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District Heating

A Survey of Practice in Europe and America

Prepared by
The Heating and Ventilating Research Association

On behalf of
The Design and Heating Study Group (Solid Fuel)

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CHAPTER 1 - INTRODUCTION

1.1 Origins of the survey

The setting up of the Design and Heating Study Group by the National Coal Board in 1964 coincided with a revival of interest in district heating in this country. The Group were conscious of the fact that district heating schemes seemed to have been successful both in Europe and America, whereas the few established in Britain had proved to be much less so. Here, corrosion of the main distribution pipes had been a major difficulty, with low load density a likely additional factor.

Clearly there were lessons to be learned from this experience, and the Group considered that a survey of overseas schemes would afford some guidance as to the factors that could determine the success or failure of a scheme, and perhaps provide quantitative data of value in new projects. Accordingly, the Heating and Ventilating Research Association (H.V.R.A.) was invited by the National Coal Board to carry out a survey during the year 1964.

It must be stressed that the information obtained, and opinions expressed in discussions, during the survey relate only to the circumstances then existing. The validity of any conclusions reached may well be affected by changes of circumstance - e.g., in the availability or the price of fuel - since 1964.

1.2 Scope of the survey

The programme of work envisaged for the survey was as follows:

(a) A review of the various descriptive papers dealing with individual installations, together with a number of theoretical papers on different aspects of district heating.

(b) The preparation of a detailed questionnaire and its circulation to all known operators of district heating schemes in Europe, America and Russia*.

(c) Visits to installations in various overseas countries for discussions with designers, operators and specialist organisations such as the National District Heating Association of America (N.D.H.A.) and the Union Internationale des Distributeurs de Chaleur (UNICHAL).+

* In the event this proved of little value, in that less than 80 of the 500 copies circulated were returned. Details of the questionnaire are given in Appendix 2.

+ Sites and installations visited are listed in Appendix 3.

1.3 Definitions

At an early stage of the survey it became evident that a clear distinction between district heating and group heating was necessary. The following definitions were therefore laid down:

(a) District heating: a system where the heat is generated by an independent firm or authority and supplied through a mains distribution system to one or more areas or buildings and sold to the users; there is normally no defined limit to the area to be served. In a general sense the term "district heating" is often used to include "group heating".

(b) Group heating: a system where the heat generated is supplied via a system of mains to one or more buildings, which are under the same control as the heat generating authority. In many cases, this means that the final extent of the scheme is known at the outset.

CHAPTER 2 - THE GROWTH OF DISTRICT HEATING

2.1 Early installations

The first recorded installation of a district heating scheme was at Lockport, New York State, in 1877. The first installation on this side of the Atlantic, according to published literature, was at Manchester in 1911, but it is known that schemes were in operation at Dresden in 1900 and Warsaw in 1901. Since those years district heating has developed to such an extent that it has become in many countries a public utility service similar to those supplying gas, water and electricity; several thousand district and group installations now exist, and many more are at various stages of planning and construction.

2.2 Present output

Although published figures on the number and types of plant show considerable differences, some statistics of reasonable accuracy can be quoted. Thus in America, 55 schemes, operated by members of the N.D.H.A., may be classed as district heating, while many others probably fall within the definition. In Europe, UNICHAL reports, outside Russia and the U.K., 140 large district heating schemes, together with several hundred group or cooperative schemes. Russia is reputed to have about 160 plants and many small communal schemes in operation. In the U.K. some 10-12 group heating schemes serve residential areas, in addition to a large number of plants supplying industrial, institutional and service buildings.

An indication can be given also of the amount of heat supplied by district networks in U.S.A., Europe and Russia. In 1962 N.D.H.A. schemes supplied 1,000 x 10^6 therms (10.5 x 10^7 GJ) and 60 UNICHAL schemes 520 x 10^6 therms (5.5 x 10^7 GJ). Other data (39), together with the known growth of district heating in Germany and Denmark, suggest that the total supply in Europe amounts now to about three times the UNICHAL figure. The Russian figure for residential supply in 1962 was 1,800 x 10^6 therms (19 x 10^7 GJ) - out of a total, mainly serving industrial heating requirements, of 13,600 x 10^6 therms (143 x 10^7 GJ).

Some idea of the growth since 1950 of the heat supplied by district and group networks in Denmark and West Germany is given by Figure 1. About 14% of Danish space heating requirements are at present met by communal plants - a percentage expected to increase to 26 by 1970 and to 37 by 1973 (113).

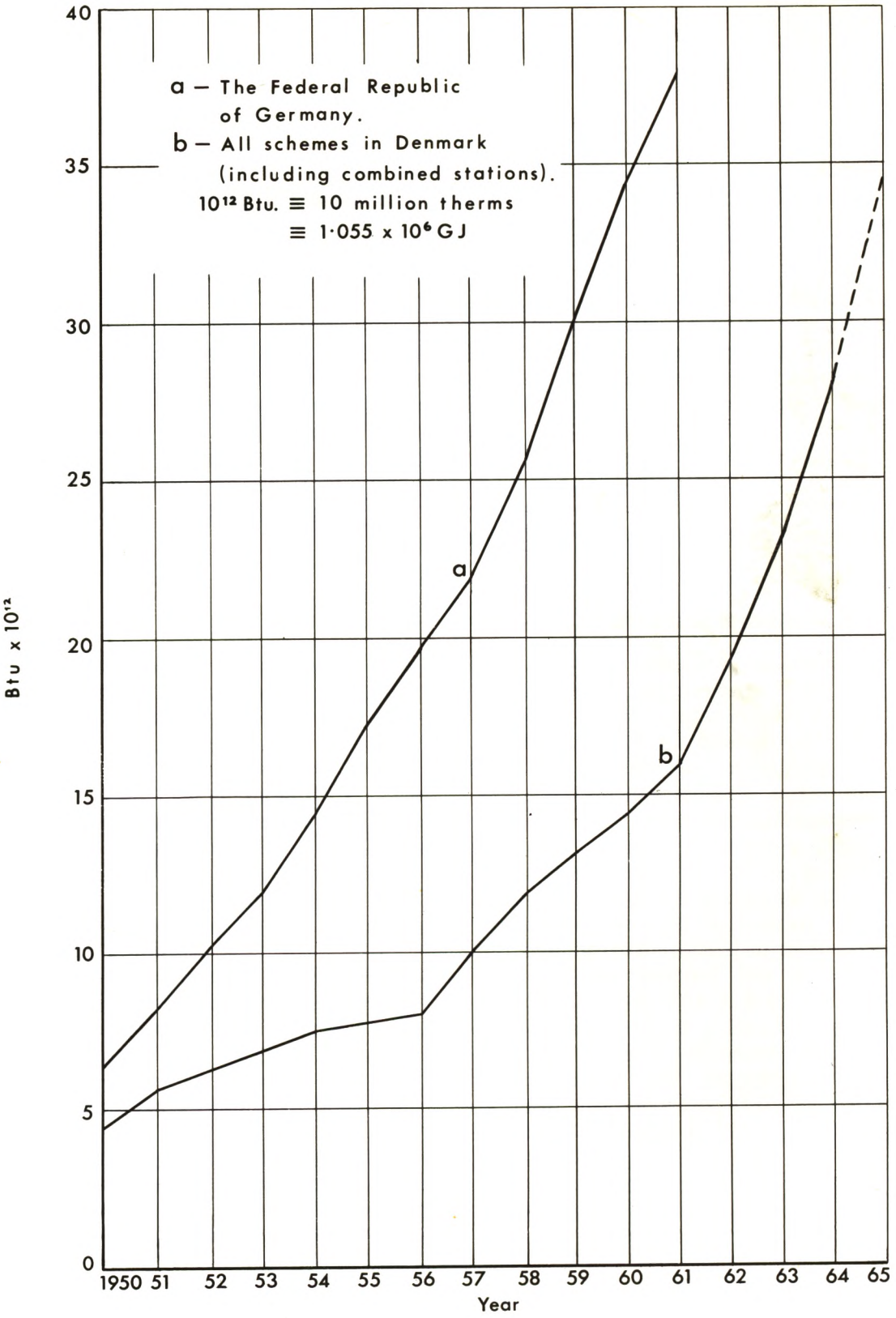


FIGURE 1 - GROWTH OF HEAT SUPPLIED IN WEST GERMANY AND DENMARK

2.3 Current trends

Certain trends now in evidence indicate the directions in which district heating is likely to develop in future years.

For instance, in America, where district heating is already an established service to the community, there is, for climatic reasons, a movement to extend it to provide summer cooling through the district mains. Examples of industrial and commercial installations can be seen at Hartford, Connecticut, and Pittsburgh, Pennsylvania. A scheme to serve some 5,800 apartments housing 20,000 people is under construction at Rochdale Village, New York. It is of the thermal-electric type*, which, while supplying all the electricity requirements of the area, provides both the summer cooling and winter heating+. Another noticeable tendency in America is the decline of steam as the chief heating medium. Hot water is now favoured for ordinary residential areas, although steam is still widely used in large tower blocks.

A development of recent years, affecting in particular the smaller group heating schemes, has been the emergence of specialist firms of contractors that undertake to design, install, operate and maintain schemes under long-term contracts - usually of 20-30 years' duration. The trend is illustrated by the rise in membership of the Syndicat National des Exploitants de Chauffage (SNEC) in France, which has increased from 75 firms in 1957 to 134 in 1963, while, over the same period, their annual output has increased from 63.2 to 310 x 10^6 therms (0.7 to 3.3 x 10^7 GJ). In some municipalities the entire responsibility for district heating has been handed over to a member of the SNEC. At Tours, Nancy and the Lille hospital centre, for example, the municipality is relieved of all financial, technical and administrative burdens. The same specialist contractors employ mobile staff - as does the Hamburg Gas Company - to operate and maintain plant in individual buildings (chauffage à forfait), and sometimes will replace existing plant with more automatic and modern equipment.

Now coming into the realm of practical possibility is district heating supplied by nuclear power stations. A paper dealing with the subject was presented at the World Power Conference in 1964, and there is now a scheme in operation in Sweden, although it cannot as yet provide heat at a competitive price.

* See p.22
+ For a fuller account of district cooling in America, see Appendix 8.

CHAPTER 3 - FACTORS AFFECTING THE CHOICE OF DISTRICT HEATING

3.1 Lack of criteria

There is little uniformity of opinion on the factors determining the successful and economic operation of a district heating scheme. Authorities in some countries consider that low-density areas comprising single family houses are particularly unsuitable for connection to a district network. Yet in others circumstances allow such areas to be heated economically: in Denmark, for instance, 250 schemes of this type exist, and many more are at the planning stage. One recent British article (1) expresses the view that the supply area must be a really large one with a minimum of 2,000 consumers, and preferably 5,000. However, in many countries schemes serve fewer than 1,000 consumers economically. A German article (106) states that the load density should preferably be around 850,000 - 900,000 Btu/h an acre (62-65 MW/km^2), but there are in Germany itself several schemes with a load density appreciably below this figure. In Denmark several schemes have densities as low as 150,000-200,000 Btu/h an acre (11-15 MW/km^2).

Again, a view held in U.S.A., Russia and some other European countries is that production of heat for a district network should be associated with production of electrical power in a large combined station; preferably this should supply the base load while the peak load is satisfied by a boiler plant situated, if possible, in the area of high load. But this does not hold good in the U.K. or France where the electricity authorities are concerned to generate the maximum of electrical energy.

3.2 Economic factors

There seem to be in fact no universal criteria by which authorities can judge whether district heating (or group heating) should be adopted, and, if it is adopted, what type of plant should be utilised. Instead, local or national economic and political factors - for example, need to utilise natural fuel resources or clean air legislation - may be decisive in determining the choice.

In Denmark, a country with no fuel of its own except for a few deposits of poor-quality brown coal, the amount of foreign exchange used in buying imported fuel is the largest item in the national budget. The fuel, 3,500-sec. heavy fuel oil is bought from Russia at about £5 per ton, and it is more economical to burn it in the large boilers of district heating plants than to incur additional expense by refining it for use in small individual heating boilers. The policy is reinforced by the levy of a tax on light oil and gas

oil, so that district heating in Denmark has a slight advantage over individual boilers in the unit cost per therm of heat used by the consumer.

The practice in Germany is different, and indeed varies within the country, although the desire for a clean, smoke-free atmosphere is general. In the South, the large network of Munich is served primarily by large combined heat and power stations. The district heating scheme, like many others in the larger German cities, was first started to heat a hospital in one area. After this relatively small beginning in 1908 the district heating network expanded considerably as the electricity network was modernised. The old electricity generating stations were first converted to heat generating stations; later large modern power stations were constructed for the combined production of heat and electricity, two of the most recent being a gas-turbine station in the southwest of the town and a refuse-burning station in the north. Now 65% of the heat requirements are met by combined stations and 35% by peak heating stations - a ratio which has been found through practical experience to offer the most economical operating conditions.

In contrast, in Hamburg the Gas Company operates several small heat-only schemes in suburbs where, experience has shown, it is uneconomic to supply heat to areas further than 1 km (0.62 miles) from the heating station, owing to excessive losses from the mains. The primary object in this case is to afford an outlet for the by-product coke; nevertheless the district heating schemes are charged a realistic price for the coke.*

Possibly the greatest progress in Germany has been made in the Ruhr, where many small schemes have been established in residential areas. They appear to owe their existence to an official policy of securing a nearby reliable outlet for the coalfield and ensuring employment in an area where two million people are directly dependent on the mining industry. It is doubtful whether all the schemes operate on an economic basis, though the state compensates for losses incurred by coal-fired plants.

The Government of North Rhine-Westphalia requires that 70% of the fuel used for space heating is coal or based on coal (coke, town's gas). This means that, since oil is preferred for small installations and for summer loads or hot water supply, coal is consumed in large plants and for district heating and electrical power generation. Connection to a group or district scheme is encouraged by clean air legislation governing the emission of SO_2 from heating plant larger than 2.8 million Btu/h (0.82 MW) in capacity. A multitude of tall chimneys is thus eliminated from urban areas. In suburban areas it is considered "unneighbourly" to emit flue gas even from one- and two-storey buildings - an attitude which, too, helps to encourage the growth or acceptance of district heating (131).

A recent German article states that "so-called block-heating stations should only be regarded as forerunners of modern combined heat and power plants". This may be true in the large cities where several such schemes are situated close together, but would seem to be inapplicable to small towns in which electrical requirements are met by the grid network.

In France there is official protection for the coal industry, which offers financial aid to projects for coal-burning installations. The effect is to

* It is interesting to note that it is cheaper for the gasworks to buy good-quality coal from America than from the Ruhr coalfields - a situation which is peculiar to about five towns on the German coast.

encourage the adoption of large group and district schemes fired by solid fuel; oil and gas are preferred for small and individual plants.

3.3 Transport savings

An incidental benefit to be obtained from district heating is the saving of the transport costs incurred in delivering fuel to individual households and removing ash. In Wurzburg 13,000 journeys, it is estimated, would be required annually to serve the 447 consumers now supplied by a district heating scheme with a connected load of 280 x 10^6 Btu/h (82 MW) (127).

A more detailed estimate has been made by Beck of the savings to be obtained in the centre of a town of 300,000 people. Without district heating the quantity of fuel transported annually is 300,000 tons for small users, and a similar quantity for larger plant. These require 78 trucks making 85,000 journeys a year and occupying 390,000 truck-hours. Taking into account the wages of the drivers, administration, and maintenance of the lorries, transport costs amount to 7.7 DM/ton for deliveries to small users and 3.5 DM/ton for the remainder. Fuel and ash handling within the consumer's premises is estimated to cost another 4.8 DM/ton of fuel in the smaller plant. The whole of these costs would not be saved by district heating, since fuel and ash have to be handled and transported to and from a central station. Nevertheless, a substantial fraction of the transport costs - totalling 3,300,000 DM - could be saved (112).

CHAPTER 4 - THERMAL DESIGN FACTORS

4.1 Climate

Climatic conditions have considerable bearing on the size and load factor of the actual plant selected. In America minimum temperatures range from -30 to +10°F (-34 to -12°C), in Canada from -40 to -10°F (-40 to 23°C), in Europe from -10 to +15°F (-23 to -9°C) and in the U.K. from 20 to 25°F (-7 to-4°C). Such differences, and the different lengths of the heating season, mean that the amount of heat required varies appreciably from country to country.

One method of comparing different countries and localities is the "degree-day" devised by the American Gas Association in the 1930's. A direct comparison of published degree-day figures is not always possible, however, because different countries employ different methods of computing their figures. In the U.K. each day's contribution to the annual total of degree-days is the difference between its mean temperature and a base temperature of 60°F (15.6°C); published figures are confined usually to the months of the heating season - i.e., from September 1st to May 31st. In America and Canada a similar method is followed but the base temperature is 65°F (18.3°C). In France and Belgium a base temperature of 15°C (59°F) for the duration of the heating season is generally accepted, while in West Germany and Switzerland an average room temperature of 18 to 20°C (62 to 68°F) is used over a period in which the external temperature is below 12°C (53.6°F.)

In order to compare climatic factors three graphs (Figures 2, 3 and 4) have been plotted from the monthly mean average temperatures in various countries. The data for most places in U.K. fall within the curves shown in Figure 2. In Europe, the curves for both Brussels and Paris are closely similar to that for Amsterdam, while Copenhagen approximates to Hamburg (Figure 3). From examining these graphs, the annual demand for heat in each place can readily be ascertained, and comparisons in terms of degree-days can be made.

4.2 Basic design temperatures

Owing to the variation in climatic conditions, basic design air temperatures differ from one country to another, and in the case of America, and to a lesser extent of some European countries, from zone to zone. Table 1 indicates the general range but it should be noted that the internal temperatures are those for living rooms; such rooms as kitchens and bedrooms are often 5 - 10°F (3 - 6°C) lower.

Country	Basic design air temperature				Temperature rise	
	Outside		Inside			
	°F	°C	°F	°C	°F	°C
U.S.A. Zones 1 to 6	-30 to 15	-23 to -9	70 to 75	21 to 24	100 to 60	56 to 33
Canada	-35	-37	70 to 75	21 to 24	110	61
Denmark	3	-16	68	20	65	36
France	20	- 7	68	20	48	27
W. Germany	10	-12	68	20	58	32
Holland	14	-10	68	20	54	30
Sweden	- 4	-20	68	20	72	40
U.K.	30	- 1	65 to 68	18 to 20	35 to 38	9 to 21

TABLE 1 - BASIC DESIGN TEMPERATURES

The annual total of degree-days for a district does not, however, indicate the capacity of the heating plant it requires. This becomes apparent from Figure 5, where the mean average monthly temperature curves for London and New York have been re-plotted to facilitate comparison. While the total annual number of degree-days to a base temperature of 65°F are 5310 and 5350 respectively, the design indoor-outdoor temperature difference, which determines the required size of the heating plant, is much larger in New York (70°F) than in London (35 to 38°F). The capacity of a New York plant therefore must be higher than that required for an identical scheme in London.

Figure 5 also indicates that the heating season is longer in London than in New York. Hence, since a heating system must be designed to provide adequate heat at the lowest temperature likely to be sustained, the heating load in the U.K. throughout the winter is more uniform, and the load factor* is higher.

This is illustrated in Table 2 where the figures for plant size and load factor in a number of cities are compared with those for London (100 in each case). In this table the plant size is proportional to the design temperature difference. The annual heat sent out (and hence the fuel used) are here assumed to be proportional to the annual degree-day total. The load factor is then simply the ratio between the fifth and third columns, though there is some doubt as to the accuracy of this, particularly for dwellings, where fortuitous heat gains are large.

$$\text{* Load factor} = \frac{\text{annual consumption}}{\text{maximum possible heat sent out}}$$

Location	Design temperature difference °F	Plant size	Degree-days per heating season*	Fuel used	Expected load factor relation
London	35	100	4995	100	100
New York	70	200	5350	108	54
Hamburg	58	165	6085	122	74
Paris	48	137	5050	102	75
Copenhagen	65	186	6510	132	71
Stockholm	72	205	8625	171	83

* All degree-day figures are given to a base temperature of 65°F for the nine months September to May.

TABLE 2 - EFFECT ON PLANT SIZE AND LOAD FACTOR

4.3 Insulation of buildings

Most countries where heating is necessary have a higher standard of building insulation than that found in the U.K. Until postwar years, it was the practice in this country for houses and other buildings to be constructed with a thermal transmittance (U) value for structural walls and roofs of about 0.4 to 0.5 Btu/ft^2 h deg. F (about 2.5 W/m^2 deg. K). Since 1945, despite the recommendations of various governmental committees, the U-value has rarely fallen below 0.3 Btu/ft.^{2}h deg. F (1.7 W/m^2 deg. F). In Europe generally U-values of 0.1 to 0.2 (Btu/ft.^{2} h deg. F (0.57 to 1.1 W/m^2 deg. K) are common and an even lower value is sometimes demanded, particularly with electric space heating. A recent O.E.C.D. report (105) shows that in Denmark, Norway and Sweden certain standards of insulation are mandatory for house building subsidised by the state; in West Germany, Austria and Holland, although high standards are observed, they are not mandatory.

In America the standard of insulation is similar to that in Europe, the normal practice being to insulate the structure so that the U-value falls between 0.15 and 0.2 Btu/ft.^{2} h deg. F (0.8 to 1.1 W/m^2 deg. K). One local power company, in Iowa, specifies a U-value of 0.068 Btu/ft.^{2} h deg. F (0.4 W/m^2 deg. K) for exposed walls as a condition of connection to the district heating network.

In some instances the specific heat loss from the building or dwelling, expressed in Btu/ft.^{2} of floor area or per ft.^{3} of volume, is subject to a statutory maximum. This criterion is perhaps more sensible than a mere specification of thermal transmittance, which does not take into account window size, for instance. In Germany, specified maximum heat losses from flats and dwellings are about 90-120 W/m^2 (30-40 Btu/ft.^{2}) (131).

Generally, it is not surprising, in view of the higher standard of insulation, that the heat requirement of a house in Europe or America is often no greater than of a house of similar size in this country, irrespective of the larger temperature differences which have to be catered for. The demand for domestic hot water is about the same in Europe as in Britain, being from a sixth to a quarter of the space heating load.

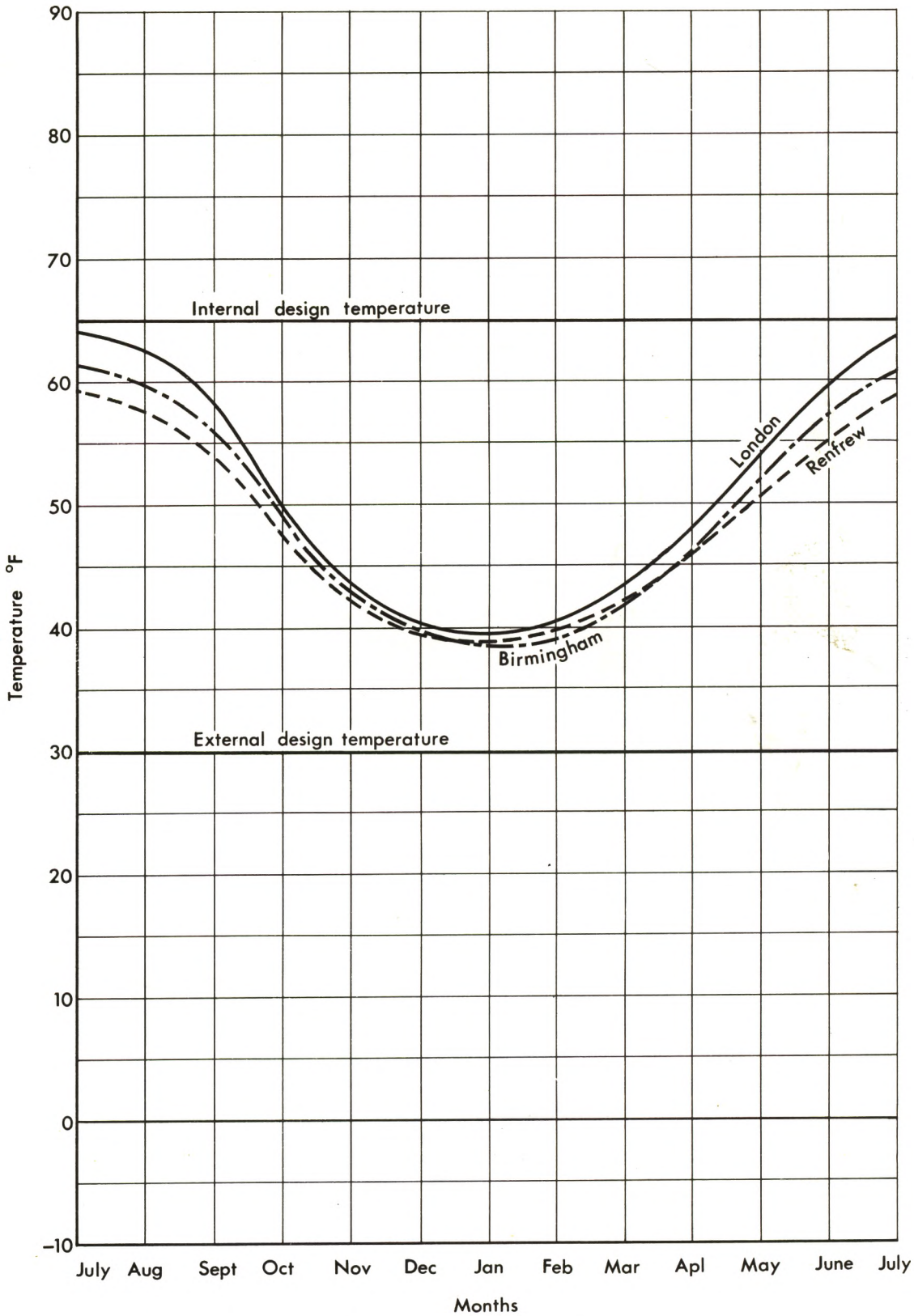


FIGURE 2 - MEAN AVERAGE TEMPERATURES - U.K.

