120·0	120·6
250°	121·1	121·7	122·2	122·8	123·3	123·9	124·4	125·0	125·6	126·1
260°	126·7	127·2	127·8	128·3	128·9	129·4	130·0	130·6	131·1	131·7
270°	132·2	132·8	133·3	133·9	134·4	135·0	135·6	136·1	136·7	137·2
280°	137·8	138·3	138·9	139·4	140·0	140·6	141·1	141·7	142·2	142·8
290°	143·3	143·9	144·5	145·0	145·6	146·1	146·7	147·2	147·8	148·3
300°	148·9	149·4	150·0	150·6	151·1	151·7	152·2	152·8	153·3	153·9
310°	154·4	155·0	155·6	156·1	156·7	157·2	157·8	158·3	158·9	159·4
320°	160·0	160·6	161·1	161·7	162·2	162·8	163·3	163·9	164·4	165·0
330°	165·6	166·1	166·7	167·2	167·8	168·3	168·9	169·4	170·0	170·6
340°	171·1	171·7	172·2	172·8	173·2	173·9	174·4	175·0	175·6	176·1
350°	176·7	177·2	177·8	178·3	178·9	179·4	180·0	180·6	181·1	181·7
360°	182·2	182·8	183·3	183·9	184·4	185·0	185·6	186·1	186·7	187·2
370°	187·8	188·3	188·9	189·4	190·0	190·6	191·1	191·7	192·2	192·8
380°	193·3	193·9	194·4	195·0	195·6	196·1	196·7	197·2	197·8	198·3
390°	198·9	199·4	200·0	200·6	201·1	201·7	202·2	202·8	203·3	203·9
400°	204·4	205·0	205·6	206·1	206·7	207·2	207·8	208·3	208·9	209·4
410°	210·0	210·6	211·1	211·7	212·2	212·8	213·3	213·9	214·4	215·0
420°	215·6	216·1	216·7	217·2	217·8	218·3	218·9	219·4	220·0	220·6
430°	221·1	221·7	222·2	222·8	223·3	223·9	224·4	225·0	225·6	226·1
440°	226·7	227·2	227·8	228·3	228·9	229·4	230·0	230·6	231·1	231·7
450°	232·2	232·8	233·3	233·9	234·4	235·0	235·6	236·1	236·7	237·2
460°	237·8	238·3	238·9	239·4	240·0	240·6	241·1	241·7	242·2	242·8
470°	243·3	243·9	244·4	245·0	245·5	246·1	246·7	247·2	247·8	248·3
480°	248·9	249·4	250·0	250·6	251·1	251·7	252·2	252·8	253·3	253·9
490°	254·4	255·0	255·6	256·1	256·7	257·2	257·8	258·3	258·9	259·4

