OFFICIAL PROCEEDINGS

SIXTY-NINTH ANNUAL CONFERENCE

OF THE

INTERNATIONAL DISTRICT HEATING ASSOCIATION

HELD AT

THE HOMESTEAD
HOT SPRINGS, VIRGINIA
JUNE 19, 20, 21, 1978

VOLUME LXIX

Published by The
INTERNATIONAL DISTRICT HEATING ASSOCIATION
5940 BAUM SQUARE, PITTSBURGH, PENNSYLVANIA

ROLE OF DISTRICT HEATING IN THE ENERGY SUPPLY OF STOCKHOLM

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1. Energy forms and energy consumption in Stockholm

By American standards, Stockholm is a small city, with no more than 700 000 inhabitants. The energy consumption per capita is 30 000 kWh per year, based on delivery to the consumer. Since Stockholm is the administrative centre of Sweden, the buildings consist of a large proportion of offices and public premises. The city has almost no heavy manufacturing industries. This structure forms the background of the distribution of energy consumption for various purposes as tabulated below:

Energy consumption in Stockholm (energy delivered to the consumer)	
Industry	4%
Heat	65%
Household	4%
Service	7%
Transport	20%

Specification of the heat demand for the heating of premises	
Public premises, offices,etc.	35%
Multi-unit dwellings	55%
Single-family houses	10%

The forms of energy available to the inhabitants are consumed as tabulated below:

Electric power	15%
Heat for district heating	13%

Fuel oils	52%	(excluding district heating)
Automotive fuel	17%	
Gas	3%	

The table illustrates that no less than 85% of the energy demand of Stockholm is dependent on fuel oils. Only the electrical energy is primarily based on domestic hydro-electric power and nuclear power.

The energy policy of the municipality should therefore be aimed at saving energy and creating the conditions necessary for reduced oil-dependence. The heating sector is that in which savings will produce the greatest results.

2. Municipal and State involvement in district heating.

District heating is now playing a very important role in the energy policy debate concerning the heating of buildings and as a basis for electric power generation. The dominating role of district heating on the present-day energy pattern in Sweden is based on the heavy municipal and State involvement in this field.

District heating utilities in Sweden are invariably run by the municipal authorities. As opposed to the legislation in any other countries, the Swedish laws on municipal administration do not restrict the opportunities available to a municipality to run business companies, provided that the project is of general benefit to the municipality and that it is not pursued with the aim of making a profit. The generation and distribution of gas, electric power and heat for district heating are typical fields in which municipal authorities have established business companies. The municipal authority finances its activities by means of levies, municipal taxes based on the income of each inhabitant and finally by loans on the domestic or foreign capital market.

The district heating generation and distribution plants in Stockholm are thus owned by the municipality. Stockholms Energiverk is then responsible for the planning, installation, operation and maintenance of the plants and for the marketing of the product. Municipal politicians now appreciate the benefits of district heating. The following arguments are advanced for heavy municipal involvement in district heating.

Energy conservation: The overall efficiency of a district heating plant is between 80 and 85% between the raw energy and the consumer. This is 15 - 20% higher than for individual oil-fired domestic boilers. If district heating is combined with the generation of electric power in a back-pressure turbine, 85% of the fuel oil energy content will be utilised, as compared to only about 40% of the energy content which is utilised in a condensing turbine.

Economy: To the individual consumer, district heating offers an economically attractive alternative. From the business aspect, district heating is a profitable project within the framework of the profit allowed by the municipal legislation. From the national economy aspect, district heating can be justified by reduced pollution and reduced oil-dependence. As an example, the present district heating installations in Sweden are estimated to save about 700 000 m^3 of fuel oil per year.

Flexibility: Heat can be generated by means of all conceivable fossil fuels, renewable types of energy and, first and foremost, by nuclear plants. This wide choice of energy raw materials and the opportunities available for stockpiling fuel provide the safeguards necessary in the event of future energy crises. Scope for accumulation is a further benefit of using water as the heat-conveying medium.