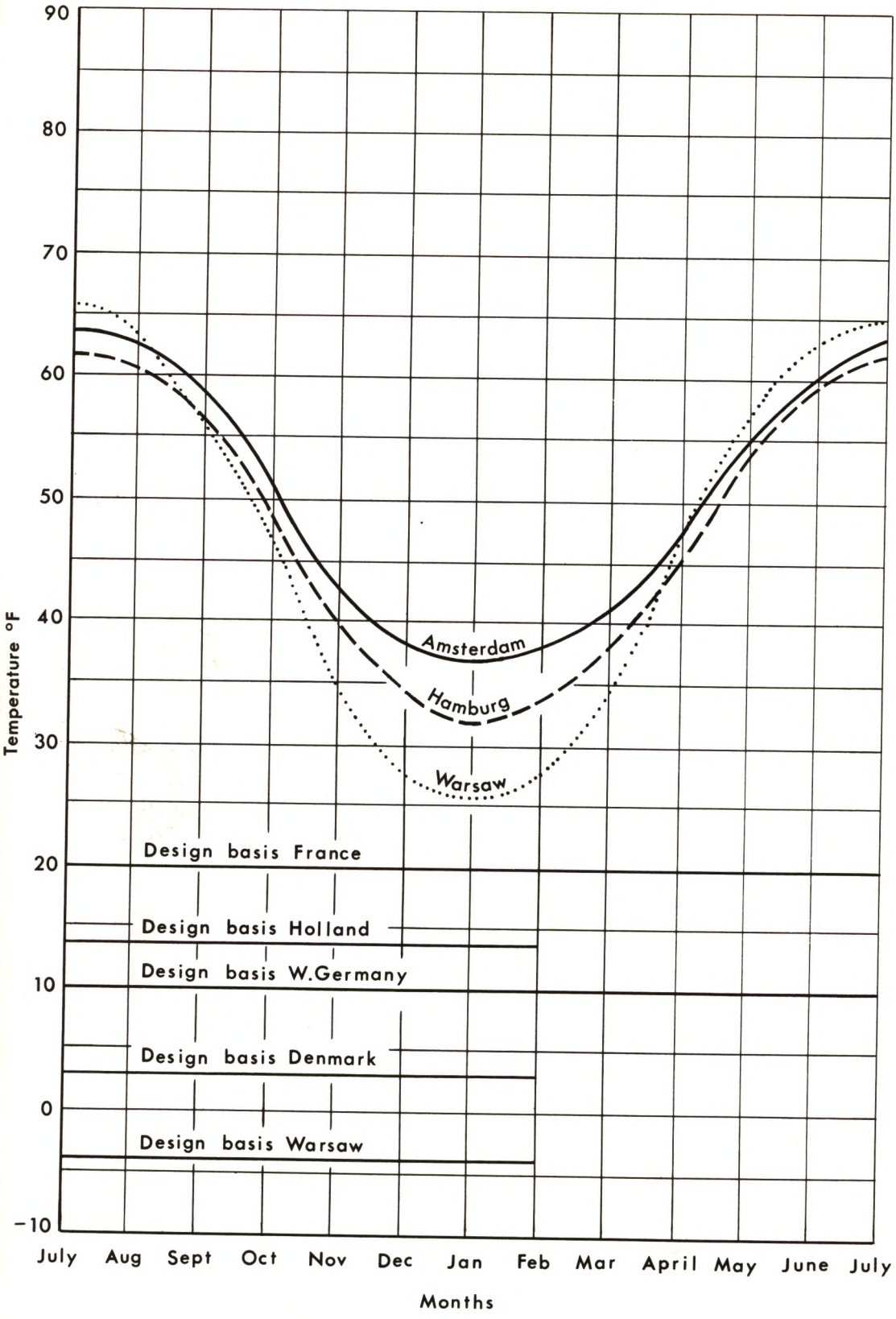


FIGURE 3 - MEAN AVERAGE TEMPERATURES - EUROPE

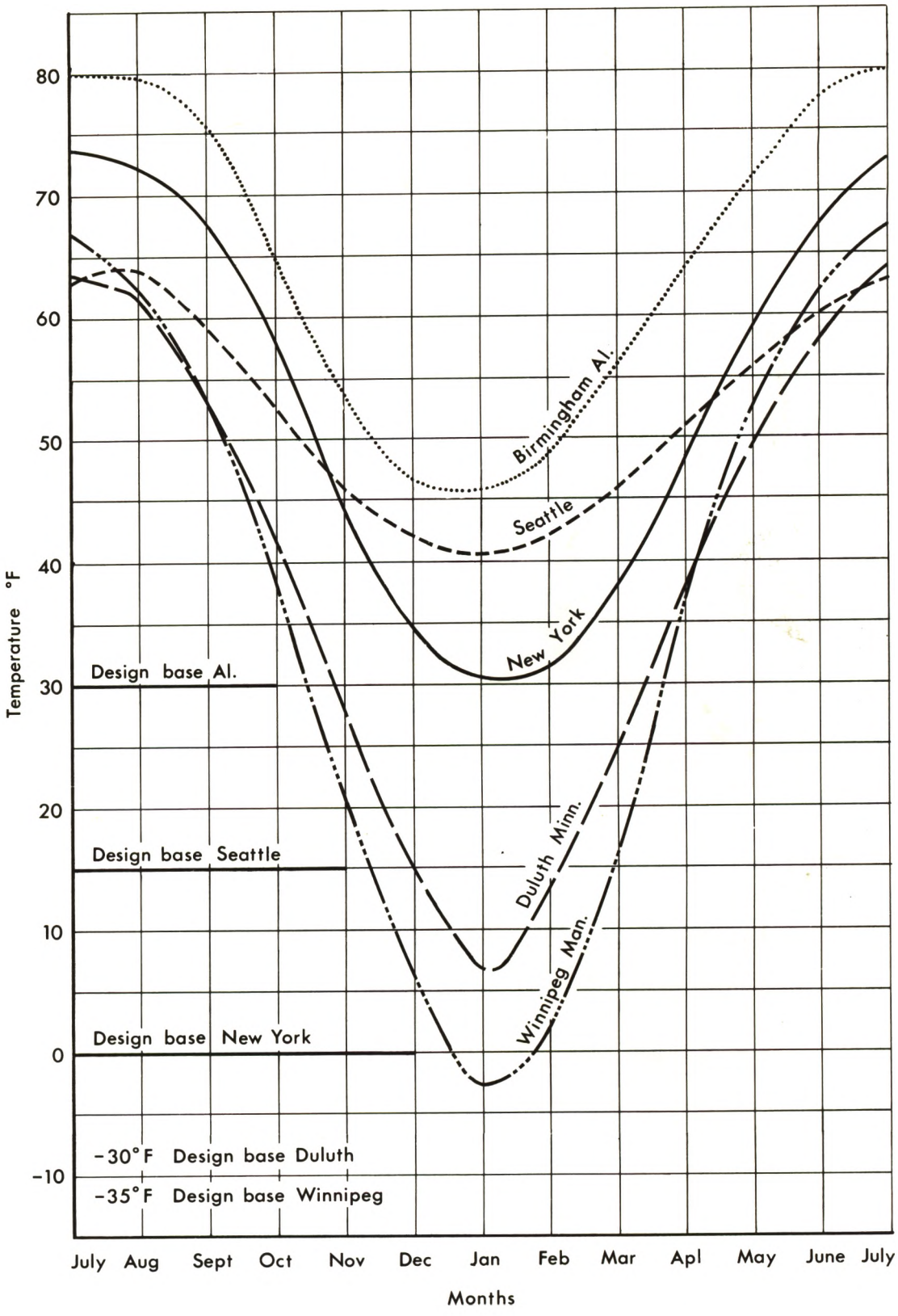


FIGURE 4 - MEAN AVERAGE TEMPERATURES - N. AMERICA

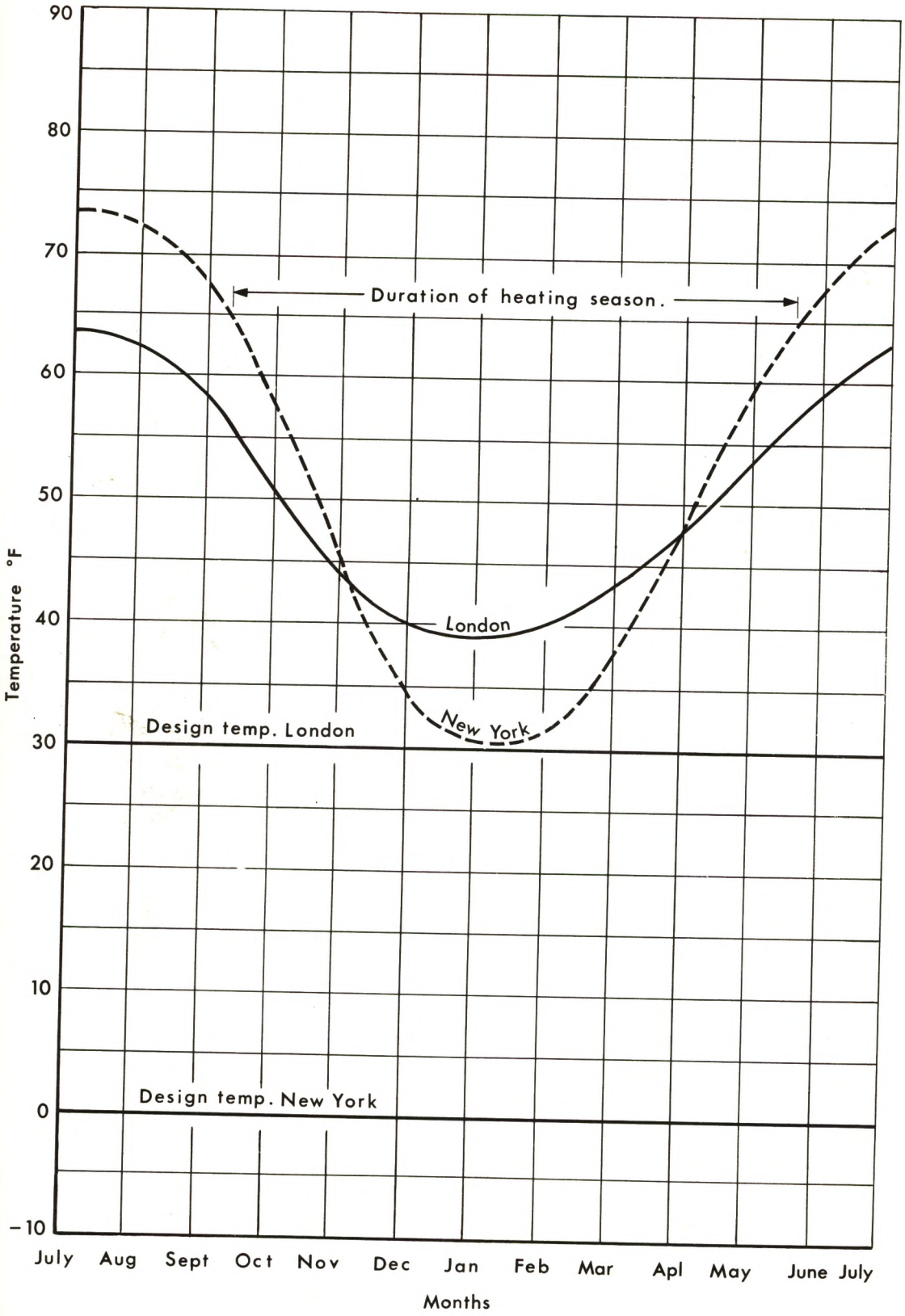


FIGURE 5 - MEAN AVERAGE TEMPERATURES - LONDON AND NEW YORK

CHAPTER 5 - LOAD

5.1 Connected load

The connected load of a district heating scheme represents a combination of a number of different types of demand. In general these are as follows:

(a) Industrial premises - space heating
(b) Industrial premises - process work
(c) Commercial premises (e.g., shops, stores, offices) - space heating
(d) Public buildings (e.g., theatres, museums, schools, hospitals) - space heating
(e) Dwellings (e.g., houses, flats, bungalows) - space heating
(f) Domestic hot water

Table 3 gives a general picture of the extent and duration of these various demands for heat.

Type of load	Heating requirements		Remarks
	Days/week	Hours/day	
Industrial premises - space heating and process work	5 - 7	12 - 24	Dependent largely on shift work
Commercial premises	5 - 6	10 - 24	Dependent on local circumstances. Night and weekend shut down in most cases.
Public buildings	5 - 6	10 - 24	Dependent on local circumstances. Night and weekend shut down in most cases.
Hospitals	7	24	Full time usage. Advantageous for high load factor.
Dwellings	7	16 - 24	Some variation with individual requirements.
Domestic hot water	7	16 - 24	Basically a uniform load throughout the year.

TABLE 3 - TYPES OF LOAD AND DURATION OF DEMAND

The demand for domestic hot water when supplied from a district network is difficult to estimate accurately in the design stage. In practice it has been found to amount to about 60 - 70 gal. per day per dwelling, which conforms generally with the recommendations of the I.H.V.E. Guide to current practice (1965). Demand will vary according to whether there is unlimited distribution of hot water from a central storage calorifier or whether there are local calorifiers supplying each dwelling. In the latter case consumption can sometimes be reduced by cutting down the primary heating surface of the calorifier and creating a longer heat-up period for the secondary water.

5.2 Load factor

The load factor of an installation is normally the ratio, expressed as a percentage, between the actual annual output of heat supplied to the system, including all mains and other losses, and the maximum annual capacity. Figure 6 illustrates three different types of installation. If the total

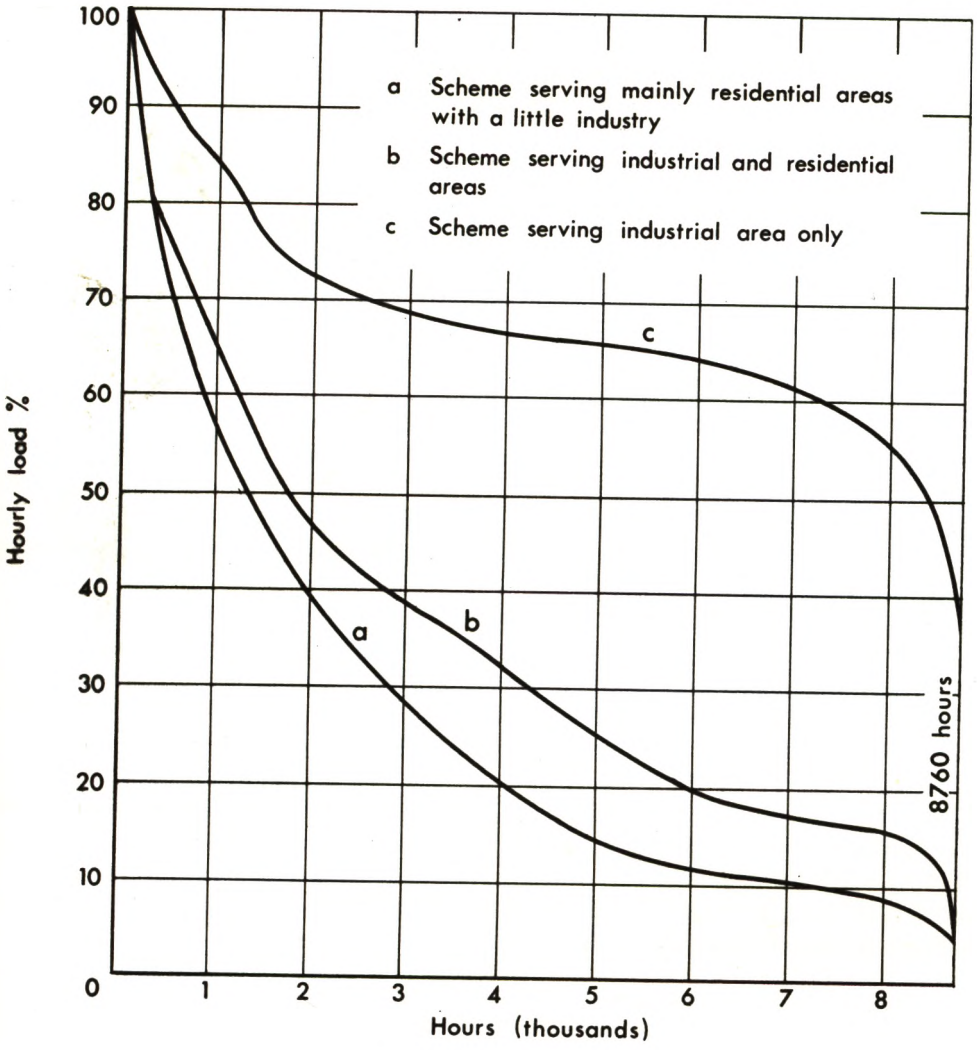


FIGURE 6 - LOAD FACTOR

area of the graph is 100%, the area to the left or below the various lines represents the system usage of heat during the year, and this as a percentage of the total area is the load factor. It is also apparent from the graph how a large industrial demand considerably increases the load factor, since process heat is generally required all year round.

In statistics compiled by the N.D.H.A. covering some 53 installations, the annual system load factor varies from 14% at Lincoln, Nebraska, to 42.9% at Quebec, Canada, the average being 28.13% (5). UNICHAL lists some 47 installations in various European countries with load factors ranging from 14% in Rotterdam to 50.7% at Reuter, with an average of 26.3%. Additional data collected from Denmark for some 58 schemes shows an average load factor of 26.5%, and from West Germany for 31 schemes an average of 20.84% (130,92).

There is now a growing practice of expressing the load factor, alternatively, as the equivalent number of hours of operation annually at full load.* This figure may vary from as low as 700 h to as high as 3,000 h. and more, the latter being associated with a predominantly industrial load. More typical figures lie within the range 1,500-1,800. There is a tendency for the annual usage to increase as time passes; in one German scheme, for example, utilisation rose from 1,740 h in 1961-2 to 2,070 h in 1963-4 (135).

Figures for equivalent hours of operation and full load vary according to the type of building. Experience in Munich shows figures for shops, warehouses and theatres of 1,250 h, for schools of 1,410 h, for dwellings of 1,800-2,000 h, and for hospitals of 2,800 h. Other German schemes report rather lower figures for dwellings - around 1500 h but a Berlin scheme - which includes domestic hot water gives 1,900 h (129). In Sweden, where somewhat higher usage is expected, hot water increases the total to 2800 h (82). Russian experience also is that the supply of hot water improves the load factor, and adds 500 h to the annual equivalent hours (128,104). Hawkins gives figures suggesting a usage of 2,000 h (133).

The precise value seems to depend inter alia on the mode of control. According to a German paper central station control seems to give a less peaky load than control of individual blocks and considerably less than control of individual dwellings. Control by individual users leads to the lowest annual usage (1,200 h) compared with 1500-1600 h for block-by-block control. If central station control is employed, the whole capacity of a scheme can be reduced by some 40% below the calculated DIN load, and the equivalent hours of use may then rise to 3,000 per annum (50).

In general it appears that installations with a higher percentage load factor are primarily industrial, and those with a low percentage primarily commercial. Residential areas are around the average percentage figures.

British experience of individual central heating installations, reviewed in a H.V.R.A. Technical Report, Heating of buildings by off-peak electricity supplies (1961), indicates that one may expect utilisation of the same order in this country as in Germany.

* The relation between this figure and the percentage load factor is expressed in the following table:

Hours full load operation	1100	1750	2200	5000	8760
Annual load factor,%	$12\frac{1}{2}$	20	25	-	100
Season load factor,%	22	35	34	100	-

It has been noted that the expected load factor for residential space heating is about 25%, and domestic hot water supply equals about a fifth of space heating consumption. Its inclusion in a district heating scheme thus raises the annual load factor to about 30% (and the annual equivalent hour by some 400 h) - as roughly confirmed by the Russian figure.

In adding domestic hot water supply to a scheme, extra plant can be kept to a minimum by the provision of adequate storage within the consumer's premises. The load factor may be increased by one or two percentage units in this way. The increased mains losses may however be so large as to suggest that a "heat only" scheme would be more economical.

Mijnlieff has pointed out that more effective use can be made of the plant if the peak load is taken by a boiler specifically provided for the purpose (134). At Utrecht, 56% of the total load is taken by the main boilers, and the peak-load boiler is designed for 45% of the maximum demand. For the plant as a whole, the equivalent hours of operation are around 2,000 per annum; but for the peak load boiler, they are only 200, whereas for the main boilers, a figure of 3,415 is reached - a significant improvement.

It is clearly apparent that the higher the percentage load factor that can be obtained, the greater will be the overall usage of the plant, with lower standing charges per therm to the user (94). Summer district cooling combined with district heating, now being developed in North America, improves the load factor and ensures more continuous usage of the boiler plant and mains.*

5.3 Diversity factor

The diversity factor in this country means the ratio of the coincident maximum demand to the sum of the individual maximum demands. In America and some European countries it is expressed in the reverse form and will therefore be a figure equal to or greater than unity.

When supplying a large number of buildings with space heating and possibly domestic hot water from one central source, it is important to consider the times at which the maximum demand of the individual buildings is to occur. This is particularly so in large industrial areas where the peak heat requirement of one process may occur at a completely different time from that of another, with the result that considerable saving in plant capacity is possible; a Berne installation which supplies a large industrial area has a diversity factor of 0.7. In residential areas, however, the maximum demands for space heating will, to a large extent, occur at the same time, giving rise to a higher diversity factor. The probability is that a scheme serving a mixed load will have a diversity which is somewhat lower than those serving industrial or residential loads separately.

Quoted figures for the diversity actually experienced vary over a wide range from 0.44 to almost unity (118,130). The range is identical for 56 UNICHAL schemes and for 63 Danish installations, and in both groups the average value is about 0.75. In the UNICHAL data, 70% of the schemes have a diversity between 0.6 and 0.9. For design purposes a figure of 0.8 is taken in both Denmark and Germany.

It has been remarked by one author that the load of large industrial users does not fit in well with the demand of an urban centre. Only if

* See Appendix 8

the industrial use exceeds 5000 h per year is the supply to industry from district heating stations likely to be satisfactory. On the other hand trends in Russia, and some installations in Germany (e.g., Wolfsburg), suggest that industrial and residential loads can be satisfactorily supplied together.

5.4 Load density

The load density of district heating schemes can be expressed in terms of connected load per unit area or per unit length of main. A survey by the Technical High School of Aachen indicates that densities in Germany can range between 18 and 145 MW/km^2 (250,000 to 2 million Btu/h acre), the average value being about 47 MW/km^2 (650,000 Btu/h acre)(115). Other available data for German schemes fall within the same range. Hamburg suburban schemes have a load density of about 400,000 Btu/h acre. The Berlin authority (operating a thermal-electric plant) aims at a density of 800,000 Btu/h acre (58 MW/km^2), although some of its installations have a lower load density (51). One writer suggests that, although 650,000 Btu/h acre was at one time assumed to be the minimum, small thermal schemes at a lower density can be economic (106).

In Germany, the load density of 650,000 Btu/h acre is achieved where 3-storey buildings cover some 30% of the ground area; the specific load of a dwelling is of the order of 90-120 W/m^2 (30-40 Btu/h ft^2) of heated area, which may be half the total floor area.

In Poland, space-heating requirements are estimated to be 320,000 Btu/h acre (24 MW/km^2) for single family dwellings, 800,000 Btu/h acre (5.8 MW/km^2) for flat developments and 1,280,000 Btu/h acre (9.1 MW/km^2) for urban centres (107).

Load density in terms of connected load per mile of main ranges in Germany between 5 and 120 million Btu/h (0.9 and 21.7 MW/km)(92) and in Denmark between 2 and 20 million Btu/h mile (0.4 and 4 MW/km)(130) (the high German value was for a steam system, probably industrial). Hawkins reports a lower limit in France of 5.8 MW/km (133). American data suggests that for large city networks and industrial areas, the load may be between 30 and 100 million Btu/h mile (5.5 and 18 MW/km) and in residential areas about 5 million Btu/h mile (0.9 MW/km) (5). The Moscow network has a connected load of about 35 million Btu/h mile (6 MW/km.)(128). The data, as might be expected, reveal that the schemes with the longest mains have lower values, and short mains lengths often indicate concentrated industrial loads. A Belgian consulting engineer believes that single-family dwellings can be economically served from a thermal station using heavy fuel oil if the dwellings are no more than 66 ft. (20 m) apart - a load of about $2\frac{1}{2}$ million Btu/h mile (0.5 MW/km)(121).

5.5 Total load

In addition to load density, total load is also an important factor. Staats has stated that the minimum economic size of a plant is about 25-30 million Btu/h (about 8 MW)(100), but both German and Danish experience seems to put the lower limit at 6 million Btu/h (1.8 MW) or even less.

