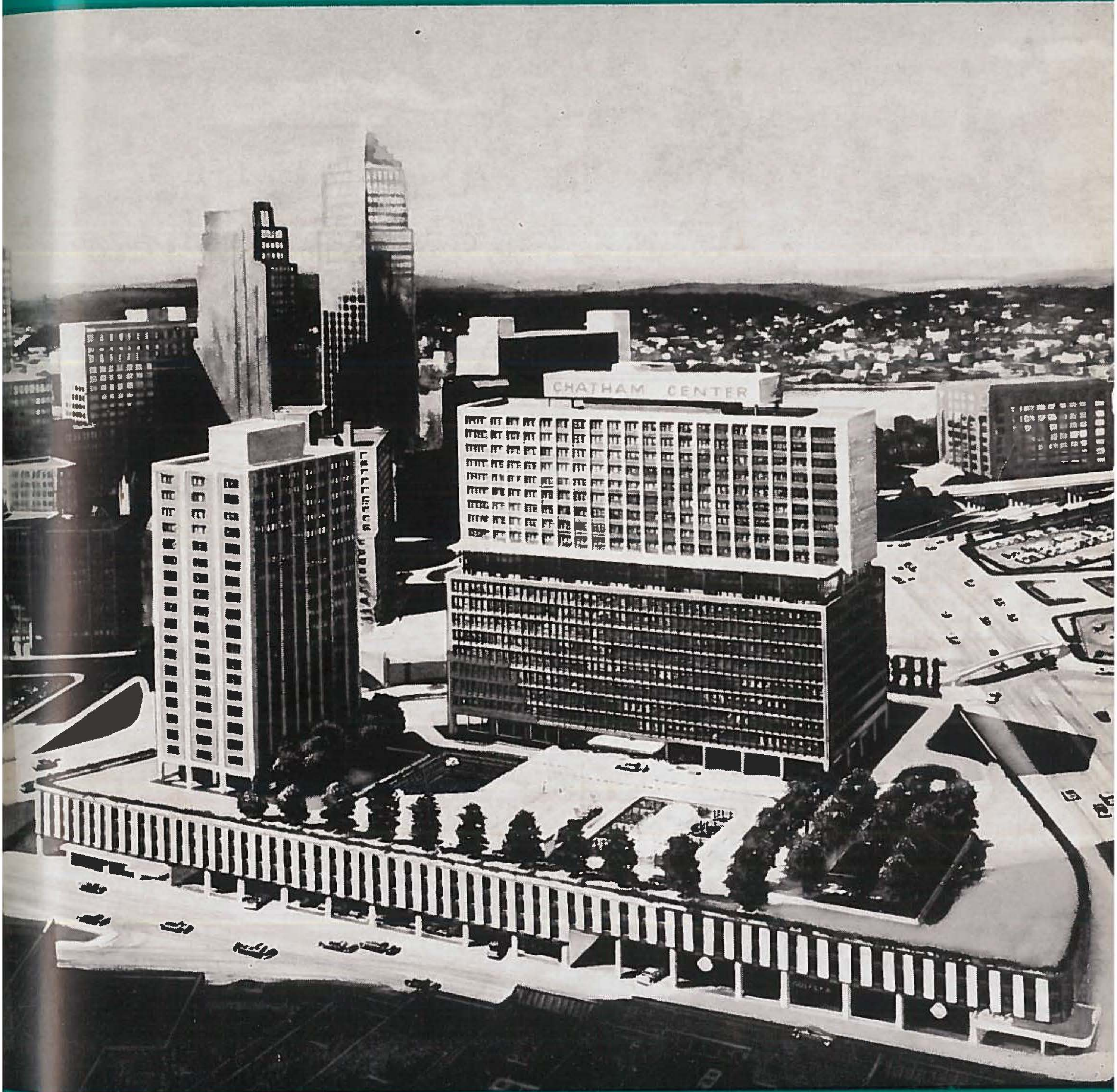
OFFICE

DISTRICT HEATING

PUBLISHED QUARTERLY SINCE 1915

NATIONAL DISTRICT HEATING ASSOCIATION — NDHA

JANUARY 1966—VOL. LI, No. 3



For Chatham Center Story, Turn To Page 98

... PUBLICATION OF THE NATIONAL DISTRICT HEATING ASSOCIATION

THE TECHNICAL AND ECONOMIC PROBLEMS ASSOCIATED WITH DISTRICT HEATING PLANTS

Frederik E. Olsen, Civil Engineer and Jurist Consultant to The Danish National Institute of Building Research, The Minister of the Interior, The Minister of Housing, Denmark. Executive to the Heating Section of the Danish Housing Association, K.A.B., Copenhagen, Denmark.