Environment protection: District heating offers environmental improvements by reducing the emission of flue gases and concentrating it to a few tall stacks. In addition, the road network is relieved of heavy oil transport.

In order to assist the municipal authorities in running district heating utility companies, the State has enacted a number of legislative actions in the energy sector and has provided extensive financing assistance to municipalities and landlords. The Swedish Parliament, which has broad responsibility for the energy policies of the country, has established, at an early stage, an energy policy programme for energy supply and energy conservation in Sweden. One of the primary aims of the programme is to ensure efficient utilisation of existing energy resources, including special emphasis on the extension of district heating plants and district heating power stations. The measures adopted to facilitate further expansion include the following:

The Municipal Energy Planning Act	Swedish municipal authorities are responsible for planning the energy supply and consumption within the municipality. The Act specifies that other social factors must be taken into account, such as high supply preparedness and a good environment.
The Public District Heating Plant Act	District heating has so far been marketed in free competition with other types of energy within the heating sector. The only exception is in cases where the municipality owns the land and specifies connection to the district heating network of the municipality as a condition for granting building permission. The

purpose of the Act is to provide the municipal heat distributors with the opportunity for long-term planning, although the distributors must also assume extensive responsibility for the district heating plants. The Act is facultative, i.e. every muncipal authority is free to decide whether or not it wishes to apply the Act. The municipal heat distribution has developed very favourably in Sweden due to the vitality imparted by free competition. The legislation can primarily be regarded as protection against unnecessary competition between municipal investments within the energy sector.

State loans and grants for district heating

New dwellings are financed by State housing loans. The district heating utility, in turn, can borrow part of these building loans to cover the investments in the distribution network. Stockholms Energiverk at present finances between 30 and 40% of its distribution installations by this type of loan.

State energy saving loans and grants are available for connecting existing dwellings to the district heating network. Corresponding financing facilities are also available if the landlord wishes to adopt other energy-saving measures.

The Bank of Sweden has given certain credit institutes permission to raise bond loans for financing district heating plants. These loans are designed to cover that part of the financing which the municipalities cannot raise by other means, such as income taxes, charges, connection levies and possibly self-financing.

Excellent conditions are therefore available in Sweden in general and Stockholm in particular for an extensive and fast expansion of district heating, particularly since political decision-makers, public and private power utilities, landlords and the general public are very favourably disposed towards district heating.

3. Presentation of the Stockholm heating plan.

Basic conditions

Stockholm municipality has recently adopted a heating plan, the ambitions of which are to guide the future consumption of energy in the field of heating. The inhabitants of the municipality will be offered forms of energy which provide the best possible economy, environment, conservation of resources and flexibility. The plan is not binding and presupposes a number of subsidiary decisions in the future.

The forms of heating studied in the investigation are district heating, electric heating, gas heating and local oil-fired heating. All of the alternatives are already used, and the technology as well as the economic structure are well-known. Forms of energy or energy conversions which are not yet established, such as solar energy and heat pumps, have not been taken into account, particularly since their significance is expected to be marginal in the foreseeable future. It may be worth mentioning that gas production takes place in a gasworks, and it is doubtful whether natural gas will ever be supplied to Stockholm. Electric power, gas and district heating water are the three collective forms of heat distributed by Stockholms Energiverk, and all three can be regarded as qualitatively equivalent from technical and environmental aspects. Each of the three types of energy also offers the user the same measure of convenience and availability. A comparison between these alternatives can therefore be made on purely economic grounds. In the investigation preceding the heating plan, the heating costs for the various types of energy were calculated for a number of typical city areas. The costs of the alternative of decentralised oil-firing in individual buildings or smaller blocks have also been calculated and compared to the collective energy supplies.

When comparing different heating alternatives, it is important for all costs and conversion losses to be taken into account between raw energy and the consumer. Consideration should also be given to State taxes and levies, since these are actual costs for the inhabitants and may actually have been imposed to guide the development. The following factors have been taken into account in the comparisons made prior to the Stockholm heating plan.