Some Belgian projects serving groups of small houses have total loads of as little as $2\frac{1}{2}$ million Btu/h (0.7 MW) - corresponding perhaps to about 100 dwellings - as does the smallest Danish scheme. The smallest schemes are purely thermal ones; combined heat and power generation is only considered for the largest installations.

Eneborg considers that minimum total annual costs (capital plus operating) are attained when the boiler plant has a capacity of 80 million Btu/h (about 24 MW) - excluding buildings, mains network and consumer's connections (82).

CHAPTER 6 - HEAT GENERATION

6.1 Types of station

Two types of station are commonly used to generate heat for district heating main circuits:

(a) The thermal station, which is a conventional boilerhouse using any of the various types of fuel to produce hot water or steam for the circuit.
(b) The thermal-electric station, where exhaust heat or steam from the turbo-generators is used with or without heat exchangers to supply hot water or steam for the circuit.

A number of schemes use both types together, sometimes in combination with refuse incineration plant (117).

Table 4, compiled from published data from various sources in Europe, shows the number of installations in various countries. It should be noted, however, that there is considerable discrepancy between published schedules of plants - the figures quoted, having been largely confirmed by visits, are felt to be the most accurate.

6.1.1 Thermal stations

The general practice in Europe and America is to install at least three boilers in a thermal station. To utilise them as efficiently as possible against variations in the demand for heat due to external temperature changes, they are not necessarily of the same capacity. In most cases boilers are sized to a ratio such as 1:2:2 to allow load variations of 20% and to provide some degree of standby capacity.

Where coal or other solid fuel is burnt, flue-gas cleaning and flue-dust or grit elimination plant is normally installed to comply with clean air legislation. In Germany such equipment, together with trained operating staff, is compulsory for all plant of 3×10^6 Btu/h (0.8 MW) and upwards. Most other European countries enforce similar standards, and they are also becoming mandatory in America.

6.1.2 Thermal-electric stations

The utilisation of the exhaust heat and steam from electrical generating stations is an attractive method of producing the heat required for district heating schemes. Not only is the overall efficiency of the generating station increased but a considerable saving of fuel results from the greater utilisation of the heat in the fuel.

6.1.3 Factors affecting choice

The choice between a thermal-electric station or the smaller thermal station will depend on many factors. Consideration must be given to such factors as:

(a) The capital cost
(b) The size of the area to be served
(c) The potential growth of the area
(d) National policy on the production of electricity
(e) The utilisation of the total energy in the fuel
(f) The relation between thermal and electric loads
(g) The location of the central station.

On the question of size, if the limits of the area to be served are known before the scheme is installed and the area is not a very large one, it is likely that a thermal station will be selected. However, if the area, relatively small in the first instance, is to be considerably increased in the future, it is possible that a combined station, or a thermal station with provision for the future addition of turbines and electrical generators, will be built.

In Poland, for loads between 10 x 10^6 and 25 x 10^6 Btu/h (3 and $7\frac{1}{2}$ MW), local heating stations with water temperatures up to 110°C (230°F) are employed, and for loads between about 40 x 10^6 and 120 x 10^6 Btu/h (12 and 35 MW) local heating stations with water temperatures up to 150°C (302°F). For loads between 120 x 10^6 and 800 x 10^6 Btu/h (35 and 235 MW) thermal-electric stations with condensing turbines are used; back-pressure turbines are preferred if the electrical load is high or if the heat requirement is 40-60% of the output (107).

The period of maximum demand for both heat and electrical energy, and whether these demands occur simultaneously, will also affect the choice. Problems of this kind can, however, be largely overcome by the use of thermal storage vessels*(118). These permit the electrical energy output to be more closely matched to the electrical load; the surplus heat is stored in vessels at times of low electricity demand, and drawn up during periods of peak power requirements to meet the thermal demands.+

Recent years have witnessed the development of gas-fired turbines for electricity generation (108). Several West German stations supplying district heating schemes use the gas turbine; two of these are at Bremen-Vahr, where the turbines are of the open-cycle type (Figure 7) and at Oberhausen where the closed-cycle turbine is installed (Figure 8). The gas turbine is also coming into use as the primary energy source for self-contained group or block schemes based on the so-called "total energy concept". The turbine drives a generator and the waste heat is employed for process and space-heating purposes. Cooling, when required, is provided either by absorption chillers using the waste heat or by centrifugal machines driven by the turbine. High overall efficiency and load factor are obtained in this way.

* Even the thermal storage in the hot water mains can be sufficient to tide over a 1-hr. or 2-hr. peak electricity demand, when no steam can be spared for heat production.

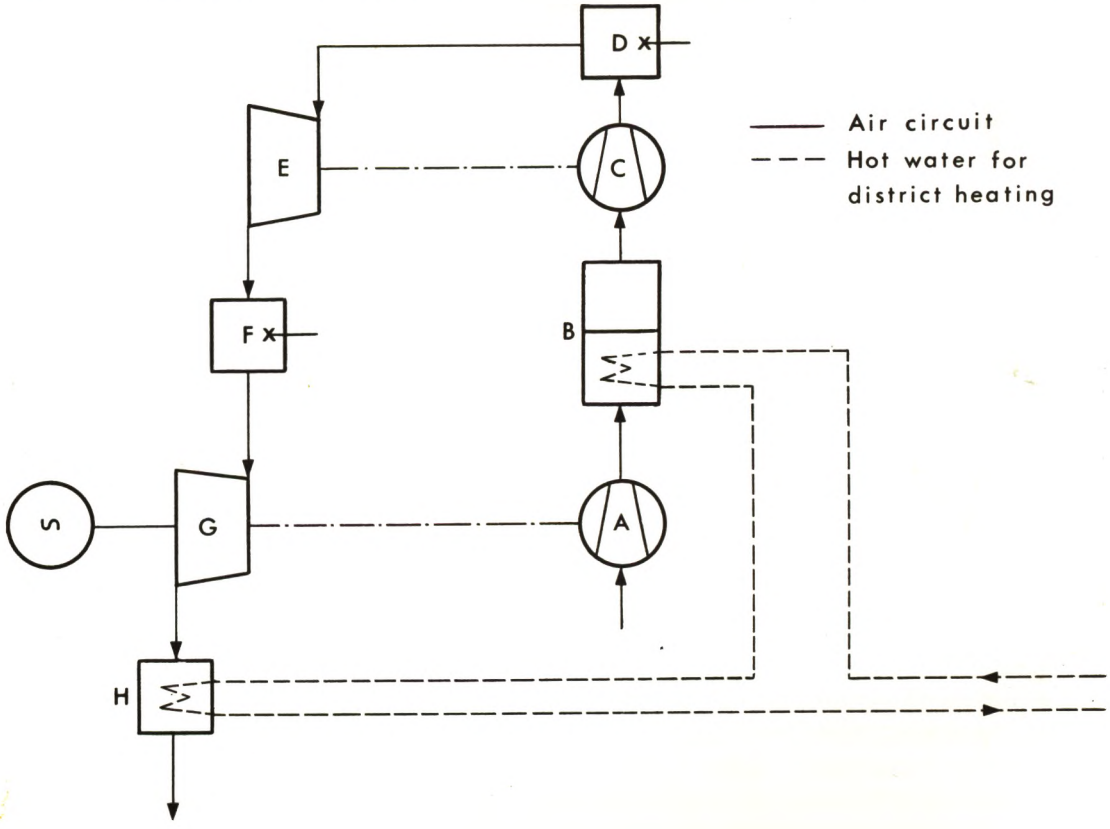
+ The pros and cons of this type of plant are discussed at length in Post War Building Studies Nos. 31 and 32 (2,3).

It would appear that, where electricity is generated by a private authority, there is a greater tendency to combine it with heat generation, in an effort to extract the maximum energy from the fuel.

6.1.4 Combined stations

As mentioned earlier, a number of combined thermal and thermal electric stations are in operation, with or without refuse incineration. Figure 9 shows a typical annual load curve for a predominantly residential area and indicates how the annual load is supplied by the various sources of heat.

In towns or cities having more than one station supplying heat to the distribution network, the stations are often interconnected by the network so



A – Low pressure compressor
B – Intermediate cooler
C – High pressure compressor
D – High pressure combustion chamber
E – High pressure turbine
F – Low pressure combustion chamber
G – Low pressure turbine
H – Heat exchanger

FIGURE 7 - LAYOUT OF OPEN-CYCLE GAS TURBINE

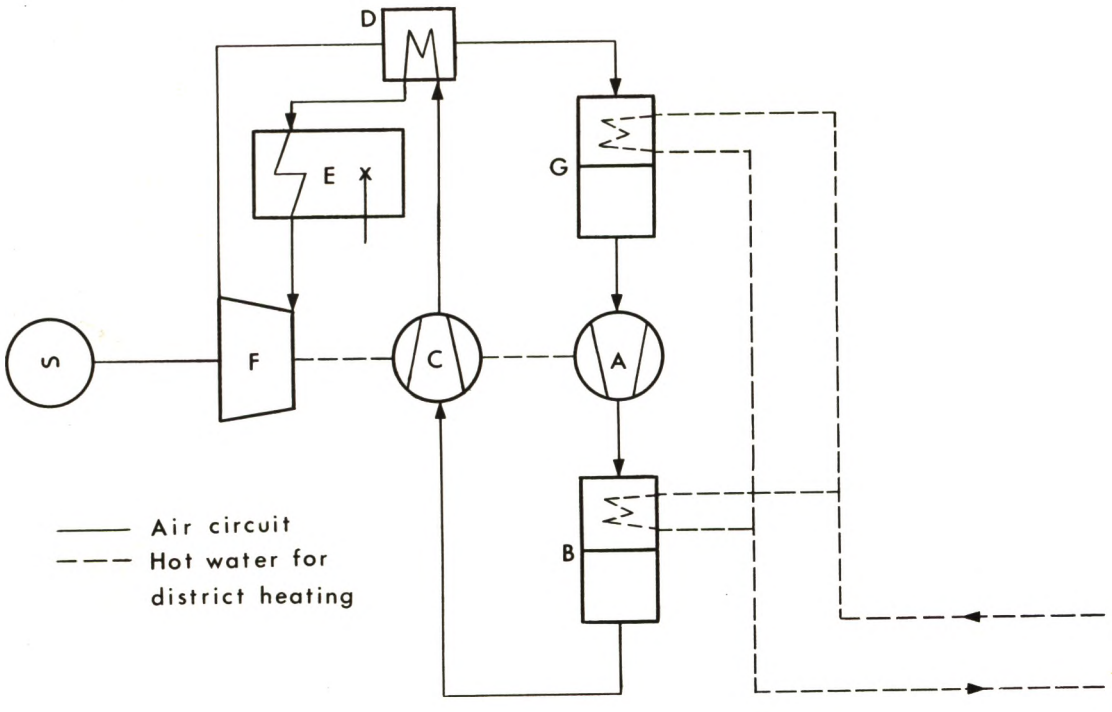
that load variations can be dealt with. Interconnection of the stations serving the city of Warsaw is illustrated by Figure 10.

Where parts of the connected load are remote from the main heating station or in relatively small areas of the network having a high peak demand, booster stations are employed.

6.2 Fuels

Oil, coal, and town and natural gas are obviously the most usual sources of heat for collective schemes, but others have been used in special circumstances. In one American scheme, sawmill waste is burnt as the main fuel; in another, off-peak hydroelectric power is employed (the cost being 0.1 cent per kWh). Nuclear energy is being used at Agesta in Sweden; and natural hot springs supply heat for Reykjavik.

Much attention is now being given in Europe to refuse incineration as a



A - Low pressure compressor
B - Intermediate cooler
C - High pressure compressor
D - Recuperator
E - Air heater
F - Turbine
G - Precooler

FIGURE 8 - LAYOUT OF CLOSED-CYCLE GAS TURBINE

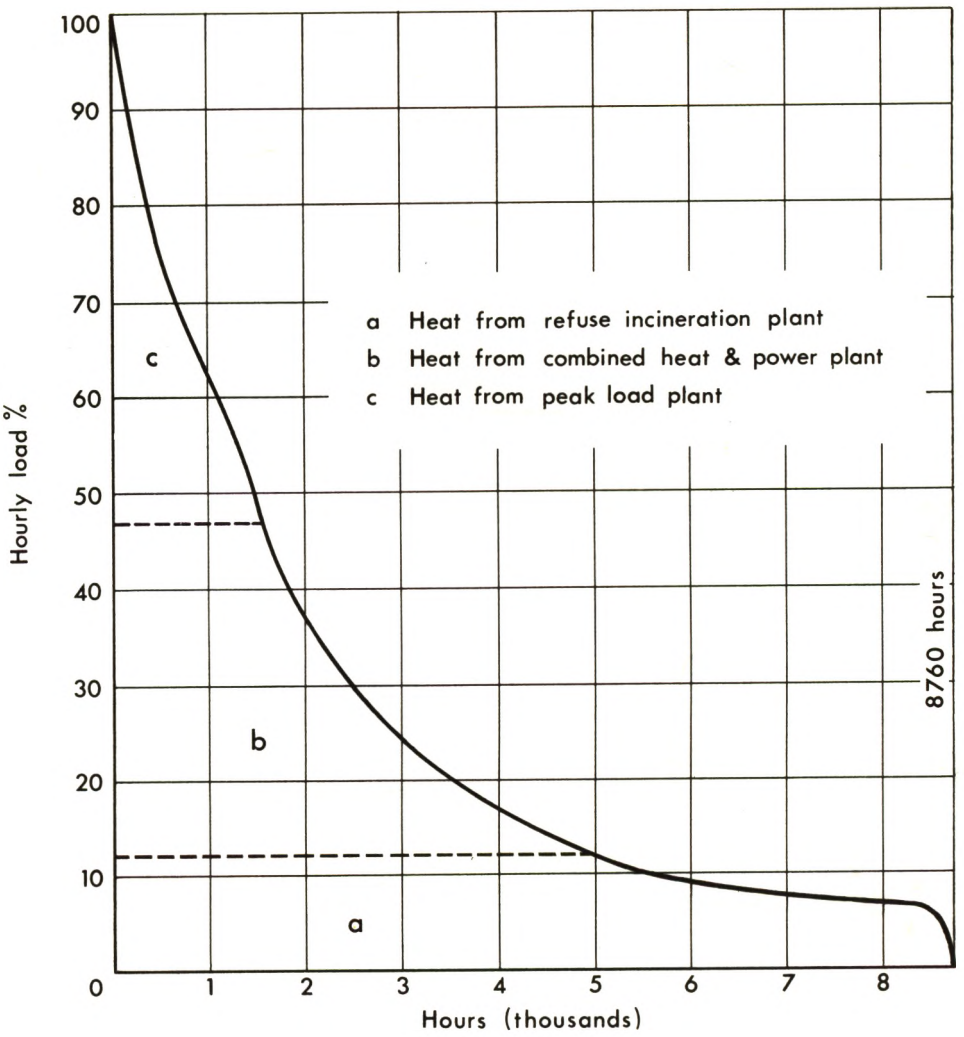


FIGURE 9 - LOAD CURVE FOR COMBINED STATION WITH REFUSE INCINERATION

source of heat, and several installations already have refuse-fired boilers in addition to those operating on normal fuels (117). It has been estimated that the refuse collected is sufficient to provide one third of a city's needs for heat*. In Basle, incineration provides some 10% of the heat distributed. Refuse incineration, being a year-round activity, is best used for supplying domestic hot water, or at least part of the base load on the plant. In some cases where the volume of the refuse is insufficient, pulverised fuel can serve as a booster.

The calorific value and the moisture content of the refuse will be subject to some variation, and some operating authorities (mainly of the smaller schemes) are in fact against refuse incineration for district heating purposes. The probable saving on the fuel bill, moreover, has to be weighed

* Refuse amounts to about ¼ ton per inhabitant per year. It has a calorific value amounting 5,000 Btu/lb. (11,600 kJ/kg).

against the capital cost of refuse-burning plant and against increased maintenance costs. In large cities, however, the high price of land for disposal purposes, and the costs incurred in transporting the refuse to the disposal areas, may have considerable bearing on the use of refuse incineration.

We have already observed* how local conditions and economic considerations can affect policy decisions both as to whether district heating should be installed in the first place and, if it is installed, what type of fuel should be consumed. In Denmark, where, as noted, most of the country's fuel has to be imported and oil is the predominant fuel used in district heating, statistics show that, of 63 existing installations, one uses coal exclusively, 7 both coal and oil, and 55 oil only; and it is probable that the 8 burning coal will change over to oil in the near future.

In West Germany, where both coal and oil are used extensively, and coal consumption is particularly encouraged in the Ruhr to assist the mining industry, there are in existence or projected 581 district and group heating schemes with a total capacity of 3 million tons of coal equivalent; about one-fifth of them are thermal-electric stations. Solid fuel is used in the majority of the schemes, catering for 87% of the total load.

Coal and gas are used together in some installations, and in the U.S.A. there is a tendency to consume gas exclusively as natural gas supplies become increasingly available. The same trend can be observed in parts of Germany and in Poland, where small group heating schemes serving a few blocks of flats are fired by gas.

Another factor governing the choice of fuel may be the size of the installation. For, in order to achieve efficient combustion of the fuel, automatic firing is necessary. With gas and oil, this can be easily carried out in small boilers, but with solid fuel there is a level below which the price of fully automatic plant may become prohibitive.

It has been suggested in Germany that the lower size limit for a coal-fired plant should be one serving 2,000 houses (about 80×10^6 Btu/h or 24 MW), though many smaller ones exist, and the lower limit for oil one serving 100 houses (about 4×10^6 Btu/h or 1.2 MW). Not only is the fuel cost higher for the small solid-fuel plant, but the capital costs for the central station and for fuel storage and handling are also greater (131). Current Danish practice would seem to substantiate this, although the political and economic considerations within the two countries are quite different.

6.3 Location of the station

The location of the heat generating station is of great importance. Theoretically it should be placed as close as possible to the thermal centre of the load so that the distribution mains can be kept as short as possible, with consequent savings in capital cost and in heat losses from the mains. In practice it is often impossible to site the station in the thermal centre of the load for reasons of availability of land, size of site, access for fuel supplies, and, if the station is thermal electric, proximity to an adequate supply of cooling water.

* pp. 6-7

Country	No. of schemes		Size range Btu/h x 10^6		Remarks
	Thermal	Thermal-electric	Thermal	Thermal-electric	
Austria	-	3	-	96 to 240	
Belgium	5	-	26.4 to 68	-	
Bulgaria	-	-	-	-	Three schemes known; no details.
Czecho-slovakia	-	14	-	60 to 1600	From statistics of heating supply schemes by A. Guichemerre.
Denmark	250	6	2.8 to 267	560 to 2800	Nearly 70% of requirements met by 6 large stations. Numerous additional small block schemes under construction or planned.
Finland	-	1	-	932	No details.
France	13	2	60 to 180	91 to 2758	Numerous additional small schemes existing and projected.
Germany (W.)	230	17	6 to 80	40 to 1168	Further 350 group schemes in various stages of construction of planning.
Germany (E.)	-	-	-	-	Nine schemes known; no details.
Holland	-	4	-	240 to 710	Few schemes. Large area with high water table detrimental to distribution system.
Hungary	-	2	-	140 to 400	Nine additional schemes mentioned in Chauff. Vent. Cond., Oct. 1963, Production to reach 70 x 10^{12} Btu/hr. in 1980.
Italy	-	-	-	-	Three schemes known; no details.

TABLE 4 - NUMBER OF SCHEMES BY COUNTRIES

Country	No. of schemes		Size range Btu/h x 10^6		Remarks
	Thermal	Thermal-electric	Thermal	Thermal-electric	
Norway	-	1	-	-	Few schemes. Hydro-electric power prominent. Rocky ground detrimental to economic distribution.
Poland	-	10	-	120 to 2800	Many block schemes with loads between 10 x 10^6 Btu/h and 120 x 10^6 Btu/h. Annual increase in heat requirements about 4000 x 10^6 Btu/h.
Russia	-	25	-	-	Some 160 believed to exist. Many large combined plants. Plant capacity of Leningrad, the oldest scheme, 5200 x 10^6 Btu/h. Annual output of all plants in 1960 1360 x 10^{12} Btu.
Sweden	1	9	260	80 to 1270	A few additional block schemes similar to those in Denmark. Also an atomic power station built mainly for experimental purposes and not at present economical in producing district heat.
Switzerland	1	3	72	120 to 304	Few district heating schemes. Hydro-electric power prominent.
U.K.	10	-	6.5 to 94	-	A few additional small schemes in London area. New larger schemes planned for Midlands, S. Wales, North East and North West.

TABLE 4 (Contd.) - NUMBER OF SCHEMES BY COUNTRIES

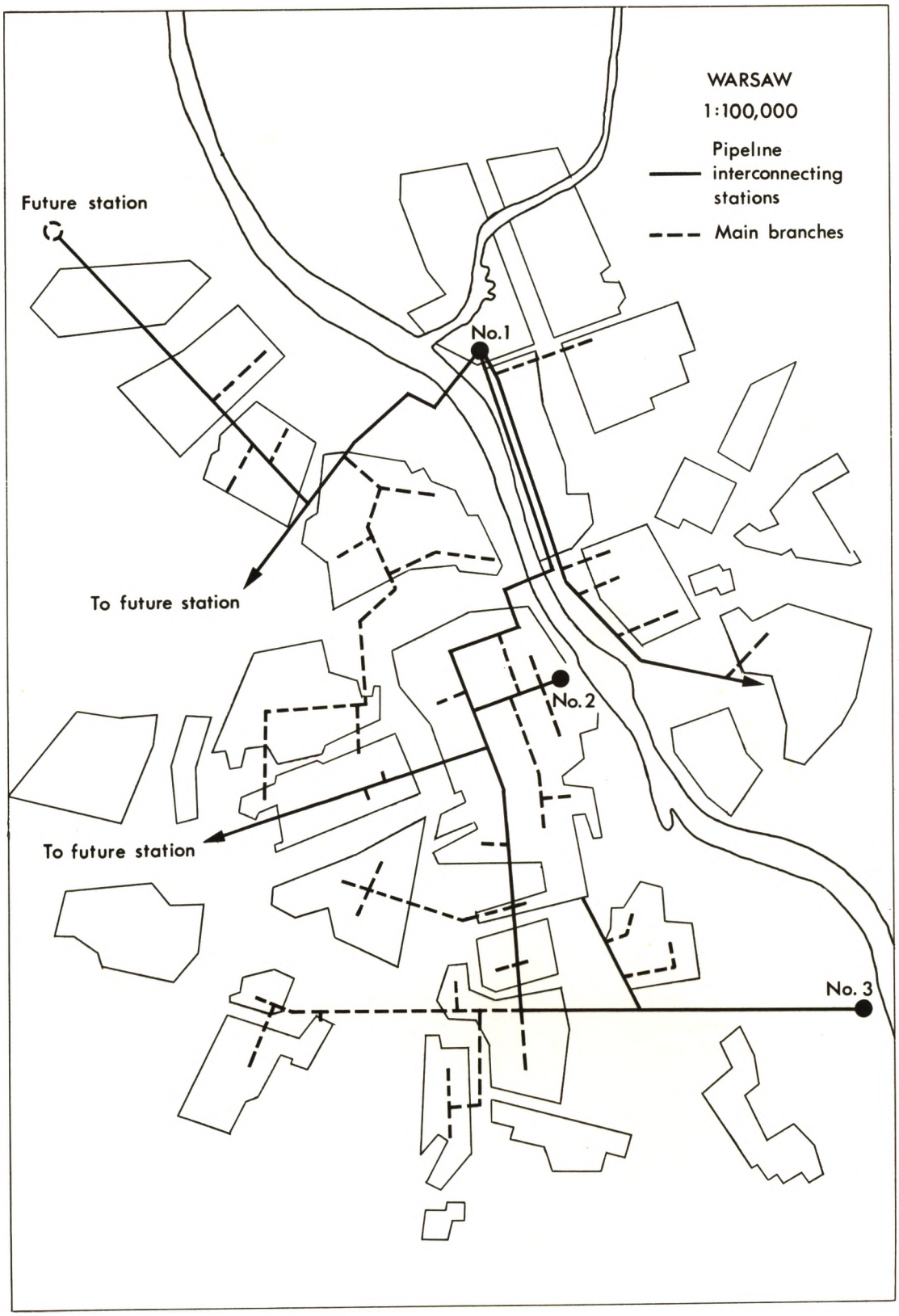


FIGURE 10 - INTERCONNECTION OF STATIONS SERVING WARSAW

CHAPTER 7 - HEAT DISTRIBUTION

7.1 Distribution media

Either steam or hot water is used to distribute the heat from the generating station to the users.

Steam was formerly the invariable medium in North America, since in very tall buildings it obviated pumping problems. In recent years, however, a number of hot water schemes, generally confined to purely residential areas of two- or three-storey houses, have been installed.

In Europe the situation is more varied. UNICHAL statistics show that, out of 123 installations, 69 use steam, 38 hot water and 16 both; while in the Soviet areas of Eastern Europe hot water predominates (119). Rosada indicates that in Poland water is more economical than steam, unless the latter is required for process work (107). Of the many schemes now being implemented in West Germany, a large percentage will employ hot water as the distribution medium.

7.1.1 Steam

Where steam is the medium used for distribution, it is generated at various pressures, up to as high as 500 lb/in^{2}g (3.5 MN/m^2), at the central station, and delivered to the mains network at varying pressures up to 300 lb/in^{2}g (2 MN/m^2). The actual delivery pressure to the mains is generally determined by the nature of the demand and the length of the supply line to the consumer's premises.