From a paper presented by the author at a convention during the 1964 HEVAC Exhibition in London.

Reprinted, with permission, from THE DANFOSS JOURNAL, No. 1, 1965, published by Danfoss, Inc., Nordborg, Denmark.

Towards the end of the 19th century, a number of cities in the U.S.A. began to centralize the supply of heat establishing common district heating stations — parallel to the water supply from a common waterworks, and the gas supply from a gas-works, etc.

Such systems are still quite common in the United States and are often of considerable size.

About the turn of the century and in the years that followed, a number of large heating plants were constructed in Europe, in which heat was produced by a common boiler plant and transmitted to a number of buildings through basement pipes or through underground pipe lines. However, it was almost exclusively to large hospital blocks or public buildings, that is, private plants with a joint mangaement which did not supply heat to outsiders.

The years following the First World War saw a rapid expansion in the electricity supply to the big cities, the old and fairly small power stations located at various points in the cities being replaced by large modern stations in the suburbs, so that the old boiler plants in the city centres became available for other purposes.

At that time, fuel prices were very high and, for instance in some German cities, the construction of district heating stations was consequently based on the available boiler plants of the old power stations. This development has been carried on to this day and there are numerous district heating stations of this type in Europe.

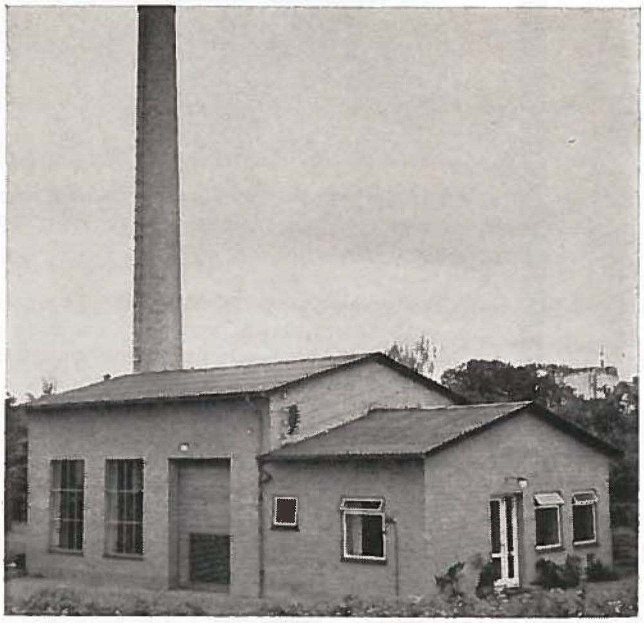


Fig. 1

The original European district heating stations were therefore designed to generate electricity and heat simultaneously. At a pressure of 170-215 lb/sq in. (12-15 kg/cm^2), the steam from the boiler plant was led to steam turbines generating electricity and exhausting the steam to the district heating station at about 43 lb/sq in. (3 kg/cm^2) for transmission through the pipes under the streets.

Traditionally, therefore, the concept of establishing district heating stations is based on the interplay between the generation of electricity and the generation of heat but the trend after the Second World War has led to the construction of pure district heating stations, that is, stations producing heat only.

There are several causes.

To supply heat in the form of steam, sometimes — as is the case with the oldest Copenhagen station — at pressures right up to 356 lb/sq in. (25 kg/cm^2) is awkward and expensive, because such high pressures put exacting demands on the mains system with its valves and other fittings. Furthermore, the need for drainage of steam pipe ducts hampers the construction of suitable pipe systems.

Another point is that connections to consumers' installations are complicated and expensive.

It was a step forward, therefore, when the change was made to hot water at about 320 F (160 C) instead of steam, but in the course of the years after the Second World War this form of heat distribution has largely been abandoned in favor of systems with water temperatures below 248 F (120 C).