Production costs

$$\left.\begin{array}{l}\text{Transmission costs}\\ \text{Distribution costs}\end{array}\right\}\ \text{including losses}$$

Installation costs

Tax costs

The comparative costs on which the decisions in the heating plan have been based and relevant parts of which are presented in this section relate to long-term marginal costs. A number of parameter variations have been applied in the investigation as regards fuel costs, interest on capital, energy-saving measures at the consumer, etc., although these are outside the scope of this presentation. A number of production alternative scenarios have also been studied, ranging from continued expansion of nuclear power for meeting the growth in the electrical energy consumption in the country, with and without long-distance transmission of nuclear heat to the Outer Stockholm region, up to the alternative of further expansion of nuclear power being banned.

The following table illustrates the long-term marginal costs of the various heating alternatives for a number of typical city areas. The examples selected are based on the following assumptions:

- The growth in electrical demand will be met primarily by nuclear power.
- Heat for district heating will be generated in large plants. Additional gains offered by back-pressure power generation have not been taken into account.
- The interest on capital is 10% and the write-off time is 25 years.
- The level of prices is that on the 1 January 1978.

Consequences of the heating plan

A transition from decentralised oil-firing to gas or electric boilers or heat exchangers for district heating water does not involve any major modifications to the equipment installed in the buildings. In order to maintain all possible flexibility in the future, the water-based systems in the buildings should be retained. Only about 5% of the buildings in Stockholm are unmodern-

Alternative Heating Costs, $/MWh

Area supplied Heating alternatives	Heat demand density, MW/km^2	Heating costs						
		Production	Transmission	Distribution	Installation	Losses	Taxes	Sum
<u>City centre area consisting primarily of dwellings</u>	70							
District heating		12.4	-	3.6	2.6	0.6	1.0	20.2
Electric heating: Direct		-	-	-	-	-	-	-
Electric heating: Night storage		17.4	1.8	2.0	9.0	1.0	8.0	39.2
Decentralised oil-fired heating		20.6	-	-	5.0	-	1.4	27.0
<u>Suburban areas with high-rise buildings</u>	16							
District heating		12.4	1.0	4.2	2.2	0.8	1.0	21.6
Electric heating: Direct		26.0	1.8	2.6	1.4	1.0	8.0	40.8
Electric heating: Night storage		17.4	-	4.8	4.8	0.8	8.0	35.8
Decentralised oil-fired heating		19.4	-	-	3.8	-	1.4	24.6
<u>Areas of single-family houses</u>	6							
District heating		12.4	1.2	20.2	3.6	2.2	1.2	40.8
Electric heating: Direct		26.0	2.0	5.2	7.0	1.0	8.0	49.2
Electric heating: Night storage		17.4	-	10.0	14.4	0.8	8.0	50.6
Decentralised oil-fired heating		24.0	-	-	12.0	-	1.6	37.6

ised and have no water-based central heating, although modernisation is gradually pursued.

Direct electric heating by means of electric radiators is therefore not recommended in densely built-up areas to which district heating may possibly be extended in the future. This applies to offices, multi-unit dwellings as well as single-family houses.

The investigations preceding the heating plan clearly indicate that district heating should be extended to all areas, with the exception of pure single-family house developments, regardless of whether the energy generation of the future will be based on nuclear power or on fossil energy raw materials. The only alternative which could compete with district heating is natural gas distribution through the existing gas distribution network which covers most of Stockholm. However, natural gas is not likely to be available in the Stockholm region, at any rate not at the price difference between natural gas and fuel oil which is necessary for a natural gas project to be profitable.

For areas consisting predominantly of single-family houses, the heating plan recommends primarily water-borne electric heating, although it is assumed that individual oil-fired heating may be employed alongside of electric heating in the foreseeable future. However, large-scale electric heating is conditional of the expansion of nuclear power plants to meet the additional electrical energy demand. On the other hand, if heat from district heating nuclear power stations should be available or if further expansion of nuclear power should be banned, district heating of areas consisting exclusively of single-family houses may also become attractive. A ban on nuclear power would presumably cause drastic restrictions to be imposed on further expansion of electric heating. In view of the high distribution costs and the relatively high thermal losses, practically none of the areas consisting of single-family houses are connected to the Stockholm district heating network. As in the case of multi-unit dwellings, water-borne systems are recommended, in order to allow for possible change-over from electric heating to some other type of energy, and to allow scope for night storage.