The standard practice in both Europe and North America is to guarantee a specified pressure of 5 or 10 lb/in^{2}g (30 to 60 kN/m^2 gauge) at the customer's stop valve and to size the supply lines on the basis of pressure drop, thus working back to determine the main supply pressure.

Condensate may or may not be returned. In the U.S.A. the practice in this respect is roughly 50:50, whereas in Europe condensate is almost invariably returned.

7.1.2 Hot water

Where hot water is the selected medium for heat distribution, it is usually either medium-pressure or high-pressure; medium-pressure flow temperatures are up to 250°F at 50 lb/in^{2}g (120°C at 0.3 MN/m^2 gauge) and high-pressure flow temperatures 250 to 350°F (120 to 180°C) at pressures over 50 lb/in^{2}g. The circuit pressure is maintained at a figure sufficiently high to prevent flashing into steam in any part of the circuit.

In general, by far the larger proportion of European schemes operate on medium pressure, with flow temperatures around 230°F (110°C) and return

around 150° - 160°F (70°C) - conditions which permit the service to be used direct on to calorifiers and radiators without undue risk. Thus, for the 48 new North Rhine-Westphalia schemes flow temperatures are as follows:

Flow temperature (°F)	265	250	230	210
No. of schemes	8	3	34	3

Temperature drops are between 70 and 140 deg F (39 and 78 deg C).

Rosada from Poland reports that capital and pumping costs are less for water at 300°F than at 260°F; but at 340°F, although these costs are still lower, the other costs of a central station and of consumer's connections are higher. This conclusion appears to justify the choice of 300°F (150°C) as the design flow temperature for the Warsaw schemes. Elsewhere in Poland, however, 230°F (110°C) is more usual (107).

Most of the installations using hot water as the distribution medium operate on a constant water volume flow, with a varying flow temperature to deal with changes in load due to outdoor temperature variations. The flow temperature may, for instance, be 250°F (120°C) in mid-winter, and no more than 100-140°F (38-60°C) at the ends of the season (somewhat higher if domestic hot water is required or supplied). In this way, mains losses (which depend on water temperature) are minimised. Furthermore, the operators often endeavour to maintain a low and constant return temperature, so that maximum cooling of the mains water can be achieved. This both reduces the volume of water to be circulated, and enables pipe sizes to be reduced.

Some installations work with a constant temperature drop between flow and return mains, to facilitate metering and charging the customer.

7.2 Distribution network

Both in Europe and North America it is the general practice to consider the mains network as consisting of two parts: the main flows and returns, and the branches.

The flow and return mains for district heating schemes are generally oversized to allow for future extensions, while the branches are sized for their specific loads. One result of this is that some lengths of main initially are uneconomically sized. The N.D.H.A., UNICHAL and other operating authorities accept that this practice is cheaper in the long run than removing a main and replacing it by a larger one at some later date. Group heating schemes, designed to serve a specified number of buildings, do not suffer from this disadvantage; the mains can at the start be accurately sized to match a known load.

Hot water circuits are normally of the two-pipe system, either three- or four- pipe systems being used where domestic hot water is supplied from the central station. There is, however, a trend to eliminate the supply of domestic hot water direct from the central station, and in these cases an indirect cylinder is installed by the consumer in his internal circuit.

The reverse-return system offers many advantages over the more conventional two-pipe system; it gives an equal pressure drop round the system, and eases balancing problems. The size and complexity of a district heating network, however, seldom lends itself to such a system without incurring excessive capital outlay.

Generally, as with steam, the standard practice is to maintain a specified pressure at the consumer's stop valve.

7.3 Booster stations

When, due to the length of the mains, it is impossible to maintain the guaranteed pressure at the customer's stop valve, booster stations are employed. Where steam is the distribution medium, they take the form of small boiler installations designed to deal with the extra demand and are usually of automatic operation by remote control. In the case of hot water, however, the booster stations are small auxiliary pump houses, also under remote control, designed to supply the necessary extra pressure in the mains circuit.

Generally their use is confined to large city installations. In Berlin, for instance, there are over 1400, each large building or block of flats having its own power station, which functions as a booster station. Outside Berlin, which may be regarded as exceptional, Utrecht has three booster stations, which combine boilers and pumps, and one booster pumping station, while Paris has five auxiliary boilerhouses.

7.4 Pipework

The general practice in both Europe and North America is to use cold-drawn seamless steel pipe up to 12 in. (300 mm.) in diameter and longitudinally-welded steel pipe for diameters above 12 in. (116)

7.4.1 Pipe sizing (steam)

The normal practice in both Europe and North America, as given in the data supplied by UNICHAL and the N.D.H.A., is to use flow velocities of the order of 10,000 ft/min (50 m/s) for sizing mains and branches, or the equivalent pressure drop method.

Instances are known in America where velocities of up to 75,000 ft/min (375 m/s) are used in high-pressure mains. This practice would appear to be on the increase, especially where extensions to the supply circuit are being made or to cater for an increase in load at some point in the network.

7.4.2 Pipe sizing (hot water)

From the replies to a questionnaire sent to their members in Europe by UNICHAL, velocities ranging from 1 m/s for 50 mm. pipe to 3 m/s for 300 mm. pipe were noted. They represent 3 ft/sec for 2 in. diameter pipe, 6 ft/sec for 6 in. diameter pipe and 9 ft./sec for 12 in. diameter pipe.

When checked against flow graphs based on Williams & Hazen formula with C=130 for clean pipe and C=100 for dirty pipe, the velocities were found to be equivalent to a pressure drop of between 20 ft. and 25 ft. head loss per 1,000 ft. run. (200 to 250 kN/m^2 per km.). These velocities appear to be consistent in all countries, including North America.

7.4.3 Jointing of pipe

Among members of UNICHAL, welding of all straight lengths of pipe seems to be the standard practice, fittings being flanged. Out of 36 installations covered by their questionnaire, 31 used flanged fittings and

5 welded fittings. Both gas and electric welding methods are employed, the choice of method generally being left to the contracting firm installing the mains network.

In both North America and Europe a very high standard of welding skill is required from the welders. In the U.S.A., contracting firms are not allowed to employ welders who are not certificated, and the same practice is now mandatory in most European countries. The high level of workmanship results in few bad welds or leaking pipes.

X-ray testing of welded pipe joints is the general practice in both Europe and North America. Among the 36 installations replying to the UNICHAL questionnaire, 3 use isotopes and 3 a mechanical test; Utrecht does not test; Mannheim tests all joints; and the remainder test random samples, generally 10-20%.

After welding, all installations test all mains and branches hydraulically to 1.5 times working pressure. In the U.S.A. the general practice is to combine a random test of 10-20% of all pipe welds, with the hydraulic test to 1.5 times working pressure.

7.4.4 Life of pipe

The normally expected life of mains and branches is about 60 years, subject to efficient insulation and protection. With the present trend of 20 to 30 year contracts for the supply of heat, the life of the pipe for amortisation purposes, like that of the rest of the plant and equipment, is now taken to be the length of the contract.

7.4.5 Pipe expansion

From the various installations visited and from the data supplied by both the N.D.H.A. and UNICHAL, it would appear that the general practice is to use bellows or slide-type expansion joints to deal with the expansion and contraction of the pipe circuits, although some instances are known where "U"-type bends are still being used. When line repairs or replacements occur, "U" bends are often replaced by either bellows or slide-type joints; one advantage that results is the reduction in the amount of road surface that has to be maintained and paid for by the heating authority. Instances were seen in Denmark, particularly at Odense, where the mains and branches alternated from side to side of the road to facilitate connections and deal with expansion.

Expansion joints are usually located at between 175 and 200 ft. (53 to 60 m.) centres.

7.4.6 Pipe supports and anchors

There appears to be no standard design for pipe supports and anchors, which vary from scheme to scheme. Upwards of 50 different designs of each have been seen, all of which appear to give complete satisfaction to the user. The distance between supports also varies from scheme to scheme, as does the method of dealing with movement of the pipe. Some installations make use of rollers for movement, some rubbing plates, whilst others fix the support to the pipe and allow the support to move.

7.4.7 Corrosion protection

(a) External

Here again, there appears to be no standard practice in either Europe or North America. Some installations take no special precautions against external corrosion other than covering the pipes with the normal thermal lagging, while in others various coatings, ranging from bitumastic to zinc chromate, are applied to the pipe surface. In a few, some form of protective sheathing over the thermal insulation protects the pipe and insulation from damp soil or the ingress of ground water*.

Only two instances (at Munster and Stuttgart) have been found during this survey where cathodic protection is used against outer corrosion. None of the schemes covered by the American Federal Construction Council Technical Report No.47 use it, despite the known corrosive state or nature of the soils (76).

At Utrecht a layer of non-conductive material between the flanges of the compensator or bellows-type expansion joint gives protection against electrolytic action caused by the dissimilar metals in the joints.

(b) Internal

For internal pipe protection, water softening treatment appears to be the standard practice in practically all installations in both Europe and North America.

Where chemical additives are used, they are generally either Na_3PO_4 or NaOH. With a pH of from 8 to 10 de-aerated water is used in most cases.

7.4.8 Valves and fittings

These generally are of the cast steel type, with, in some cases, stainless steel inserts. For small sizes, cast iron is often used.

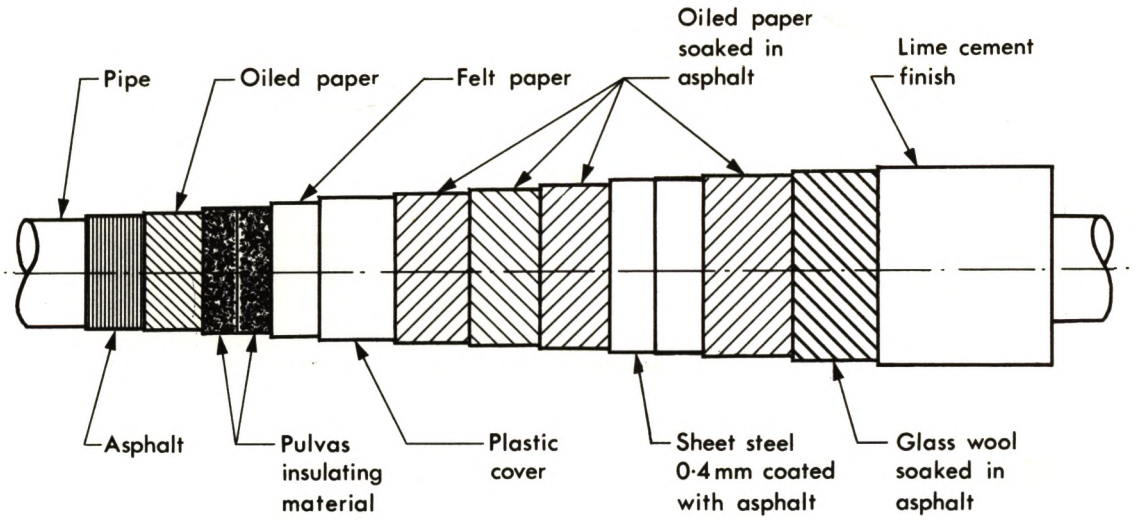
Both slide-pattern and rotating-type valves are in general use in Europe and North America, and it would appear that the slide pattern is preferred, being absolutely watertight and easy to service and having little or no pressure loss. There seems to be no common rule for using different types of valve for different sizes of main or branch.

Isolating valves for shutting off parts of circuits are generally located at between 1000 ft. and 1500 ft. (300-450 m.) centres, although cases are known where these distances vary up to 3000 to 6000 ft. (900-1800 m.) (116).

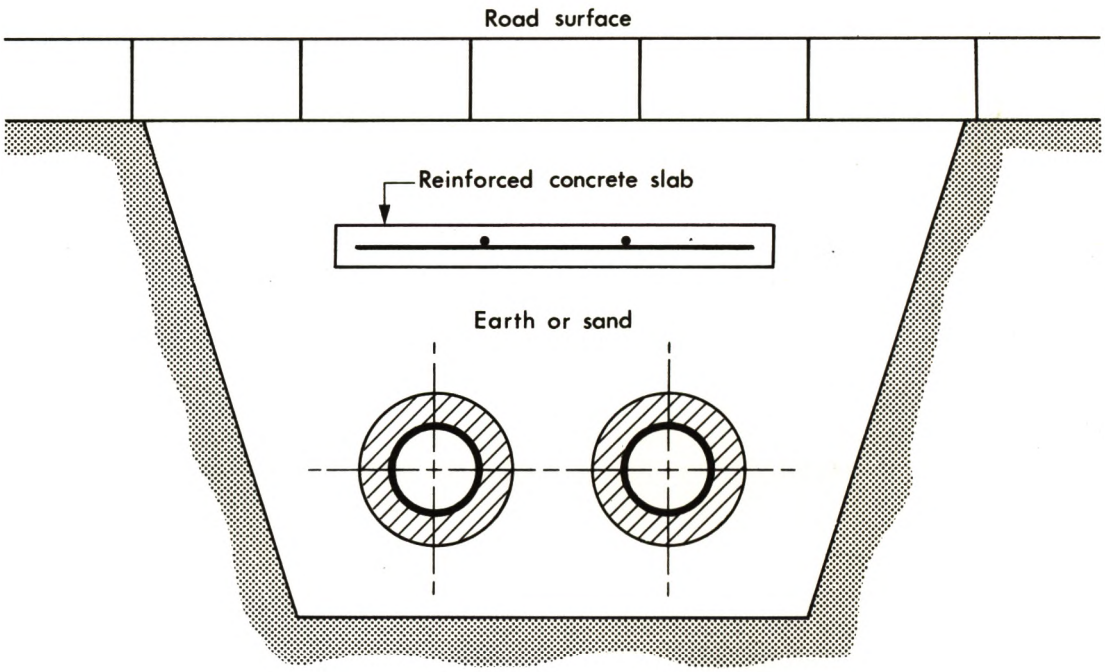
7.4.9 Tests

Apart from the hydraulic tests referred to above, some installers carry out tests to check the frictional heat loss in the various circuits against the calculated or designed figures, generally in order to regulate.

*In some proprietary forms, the protection may be a steel pipe, within which the pre-insulated main is suspended.



Detail of pipe insulation



Cross section of typical trench

FIGURE 11 - PREINSULATED PIPE INSTALLATION (UTRECHT)

7.5 Pipe trenches and conduits

Fundamental to the success of any heat distribution system are the ducts and trenches in which the distribution pipes are laid. As the full distribution system accounts for anything up to about 55% of the capital cost of the entire scheme, it is important that the heat loss from the mains is kept to a minimum and that the ducts are of a robust and watertight construction; at the same time the capital outlay must not be so excessive as to jeopardise the competitiveness of the service on a basis of unit cost per therm to the consumer.

The ducts are constructed of either pre-cast concrete, cast-in-situ concrete or brick, while the insulation may be of the aerated concrete, sectional or loose-fill type. A current trend in both America and Europe, particularly the former, is the use of pre-insulated and sealed pipe* which is laid directly in a rough trench. Figure 11 shows a typical installation of this nature.

7.5.1 Alternative types

Trenches or ducts of brick construction are generally more expensive than the precast or cast-in-situ concrete types of duct, and for this reason the latter are more widely used.

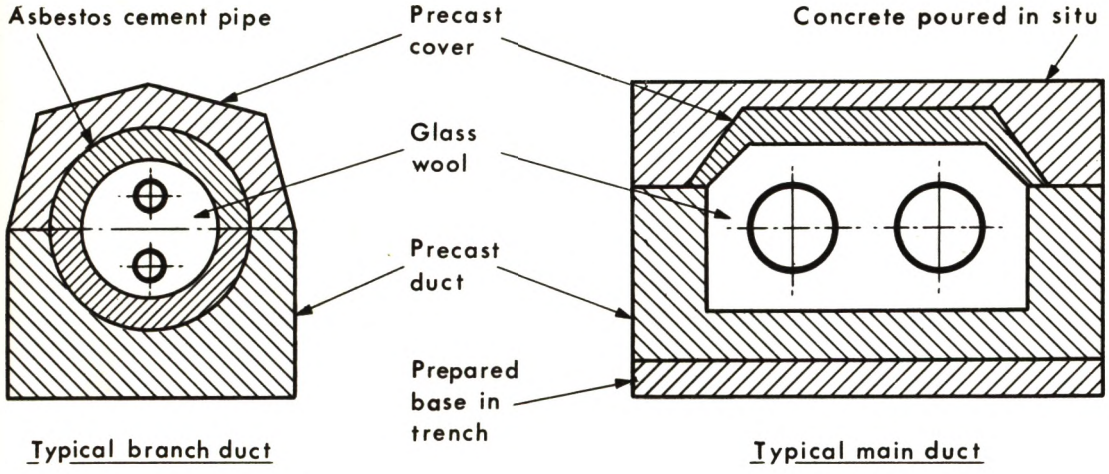


FIGURE 12 - SEALED CONCRETE DUCT (BASLE)

One of the greatest savings in concrete construction can be achieved by casting the concrete direct against the earth face and so eliminating the cost of external shuttering. It will nevertheless be impossible to do this on every occasion as the nature of the soil may prevent a reasonably clean cut being made. Concrete ducts are generally of rectangular cross section, reinforced as necessary, with cover slabs laid on top and sealed with a suitable mastic compound. One installation in Germany was seen to use bitumen-impregnated rope for sealing purposes, which has proved quite successful. In other cases the ducts are sealed by pouring additional concrete over the precast covers (Figure 12).

*See also p. 40

Perhaps the commonest type is the precast concrete conduit. Generally more compact than the duct, it is supplied in two sections and in lengths of about 6 ft. (2 m.). No prepared base is needed, though obviously care must be exercised in the jointing of the sections. Various forms of precast conduit can be found. Figure 13 illustrates one used in Denmark, where aerated concrete is the usual insulating material. Another type of conduit with glass wool as the insulating material (Figure 14) is commonly used in Poland.

Tunnels, with mains racked off the walls, large enough for maintenance personnel to walk or crawl through, were observed in a few of the larger installations visited. However, it is considered unlikely that they are in extensive use, being considerably more expensive in first cost than the smaller trenches and ducts.

Valve pits are provided at junctions in the main distribution system. For the small branches to the consumers' premises, however, it is usual for valves to be fitted at the point of entry to each block of flats and also to each individual flat, with suitable access for the operating authority's personnel to maintain the valves without disturbing the occupants.

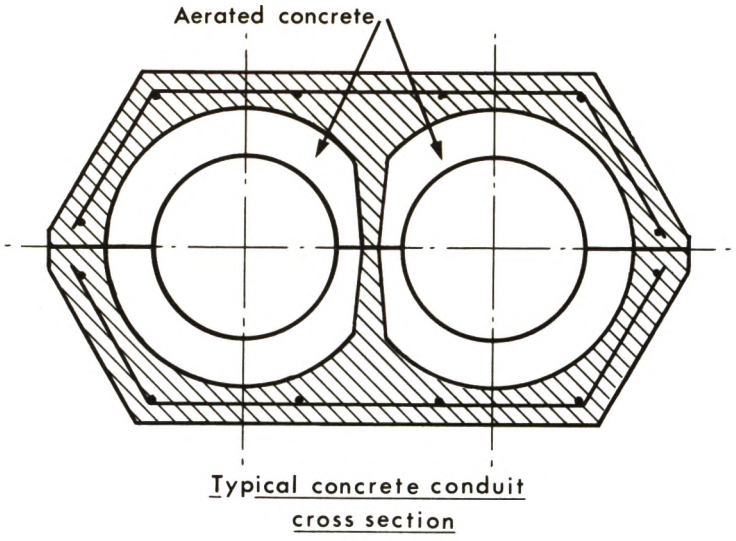
7.5.2 Factors affecting trenches and ducts

The main factor affecting buried pipes, whether they are in trenches or ducts or laid direct in the ground, is the nature of the ground and its permeability. Where rocky ground is encountered, it is often of a dry nature with the result that little or no provision need be made for drainage, and fractures of the duct due to soil subsidence are unlikely. Ground of this kind has its disadvantages, however, in that excavation for the trenches can be a costly item.

The presence of water is detrimental to any underground piping system, and it has been found that many district heating authorities will not install mains in areas where the ground water level is high. It is doubtful, however, if water will be entirely absent, so that adequate provision must be made to drain the duct of any seepage from the surrounding ground or from any pipe fracture or leakage. External drains, fitted where difficult ground conditions exist, usually take the form of a tile drain below the trench or duct. They are covered with a few inches of crushed rock, before laying the duct base to allow the water to seep quickly into the drain.

A small drain trough or channel is often cut in the base of the duct to allow the escape of any water which seeps into the duct or leaks from the pipes. The water flows freely to a manhole or valve pit where it can be removed from the network. Automatic electric pumps are commonly used for this purpose. Electrical components should be weatherproofed and located outside the manhole or installed in a separate manhole which is not subjected to the hot and often damp atmosphere of the main manhole. Rapid deterioration has been found to occur where electrical equipment has been installed in hot manholes.

A recent report by the F.C.C. on underground heat distribution gives a system-by-system summary of various ducts and describes the conditions of ducts, pipes and insulating material after several years' service (76).



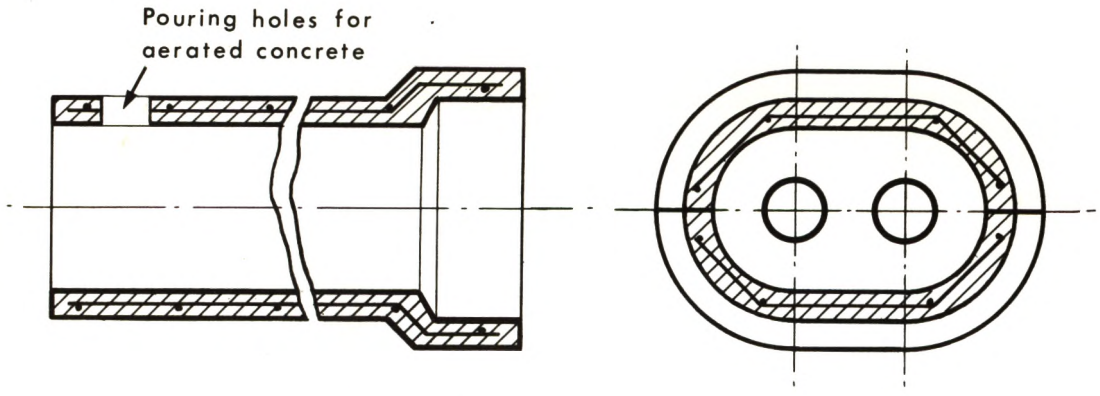


FIGURE 13 - INSULATED CONDUIT (ODENSE)

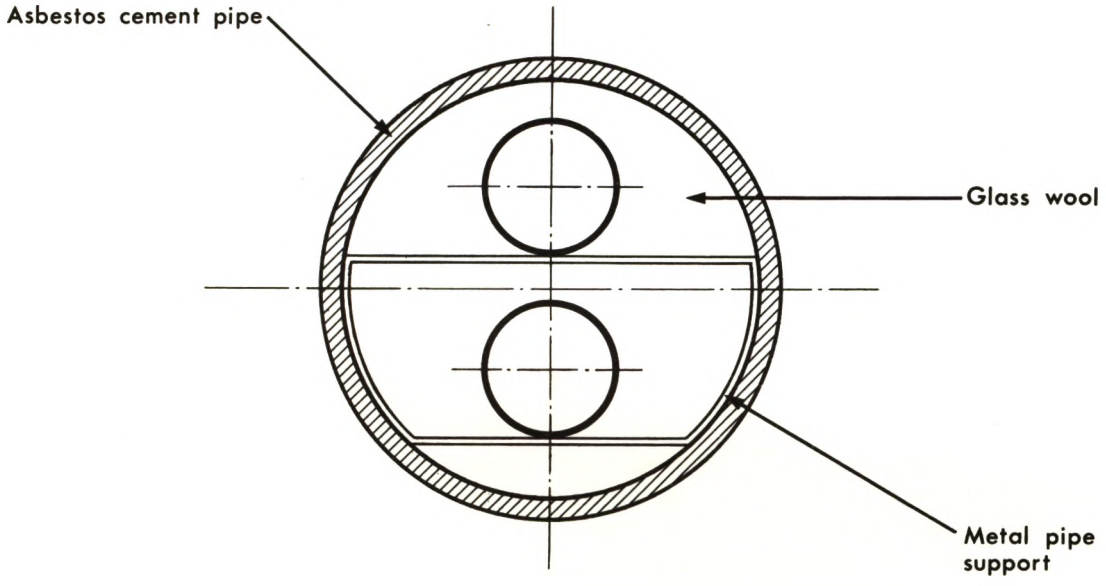


FIGURE 14 - INSULATED CONDUIT FOR BRANCHES (WARSAW)

7.6 Thermal insulation

The materials used for insulating underground mains can generally be divided into three groups:

(a) Preformed sectional insulating material
(b) Aerated concrete
(c) Loose-fill insulating materials

An alternative method is to install pre-insulated pipe.

It is evident from the survey that no one insulating material has found particular preference either universally or nationally; each has had its successes and its failures. In the few schemes in the U.K. which use aerated concrete as the insulating medium it has proved to be far from satisfactory, owing mainly to the degree of aeration. In Denmark, however, the only country perhaps in which aerated concrete is used almost exclusively, it has proved successful.