$F=(C\times 1{\cdot}8)+32$

FEET AND INCHES TO METRES

Ft.	In.											
	0	1	2	3	4	5	6	7	8	9	10	11
	m	m	m	m	m	m	m	m	m	m	m	m
0	—	0·0254	0·0508	0·0762	0·1016	0·1270	0·1524	0·1778	0·2032	0·2286	0·2540	0·2794
1	0·3048	0·3302	0·3556	0·3810	0·4064	0·4318	0·4572	0·4826	0·5080	0·5334	0·5588	0·5842
2	0·6096	0·6350	0·6604	0·6858	0·7112	0·7366	0·7620	0·7874	0·8128	0·8382	0·8636	0·8890
3	0·9144	0·9398	0·9652	0·9906	1·0160	1·0414	1·0668	1·0922	1·1176	1·1430	1·1684	1·1938
4	1·2192	1·2446	1·2700	1·2954	1·3208	1·3462	1·3716	1·3970	1·4224	1·4478	1·4732	1·4986
5	1·5240	1·5494	1·5748	1·6002	1·6256	1·6510	1·6764	1·7018	1·7272	1·7526	1·7780	1·8034
6	1·8288	1·8542	1·8796	1·9050	1·9304	1·9558	1·9812	2·0066	2·0320	2·0574	2·0828	2·1082
7	2·1336	2·1590	2·1844	2·2098	2·2352	2·2606	2·2860	2·3114	2·3368	2·3622	2·3876	2·4130
8	2·4384	2·4638	2·4992	2·5146	2·5400	2·5654	2·5908	2·6162	2·6416	2·6670	2·6924	2·7178
9	2·7432	2·7686	2·7940	2·8194	2·8448	2·8702	2·8956	2·9210	2·9464	2·9718	2·9972	3·0226
10	3·0480	3·0734	3·0988	3·1242	3·1496	3·1750	3·2004	3·2258	3·2512	3·2766	3·3020	3·3274
11	3·3528	3·3782	3·4036	3·4290	3·4544	3·4798	3·5052	3·5306	3·5560	3·5814	3·6068	3·6322
12	3·6576	3·6830	3·7084	3·7338	3·7592	3·7846	3·8100	3·8354	3·8608	3·8862	3·9116	3·9370
13	3·9624	3·9878	4·0132	4·0386	4·0640	4·0894	4·1148	4·1402	4·1646	4·1910	4·2164	4·2418
14	4·2672	4·2926	4·3180	4·3434	4·3688	4·3942	4·4196	4·4450	4·4704	4·4958	4·5212	4·5466
15	4·5720	4·5974	4·6228	4·6482	4·6736	4·6990	4·7244	4·7498	4·7752	4·8006	4·8260	4·8514
16	4·8768	4·9022	4·9276	4·9530	4·9784	5·0038	5·0292	5·0546	5·0800	5·1054	5·1308	5·1562
17	5·1816	5·2070	5·2324	5·2578	5·2832	5·3086	5·3340	5·3594	5·3848	5·4102	5·4356	5·4610
18	5·4864	5·5118	5·5372	5·5626	5·5880	5·6134	6·6388	5·6642	5·6896	5·7150	5·7404	5·7658
19	5·7912	5·8166	5·8420	5·8674	5·8928	5·9182	5·9436	5·9690	5·9944	6·0198	6·0452	6·0706
20	6·0960	6·1214	6·1468	6·1722	6·1976	6·2230	6·2484	6·2738	6·2992	6·3246	6·3500	6·3754
30	9·1440	9·1694	9·1948	9·2202	9·2456	9·2710	9·2964	9·3218	9·3472	9·3726	9·3980	9·4234
40	12·1920	12·2174	12·2428	12·2628	12·2936	12·3190	12·3444	12·3698	12·3952	12·4206	12·4460	12·4714
50	15·2400	15·2654	15·2908	15·3162	15·3416	15·3670	15·3924	15·4178	15·4432	15·4686	15·4940	15·5194
60	18·2880	18·3134	18·3388	18·3642	18·3896	18·4150	18·4404	18·4658	18·4912	18·5166	18·5420	18·5674
70	21·3360	21·3614	21·3868	21·4122	21·4376	21·4630	21·4884	21·5138	21·5392	21·5646	21·5900	21·6154
80	24·3840	24·4094	24·4348	24·4602	24·4856	42·5110	24·5364	24·5618	24·5872	24·6126	24·6380	24·6634
90	27·4320	27·4574	27·4828	27·5082	27·5336	27·5590	27·5844	27·6098	27·6352	27·6606	27·6860	27·7114
100	30·4800											