Implementation plan

The recommendations of the heating plan imply that about 90% of all energy for the heating of buildings and for water heating will be distributed in the district heating network, using water as the heat-conveying medium. The present situation and the expected expansion of district heating are shown in the table below and the schematic maps (Fig.3:1 and 3:2).

	District heating on 1 Jan. 1978	Decided but not implemented expansion	Expansion according to heating plan	Finally around year 2000
Percentage of total heat demand in Stockholm	27	38	25	90
Max.power to the distribution network, MW	1100	1600	1000	3700
Energy deliveries, GWh/year	2700	3800	2500	9000
Capital, M$, invested in the distribution network at 1978 prices	90	90	140	320

EXPANSION OF DISTRICT HEATING IN 1978

Production plant

Distribution net work

" " in course of construction

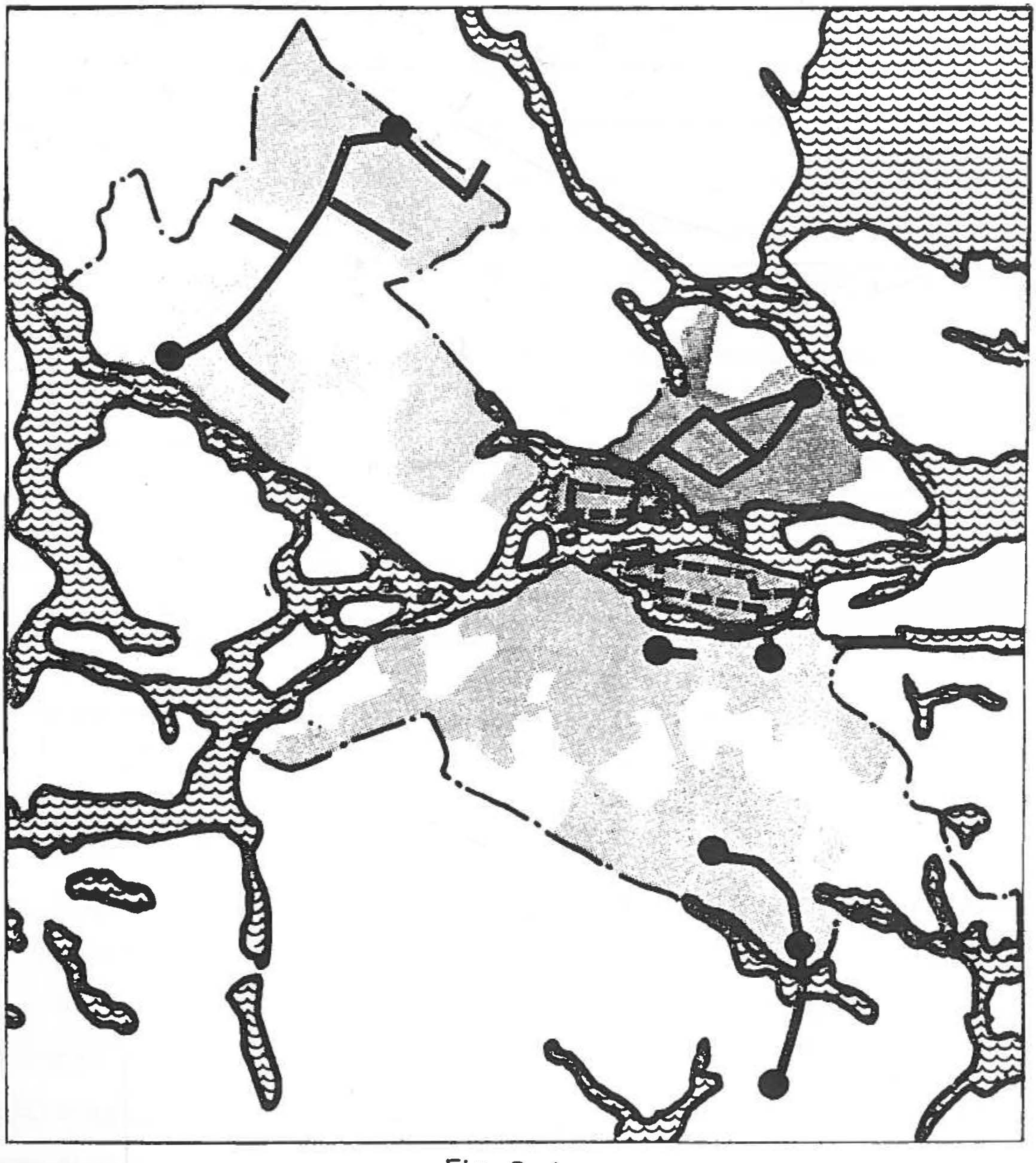

Fig 3:1

City Centre

Suburban areas, densely populated

0 1 2 3 4 5 Miles

EXPANSION OF DISTRICT HEATING IN 2000

● Production plant

▬ Distribution net work

Fig 3:2

City Centre

Suburban areas, densely populated

0 1 2 3 4 5 Miles

4. Production of hot water in district heating power stations.

The competitiveness of district heating as compared to other heating alternatives has been illustrated in the preceding section, and it was then assumed that the hot water was produced in large hot water boilers rated between 70 and 200 MW. This section will consider the economic conditions for the combined generation of electric power and district heating water in a district heating power station. The presentation will be based on a recently installed back-pressure turbine for our largest district heating network, with an electrical output of 210 MW at a thermal output of 330 MW. On cold-condensing operation, the unit can generate 250 MW of electric power. The investment costs are stated at present-day values.

Investment costs

If a planned, fossil-fired condensing power station is designed instead for back-pressure operation, the investment costs will increase. Since district heating is carried out by means of hot water at a maximum temperature of 120°C, extra costs will be incurred for the hot water condenser and the equipment for pumping the district heating water. In the example outlined here, the