To prevent the aerated concrete from cracking under the expansion and contraction of the mains it is necessary to provide some flexibility in the system. This is usually achieved by wrapping the pipes with corrugated paper before pouring the concrete. In Denmark, the density of the aerated concrete was found to be about 18 lb./ft^3 (288 kg./m^3), and it is perhaps worthwhile recalling a remark made during a recent discussion on district heating, "In Denmark aerated concrete looks like aerated concrete".

In cases where pipes are individually wrapped, glass wool is perhaps the commonest insulating material - presumably on account of the ease with which it can be applied in preformed sections and because it is chemically inert. Loose-fill materials, used in several installations, have not proved to be very satisfactory. The granular insulating materials, such as vermiculite, which are non-hygroscopic and do not alter with heat, have a tendency to settle and compact, and take a long time to dry out after wetting from external water seepage or pipe leaks. They must be used in completely dry ducts and must be well vibrated to minimise settling.

The insulating hydrocarbons such as Gilsulate do not require ducts. They are poured dry around the distribution mains and then heat-cured by passing steam or hot water through the pipes. The purpose is to provide three zones of the material - namely, consolidated, sintered, and loose. The consolidated zone, located next to the piping, is intended to give protection against corrosion. The loose material of the outer zone provides most of the thermal insulation, while the sintered zone is basically a transition zone between the other two, although it also adds some insulating value. Several authorities express doubts as to the proper formation of the three zones, and in some cases the mains have been re-insulated. Occasional failures in Sweden (leading to pipe corrosion) have been attributed to imperfect curing and sintering.

Pre-insulated pipe, which, as indicated above, is becoming increasingly popular, seems to have proved very satisfactory in use so far. Straight lengths of pipe are factory-wrapped with a suitable thickness of insulating material and sealed with a sheath of metal or plastic. To facilitate site welding 3-6 in. at both ends of the pipe are left bare, after which insulated cover sleeves are fitted over the joint and sealed with plastic tape or some other form of waterproof seal. Examples of pre-insulated pipe are shown in Figure 11.

7.7 Mains losses

In any heat distribution system a percentage of the heat generated will be lost between the point of generation and the area of demand.

It has been found that the average annual heat loss from the mains is about 12-15% of the heat generated, though for individual plants the losses may range from 5 to 25%, without any obvious relation to the size of the scheme. Figures for America tend to be slightly higher than those in Europe, probably due to the fact that the majority of American installations are older and therefore slightly less efficient. To express the mains loss as a percentage of the design load is misleading, since it takes no account of the utilisation of the plant. Thus, if we assume that a mains loss of 10% is estimated for a design load of 1×10^6 Btu/h (0.29 MW), then the maximum possible heat send-out is $1.1 \times 10^6 \times 8736$ Btu/y. If the load factor is 30% then the heat sent out must be $1.1 \times 10^6 \times 8736 \times 0.3$ Btu/y (2900 million Btu/y or 3100 GJ/y).

For constant temperature, variable-flow operation, the mains loss will be 0.1 x design load for every hour of operation, so that the actual annual loss from the mains will be:

$$\frac{0.1 \times 10^6 \times 8736}{1.1 \times 10^6 \times 8736 \times 0.3}$$

i.e., 30% of the total heat sent out.

With operation at constant volume but varying temperature, the loss from the mains will always be approximately 10% of the instantaneous load and hence of the total annual heat sent out. In this case, the supply of domestic hot water will impose a minimum operating temperature on the network, and have the effect of increasing the losses expressed as a percentage of the annual heat sent out. It will however, tend to increase the load factor, although not to a very significant extent. It is desirable, therefore, that the mains losses should always be expressed as a percentage of the annual heat sent out.

It is to be expected that the economic thickness of insulation will normally be calculated at the design stage. According to a Swedish study, the mains losses then amount to 30-80 Btu/h ft. run (29-76 W/m) according to pipe diameter, and with a water-air temperature difference of 110 deg. F. (61 deg. C.) (81). The annual losses are about 15% of the total heat sent out, though a higher figure should be assumed for systems serving mainly small houses (where load per unit length of main will be small).

CHAPTER 8 - CONSUMER INSTALLATIONS

8.1 Connection to consumers

The connection between the underground piping system and the consumer's premises can be carried out in two ways;

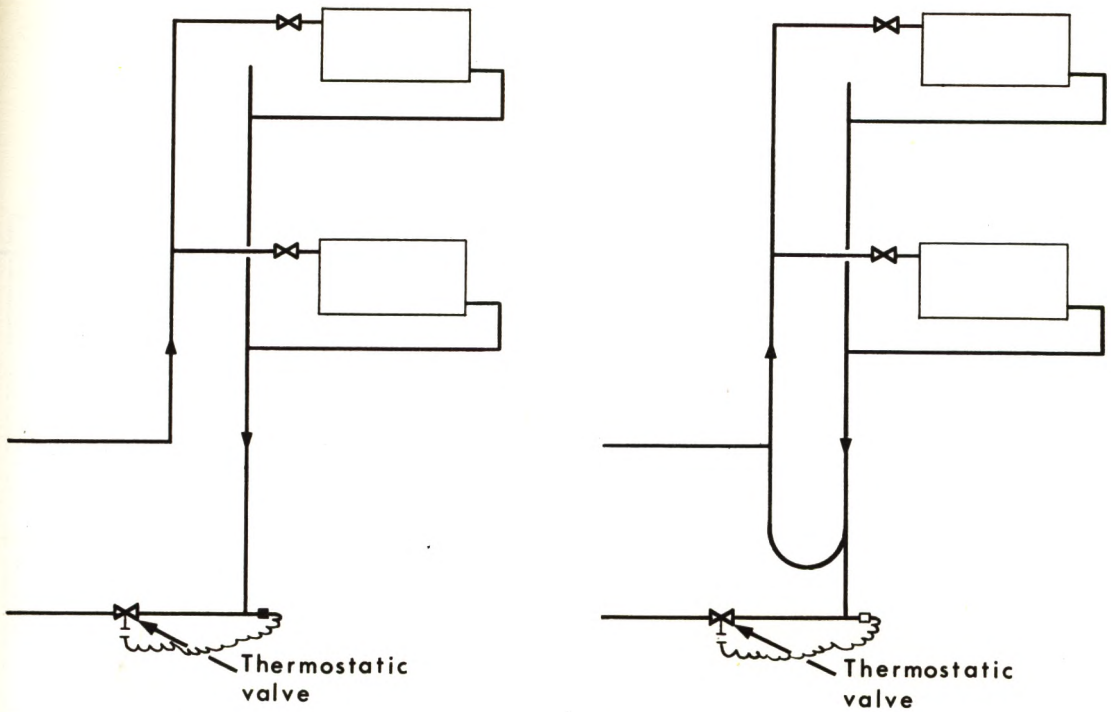
(a) without heat exchange equipment
(b) with heat exchange equipment

Irrespective of the method of connection, the common aim is to effect the maximum economic cooling of the district heating water. A large temperature reduction of the district heating water - (say) from 210°F (99°C) to 130°F (55°C) - will lead to a reduction in pumping costs due to the reduction in water volume flowing in unit time; also some saving will be made by reason of the smaller pipes required.

8.1.1 Without heat exchange equipment

Connection without heat exchange equipment can be further sub-divided into systems working on direct flow, in which the district heating water flows through the consumer's installation once, and those in which a percentage of the water is recirculated by means of a mixing bend or valve, the actual quantity depending on the outside temperature (Figure 15). In recent years the direct system has become increasingly popular in Denmark because of improved utilisation of the heat of the district heating water, and many of the installations incorporate a return water cooler which pre-heats the domestic hot water before the district heating water is passed back to the network.

The direct connection to the consumer's premises can either have a pressure-controlled or a temperature-controlled house installation (Figures 16 and 17). With the former a pressure differential regulator is fitted to the main supply pipe from the district heat network, giving a constant differential across the radiator valve, so that a constant volume of hot water at the mains flow temperature will pass through the radiator for a given setting of the radiator valve. The pressure-controlled system has the disadvantage, however, that in order to secure the most economical running conditions and a comfortable room temperature, the valve must be adjusted manually to compensate for heat gains from the sun or high occupancy. Also, if the radiators have been shut off during the night, the valve should be fully opened to provide some early morning boost. The valve has a further use in balancing the system. The dwellings close to the boiler plant will have a greater pressure differential between flow and return than those at the end of the circuit. The pressure differential regulator therefore absorbs the excess



Connection with direct flow

Connection with mixing bend

FIGURE 15 - CONNECTION WITHOUT HEAT-EXCHANGE EQUIPMENT

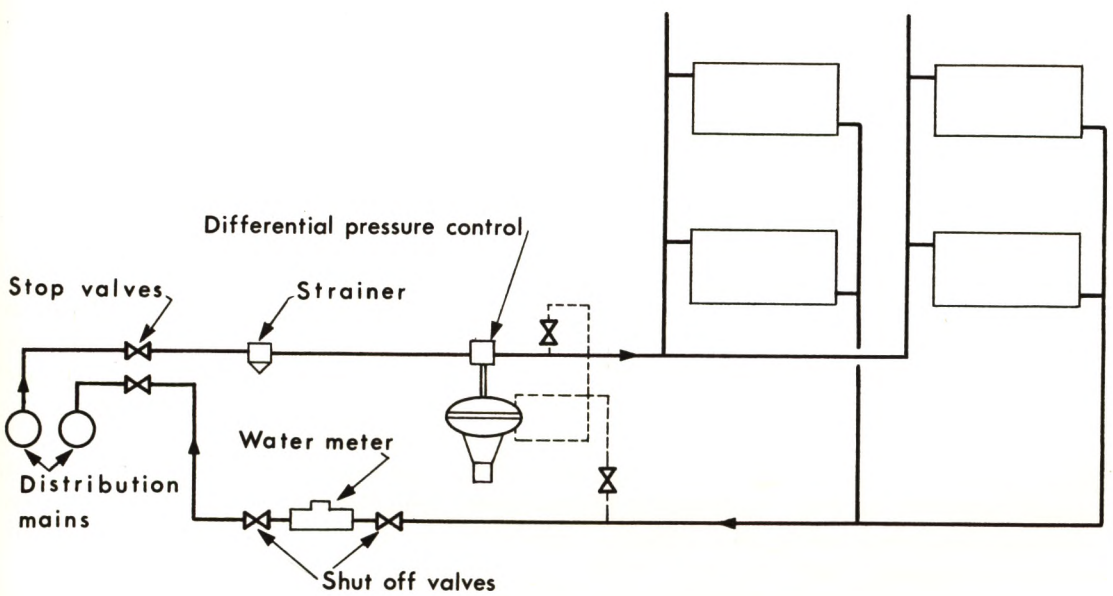


FIGURE 16 - PRESSURE-CONTROLLED DIRECT CONNECTION

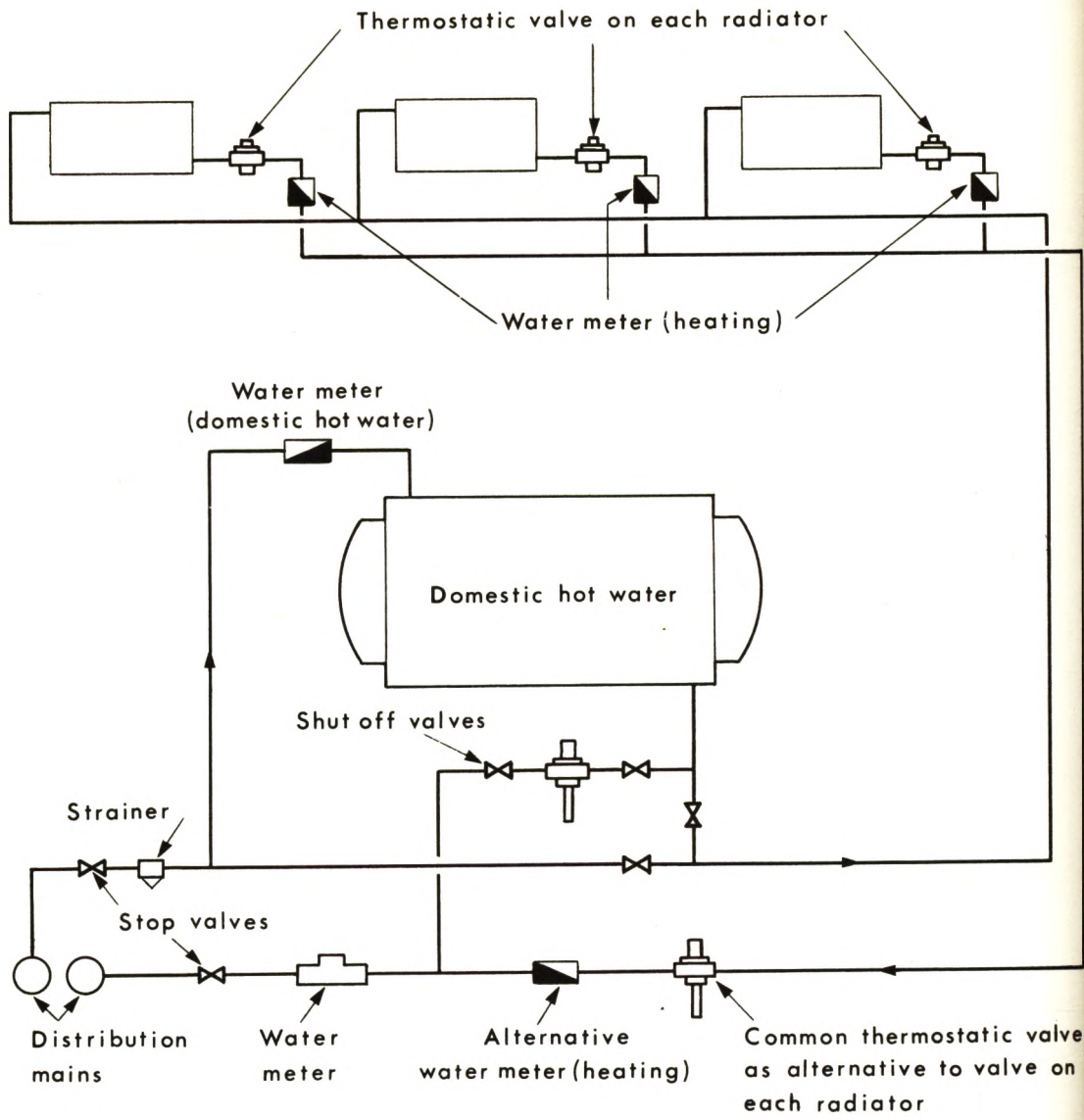


FIGURE 17 - TEMPERATURE-CONTROLLED DIRECT CONNECTION

pressure and maintains the correct pressure drop for all the dwellings.

The manual adjustment required with the pressure-controlled system is to a large extent obviated in temperature-controlled systems. In these, control is achieved by:

(a) A common thermostatic valve fitted in the main return line (in which case pre-setting of the radiator valves in relation to the radiator size is more important than in the pressure-controlled system since an excessive return temperature from a single radiator may cause the main thermostatic valve to close); or

(b) A thermostatic valve on the return line from each radiator so that in effect each radiator is an independent entity making pre-setting superfluous, an almost constant temperature being maintained once the required radiator return temperature has been decided.

8.1.2 With heat exchange equipment

If the heat transfer medium is steam or hot water at a temperature above 230°F (110°C), it will be necessary to install a heat exchanger between the district heating network and the consumer's installation. Heat exchangers, however, are sometimes used at lower temperatures, the advantage being that the district heating water has no direct connection with the consumer installation, so that any fluctuation in pump pressure is not transmitted to the radiators of the consumer's installation. This may be undesirable in networks supplying older buildings in which the radiators are incapable of withstanding very high pressures.

8.1.3 One- and two-pipe systems

The choice of one- or two-pipe distribution system within the consumer's premises would seem to depend to some extent on local experience, and, of course, on the type of building being served. The two-pipe system is considered by Danish engineers to be more suitable for connection to district heating and in particular for control of the network. Both systems are widely used in Germany, however, the one-pipe system being particularly favoured, on economic grounds, for large blocks of flats.

8.1.4 Steam installations

The use of steam in district heating networks is in general on the decline; for house heating, hot water distribution is preferred, steam being used only when the industrial requirement for process work is large enough. In some of the older schemes which have survived the march of time, particularly in America and Germany, steam is still supplied to mainly residential areas; many of these schemes, primarily in America, extract the useful heat from the steam and run the condensate to waste - a practice which is to be discouraged today on grounds of economy.

Control of the steam installations may be broadly classified into continuous flow and on/off systems. The latter are popular in certain American schemes in the form of room thermostats controlling radiators through which the steam from the district network is passed direct via a pressure-reducing valve. Continuous or, more accurately, modulating flow is more widely used in the newer installations; the secondary hot water circulated through the building is first brought up to the required temperature in a steam/water heat exchanger, the steam flow being regulated by means of a motorised valve operating under the dictates of a room thermostat and outside compensator.

8.1.5 Once-through systems

A system which is at present the subject of much interest in Russia is the once-through district heating system. Ordinary mains water heated and chemically treated at the heating or power station, is sent through a single-pipe network to the consumer's connection where it passes through two mixers - one for heating and one for domestic hot water (Figure 18). The return water from the heating system is recirculated to the system by a pump and through the heating mixer, while the excess passes to the domestic hot water side through the other mixer, any fluctuation in hot water demand being com-

pensated by a storage vessel. Temperatures in the heating and hot water system are regulated by thermostatic valves, and the water level in the storage vessel by a pressure controller acting in response to the amount of excess return water discharged to waste.

The system is claimed to offer economic advantages in both capital and operating costs over a more conventional system. It is doubtful, however, whether it would be allowed in many countries, on account of the large quantities of chemically treated hot water which must be discharged to waste.

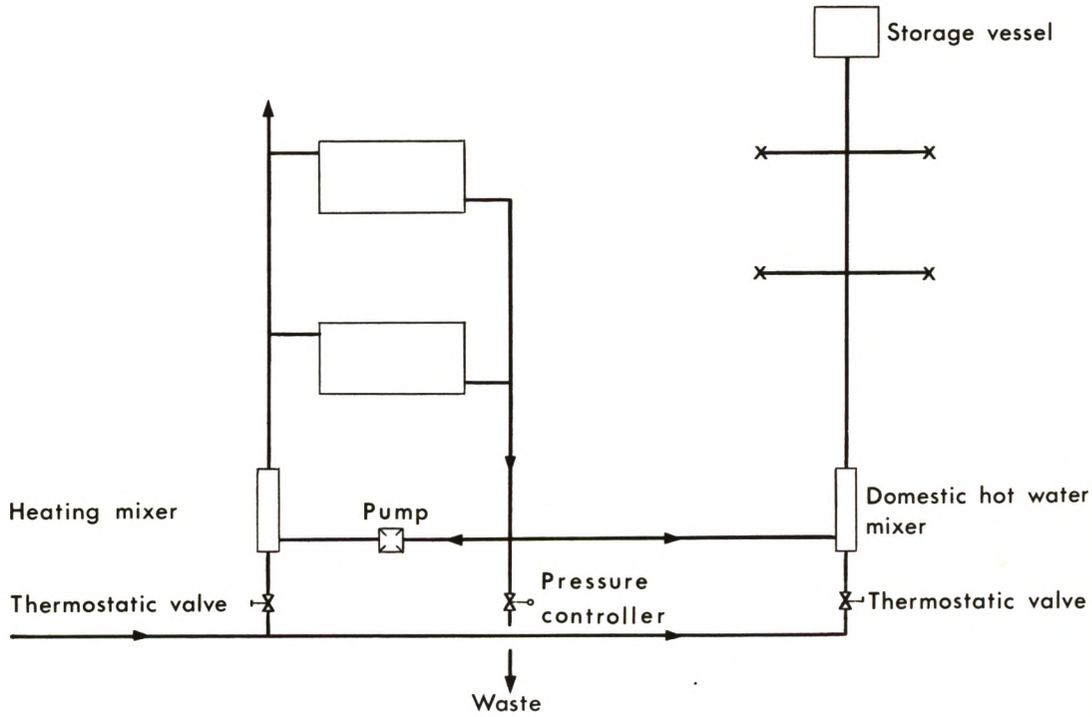


FIGURE 18 - ONCE-THROUGH SYSTEM

8.2 Metering

If heat is supplied from a central source to a number of different consumers, it is desirable to find some means whereby the costs can be distributed in proportion to the quantity of heat used by the individual consumers. This can be done by metering the supply of heat to each consumer.

The function of the meter is fairly easy to define: it is the integration of temperature difference and fluid flow in relation to time. In practice, however, this is an extremely difficult integration to perform cheaply and accurately, especially under conditions of low flow rates and fluctuating temperature differences.

Views in this country and elsewhere on the merits of metered heat supply differ widely, and practice varies accordingly. Tests carried out in Denmark on two schemes, one with metered supply and one without, have indicated that there is little difference in the heat taken by the various consumers. However, it is more widely believed that the total heat consumption in a block of flats with metered supply can be about 25% lower than

in a similar block without meters (137). The human element is, of course, unpredictable: generally there is little incentive to economy when heating and hot water services are provided at an inclusive charge.

Of the recent North Rhine-Westphalia schemes, a substantial proportion - largely those which also provide domestic hot water - have some form of metering (131).

The S.N.E.C. takes the view that the metering of large consumers (or of a whole block of flats) is desirable and necessary (136). On the other hand, individual metering is difficult, and its value illusory. Metering is moreover costly, and any resulting economies of a minor nature. The larger meters may be expected to have an accuracy of about 3% (presumably at full load), but metering of seasonal consumption is believed to be accurate to no more than 8 to 10%.

A Belgian consulting engineer responsible for a number of small residential schemes takes a similar view, and even discounts the value of the larger meters (121). The same opinion is expressed by the engineer in charge of the Brussels (Gare du Nord) scheme.

In the three Stockholm schemes, metering is confined to the large consumers.

The cost of metering in Wolfsburg is around 0.4 DM/GJ and in Hamburg 2 DM/month - about 10% of the total bill to the consumer.

In Switzerland, the disadvantages of metering domestic hot water consumption have led to its abandonment. Here, it is recognised that a flat rate charge based on floor area may often lead to a higher consumption of water; but the cost is said to be outweighed by the improved load factor on the plant and by the saving of metering costs. The futility of attempting accurate metering is illustrated by the fact that hot water costs a sum equal to about 2% of the rent, and is only about one-quarter of the cost of heating.

In Europe generally, small consumers seem prepared to accept rough and ready means of heat metering, such as the evaporative types of meter. These, although known to be subject to quite considerable errors, are nevertheless used to apportion the total cost of heating between the tenants in (say) a block of flats. Greater accuracy is not demanded of other methods of metering, so that approximate charges based on water volume are also accepted. For this purpose, several operating authorities of district heating plants assume an arbitrary temperature drop - usually about 40 deg. C - across the consumer's installation.

A thermostatic valve will in such cases be fitted to the consumer's return line, preventing any water at a temperature above a pre-set value from being discharged to the district network. The volume of water which has passed through the consumer's installation is read from the water meter, and the costs apportioned according to the quantity circulated. With such a system it is possible for the tenant to alter the setting of the thermostatic valve to obtain a greater temperature drop across his installation; but this is generally accepted by the district heating companies since they also benefit to some extent by reason of reduced losses in the cooler return main (Figure 17).

Although evaporative meters have been extensively used in Scandinavia, it is now believed that metering is less popular than it was with the operator. It is thought that metering can give rise to fairly considerable load variations, leading to difficulties in central station control and to some inefficiency.

Combined with the extra cost which metering entails, the possible overall monetary saving seems marginal.

When metering is being discussed, it should not be forgotten that from 50 to 60% of a consumer's total bill for district heat consists of fixed charges, leaving half or less based on units consumed. A saving of 10% of the heat used by an individual consumer yields only about 5% reduction in the bill. If this is, as it may be, about equal to the total cost of metering and accounting, the consumer does not benefit, and the whole scheme is needlessly complex.

Financial aspects may sometimes be outweighed by social considerations. In low-cost housing for example, it is often felt to be unwise to encourage, by metering, too stringent economy on the part of the occupants. For inadequately heated dwellings are unhealthy; in addition, they may deteriorate rapidly and require substantial maintenance.

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CHAPTER 9 - COSTS

9.1 Capital costs

From the replies to our questionnaire, and the statistics published by both the N.D.H.A. in America and UNICHAL in Europe, data are available on the capital cost of some 100 installations up to the end of 1963. They are tabulated in Appendix 5. For the U.S.A. the capital cost figures given are cumulative totals from the date of installation up to 1963, and include all extensions and other capital works.

Capital costs reported in the questionnaire replies, and in technical literature, vary over a wide range - from £90 to over £1,000 per therm/h of installed capacity. One important cause of this variation is, of course, the date of the installation. Some figures relate only to the street network, as when heat is purchased from a power station; they naturally tend to be low. Some include the cost of the consumer's installation, and of meters; some include domestic hot water supply. They relate, too, to widely varying types and sizes of load.

The most homogeneous data derive from Denmark. Olufsen states that the capital cost of a scheme is of the order of £500 per therm/h (£17/kW) of installed capacity (say £400 per dwelling) and is nearly independent of the actual size (113). Belgian residential schemes are estimated to cost between £440 and £510 per house (or £330 to £350 per flat), including the internal installation (121). German estimates for the central plant and the main distribution range from £300 to £600 per therm/h (£10 to £20/kW) (about £200 per flat). Staats gives estimates (for Europe) of £200 to £320 per flat depending on density of development (100). A 1967 figure for typical costs in France (excluding the installation within the building) is from £310 to £385 per therm/h (133). The cost of one British scheme was estimated to be £550 per flat at 1964 prices.