This development is particularly due to the fact that, in many countries, district heating has spread to the smaller towns which have built pure district heating stations thus eliminating the connection with the generation of electricity altogether. Plants with this lower water temperature have proved competitive to steam-raising plants and high-temperature, hot-water plants, both in regard to initial cost and operating economy.

Technically, such stations do not differ materially from the large plants serving one or more blocks of flats, but while the latter type of plant serves consumers who are tenants and consequently belong to a joint heat supply scheme, the pure district heating stations are designed to serve a more undefined and heterogenous circle of consumers. This results in considerable differences from economic and legislative points of view, while the technical differences are mainly in the field of the connection system used in district heating plants where it is often desired to lower the temperature of the water by recirculation before delivery to the consumers' installations. Furthermore, it will be necessary to insert a meter of one type or the other to provide for the billing of the various categories of consumers.

The technical and economic comments made hereafter apply only to district heating stations using water at a maximum temperature of 240 F (120 C) and serving buildings which may differ as to size and type but have the common feature of being owned by different persons.

Technical Layout

A district heating system may conveniently be split up into the following main parts: (1) the generating system comprising the boiler house with chimney and boiler room installation; (2) the distribution system consisting of the mains under the streets and roads and the service pipes for the individual houses; and (3) the local connection devices where the heat supplied by the station is received and passed on to the local central heating system.

Generating System

Fig. 1 shows a heating station in a small Danish town. A building and chimney of this size will be designed for generation of about 31.7 million Btu/hr (8 million, kcal/hr), corresponding to the heat requirement of about four or five hundred single-family houses and a few larger buildings, for example, schools, homes for the aged, hospitals and similar public institutions.

As boilers and boiler room installations are not very much different to what is used on normal large heating plants, a detailed description will not be made here.

The boiler house is usually designed for three or four boilers, but only two of them are installed initially. When the station is subsequently extended, the remaining boilers may be erected as required, and their size may to some extent be adjusted to the consumer acceptance found in the supply area.

Mains are laid from the boilers to circulating pumps which, in such systems, are always fitted in the flow and the pipes are continued in ducts under the streets.

To the boiler flow is also connected an expansion system common to all connected buildings thus replacing local safety arrangements.

The common expansion system can be made in three different ways, either as a U-pipe carried alongside the chimney of the central, as a mercury-filled pipe loop located in the boiler room or as a number of water-filled pipe loops connected in series so that the pressure head is slightly higher than that obtaining at the uppermost radiator.

Such open systems are practically always used at heating centrals with water temperatures up to 248 F (120 C) as service and maintenance requirements on these systems are considerably less than similar requirements on closed systems.

A type of boiler which at present is used rather frequently in district heating centrals in Denmark is a cylindrical Scotch-type boiler. The oil burners are rotary burners for heavy fuel oil having a viscosity of approximately 3600 sec. Redwood.

Pre-heating of the oil is effected electrically when starting up and later on the warm boiler water is used.

Distribution System

The mains system is the most expensive part of a district heating plant. If we include service pipes and final connections in the distribution system, it will account for about two-thirds of the initial cost. Moreover, as the pipe system under the streets is the most vulnerable part of the plant, and yet that which is most likely to escape continuous attention and servicing, it is extremely important that the ducts with pipe lines and structures are carried out as carefully as possible according to designs ensuring the highest degree of durability at a reasonable cost.

In the course of time, consequently, great endeavors have been made, and much ingenuity has been shown, in designing suitable ducts.

The duct is often made as a box of rectangular cross section, which is cast in place. When the sides and bottom of the duct are cast, the pipes are laid on transverse sleepers of clinker brick, and then the entire duct space is filled with light-weight concrete which, when dry, has a specific weight of 18 lb/cu ft (300 kg/m^3). The duct is eventually covered with reinforced concrete slabs whose longitudinal joints are sealed with asphalt or the like.

Often a type of duct made of precast sections — in this case a lower and an upper part — is used. First, the lower part is placed on the levelled bottom of the ditch. Next, the pipes are laid and the top part lowered in position. Finally, both spaces are filled with light-weight concrete through holes in the top part. Longitudinal and transverse joints are sealed with cement or asphalt.