BRITISH THERMAL UNITS TO KILOCALORIES

Btu	0	100	200	300	400	500	600	700	800	900
	kcal	kcal	kcal	kcal	kcal	kcal	kcal	kcal	kcal	kcal
0	—	25·2	50·4	75·6	100·8	126·0	151·2	176·4	201·6	226·8
1,000	252	277·2	302·4	327·6	352·8	378·0	403·2	428·4	453·6	478·8
2,000	504	529·2	554·4	579·6	604·8	630·0	655·2	680·4	705·6	730·8
3,000	756	781·2	806·4	831·6	856·8	882·0	907·2	932·5	957·6	982·8
4,000	1,008	1,032·2	1,058·4	1,083·7	1,108·8	1,134·0	1,159·2	1,184·4	1,209·6	1,234·8
5,000	1,260	1,285·2	1,301·4	1,335·6	1,360·8	1,386·0	1,411·2	1,436·4	1,461·6	1,486·8
6,000	1,512	1,537·2	1,562·4	1,587·6	1,612·8	1,638·0	1,663·2	1,688·4	1,713·6	1,738·8
7,000	1,764	1,789·2	1,814·4	1,839·6	1,864·8	1,890·0	1,915·2	1,940·4	1,965·6	1,990·8
8,000	2,016	2,041·2	2,066·4	2,091·6	2,116·8	2,142·0	2,167·2	2,192·4	2,217·6	2,242·8
9,000	2,268	2,293·8	2,318·4	2,343·6	2,368·8	2,394·0	2,419·2	2,444·4	2 469·8	2,494·8

GALLONS TO LITRES

gal.	0	1	2	3	4	5	6	7	8	9
	l	l	l	l	l	l	l	l	l	l
0	—	4·546	9·092	13·638	18·184	22·730	27·276	31·822	36·368	40·914
10	45·460	50·006	54·552	59·098	63·643	68·189	72·735	77·281	81·827	86·373
20	90·919	95·465	100·011	104·557	109·103	113·649	118·195	122·741	127·287	131·833
30	136·379	140·925	145·471	150·017	154·563	159·109	163·655	168·201	172·747	177·293
40	181·839	186·384	190·930	195·476	200·022	204·568	209·114	213·660	218·206	222·752
50	227·298	231·844	236·390	240·936	245·482	250·028	254·574	259·120	263·666	268·212
60	272·758	277·304	281·850	286·396	290·942	295·488	300·034	304·580	309·125	313·671
70	318·217	322·763	327·309	331·855	336·401	340·947	345·493	350·039	354·585	359·131
80	363·677	368·223	372·769	377·315	381·861	386·407	390·953	395·499	400·045	404·591
90	409·137	413·683	418·229	422·775	427·321	431·866	436·412	440·958	445·504	450·050

Pounds to Kilogrammes

lb	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	kg	kg	kg	kg	kg	kg	kg	kg	kg	kg
0	—	0·4535	0·9071	1·3607	1·8143	2·2679	2·7215	3·1751	3·6287	4·0823
10	4·5359	4·9895	5·4431	5·8967	6·3503	6·8039	7·2574	7·7110	8·1646	8·6182
20	9·0718	9·5254	9·9790	10·4326	10·8862	11·3398	11·7934	12·2470	12·7006	13·1542
30	13·6078	14·0614	14·5150	14·9686	15·4222	15·8757	16·3293	16·7829	17·2365	17·6901
40	18·1437	18·5973	19·0509	19·5045	19·9581	20·4117	20·8653	21·3189	21·7725	22·2260
50	22·6796	23·1332	23·5868	24·0404	24·4940	24·9476	25·4012	25·8548	26·3084	26·7620
60	27·2155	27·6691	28·1227	28·5763	29·0299	29·4835	29·9371	30·3907	30·8443	31·2978
70	31·7514	32·2051	32·6587	33·1122	33·5658	34·0194	34·4730	34·9266	35·3802	35·8338
80	36·2874	36·7410	37·1946	37·6482	38·1018	38·5554	39·0090	39·4626	39·9162	40·3697
90	40·8233	41·2769	41·7305	42·1841	42·6377	43·0913	43·5449	43·9985	44·4521	44·9057