These may be compared with the cost of central heating systems for individual blocks of flats. The Belgian figure is £220 to £290, according to type of fuel; a British figure is £300. German opinion is that, certainly for large plant, oil-fired installations are cheaper than district heating (131).

It is evident that the capital charges have risen considerably in the past twenty years. Part of the increase is due to rising initial cost; part is due to the rise in interest rates. In Denmark, the capital charge per unit of heat sold has risen by 50% since 1945.

Numerous efforts were made during the survey and during visits to the various countries and installations to obtain some realistic breakdown of the overall capital costs into headings such as plant, mains, trenches, etc. They met with little success since most operators were extremely reluctant to discuss financial items. It would appear, however, that the relationship in

capital cost between the three major parts of the installation is roughly as follows:-

(a) Boiler plant 25%
(b) Distribution network 45%
(c) House installation 30%

The main distribution network is often the most expensive item and will vary between about 35% and 55% of the capital costs, depending on the extent of the network and the type of buildings served.

In 1965, UNICHAL's pipe study committee began an examination of the question of heat distribution with a view to preparing a comprehensive analysis of the cost of all types of ducts, trenches and insulating materials (116). A recent paper suggests that one of the prefabricated systems for heat distribution mains is probably cheaper than the conventional methods and may offer better possibilities for use in wet conditions (109).

The cost of excavation, trench building, piping and insulation for the scheme in Warsaw is shown in Figure 19. In Germany, the cost of the distribution network alone is usually 70,000 to 80,000 DM per MW installed (£190 to £225 per therm/h), and may be as high as 200,000 DM per MW (£550 per therm/h) in schemes serving single family dwellings (106). Data for France show costs of the order of £200 per therm/h (133). The capital cost of the generating station can be of the same order, so that a total of (say) 150,000 DM per MW (£400 per therm/h) for the boiler plant and distribution system would be a realistic figure. The average cost of a conventional central heating system in each dwelling has been estimated at about 80,000 to 100,000 DM/MW/h (£25 to £275 per therm/h), so that the difference must be found in economy of operation of the district heating plant and in other, non-monetary, factors.

It is clearly advantageous to secure repayment of capital as rapidly as possible. There is a growing practice of charging the consumer a connection charge, comparable (in new property) to the saving he has realised in not having to provide either a boiler plant or a chimney. Connection charges of the order of £100 are levied in Denmark; and somewhat similar charges are made in Sweden and parts of Germany. In new development, as at Farsta (Stockholm), all potential consumers may be required to be connected from the outset, thus ensuring both adequate demand and the early repayment of the connection charges. In France, where the Government is encouraging the construction of groups of tall blocks of flats, the developer is required to pay to the heating contractor a sum equal to the estimated cost of providing heating in each block. This sum helps to defray the capital cost of the group heating scheme.

9.2 Amortisation

Until recent years, the period over which the capital cost of a scheme has been amortised has varied from about 10 to 60 years. At present, however, the amortisation period is usually about 20 to 30 years, in most cases coinciding with the number of years for which the initial contract to supply heat is made.

The rate of interest on capital loans varies from time to time and from

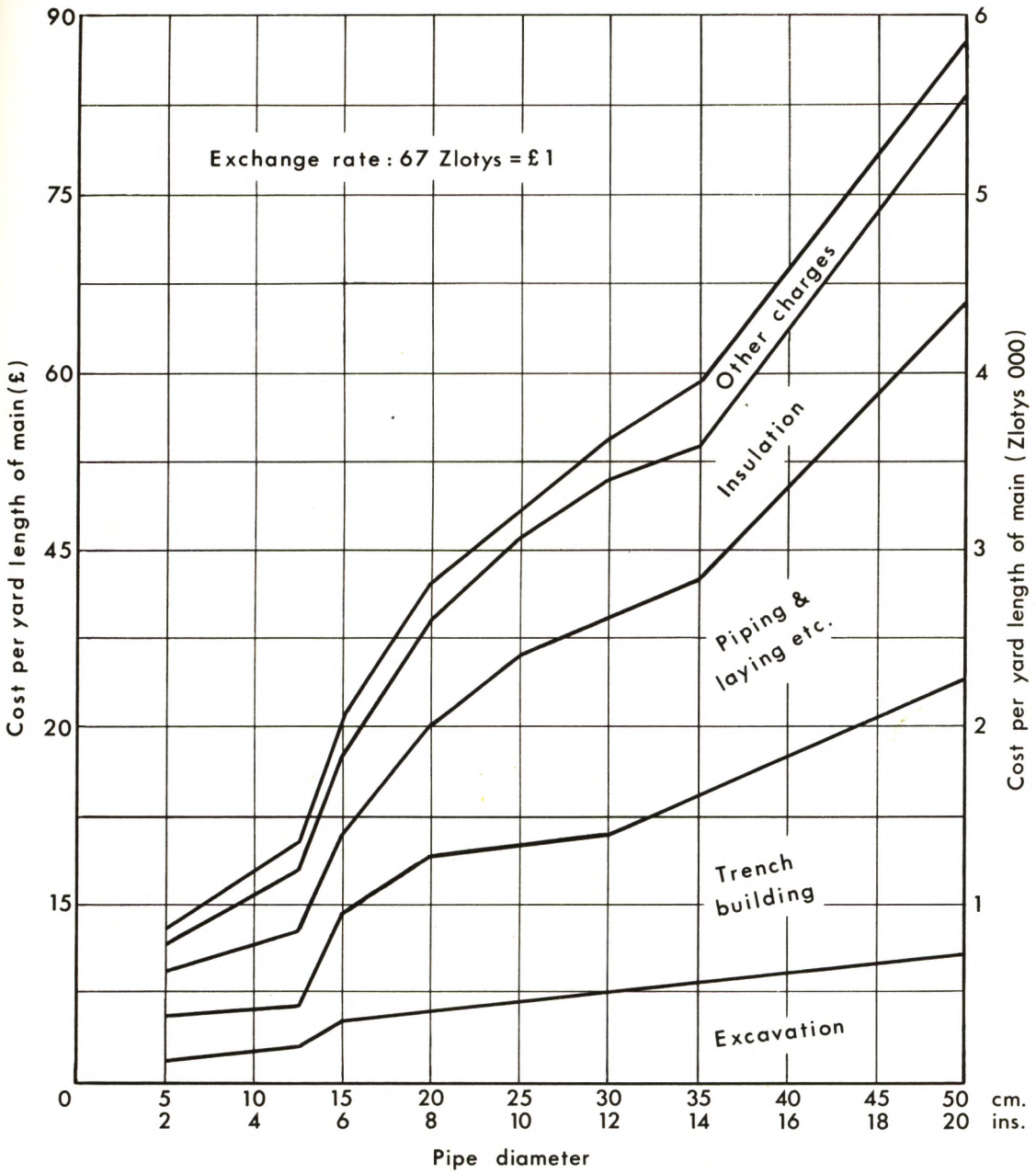

FIGURE 19 – CAPITAL COSTS IN WARSAW SCHEME

country to country, and in general is closely tied to the prevailing bank rate.

In some cases, the several items of plant and equipment have different rates of amortisation, often at what appear to be very low rates. Thus, a new boiler plant was installed in one American system in 1962, and the additional depreciation allowance was only 2% of the extra cost. It is reported that in the Strasbourg scheme (1962) no allowance is made either for depreciation or for interest on borrowed capital, while at Metz (1956) the total charges are under 2%. Of 63 Danish schemes, only 7 are known to have amortisation rates over 5% while 6 show no figure at all. For the same schemes, interest rates average some 3% (130). No doubt these figures are coloured by the impact of the connection charges. True allocation of capital charges is difficult in the case of thermal-electric schemes; and it is interesting to note that in one instance (in America) an operating loss was transformed into a "profit" by a redistribution of capital charges between the sales of heat and electricity. In Denmark, an agreed scheme of allocation of costs between the two products has been worked out, and capital charges of 8% are allowed for that part (also 8%) of the total capital allocated to the heating service.

Station buildings are assumed to have a life of 25 to 50 years, plant generally 20 to 25 years, pumps and boiler settings 10 years or less, and meters and controls also 10 years. Normal working lives for some items are given in VDI 2067.

In very few of the schemes for which information was available did the total cost of capital service exceed 10%.

9.3 Operating costs

The cost at which heat can be made available to the consumer is of considerable importance to the success of any district heating system. It must necessarily approximate to the cost at which the consumer could otherwise generate his heat by means of individual central heating, giving due consideration to the added amenities of district heating.

The operating cost of any district heating scheme will be a composite figure made up of a number of different items. Some of these charges are constant, whilst others will vary from time to time according to the quantity of heat taken and the ruling fuel prices. Such charges fall into five groups:-

(a) Repayment of capital loan, interest and amortisation*
(b) Labour and management
(c) Fuel
(d) Maintenance
(e) Other charges, such as electricity used by plant

The relationship between these charges for various schemes is set out in Appendix 6, in which the cost of each item is expressed as a percentage of the total annual operating cost. Operating, as well as capital, costs for a typical scheme is Germany are set out in Appendix 7.

* See above, p.50

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9.3.1 Labour and management

This item in the annual running cost is usually a fairly constant figure for any one scheme. It will, however, vary considerably according to the type and extent of the scheme and the degree of automatic control employed. Generally firing and fuel handling are automatic so that the number of operational staff can be kept to the minimum necessary for efficient operation.

For the small, completely automatic oil-fired plants seen in Denmark, one man is sufficient to maintain efficient operation, but for the planning, legal, technical and maintenance aspects of an extensive thermal-electric scheme the staff can be quite large. In Munich, a special section of the electricity company's staff is responsible for the district heating network, which has a total connected load of 620 MW (2,130 million/Btu/h). It consists of 3 graduate engineers, 25 technicians and engineers, 7 supervisors and 57 workmen, and there is also a motorised service unit equipped with radio.

The Hamburg Gas Company, too, employs a radio-equipped mobile team to operate and maintain the small local boilerhouses associated with the suburban group heating schemes. The four principal thermal-electric stations in Berlin, with a total connected load of 400 MW (1360 million Btu/h), employ 4 engineers and 25 maintenance staff for the district heating network (129). For a small scheme serving a neighbourhood of 1200 dwellings (connected load 15 MW or 52 million Btu/h), Beck suggests that an operating staff of 4 is adequate (112).

9.3.2 Fuel

Attempts have been made to obtain information on the fuel prices charged both to small users and to large consumers. Tables 5a and 5b summarise the data obtained from a number of sources. There can be substantial price differences within one country (caused, for instance, by distances from port or coalfield). The cost to the consumer often depends also on the quantity consumed (either because of the operation of a two-part tariff, or because a contract for the supply of fuel over a period of time has been negotiated).

It is apparent that the pattern of fuel availability is changing, chiefly owing to the development of natural gas-fields, and this will undoubtedly be reflected in fuel prices. Moreover it cannot be assumed that the costs of the various fuels will continue to stand in the same relation to one another as hitherto.

An examination of the fuel costs reported in the replies to our questionnaire suggests that prices in the U.S.A. may be as low as half the British prices, while in Europe they may be 25-35% lower. In some cases, extremely low prices are reported - e.g., Polish coal at 52s. a ton is used at Randers in Denmark.

In many European countries, quite large price differentials exist, especially between the light and heavy fuel oils. They confer a marked advantage on those plants which can burn heavy (3500 sec.) fuel oil, and heat produced in small individual plants restricted to the light grades is relatively costly. (In Denmark, the fuel price ratio can be as high as three to one).

Country	Gas	Heavy oil		Coal/coke	
	Pence/therm	£/ton	Pence/therm	£/ton	Pence/therm
Austria		8.5	5.3	2.3 to 4.5	2 to 4
Belgium		7.2 to 8.8	4.3 to 5.1	5.8 to 7.0	5.2 to 6.2
Denmark		5.1 to 6.2	3.1 to 3.7	2.6 to 10.0	2.3 to 9.0
France		8.4 to 13	5.0 to 7.8	5.9 to 7	5.2 to 6.2
Germany (W)		7.1 to 7.5	4.2 to 4.5	7.2 to 7.6	6.4 to 6.8
Holland	8.2 to 24	7.2 to 8.1	4.3 to 4.9	6.8	6.0
Italy					
Sweden		6.4 to 10.0	3.8 to 6.0		
Switzerland		6.2 to 7.4	3.7 to 4.5	6.5	5.8
U.S.A.	1.9 to 3.7	4.3 to 8.5	2.6 to 5.0	1.5 to 4.5	1.3 to 4.0
U.K.	16 to 17	9.5	4.7	4.1 to 5.8	3.7 to 5.2

TABLE 5a - FUEL PRICES (LARGE CONSUMERS)

Sources of data:
Chaleurs et Climats (1963)
Shell-Mex B.P. (1965)
Gas Council (1965)
National Coal Board (1964)
Visits and Questionnaires (1964)
N.D.H.A.

Country	Gas	Gas oil		Coal/coke	
	Pence/therm	£/ton	Pence/therm*	£/ton	Pence/therm
Austria	16.4	14.6	8.5	13.9	12.5
Belgium	14.4 to 15.7	15.7 to 19	9 to 11	10 to 20	7.5 to 15
Denmark		11.2 to 15	6.5 to 8.7	10	8.9
France	33.9 to 40**				
	12.1 to 31.7+	11 to 14.8	6.4 to 8.6	8.3	7.4
Germany (W)	35.8**	11 to 12.4	6.4 to 7.2	9.7	8.6
	14.1 to 29.4				
Holland	15.8 to 43.5	15.7	9.1	15.4	13.7
Italy	15.3	12.9	7.5	12.9	11.5
Sweden		11.7 to 15.3	6.8 to 8.9		
Switzerland	25.3	10.4 to 12.8	6.0 to 7.4	14.7	13.1
U.S.A.					
U.K.	30 to 36**	21.6	12.5	8 to 12	8.1 to 10.7

* Based on assumed calorific values
+two-part tariff (standing charge to be added)
**Flat rate

TABLE 5b - RETAIL FUEL PRICES (DOMESTIC AND SMALL CONSUMERS)

Sources of data:
Chaleurs et Climats (1963)
Shell-Mex B.P. (1965)
Gas Council (1965)
National Coal Board
Visits

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It must be remembered, however, that fuel costs contribute only about one-third to the total owning and operating costs. Hence substantial variations in fuel prices cause much less variation in the average cost per therm sold.

9.3.3 Maintenance

Costs under this heading cover all running repairs and general maintenance of the plant and the distribution network, including excavation of mains in roads, etc., relaying and resurfacing or making good the road surface. Consequently, they can vary from year to year. Where careful attention has been given to the initial installation work, the annual charge is low, and it can be kept low by careful inspection and prompt attention to all leaks or repairs during the lifetime of the scheme or plant.

In Germany maintenance costs have been estimated to amount to 1% per annum of the initial cost of the system. For the 63 Danish schemes, they show a tendency to increase with the age of the system, though the range is very wide. Figures of $2\frac{1}{2}$ to 15 ore/GJ (¼ to 2d/million Btu) sent out are quoted for modern plant, rising to as much as 60 to 75 ore/GJ (8d/million Btu) for plant 10 to 15 years old. For the oldest plants (30 to 40 years old), maintenance costs range from 25 to 50 ore/GJ sent out; there is no relation to the size of the plant. The lower figures for modern plant are typically around 1% or so per annum of the capital cost (130)

9.3.4 Other charges

Apart from the charges for labour, management, fuel and maintenance, a number of others are likely to be incurred in the course of the operational year. These include such items as water, electricity, lubricating oil, paint, miscellaneous stores, etc.

9.4 Cost per therm

The cost per therm of heat supplied to the customer for space heating and domestic hot water was the subject of a specific question in the questionnaire sent out to all installations. Very few of the returned questionnaires, however, answered the question fully: by far the greater proportion of the replies stated that the charge was a variable one, usually based on a sliding scale coupled with a fixed standing charge. The standing charges embody in their make-up all or part of the fixed annual charge and sometimes part of the cost of connection to the mains.

Information on various American schemes indicates that the cost to the consumer varies between about 6 and 21 pence per therm, with an average of 12 pence per therm. In Europe, charges for district heat are similar to those in America with a general average of 12 to 14 pence per therm (about 10s. per GJ).

The size of the scheme, and also the type of buildings it serves, are bound to have some effect on the final cost at which heat can be provided. Obviously, the capital and production costs of a scheme serving a few hundred single-family houses are going to be greater than those of a scheme of equal plant capacity serving a dense commercial or industrial area. An indication of

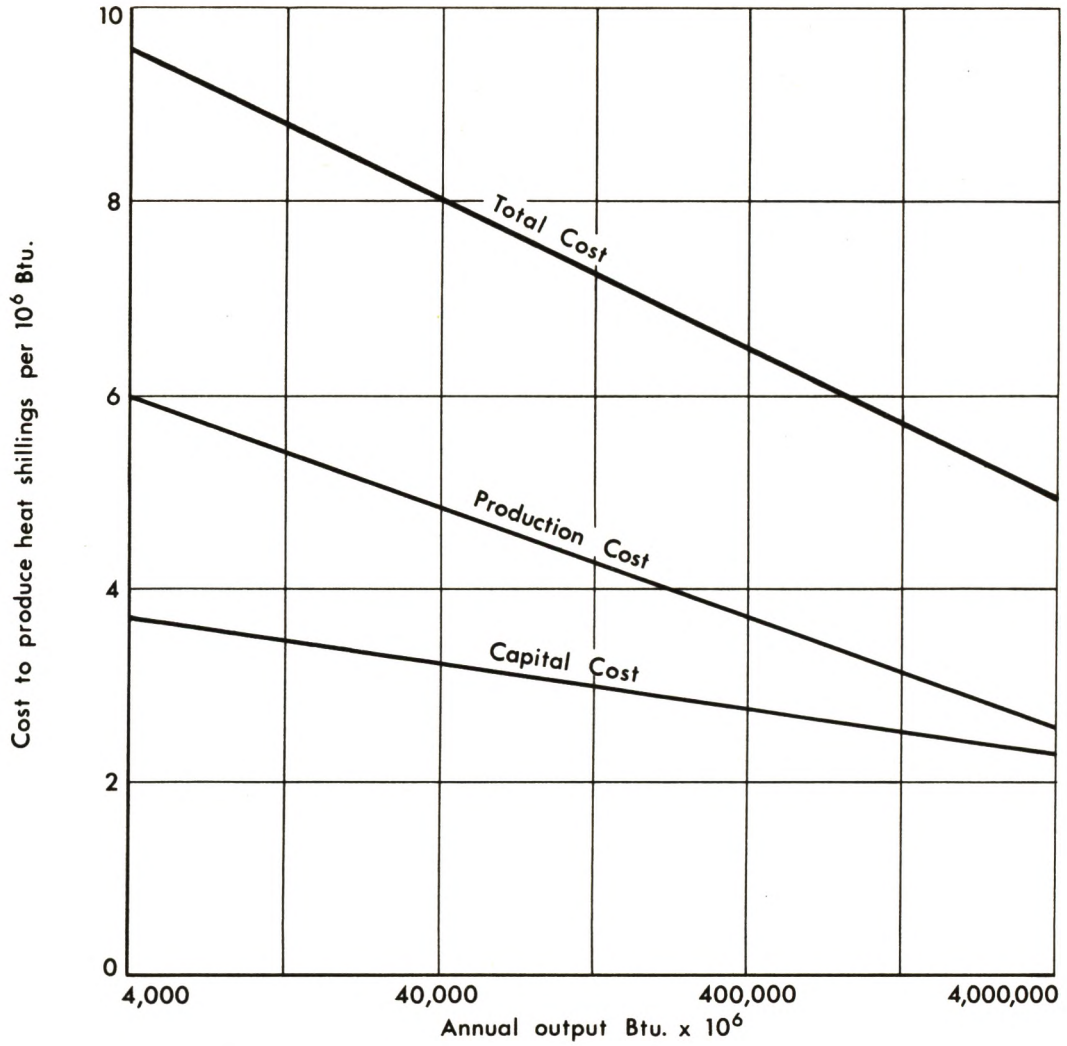

FIGURE 20 - COST OF GENERATING HEAT IN DENMARK

how in Denmark the cost of generating heat and the cost to the consumer decrease with an increase in plant capacity is given in Figures 20 and 21.

It is probable that the load factor will also influence the cost per therm; however, from information available, there does not seem to be any direct or close relation between the two.

The view has been expressed on a number of occasions that district heating is not always truly economic, nor always cheaper than alternative methods. Thus, Jacobi has stated that for a large installation, oil firing will often be cheaper than the district supply (131). Officials of the Stockholm system believe that individual heating, even of flats or houses, is no more expensive, though users prefer the manifest advantages of a district scheme. In Denmark, the balance is marginally in favour of district heating. Kemmer points out that in Germany few purely thermal schemes are really economic unless capital costs are subsidised or financed at very low interest rates (1). He adds that, from the economic viewpoint, combined heat and power systems are usually much more satisfactory, though high profits are only

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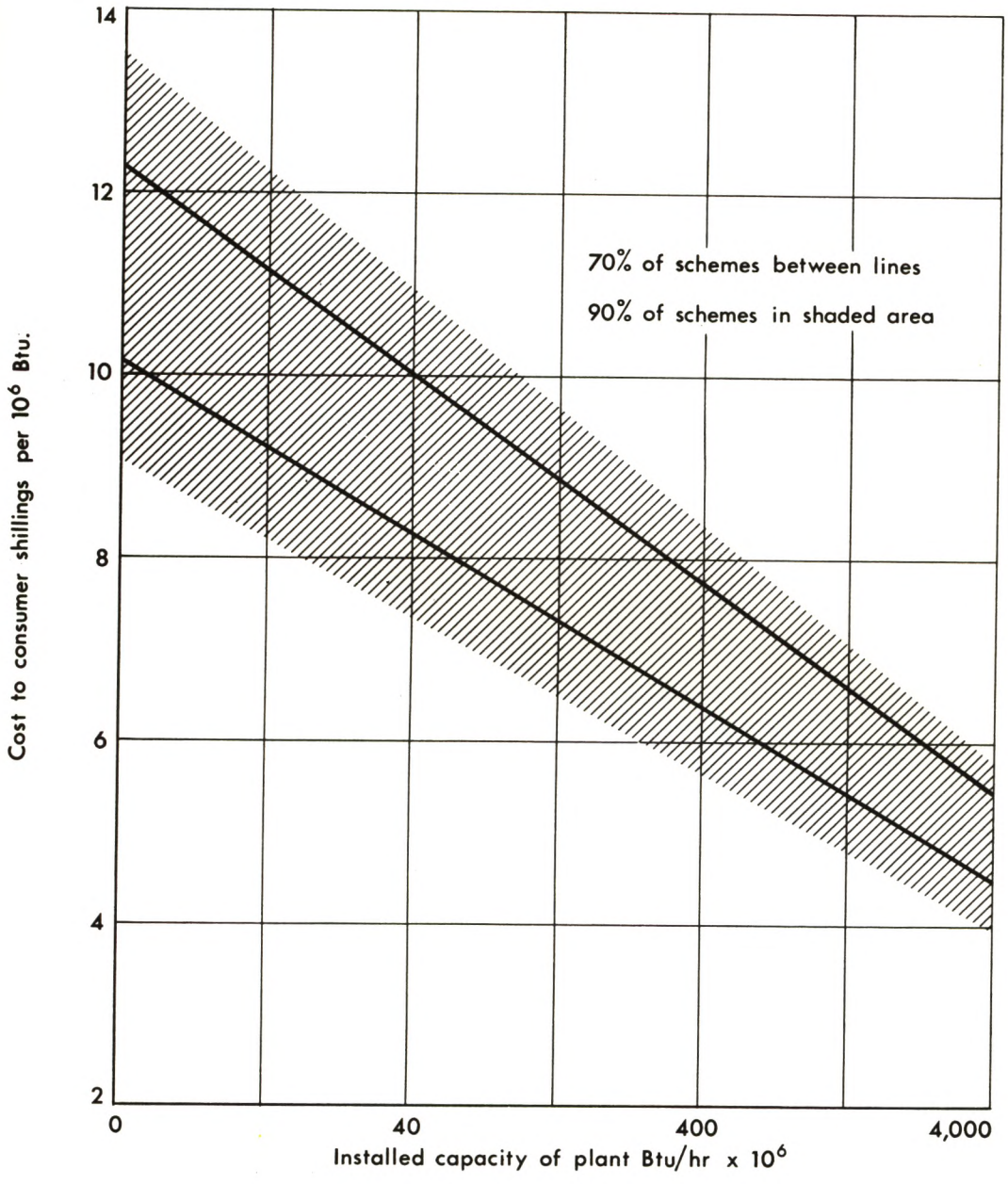

FIGURE 21 - COST TO CONSUMER IN DENMARK

found in exceptionally favourable circumstances. These last - the objectives of the operating companies - are high load density, short distribution mains, high load factor, rapid development to final size, and 100% connection of all possible consumers (often achieved compulsorily in new development).

It is generally assumed that district heating must offer a service which is at least as cheap as any alternative method. Experience in France indicates, however, that a customer may be prepared, in view of the freedom from responsibility and trouble, to spend up to 15% more for district heating. It is obviously desirable to take some account of the customer's capital savings in fixing the charges or evaluating the cost of alternative sources. The

Scandinavian practice of levying a connection charge (and the French equivalent) do this automatically, and thereby lower the cost of supplying heat.