Another type of duct employing half-cylindrical ready-made sections is probably the most frequently used type in Denmark next to the rectangular-type. It is popular especially with the pipe fitters as the pipes lie fully exposed at the bottom of the duct and are thus easily accessible for welding. For this type of duct the insulation material is always mineral wool.

The light-weight concrete filling is now and then replaced by mineral wool lagging. Many people consider it an advantage that water seeping into the duct is allowed to run unobstructed along the bottom without soaking and ruining the lagging and corroding the iron piping.

In the long run, nearly all types of ducts will be ruined through the action of water, so that positive measures must be taken to keep the ducts as dry as possible.

It should also be considered, though, that the nature of the ground may be of great importance as far as the durability of the pipes is concerned.

To permit cutting-off and draining of part of the piping system without interruption of the heat supply to all the consumers, wells with shut-off cocks and drain cocks are placed at suitable points in the network.

To facilitate the discharge of water, the well is provided with an outlet leading direct to the sewage system.

When the pipes are long, expansion devices must be fitted at suitable intervals. For this purpose, bellows compensating devices may be used, but U-shaped expansion loops are the rule.

The expansion problems, however, can often be solved by simply laying the pipes on alternate sides of the street at suitable intervals, resulting in S-shaped expansion bends rather than U-shaped ones.

To ensure the desired action of the expansion devices, the pipes must be secured at intervals. This may be achieved by means of two transverse iron girders cast in the sides of the duct.

Connection Between The Underground Pipe System From The Heating Stations and Consumers' Houses

This connection can be carried out in various ways.

The service pipes are taken from the mains under the street to the building, which is normally equipped with a boiler, hot-water tank, radiators, and expansion tank. Upon connection to the district heating system, the boiler is used no longer and the expansion tank is cut off from the system.

In the past, connection was carried out by way of a so-called recirculating manifold. The flow is led from the station to one leg of the manifold communicating with the radiators of the system. The other leg is the main return line from the system, serving partly to lead the water back

(Continued on Page 104)

(Continued from Page 103)

to the station and partly to reduce the temperature in the system through the recirculation taking place at the bottom of the manifold.

On the return side there is a Danfoss thermostatic valve controlling the flow of water through the system.

If the heat-transfer medium is steam or hot water above 248 F (120 C), it will be necessary to insert a heat exchanger between the district heating water and the local installation. Heat exchangers are sometimes also used for media temperatures below 248 F, the advantage being that the district heating water has no direct connection with the local installations, so that sudden pressure increases due to errors in operation at the district heating station are not transmitted to the radiators of the local installations which, in the case of old-fashioned mild steel radiators, will only withstand limited pressures in the majority of cases. Where district heating stations are operating with water temperatures below 248 F, the use of heat exchangers however, is usually regarded as an unnecessary and expensive measure.

If heat exchangers are used, the temperature control of the radiators and the domestic hot water is likewise achieved by means of thermostatic regulating valves.

Whether one or the other system is used for the connection between the district heating plant and the local installations, it means the introduction of an intermediate link which certainly does not take up as much room as a boiler but still requires some wall space. Furthermore, the system requires some attendance on the part of the consumer. Consequently, it must be said to be a very great step forward and a great acquisition for district heating that a special district heating valve has been placed on the market, the valve being fitted in the return line of the radiators, so that a regular connection system is no longer required.

In this case the district heating water is led direct to the local installation. A Danfoss FJVL valve is fitted in the return connection from each radiator. This valve can be set to a constant temperature, so that readjustment will be required only in the event of a change of about 9 to 11 F (5 or 6 C) in the daily mean temperature which, in maritime climates, happens only a few times in the course of a heating season. Such a valve, regulated by the return water temperature, provides many advantages.

In the case of new installations, radiators and pipes may be of very small dimensions, and the individual control in each room ensures economic operation and pleasant physiological conditions. Thus there will be no problems associated with recirculation systems and individual radiator pre-setting. Furthermore, weather compensating systems are wholly unnecessary for larger installations.

To the district heating station the substantially reduced return temperature means modest initial cost and reduced pumping work, since the dimensions of the pipes under the street can be reduced on account of the high cooling rate and the consequent reduction in volume of the circulating water.