Pounds per Square Inch to Kilogrammes per Square Centimetre

lb/in^2	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	kg/cm^2	kg/cm^2	kg/cm^2	kg/cm^2	kg/cm^2	kg/cm^2	kg/cm^2	kg/cm^2	kg/cm^2	kg/cm^2
0	—	0·07031	0·14061	0·21092	0·28123	0·35154	0·42184	0·49215	0·56246	0·63276
10	0·70307	0·77338	0·84369	0·91399	0·98430	1·05461	1·12491	1·19522	1·26553	1·33583
20	1·40614	1·47645	1·54676	1·61706	1·68737	1·75768	1·82798	1·89829	1·96860	2·03891
30	2·10921	2·17952	2·24983	2·32013	2·39044	2·46075	2·53106	2·60136	2·67167	2·74198
40	2·81228	2·88259	2·95290	3·02320	3·09351	3·16382	3·23413	3·30443	3·37474	3·44505
50	3·51535	3·58566	3·65597	3·72628	3·79658	3·86689	3·93720	4·00750	4·07781	4·14812
60	4·21483	4·28873	4·35904	4·42935	4·49965	4·56996	4·64027	4·71058	4·78088	4·85119
70	4·92150	4·99180	5·06211	5·13242	5·20272	5·27303	5·34334	5·41365	5·48395	5·55426
80	5·62457	5·69487	5·76518	5·83549	5·90580	5·97610	6·04641	6·11672	6·18702	6·25733
90	6·32764	6·39795	6·46825	6·53856	6·60887	6·67917	6·74948	6·81979	6·89010	6·96040

INDEX

Accumulators 63, 65, 66, 146
Acoustical treatment 104
Administration 77
Adventitious heat gains 128–29
Air conditioning of office building 52
Air diffusers 51
Air temperature 24, 25
Amortisation 76
Anchorages 42
Annual loan repayments 134
Artificial pressurisation 34
Automatic control *See* Control of heat supply

Back pressure turbines 67
Background warmth 47, 53
Bacterial contamination 109
Bath Spa 114 *See* Frontispiece
Battersea Power Station 4, 5
Billingham New Town centre 5, 72
Bills of quantities 112–13
Block rate charges 100
Block rate tariff 101
Boiler design 70–71
Boiler house requirements 104
Boiler plant 66, 70, 71–73, 104
Building units 114
By-product 58

Calorifier 89
Capital cost *See* Costs
Central station, layout of 73
  location of 104–05
  situation of 70
Charges 10
  apportionment between residential and non-residential consumers 98
  average 96
  development 96
  fixed 99
  for heat supply 95–103
  methods of 15, 16, 99–100
  per therm 95
  revision of scale of 101
  standing 75, 93, 98, 103
  to residential and non-residential consumers 100
  weekly 102–03
Chimneys 105–07
Circulating head 34–35
Circulating pumps 38, 39
Civil engineering work 104
Clean Air Act (1956) 73, 109
Collection of payments 94, 101
Commercial consumers 27, 28, 37–38
Concrete conduit 45
Condensation 53
Conduction 50, 51
Consumer's installation 47–56
Contractural procedure 112
Controllers for pressure, volume and temperature 37–38
Convection 50
Conversion tables 154–58
Corrosion 109
Control of heat supply 9, 10, 14–21, 47
  accuracy of 20, 21
  arbitrary standards 15
  automatic 20, 21, 48, 83, 116
  automatic equipment 48
  by consumer 16, 19, 95
  by supplier 15, 29
  factors affecting 14
  individual 85
  individual automatic 21
  methods of 17, 19
  programming 15, 21
  starting and stopping 49
Costing 10, 11, 83
Costs 74–84
  annual 74, 83
  annual operating 137–38
  capital 10, 74, 77, 78, 96, 134
    heat transmission 23
  comparison of combined heat and electricity generation and direct heat generation 81
  comparison with other methods 76
  factors affecting 7
  fixed 80, 98
  fuel 77
  heat 7
  heat production and transmission 23
  heat supply 17, 76, 135
  heat transmission 33, 46, 81, 113
  heaters 76
  items of 78
  measuring devices 16

Costs *continued*
  metering 88
  operating 77
  per therm 74, 96, 99, 117
  saving in 6
  summary of 149
  thermal 7
  total annual 75, 78, 80, 96, 135
  unit 18
  variable 80, 98
  variation in annual 23
Creaking noises 54–55
Curtain-wall construction 53
Cwmbran New Town 40, 41, 66