For the few installations supplying cooling as well as heating, it is evident that the capital costs for cooling are much higher, as is the cost per therm. For schemes at La Moue (94) and Hartford, Conn. (122,123), the costs are:

	Capital per therm	Selling price per therm	Annual use
La Moue:			
Heating	£230	1s. 5d.	2,200 h.
Cooling	£1,900 (incl. mains)	5s. 6d.	1,900 h.
Hartford:			
Heating	£530 plus £260 for mains	15c plus standing charge	2,050 h.
Cooling	£620 plus £200 for mains	40c plus standing charge	1,000 h. (ca)

9.5 Tariffs

A variety of tariff structures is in use in the different countries. A straightforward charge based on a fixed unit price is rare, except in U.S.A. The normal method is a stepped tariff, and, although no charge is made to the consumer in the form of a basic price, a minimum charge of about 35s. to 40s. per month during the heating season is usually levied by the operating authorities. Typical charges at Duluth are shown in the table below:

Consumption of steam		Rate per 1000 lb.
Winter months (September to May)		
First	35,000 lb	12s. 8d.
Next	200,000 lb	11s. 7d.
Next	300,000 lb	11s. 3d.
Next	1,000,000 lb	10s. 6d.
Next	2,000,000 lb	9s. 9d.
Over	3,000,000 lb	9s. 6d.
Summer months (June to August)		
First	35,000 lb	12s. 8d.
Next	300,000 lb	10s.10d.
Over	335,000 lb	9s. 6d.

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In Europe, some form of two-part tariff is almost universal. The fixed charge which the consumer has to pay, irrespective of the heat taken from the district network, is usually calculated in relation to the design heat requirement of the individual buildings. It may be related to the heated floor area, or to the maximum demand of the consumer's installation.* The former is practicable when standards of insulation (specific heat loss) are laid down, but can lead to inequity between one flat and another, as Jacobi has demonstrated (Figure 22). An initial connection charge and a quarterly meter rent are also frequently imposed.

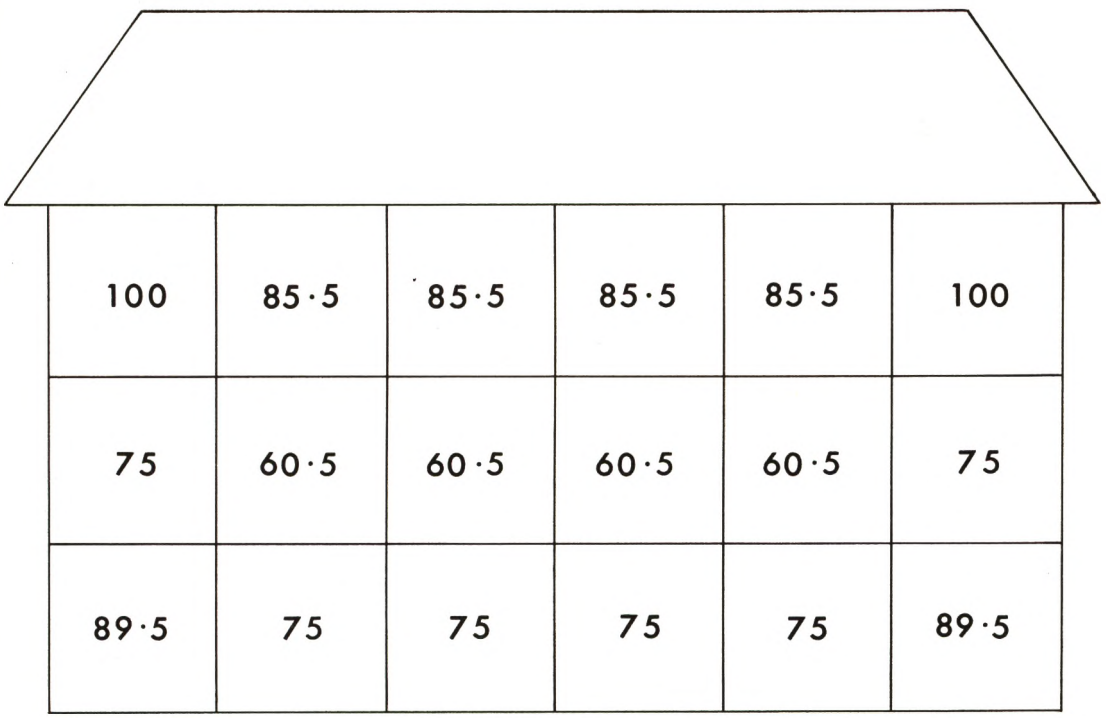

FIGURE 22 - PERCENTAGE HEAT REQUIREMENTS IN BLOCK OF FLATS

The heat used is charged for at a unit rate, which may be varied in accordance with a consumer price index and/or a fuel price clause. As a result of this two-part tariff, the cost per therm for any scheme can vary quite considerably with the heat requirements of the various consumer installations. This is illustrated by the calculations on p.60 for a scheme in Germany.

When "proportioning" meters+ are used, the running cost of the heat supplied to a complete block is found from the readings of an accurate main meter. This is then divided amongst the separate consumers in accordance

* Either basis may also be used when metering is not in force, though the charge per m^2 or kW is then naturally greater.

+ i.e. less accurate meters of the evaporative or inferential type, which do not record actual heat consumption, but some parameter more or less closely related to it.

(a) Charge for a flat of 806 ft^2 floor area

Specific heat requirement	41 Btu/ft^2h i.e. 33050 Btu/h
Hours of utilisation	1300 per annum (full load equivalent)
Basic charge at 12s. 6d. per 1000 Btu/h	12s. 6d. x 33 = £20 13s. 0d.
Working price	6s. 6d. per 10^6 Btu
∴ Running cost 6s. 6d. x 33050 x 10^{-6} x 1300	= £14 7s. 0d.
Therefore total annual cost	= £35 0s. 0d.

The average price per therm of heat used:

$$\frac{35 \times 20 \times 10^5}{33050 \times 1300} = 1.63\text{s.}, \text{ i.e. } 1\text{s. } 7\tfrac{1}{2}\text{d. per therm.}$$

or 35×20

$$\frac{35 \times 20}{806} = 0.87\text{s.}, \text{ i.e. } 10.4\text{d. per sq. ft. yr.}$$

(b) Charge for a hospital served by the same scheme

Heat requirement	16×10^6 Btu/h
Hours of utilisation	2000
Basic price	7s. per 1000 Btu/h
Standing charge	7s. x 16000 = £5600 0s. 0d.
Working price	6s. 6d. per 10^6Btu
Running cost	6s. 6d. x 16 x 2000 = £10400 0s. 0d.
Total annual cost	= £16000 0s. 0d.

Therefore average price per therm of heat used

$$\frac{16000 \times 20\ 10^5}{16 \times 10^6 \times 2000} = 1.0 \text{ s.}$$

CALCULATIONS OF COST PER THERM

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with the indications of the individual meters. A fixed charge is levied in addition.

In some cases, as in the U.K., a fixed charge only is made, as an addition to rent, and there is no incentive to economise in the use of heat or hot water. The standard amount in the U.K. is usually between 15s. and 20s. per week, which compares with a normal expenditure on domestic heating in European countries of between about £40 and £70 a year.

In Hamburg, domestic hot water is also supplied on a two-part tariff, the unit being m^3 of water used. Here, too, the standing charge and the unit price for heat may differ for ordinary and local authority housing.

Goepferts has suggested that the charge for domestic hot water should be close to that for generation by gas or electric water heaters, on account of the high mains losses (137).

It is by no means uncommon to read of the charges varying as the scheme develops.

APPENDICES

APPENDIX 1 - REFERENCES

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APPENDIX 2 - QUESTIONS FOR SURVEY

1. GENERAL
   - 1.1 Name of scheme
   - 1.2 Town
   - 1.3 Country
   - 1.4 Operator
   - 1.5 Owner (if different from above)
   - 1.6 Consulting Engineer
   - 1.7 Installation date
   - 1.8 Has scheme been extended?
   - 1.9 Date and nature of extension
   - 1.10 No. and types (industrial, commercial, etc.) of buildings now served.
   - 1.11 Area now served
   - 1.12 Population of area

2. CLIMATIC CONSIDERATIONS
   - 2.1 Length of heating season
   - 2.2 Degree days
   - 2.3 Mean monthly external temperature
     - (a) January
     - (b) July
   - 2.4 Design temperature
     - (a) Internal
     - (b) External

3. GENERATING PLANT
   - 3.1 Thermal-electric
     - 3.1.1 Number of stations
     - 3.1.2 Efficiency
     - 3.1.3 Total boiler power
     - 3.1.4 Capacity of heat generating plant
     - 3.1.5 Annual heat output
     - 3.1.6 Annual electric output
   - 3.2 Thermal only
     - 3.2.1 Number of stations
     - 3.2.2 Efficiency
     - 3.2.3 Total boiler power
     - 3.2.4 Number and type of boiler (fire tube, water tube, etc.)
     - 3.2.5 Annual heat output
   - 3.3 General
     - 3.3.1 Connected load
       - (a) actual
       - (b) % of possible

3.3.2 Calculated annual load
3.3.3 System load factor
3.3.4 Load per hour
(a) Maximum
(b) Minimum
3.3.5 Diversity factor
3.3.6 Number and rating of water circulators
3.3.7 Are accumulators used?
3.3.8 Capacity of accumulators
3.3.9 Type of fuel used
3.3.10 Reason for choice of fuel used
3.3.11 Is refuse incinerated?
3.3.12 Heat obtained from incineration

4. DISTRIBUTION

4.1 Distribution medium
4.2 Any specific reason for choice of medium
4.3 If steam, is condensate returned, or reasons for running to waste
4.4 If hot water, 2, 3 or 4 pipe system? Any specific reason for choice?
4.5 Type of expansion joints
4.6 Design velocity of medium (constant or variable)
4.7 Length of mains network
4.8 Design temperature of flow and return
(a) Summer
(b) Winter
4.9 Mains losses
(a) % over year
(b) % over heating season
4.10 Type of insulation
4.12 Soil condition - wet, dry, soft, rocky
4.13 Distance of generating plant from load centre
4.14 Number of sub-stations and nature of plant

5. CONSUMER INSTALLATIONS

5.1 Consumers' connections. Calorifiers, mixing valves, injectors or other
5.2 Are meters used? Give details of application and type

6. COSTS

6.1 Capital cost of schemes
6.2 Annual charges for
(a) Capital interest and depreciation
(b) Fuel
(c) Labour and maintenance
(d) Electricity used by plant
(e) Other costs
6.3 Fuel consumption
6.4 Fuel cost per ton, gallon, etc.
6.5 Heat content of fuel
6.6 Cost to consumer
(a) Standing charges
(b) Per therm used

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APPENDIX 3 - SITES AND INSTALLATIONS VISITED

GREAT BRITAIN

Dagenham (Mr. Durrow, Engineer to Borough Council).
Pimlico (Mr. Crowhurst, Superintendent Engineer, Westminster City Council).
Pimlico (Mr. F.B. Turpin, Kennedy & Donkin, Consulting Engineers).
Swindon (Mr. Richmond, Assistant Engineer to Borough Council).
Salisbury (Mr. J.A. Fisher, Assistant Engineer to City Council).
Urmston (Mr. A.N. Potter, Borough Surveyor).
East Kilbride (Mr. J.S. Raitt, Chief Production Officer, East Kilbride Development Corporation).
Cupar - Woodside (Mr. R.S. Lawrie, County Architect).
Leicester - Aikman Road (Mr. J.S. Middleton, City Architects Dept.).
Paddington - Hallfield (Mr. C. McDowall, Chief Engineer to Borough Council).
Chelsea - Cremorne Estate (Mr. R.G. Smith, Borough Engineer's Dept.).
Sheffield - Parkhill (Mr. J. Baxter, Chief Heating Engineer, City Architect's Dept.).
Roehampton - Alton West (Mr. N.S. Trenhaille, L.C.C. Chief Engineer's Dept.).

UNITED STATES OF AMERICA

New York - Parchester (Mr. J.A. Dondero, Manager Operations, Metropolitan Life Insurance Co.).
New York - Steyvesent (Mr. J.A. Dondero, Manager Operations, Metropolitan Life Insurance Co.).
New York - Rochdale Village (Mr. Lucknell, Resident Engineer for Consultants).
Hartford, Conn. - Constitutional Plaza (Mr. F.S. Pickford, Vice-President, and Mr. A.C. Taylor, Manager Operations, Hartford Gas Co.).
Pittsburgh - Down Town Area (Dr. F.S. Whirl, Chemist, and Mr. F.L. Stephens, Manager Operations, Alleghenny Country Steam Heating Co.).
Pittsburg - National District Heating Association (Mrs. R.S. Hauser, Secretary/Treasurer).
Windber, Pa. (Mr. A.F. Verna, Secretary, Windber Heat Consumers Inc.).
New Castle, Pa. (Mr. L.J. Lewis. Central Supervisor, Rates and Tariffs, Pennsylvania Power Co.).
Virginia, Minn. (Mr. C.L. Elliott, Supervisor, Virginia Water and Light Dept.).
Eveleth, Minn. (Mr. R.D. Rutka, Supervisor, Steam Prodn., Minnesota Power and Light Co.
Duluth, Minn. (Duluth Power and Light Co.).

CANADA

Toronto - Stores (Mr. J.H. Speirs, T. Eaton Co. Ltd.).
Ottawa - New Government Buildings, Confederation Height (Mr. J.M. Kennedy, Chief Mechanical Engineer).
Ottawa - Old Government Buildings, Down Town (Mr. B.F. Smith, Mechanical Engineer, P.W. of C.)
Montreal - New Housing Project, World Fair Corp. (Mr. A.A. Peters, Architect).

BELGIUM

Antwerp (M. M.J.Varendonck, Consulting Engineer).
Brussels - S.N.C.F. (M. Dogniez).

HOLLAND

Utrecht (Mr. A.J. Mijnlieff, Managing Director, N.V. Pegus).

FRANCE

Paris - Chauffage Urbain de Paris (M. Delestaing).
Lyons - Villeurbanne. (M. Egg, Regie Municipale du Chauffage Urbain).

SWITZERLAND

Basle (M. W. Aebi, Eng. Elektrizitatswerk, Basel).

DENMARK

Randers (Mr. B. Boberg, Kommunale Vaerker).
Odense - District Heating Supply Board (Mr. L. Jensen).
Copenhagen - Danish Nat. Inst. of Building Research. (Mr. P. Olufsen; Copenhagen Consultant to Min. of Interior, Mr. F.E. Olsen).

GERMANY

Munich - Stadtwerk Munchen Electrizitatswerk (Dr. Andritsky, Mr. Linder).
Munich - Caliqua Munchen (Mr. Bormann and Mr. Roger, Consulting Engineers).
Hamburg - Hamburger Gasworks (Mr. Mattersdof and Mr. Krincker).
Bonn - Venusberg
Bonn - Duisdof (Dr. Jacobi and Mr. Ruhfus).
Bonn - Stein Kohlen Electrizitats
Julich Power Station
Essen - Innenstadt
Essen - Margarethen Hone
Munster - Angel Modde (Dr. Jacobi and Mr. Ruhfus).
Munster - Conde
Munster - University

POLAND

Warsaw (Prof. J.Kozierski, Mr. Pilatowics and Mr. Rosada).

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APPENDIX 4 - DISTRICT HEATING IN INDIVIDUAL COUNTRIES

1. America

District heating in America is in most cases provided by private companies, and it is not surprising therefore that it is perhaps most common in the business areas of large cities where the heat load is highly concentrated. Steam is generally used in such applications, since it obviates the high cost involved in pumping hot water to the upper floors of tall buildings; elsewhere, in the newer networks, high-pressure hot water is coming into increasing use as the heating medium. The normal distribution pressure for steam is about 40-60 lb/in^{2}g, and, as it leaves the plant, it usually receives a minimum of 30 deg F of superheat to ensure that all customers receive relatively dry steam. Return of condensate to the central station is a relatively new practice in America. Low fuel prices some 30 or 40 years ago rendered it uneconomic to incur the additional expense of providing a return line, the consumers being encouraged to utilise the heat in the condensate for domestic hot water.

The area covered by the U.S.A. is so vast that for the purpose of comparing heating installations the country has been split into six "degree-day zones", ranging from Zone 1 - covering Florida and the extreme south - with an annual degree-day figure up to about 1500, to Zone 6 - the northern states - with an annual degree-day figure in excess of 6500.

Typical costs for house heating in the northern states - namely, at Virginia, Minnesota, where the annual degree-day total is 11,000 - are about £64 per year for a six-roomed house, a temperature of 70°F being maintained within the buildings when the outside temperature is -30°F. As is apparent from Figure 23, the cost per therm to the consumer, however, varies quite considerably from network to network, although one might expect it to decrease as the load per mile of main increases. It is probable that the large time factor involved is responsible in part for the scatter of points on the graph, since the older schemes can provide heat at a cheaper rate, the amortisation period being over.

Convectors are strongly preferred to radiators, especially for heating hotels and other large buildings, including blocks of flats. They frequently embody a small fan to assist the air circulation and a chilled water coil for summer cooling. In houses warm air, ducted to the various rooms from a fan coil unit in the basement, is common, when cooling mains are available; the system is readily adapted for cooling by adding a cooling coil unit.

The climate of any given locality in America may vary so much seasonally that summer cooling is just as necessary as winter heating. Several networks, therefore, are beginning to supply district cooling in addition to district heat.*

* See Appendix 8

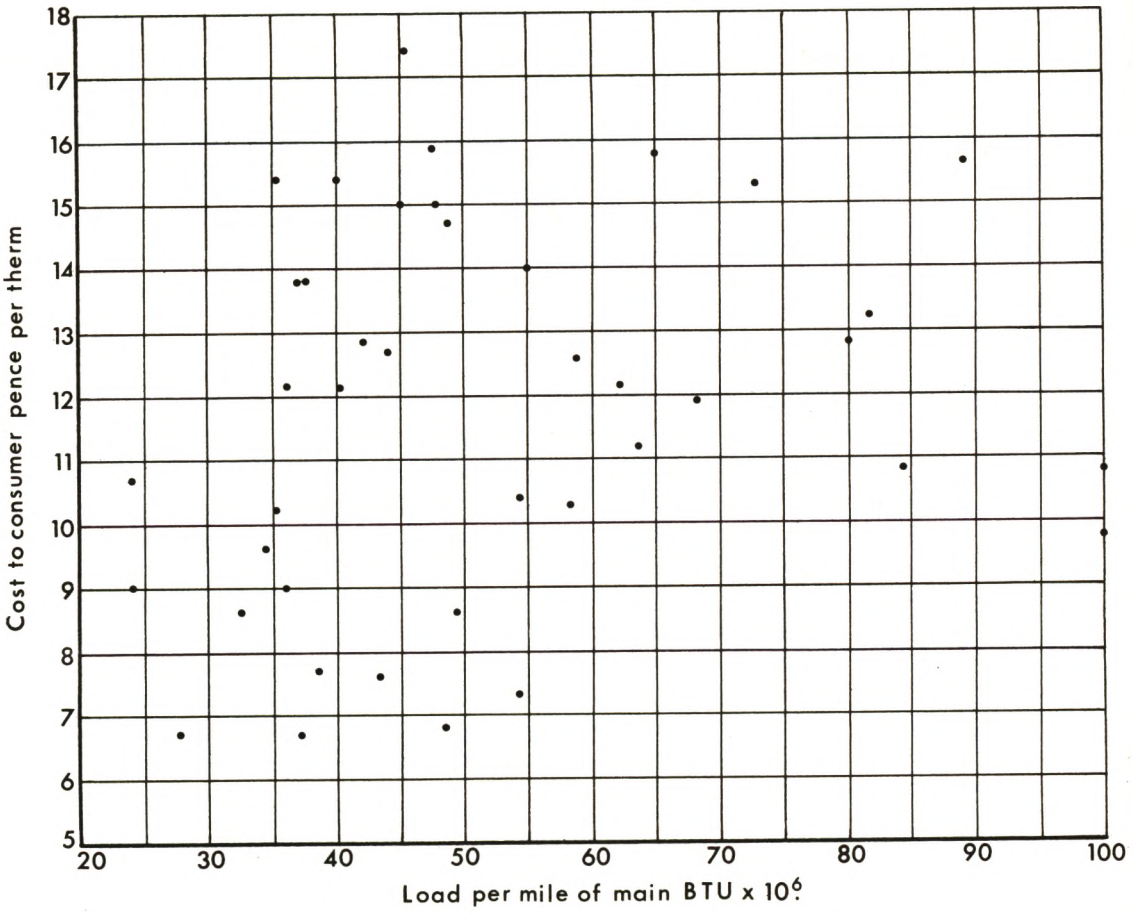

FIGURE 23 - HEATING COST TO CONSUMER IN NORTHERN STATES, U.S.A.

2. Denmark

Early district heating stations in Denmark were designed for the combined production of heat and electrical energy. Steam from the boiler plant at a pressure of 170-220 lb/in^2 was led to steam turbines generating electricity which exhausted it at about 40 lb/in^2 to the district heating plant for transmission through the mains network.

Although nearly 70% of the heat requirements of all the district heating networks is met by six large combined stations (Figure 24), it is with numerous small stations that we tend to associate Denmark. There are at present some 250 of them in the smaller towns, serving in the main part low-density housing areas with a few commercial buildings and sometimes a little light industry (130).

From the six combined stations with an installed capacity ranging from 560 x 10^6 to 2800 x 10^6 Btu/h (160-800 MW) there is an annual heat output of 13.2 x 10^{12} Btu (14 million GJ), and from the 250 or so small plants, ranging in size from 2.8 x 10^6 Btu/h to 260 x 10^6 Btu/h (0.8 to 76 MW), an output of 8.0 x 10^{12} Btu (8.5 million GJ) per annum. Most of these Danish schemes provide domestic hot water and incorporate some form of metering of the heat supply.

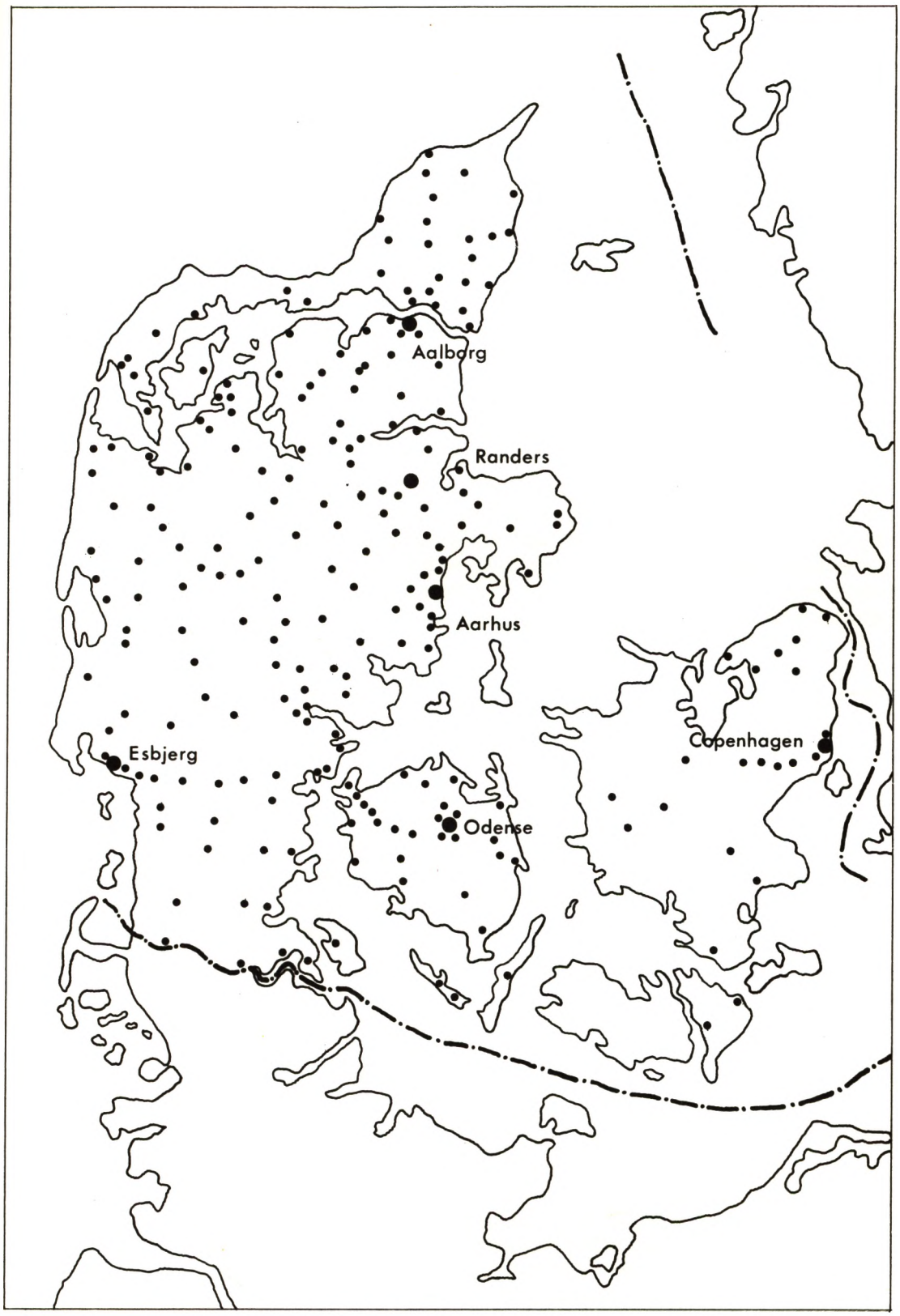

FIGURE 24 - DISTRICT HEATING STATIONS IN DENMARK

The Copenhagen network, the largest in Denmark, is a combined heat and power station, with four Ruths accumulators each of 100,000 lb steam capacity to cater for peak loads.