The valve has the added advantage that replacement bellows units can be made without draining the system, and the valve seat can be defouled by forcibly opening the valve to permit flushing.

Economy

District heating has many advantages over local and individual heat source installations. Houses designed for connection to a district heating system need no chimney, and space allocated for the boiler room can be put to other use, as a hobby room or the like. The capital cost of a boiler with oil burner, oil tank, circulating pump, etc., is also avoided. In Denmark, this saving would amount to about 4,800 Danish kroner (about $700).

These economic advantages are not fully obtainable when an existing central heating system in a house is converted for connection to a district heating system. However, a houseowner will often benefit from the connection to a district heating system if he is about to replace the boiler or to buy an oil burner. In any case, some valuable basement space is gained when the boiler is discarded, particularly when the above-mentioned FJVL thermostatic valves are fitted on the radiators so that no special devices are required when connecting to the district heating system.

If the rooms of a house have had separate heating facilities and conversion is made to a central heating installation connected to a district heating system, a considerable saving on the central heating installation can be obtained by using the thermostatic valves FJVL because, as mentioned above, the district heating water is, in this case, conducted to the radiators without any reduction in the temperature. This means that both the pipe system and the radiators may be of smaller dimensions than those of a conventional central heating plant, and the consequent saving will more than offset the additional cost of the thermostatic return valves.

When a house is connected to a district heating system, the drudgery of refueling is eliminated and this, in particular, has made this type of heating popular with housewives. Furthermore, one is ensured of a constant and unfailing heat supply all through the heating season and plenty of hot water all the year round without the worries of fuel buying and removal of soot and clinker.

From the health angle, the result is that the heat production of a whole district is concentrated at one place whereby, given a chimney of adequate height, the neighborhood can be kept free from air pollution in the form of soot, sulphur dioxide, etc.

Anyone would suppose that these conspicuous advantages of district heating would cause this heating method to be extremely popular in all countries. That this has not been the case so far is due, among other things, to the fact that district heating depends on the acceptance of central heating systems by the consumers so that, even for this reason, the use of district heating is severely limited in many countries.

An additional factor, which no doubt has greatly contributed to the interest in district heating in some countries, is the trend in fuel prices.

In fuel-producing countries there will be a tendency to a certain equalization of the prices of the various types of fuel, but in countries which have to import all their fuel, as for example Denmark, the price formation in the fuel trade is more free and this leads to very great differences in the price between coal and oil and between various oil grades.

The heavy oil used today by the Danish district heating stations is about 110 Danish kroner (about $16.) per ton, whereas coke is 200 Danish kroner (about $29.) a ton.

Considering that the calorific value per unit weight of the heavy oil is about 1.6 times that of coke, it is about three times as expensive to burn coke instead of heavy oil in Denmark.

As to gas oil the grade of oil used in one-family houses, the cost is on a level with coke firing.

It is understandable, therefore, that district heating has made good progress in Denmark these last ten years where the ratio between the fuel prices has followed that mentioned above, because service of the capital, however considerable, that must be invested in the underground pipes of the district heating stations is within the limits of the cost of coke or gas oil firing in individual plants.

It is estimated that district heating accounts for about 15 per cent of all room heating in Denmark at present. As it may be assumed that about 40 per cent of all room heating in Denmark is central heating, and as district heating, as mentioned above, is dependent on central heating, about 35 per cent of all central heating installations are connected to a district heating system. This is not at all unlikely, because in addition to six big compound plants, there are about 300 pure district heating stations in Denmark.

The position still is, however, that the compound plants account for the greater part by far — about three-fourths — of all district heating in Denmark, and the Copenhagen stations account for about 25 per cent of all district heating in Denmark.

Initial Cost

The initial cost of a district heating station may obviously be split up between the distribution system and the heat generating plant, and the position is, in the case of conventional, regular district heating stations, that buildings, chimney and boiler room installations account for about 35 per cent of the cost, while about 65 per cent is absorbed by mains, service pipes and connection equipment in the buildings.

The initial cost of an ordinary district heating station in Denmark today amounts to about 40 ore per kcal/hr (4.4 cents) of rated boiler output, and as this will be about 25 per cent higher than the heat requirements of the supply area, the initial cost will amount to about 50 ore per kcal/hr (4.8 cents) of the maximum hourly requirements of the relative supply area.