Daily supply loads 65
Design requirements 148
Development charge 96
Development periods 96
Development rate 78
Differential pressure controller 37
Direct thermal generation 47
District heating, advantage of 8, 11
  design and operation 5
  development programme 23
  diversity conditions 24
  economic use of 116
  failures in 5
  general considerations 8–13
  general requirements 8–13
  historical evolution 2
  planning requirements 11
  position and prospects 111–19
  promotion and operation 111
  slow development of 119
Diversity factor 24, 25
Diverting valve 37, 49
Domestic consumers 29
Double glazing 25
Drainage 43
Drawings, requirements for 150
Ducted warm air 53

Economics of service 11
Efficiency of boiler plant 73
  of generation 60–61
  thermal 82
Elapsed-time counter 86
Electrical engineering work 108
Electrical loading 139
Electricity consumption 78
Electricity generating plant 115
Electricity generation 61
Environmental engineering 50
Equalised flow 37
Equivalent temperature 50
Erection requirements 151
Estimating 74
Evaporative meters 90
Expansion bellows 46
Expansion chamber 45–46
Expansion devices 42
Expenditure, estimated annual 79

Factories Acts 110
Farsta 59
Fire risk 83
Fixed price 15
Flat rate 15, 16
Fluorescein dye 109
Fuel, oil 73
  solid 71, 73, 104–05
  terms of purchase 77
Fuel bunkers 105
Fuel cost 57, 77
Fuel storage 105
Fuel supplies 83
Fynsvaerket system 3

Gas analysis 73
Geothermal heat 114–15 *See* Frontispiece
Germany 2
Glossary 121
Government buildings 111
G.P.O. lines 108

Hazards 116
Heat, purchase of 117
Heat consumption, calculation of 15
  excess 95
  measurement of 85–94
Heat demand 9, 116
  analysis of 25
  annual 27, 28, 29, 30, 78
  assessment of 28
  diversity in 26, 113
  estimated annual 75
  estimation of 27
  factors affecting 28
  fluctuating 39
  increased 70
  inequalities in 99
  maximum hourly 24–29
  metered analysis of 31
  sudden rises in 84
  summaries of 29, 30, 31

Heat economy 61
Heat exchangers 37
Heat gains, adventitious 128–30
Heat generation 57
  combined with power generation 57
Heat insulation *See* Thermal insulation
Heat load 9, 10, 22–31
  estimation of 22, 24
  factors affecting 24
  future requirements 114
  increasing the 22
Heat loss 26, 32, 35, 36, 48, 50, 53, 56, 99
  tests on 26, 132–33
Heat measurement 10
  inferential method of 20, 86
Heat meters 10, 88–94
  British Coal Utilisation Research Association 93
  electrical 91
  mechanical 91, 92
  thermo-electric 93
Heat output 53
Heat production 57–73
  control of 70
  cost of 23
  direct thermal generation 59
  from thermal generating plant 58
  independently of electricity generation 58
  method of operation 70
  thermal-electric 59
Heat rejected 59
Heat sources 114–15
  selection of 11
  underground 114
Heat storage 58, 65, 66
Heat supply, appraisal of methods 117–18
  control of *See* Control of heat supply
  cost of 135
Heat transmission 32–46
  capital cost 23
  cost of 23, 33, 46, 81, 113
  determination of best system for 32
  economics of 32
  effect of heat load 32
  equalised flow 37
  factors affecting 33
  fittings 33
  installation standards 43
  mains economy 35
  mains routing and levels 39
  mains size 35
  mains testing 43
  nature of network 9–10
  operating pressures and temperatures 33
Heat transmission *continued*
  pressure loss 36
  sub-stations 32, 33
  transmission media 33
  underground mains 42, 45
Heaters, choice of type of 50
  cost of 76
  panel type 53
  position of 53
  skirting panel 51
Heating authority 110, 111
Hot tap water 17
  rationing supply of 18
  requirements 25
  temperature 24, 25
Hot water, as transmitting medium 34
  control of supply 49
  flow meters 94
  system 48, 54–55
  temperatures 34
Hour meter 86–88
Hypothermia 116

Incidental builders work 108, 141
Income 11
Industrial consumers 28, 37–38
Inferential method of heat measurement 20, 86
Ingoing water temperature 19
Inspection 109, 150
Installation requirements 43, 151
Instruments 71, 73
Insulation 24, 25, 56, 114
  materials 42, 56
  of pipework 45
Insurance 75, 77, 109
Isolating valves 39