hot water condenser is designed for the entire steam flow through the turbine. Scope is also available for running the unit as a conventional condensing machine, e.g. when the heat demand in the district heating network is low. The turbine therefore includes additional stages after the steam outlets to the district heating condenser, and a cold-water condenser for the entire steam flow is also installed.

If the turbine plant is designed for combined electric power generation and district heating, the investment costs can be assumed to be between 10 and 20% higher than a comparable condensing power station. Coal-firing is estimated to increase the investment cost by a further 30 - 40% if sulphur removal equipment must be installed. The specific costs of an oil-fired district heating power station rated at 210 MW electrical at 330 MW thermal, with scope for a peak electrical output of 250 MW on cold-condensing operation, is about $450 per kW of installed electric power.

If the installation of a large back-pressure turbine is conditional on several district heating systems being interconnected, the costs of the interconnection pipes must obviously be included in the cost calculation for a project of this nature.

Operating conditions

Factors of decisive importance to the economics of a combined plant are its expected utilisation, i.e. its capacity factor, and the value of the electric power it will generate. These factors are determined by the nature of the district heating load and by the composition and loading nature of the electric power system. The following graphs are applicable to geographical locations with climates similar to that of Stockholm (about 3 570 degree days).

The thermal load on the Swedish district heating systems has a relatively short utilisation time of 2 500 - 3 000 hours per year, and this corresponds to a load factor of 0.3 - 0.35. The loading is highly dependent on the outdoor temperature. The dependence can be illustrated schematically by Fig. 4:1. The figure illustrates that the loading is directly proportional to the outdoor temperature between $-20^{o}C$ and $+15^{o}C$. At outdoor temperatures above $+15^{o}C$, practically all of the thermal energy is employed for heating domestic water, and the load is therefore not dependent on the outdoor temperature.