The advantages of the combined production of heat and electrical power are numerous. However, with the introduction of a grid system it has become no longer necessary for each small town to have its own power station. Moreover, modern power stations, built with increasing electrical capacity and seldom sited in the town centres, render the heat distribution system necessary for utilizing the waste heat completely uneconomical. Consequently, most schemes in Denmark operate a hot water plant and distribution network with temperatures below 120°C (284°F). To supply heat in the form of steam at high pressures - as for example in Copenhagen where the pressure reaches 356 lb/in^2 - becomes expensive because of the demands on the distribution mains and their associated valves and fittings. Also, the need for drainage of steam pipe troughs complicates the construction of the distribution network.

Climatically, Denmark differs quite considerably from other Scandinavian countries; it is much milder than one might expect, being influenced to a large extent by the sea. No part of the country is further than 40 miles from the sea, so that in winter the average daily minimum temperatures are appreciably higher than in many other countries of the same latitude. In the U.K. the climate is influenced in the same way, and it can be seen from Table 6 that the average temperatures for Denmark are not too dissimilar to those experienced in this country. The absolute daily minimum temperatures in the winter months are, however, a good deal lower in Denmark, and, although they are only experienced for a very short period during the heating season, their effect is taken into account in the design of heating systems far more than in this country.

	Copenhagen			Edinburgh		
	Average daily		Absolute	Average daily		Absolute
	Max.	Min.	Min.	Max.	Min.	Min.
January	36	29	6	43	35	17
April	50	37	-	50	39	-
July	72	55	-	65	52	-
October	53	42	-	53	44	-

TABLE 6 - TEMPERATURES IN COPENHAGEN AND EDINBURGH

Heating systems must be designed to provide the consumer with adequate heat at the lowest possible temperature likely to be sustained. One might assume that, since the climate in Britain is more uniform, it is more suitable for district heating in that the load factor of a plant might reasonably be expected to be higher. However, in Denmark there is a far greater incentive initially to provide dwellings with some form of central heating,

irrespective of connection to a district network. In Denmark, when the external temperature is 5°F., the required internal temperature to be maintained by the heating system is 68°F. (a temperature difference of 63 deg. F.), while in this country systems are designed for an internal temperature of 65°F. when 30°F. outside (35 deg. F. difference). A maximum hourly load of 60 W/m^3 of heated volume (including an allowance for hot water supply) is assumed in preliminary design (133).

The original combined heat and power stations in Denmark are all owned by the municipal authorities, and the consumers have, therefore, no influence on the operation of the station and its financial affairs; the heat is purchased by them on certain contractual terms of delivery and payment. Many of the new district heating stations serving the smaller residential areas, however, have been established as co-operative undertakings. Installation is undertaken by about six firms who specialise in this work. Many employ a representative whose job it is to carry out an initial survey of any area in which it is considered there is some potential; he also meets the house owners and discusses the advantages of district heating with them.

The usual procedure is for a society to be formed which will apply to the municipality for the necessary loan to finance the construction of the station, although before this is considered the Ministry of Home Affairs will require it to comply with certain financial and technical conditions. Secondly, to make a district heating network eligible for municipal support, the society must have secured in advance a certain number of members - usually about 100 to 150 - in the supply area, who in turn pledge themselves to pay the connection charges and also register their property under contract to buy heat from the station over a period of 20 years. This is to some extent an insurance by the Ministry of Home Affairs who require that the loans guaranteed by the municipal authorities must be repaid over the 20-year period. About 80% of the capital may be raised by loan, the remainder being obtained from the consumers' connection charges (113).

Higher connection charges are made to consumers who may wish to be connected after the network, as first planned to supply the required 150 or so consumers, has been completed. This, as well as covering the additional cost of excavation and laying of branch connections, provides a little more incentive for early connection to the network. Apart from the few large combined heat and power stations in Denmark, the 250 or so smaller schemes use oil as the main fuel.

	Maximum station output (Btu x 10^6/h)	Consumers connected	Length of channel (miles)	Annual heat output (Btu x 10^6)
Odense	1,140	6,803	76	2,349,128
Viborg	160	1,279	15	458,104
Dalum	80	737	20	306,644
Aars	40	550	7	101,184
Lokken	20	289	5.5	48,108
Gentofte	10	70	1.0	19,200
Raskmolle	4.8	38	0.56	4,840

TABLE 7 - DANISH DISTRICT HEATING STATION DATA

There is an appreciable difference in send-out capacity between the largest and smallest station; however, in the purely heating stations the hourly maximum send-out capacity is rarely above 100 x 10^6 Btu/h, and a high percentage of schemes are well below this figure. All the plants shown in Table 7 are heat-only stations, with the exception of Odense, which is one of the larger combined heat and power stations.

Owing to the size of the networks, the boiler plant and associated boiler-room installations do not differ materially from those used in conventional large heating plants in this country. The boiler-houses are usually designed for three or four boilers, two being installed first and the remainder

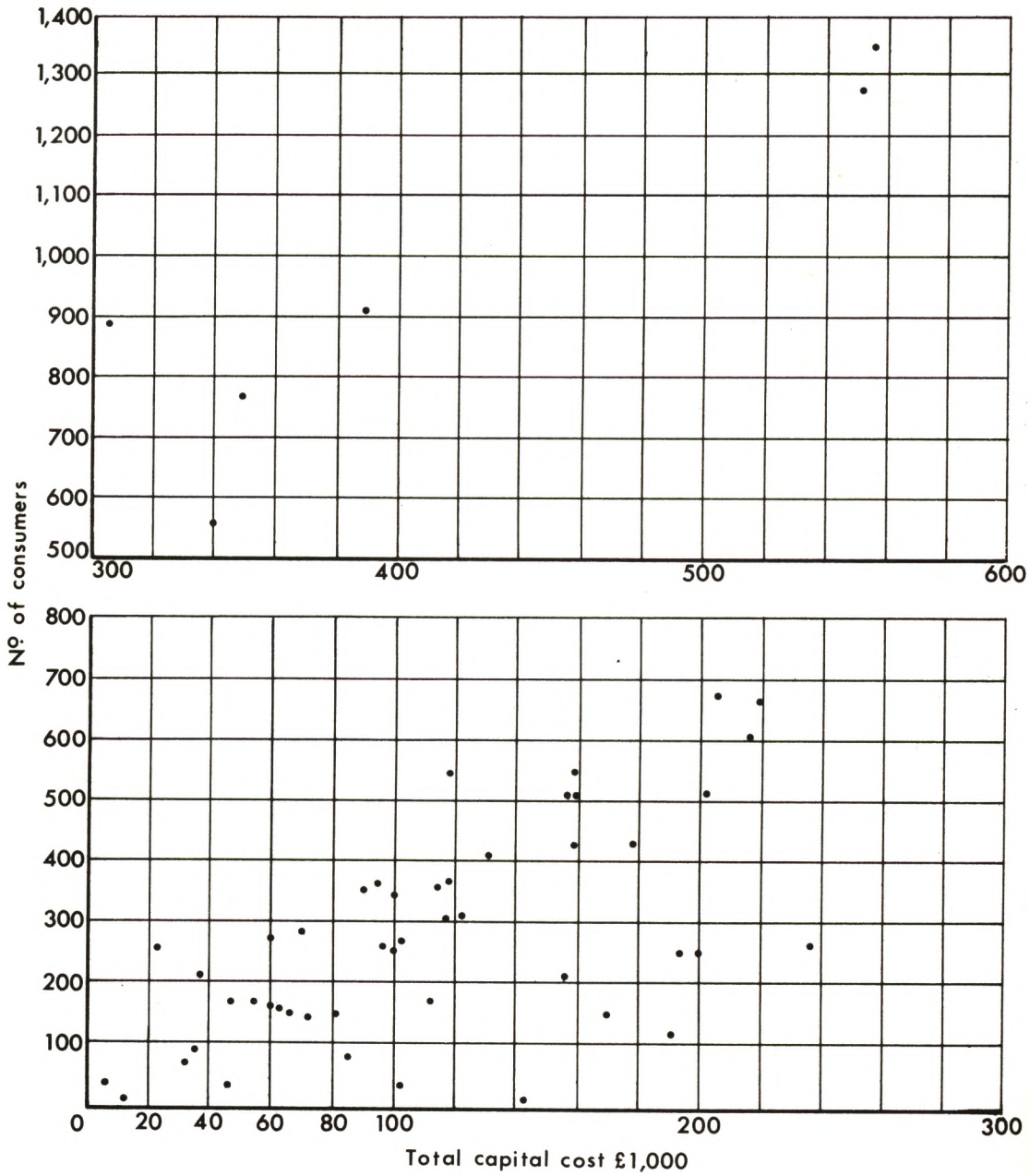

FIGURE 25 - CAPITAL COST OF SMALL NETWORKS IN DENMARK

when the station is eventually extended. A boiler in wide use in the district heating schemes in Denmark is a cylindrical wet-back type fired by rotary cup burners designed to burn heavy fuel oil with a viscosity of about 3600 sec. Redwood. Powdered magnesite is continuously mixed with the oil flame in the combustion chamber to minimise the corrosive effect of the sulphur in the fuel oil.

The circulation pumps are in such systems always fitted to the flow mains, as is the expansion system of the plant, which, being common to all the buildings of the network, makes local safety devices unnecessary. The expansion system may assume three different forms. Either an upturned loop is taken along the boilerhouse chimney, or a mercury-filled pipe loop is located in the boilerhouse; or the latter is replaced by a series of water-filled loops side by side, providing between them the pressure head required to keep the topmost radiators of the network filled with water. In the case of district heating plants with water temperatures up to 120°C (248°F) these open systems are practically always used, since they require little attendance.

For the purely thermal schemes, the consumers' installations are usually designed as two-pipe systems, with a minimum temperature drop of 20 deg. C (36 deg F). Most often, the actual temperature drop is from 30 to 40 deg. C (54 to 72 deg F), giving flow and return temperatures of 110°C (230°F) and 70-80°C (160-176°F) respectively. Thermostatic valves are provided on individual radiator returns to ensure low return water temperatures, and water meters are installed on the house return.

With the possible exception of the six large combined heat and power stations, the networks are very similar in design and type of load served, with the result that a direct comparison of the number of consumers and the total capital cost does reveal some relationship between them (about £400-500 per consumer) (Figure 25). Olufsen (113) estimates that the central plant and buildings account for about one third of the total capital outlay of the scheme, the remaining two thirds being absorbed by the distribution mains and the consumer's connections.

Capital charges are higher in the more recent schemes. They have risen from under 3d./therm for schemes built in 1947-50, to about 5d./therm for one built in 1962. Running charges amount to about 6d./therm (130), and the annual cost of heating a typical one-family dwelling is of the order of £40-£50, or marginally less than by an individual central heating installation.

An examination of the statistics for 63 of the Danish schemes shows that their profitability depends very much on the capital charges levied. Some show a profit only because the charges are very low; two make a loss (130).

3. Germany

About the beginning of the century, a number of large heating plants were constructed in Europe, and in Germany particularly. They were private plants serving mainly hospitals and public institutions from a network of underground mains; in no case was heat supplied to individual domestic consumers. With the rapid expansion of the electricity supply in the big cities after the First World War, several of the old and fairly small power stations located at various points in the cities became available for other purposes. It is not surprising, therefore, that many of these were converted

to producing heat for district networks in conjunction with the waste heat from the new power stations. Since then, the tendency has been to build heat-only stations.

Due to the greater extremes of temperature experienced in Germany, the difference in the design temperatures between inside and outside air is about 40-50% higher than in this country, the internal temperature being maintained at 20°C (68°F) when the outside temperature is -12°C (10°F). If the minimum load on the system is experienced when the difference between inside and outside temperatures is 6 deg. F., then this represents a load variation of 10 to 1, a factor which will have considerable influence on the sizing of the boiler units and also on the subsequent economics of operation. In Munster, for example, a new plant serving a suburban residential area is to have a total capacity of 35 Mw (120 x 10^6) Btu/h, split up into units of 14, 14 and 7 MW respectively, so that at minimum load periods the smallest boiler will still be working at 50% of its maximum output.

The three factors which have had a considerable influence on the success of district heating schemes in Germany are:

(1) the higher price of land for building purposes,
(2) clean air requirements, and
(3) the national economy and fuel policy.

In keeping with the clean air legislation, all except small plants are required to have tall chimneys. This, and aesthetic objections to a forest of chimneys in an urban centre, has encouraged the development of district heating.

In addition to the large networks served by combined heat and power stations, there are in Germany some 230 so-called block heating schemes, with a further 350 in various stages of building or planning. Of the 230 existing schemes, ranging in size from 5 to 300 million Btu/h (1.5 to 90 MW), 59 are fired by coal, 92 by coke and 79 by oil. The schemes are mostly operated by public utilities; few are municipally owned.

During installation it is important to have the close co-operation of the various authorities whose service pipes are buried under the streets. In Munich, for example (one of the large networks supplied from combined heat and power stations), the plans of the proposed run of district heating main are sent to the gas, electricity and water authorities for a period of 6 days, in which the authorities must indicate on them any areas in which their respective pipes are likely to cause an obstruction to the run of heating mains. The authorities are also required to state what alterations must be made to their pipes or cables and the person to be contracted when the work has to be carried out. In the town centre, the cost of network extensions is about 36,000 DM/GJ (£3,300 per 10^6 Btu).

There seems to be no national policy on questions of maximum length of main, load density and method of distribution. It was at one time maintained that the minimum load density required for district heating was 47 MW/km^3 or 650,000 Btu/acre, but there are now several schemes in various parts of Germany serving areas in which the load density is half this figure or less. More important are the local conditions affecting a particular scheme and the experience which has been gained by the authorities in the design and operation of such schemes. In Hamburg, for instance, load densities of about 0.4 million Btu/h acre (29 MW/km^2) are achieved, but it is considered un-

economic to extend a scheme further than about 1 km. from the boilerhouse.

Jacobi, in discussion, has suggested that for a neighbourhood of 500-600 flats in a few blocks, a group heating scheme is feasible; a fully fledged district heating scheme only becomes possible when much larger numbers of dwellings (of the order of several thousand) are involved (131).

In the Ruhr, where several schemes have recently been constructed and many more are planned, the main driving force would seem to be a policy of providing a close and continuous outlet for the vast quantities of coal mined in the area, on which two million or so people directly depend for their livelihood. Here 70% of the fuel consumed must be based on coal; this is an important spur to the use of district heating, and leaves oil free to be used in the smaller plants. Roughly, 15% of the charge to consumers is devoted to paying back capital charges, 60% to generating and distributing the heat, and 25% to maintaining the service. In coal-fired schemes which experience financial difficulties the state will pay for the interest on capital and also compensate for any losses incurred. Such contributions are in effect a subsidy to the coal industry (131).

In Hamburg, the sixteen small schemes operated by the gas company provide a reliable outlet for a by-product, coke. They serve suburban residential areas, and are maintained by a fleet of radio-controlled vans.

In the three parts of Germany visited, namely Munich, the Ruhr area and Hamburg, one factor has perhaps influenced the growth of district heating more than the usual, more publicised, advantages of district heating. The generation of electricity in Germany being under the control of private companies, it is in their interest to extract the maximum amount of energy from the fuel which is economically possible. Hence in Munich, as in many other large towns in the country, the waste heat from the generation of electricity is used for district heating, thus providing an additional source of income.

The whole energy needs of Bielefeld and Mannheim have been reviewed, a procedure facilitated in the case of the former by unified control of the gas and electricity supply authority. A city of some 175,000 inhabitants within an area of 18 miles^2, Bielefeld has been served by a combined thermal-electric scheme for ten years, and natural gas has been available for four. The combined heat and power station has a heating capacity of 580 million Btu/h (170 MW), and supplies some 800 consumers in the central area via a mains network of twenty miles; its annual heat output is of the order of 10^{12} Btu, i.e. between one-quarter and one-third of the total needs - estimated at 3.2×10^{12} Btu (3.4×10^6 GJ). The review indicates that for the central urban area (about 3 miles^2) (8 km^2), district heating is most appropriate, for the inner ring and a few isolated suburbs, natural gas heating, and for the outer ring, off-peak electric heating (for which the station would provide the power) (111).

In Mannheim, too, district heating was chosen for the centre of the city, natural gas being proposed for the outer areas (72).

4. Poland

In Poland, about 80% of public buildings and all industrial buildings are provided with central heating (107). The country's annual increase in heat requirements of about 4000×10^6 Btu/h (1160 MW) will obviously pose im-

portant technical and economic problems for every town.

As in the rest of Eastern Europe, district heating has been adopted as a matter of state policy. All fuel and energy resources are under state control; from what was seen of the quality of the coal available, it is doubtful whether it would be suitable for use in open fires or small stoves. Various sources of heating are employed, and, although local heating stations with water temperatures about 230°F (110°C) often cater for loads up to about 120 x 10^6 Btu/h (35 MW), the emphasis is on the large combined heat and power stations.

Water seems to offer the most economical heating medium, and investigations have shown that the capital costs and pumping costs are higher with a flow temperature of 260°F than of 300°F. At 340°F, although the pumping costs are smaller, the other costs of the heating station and consumer's installation are higher. A flow temperature of 300°F (150°C) is chosen as the most economical for the large Warsaw schemes.

Three systems of heat generation are used in Poland:

Local boiler plant,
Group heating schemes, and
Large combined heat and power stations.

A study has shown that the minimum cost is attained by district heating from the large combined heat and power station, with coal-fired group heating schemes next.

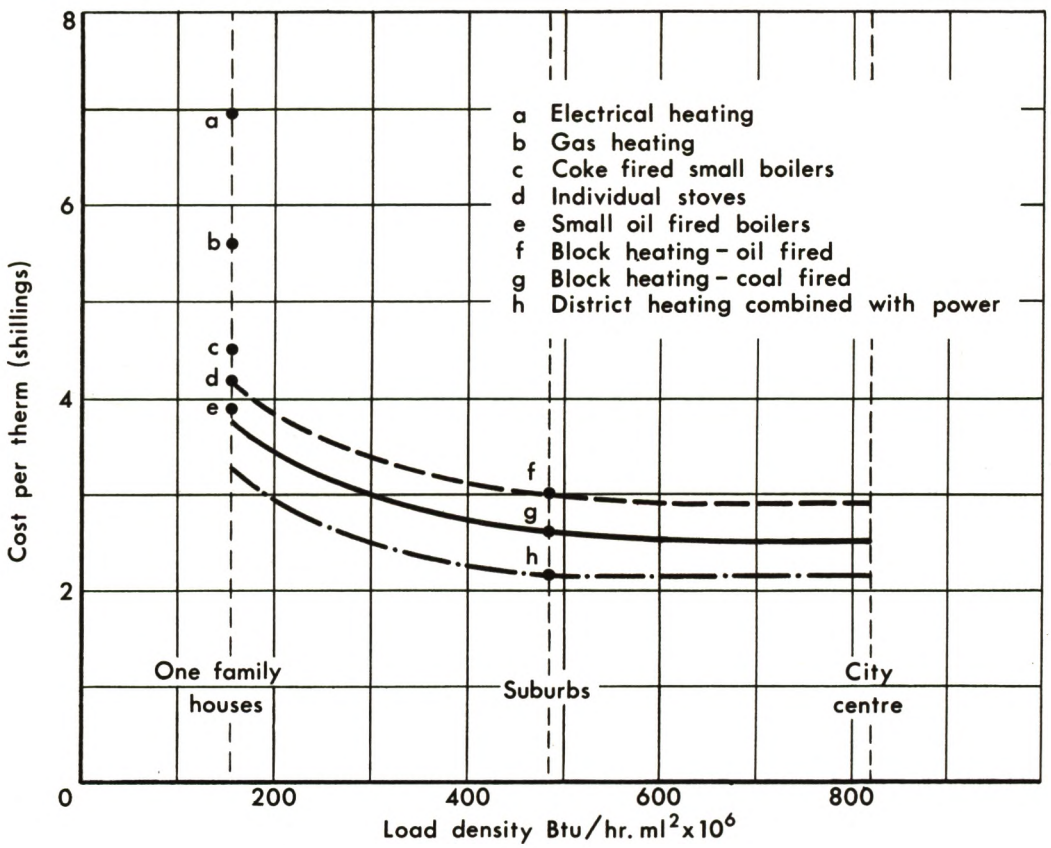

FIGURE 26 - COST IN RELATION TO LOAD DENSITY IN POLAND

The cost in relation to load density is shown in Figure 26, and further studies are in progress to determine the most economic size of group heating scheme in relation to the service area and load factor. The supply of domestic hot water in conjunction with district heat is regarded as having economic advantages over gas or electricity and is provided by all district heating schemes in Poland.

In Warsaw, three large combined heat and power stations supply 75% of the buildings with district heat, giving a total heat load at present of $4,400 \times 10^6$ Btu/h (1300 MW), which it is planned to increase by three- or four-fold. In addition, there are about 100 small thermal stations and central heating plants with a total load of $2,400 \times 10^6$ Btu/h (700 MW) dealing with areas or individual buildings not served by the mains network. The small stations may have a capacity as low as 3 million Btu/h (1 MW). As and when possible, the mains are extended so that eventually all these small thermal stations will disappear and the mains circuit will cover the whole city.

One company, under state control, operates the electricity generating stations supplying exhaust heat for the district heating network, while another company, also under state control, is responsible for the distribution system. It has been estimated that approximately 800×10^6 Zlotys have been spent to date on the mains distribution system, which at the ruling rate of exchange of 67 Zlotys to £1 amounts to about £12,000,000. This figure, however, may not be very accurate, since the "unofficial" exchange rate is around 280 Zlotys to £1.

The longest mains is 12 km. in length, and the mains losses are between $\frac{1}{2}$ and $\frac{3}{4}$ deg. C/km. The water flow temperature is varied, according to the outdoor temperature, between 150 and 70°C (300 and 160°F); the corresponding return temperatures are 70 and 30°C (160 and 86°F). In schemes elsewhere, the flow and return temperatures are usually 110°C and 30°C (230° and 86°F). All schemes include the supply of domestic hot water.

All connections to buildings have a by-pass between flow and return mains, to prevent damage if the building is shut off from the main and not occupied. The maximum heat loss permitted from blocks of flats built by the State is 19 W/m^3 (ca. 2 Btu/ft^3h).

APPENDIX 5 - CAPITAL COSTS

Country	Town	Capacity therms/h	Length of mains miles	Capital Cost (1963) £ sterling	Date of inst'l'n year
U.S.A.	Harrisburgh, Pa.	4,350	7.5	1,770,000	1887
"	Wilkes-Barre, Pa.	2,700	4.5	216,000	1890
"	Philadelphia, Pa.	10,600	24.5	9,350,000	1900
"	Detroit, Mich.	32,550	53.5	12,000,000	1903
"	Cleveland, Ohio	14,500	17.0	4,610,000	1903
"	Dayton, Ohio	11,700	18.2	3,490,000	1907
"	St. Paul, Minn.	6,000	6.3	1,675,000	1910
"	Spokane, Wash.	3,488	7.6	1,070,000	1961
"	Duluth, Minn.	4,000	10.0	715,000	1932
"	New York, N.Y.	115,260	n.k.	32,500,000	n.k.
"	Indianapolis, Ind.	15,060	43.4	5,970,000	"
"	Boston, Mass.	13,930	15.7	3,760,000	"
"	St. Louis, Mo.	12,350	23.4	3,180,000	"
"	Milwaukee, Wisc.	12,200	19.5	3,300,000	"
"	Pittsburgh, Pa.	9,930	13.7	4,200,000	"
"	Baltimore, Mo.	8,990	13.8	2,025,000	"
"	Erie, Pa.	2,500	5.8	388,000	"
"	Sioux City, Iowa (Lewis Jones)	2,700	7.5	250,000	"
"	Philadelphia, Pa.	2,050	18.2	455,000	"
"	Rockford, Ill. (Overbrook)	1,500	3.9	255,000	"
"	Philadelphia, Pa.	2,000	15.0	445,000	"
"	San Diego, Cal.	1,000	4.2	243,000	"
"	Grand Rapids, Mich.	2,400	4.35	625,000	"
"	Lincoln, Nebr.	1,800	3.65	100,000	"
"	Cincinnati, Ohio	1,200	0.67	100,000	"
"	Evansville, Ind.	1,600	4.35	390,000	"
"	Piqua, Ohio	800	0.61	25,000	"
"	Johnstown, Pa.	1,270	2.9	299,000	"
"	Saginaw, Mich.	840	2.1	208,000	"
"	Kalamazoo, Mich.	1,200	3.2	162,000	"
"	Battle Creek, Mich.	1,080	2.4	306,000	"
"	Concord, N.H.	630	1.4	111,000	"
"	Rice Lake, Wisc.	600	2.7	42,500	"
"	Hartford, Conn.	2,250	5.3	1,782,000	1962

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