Killingworth system 118

Load factor 6, 78
  estimation of 27
Loan repayments 136
Local authority 111
Lockport system 2
London County Council (General Powers) Act (*1949*) 110, 147

Mains *See* Heat transmission
Maximum hourly heat demand 24–29
Mean radiant temperature 51

Measuring devices 18
  capital expenditure for 16
  See also Heat meters
Meter reading 94, 101
Metering 39, 85
  cost of 88
  See also Heatmeters
Metering service 86, 93
Mixing device, thermostatically actuated 19
Mixing valve 38, 49
Multi-corrugated bellows 42
Multiple glazing 25

Natural gas 115
Negotiated price 113
Nuclear energy 58

Occupancy period 27
Off-peak periods 66–67
Office building, air conditioning of 52
Offices, Shops and Railway Premises Act (1963) 110
Oil fuel 73
Oil storage tanks 105–106
Outflow water temperature 19

Pass-out steam 66
pH indicator 109
Phasing period of development 22
Pimlico District Heating Undertaking 4, 7, 11, 63, 64, 145–47
  adventitious heat gains 128
  heat loss tests 132–33
  operating results 124–25
Pipe coils, embedded or interposed 51
Pipework 54
  concealment of 55–56
  corrosion of underground 45
  defects in 43
  expansion and contraction 54–55
  protection and insulation 45
  testing 43
    of welded 144
  underground 106
  welding of 43
Planning requirements 11, 148–52
Plant commissioning and acceptance of requirements 152
Power generation 57
Pre-heating 50
Pre-payment meter 88, 102
Pressure control 36–38
Pressure head 36
Pressure loss 36
Price fixing 113
Profit-making 80, 82, 98

Radiant heating 51
Radiant panels 51
Radiation 50, 51
Rates 77
Refuse disposal 11
Restrictive practices 112
Revenue 80
  deficit in 96, 101
  estimated annual 79
Reykjavik 114
Roadway heating 113
Russia 2

St. Pölten system 3
Sale price 80
Scale formation 109
Selective tendering 113
Service connections 37–38
Skirting panel heaters 51
Smoke discharge *See* Smoke emission
Smoke emission 73, 109
Solid fuel 70, 73
Specification requirements 149
Standing charges 75, 93, 98, 103
Statutory powers 110
Statutory regulations 119
Statutory requirements 109
Steam generators 33
Steam supplies, control of 48, 49
Steam systems 33–34, 54
Storage heaters for hot tap water 18
Straight thermal generation 58
Sub-stations 32, 33, 108

Tanks, oil storage 105, 106
Tariffs 95, 98
  block rate 100–01
  two-part 10
Telephone lines 108
Temperature control devices 20, 37
Temperature conversion tables 154–55
Temperature gradients 50, 53
Temperature modulation 37–38
Tenders, requirements for 150–51
Terrestrial heat 115

Testing 109
  of welded pipe joints and flanges 144
  requirements 152
Thermal efficiency 82
Thermal-electric scheme 7
Thermal insulation 24, 25, 56, 114
Thermal Insulation (Industrial Buildings) Act (1957) 110
Thermal power stations 59–61
Thermostatic control 18
Thermostatic control valves 20, 88–89
Thermostatically actuated mixing device 19–20
Time control 49
Time switch 21
Toronto 3
Transmission *See* Heat transmission
Two-part tariff 10
Two-stage turbines 67

Underground conduits 106, 108
Underground heat sources 114
Underground services 113
Unit cost 18
Unit prices 81
United States 2
Unmetered supply 85

Variable-speed pumps 39
Venting 43
Vertical temperature gradients 53
Volume control 36–38

Wages 78
Wairakei 114
Warm air systems 51, 52
Water coloration 109
Water flow meter 88–90
Water temperature, ingoing 19
  outflow 19
Water treatment 109
Wayleaves 42
Welded pipe joints and flanges, testing of 144
Welder's qualification tests 142–43
Welding of pipework 43

Zone control 49