The original compound plants are nearly all owned by the municipality, and consumers of the heat supplied by these plants are consequently the customers of the municipality, buying the heat on certain contractural terms of delivery and payment but having no influence on the operation of the station and its financial affairs on the whole.

Ever since the turn of the century, cooperative societies have been operating in Denmark within a great many fields of trade and industry, and it is only natural, therefore, that many of the new district heating stations should have been established as cooperative undertakings.

The usual procedure is to apply for a municipal guarantee for the loans required to finance the construction of the stations, and the Ministry of Home Affairs, which controls the municipalities, either direct or through the medium of the county councils, will require the district heating stations to comply with certain financial and technical conditions, before any municipal guarantee may be granted. In the first place, the project must be satisfactory from a technical point of view and the cost of construction must be acceptable. Secondly, the members of the society are required to pay down 20 per cent of the initial cost, partly to reduce borrowing and partly to prove that they are genuinely interested in the construction of the station.

To make a district heating station eligible for municipal support a certain number of members in the supply area must have been secured in advance and such members must have pledged themselves to pay the connection charges and to let a covenant to buy heat from the station over a 20-year period be registered on their property. The explanation is that the Ministry of Home affairs requires that loans guaranteed by municipalities must be repaid by installments within 20 years. A further stipulation is that all houseowners can be connected to the system on uniform financial terms.

The members' heating expenses are made up of (1) fixed expenses, that is, expenses which exclusively comprise the servicing of the loans taken up by the station, and (2) variable expenses, mainly the fuel cost but also comprising electricity for oil burners and pumps, boiler plant attendance, management, etc.

The fixed expenses are distributed on the members according to an advance estimate of the maximum heat consumption per hour, while the variable expenses are distributed according to readings of the water meters or calorimeters fitted on the members' installations.

Consumers' installations are often fitted with ordinary water meters only. These meters measure the flow of water, and distribution is then based on these volumes of water. As the heat consumption is dependent on both the volume of water consumed and the rate of cooling, this costing method requires a uniform cooling rate for all the buildings in the supply area which, in fact, is far from being the case.

By way of example, the district heating water will be cooled far more when FJVL valves are used than if recirculating manifolds are used. If the variable expenses are distributed on the basis of water flow alone, these dissimilar connection systems should never be employed by one and the same station.

A very cheap calorimeter has recently been marketed in Denmark, and the trend is towards a more equitable distribution of cost on the basis of the quantity of heat that actually has been consumed.

The cost of the heat supplied at the consumers' installation, based on current oil prices and the present borrowing climate in Denmark, amounts to about 43 Danish kroner per million kcal (about $4.53 per million Btu), and this cost is broken down as follows:

Fixed expenses:
Service of loans:
21.40 Danish kroner/10^6 kcal ($0.76 /$10^6$ Btu)
Variable expenses:
Fuel (heavy oil):
16.90 Danish kroner/10^6 kcal ($0.60 /$10^6$ Btu)
Electricity:
1.50 Danish kroner/10^6 kcal ($0.055/$10^6$ Btu)
Attendance:
2.50 Danish kroner/10^6 kcal ($0.09 /$10^6$ Btu)
Sundry expenses:
0.70 Danish kroner/10^6 kcal ($0.025/$10^6$ Btu)
TOTAL:
43.00 Danish kroner/10^6 kcal ($1.530/$10^6$ Btu)

If a houseowner had burned coke or gas oil in a plant of his own, the actual fuel cost, that is, without payment of interest and depreciation on his own boiler plant, would have been 47 Danish kroner per 10^6 kcal ($1.68 per 10^6 Btu).

It may be open to doubt whether district heating would be just as economical in other countries as in Denmark. It depends on fuel prices, finance, and many other factors which cannot be estimated without detailed knowledge of the actual conditions. District heating, in view of the expansion in this field in recent decades, certainly offers so many advantages that this type of heating should be considered when designing centrally heated houses or blocks of flats. As mentioned above, the point here is that it is possible to construct simpler and cheaper central heating plants if they are connected to the district heating system in a suitable way. +