The loading varies widely during the year, and is about ten times higher in January and February than it is in July, which is the height of summer in Sweden. The variation during the year is shown in Fig.4:2. On the other hand, the variation between day and night is relatively insignificant, the maximum loading during the day only exceeding the mean 24-hour loading by a maximum of 15%.

The variation in loading can also be illustrated by means of a load duration curve, such as that shown in Fig.4:3 which represents the thermal load in Stockholm. The curve has a distinct peak which corresponds to little energy. No less than 90% of the thermal energy is thus below 50% of the peak. It will thus be clear that costly heat generation plants, such as combined heat and power generation plants, cannot be designed to cover much more than 50% of the peak district heating demand. The maximum conceivable value is largely dependent on the electric power system.

The example below is derived from the central Stockholm district heating network which has a design district heating load of about 660 MW, i.e. twice as large as the thermal output of the unit. The energy delivered to the district heating network is estimated to be 1 980 GWh/year.

Valuation of the outputs of a district heating power station.

The somewhat generalised profitability calculation below for a combined district heating and power generation plant illustrates the marginal benefit as compared to the alternative generation of corresponding quantities of electrical and thermal energy

HEAT LOAD AS A FUNCTION OF OUTDOOR TEMPERATURE

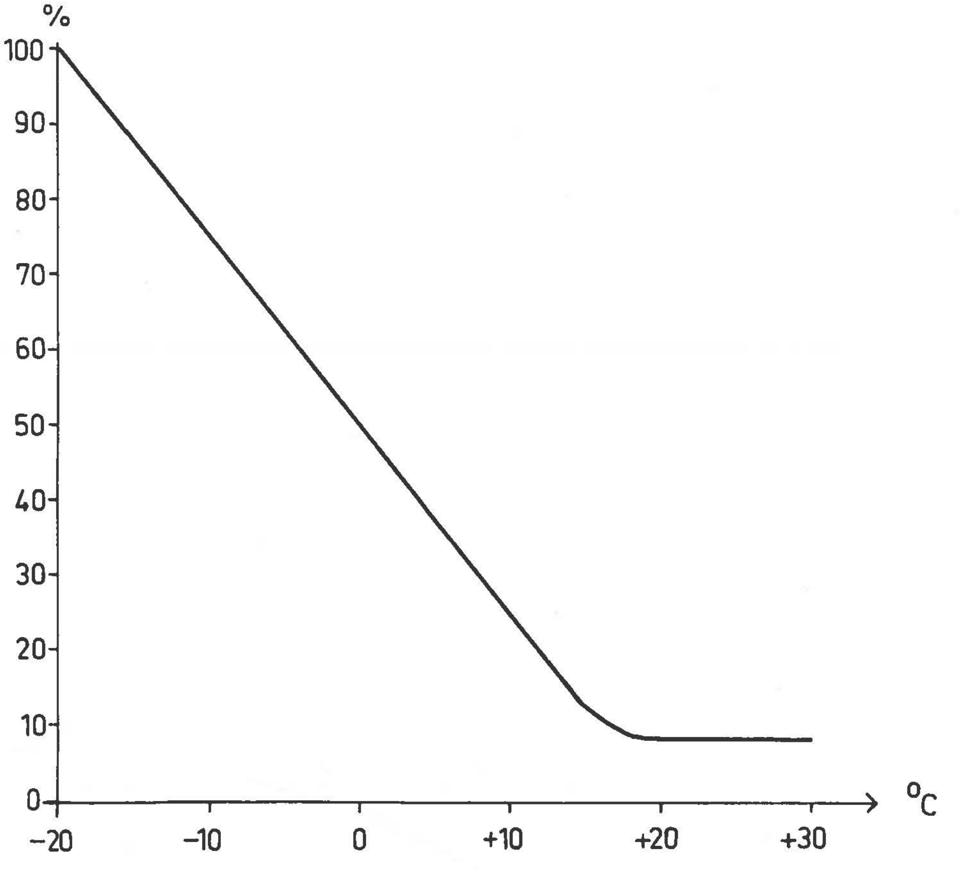

Fig. 4:1

HEAT LOAD VARIATION DURING A YEAR

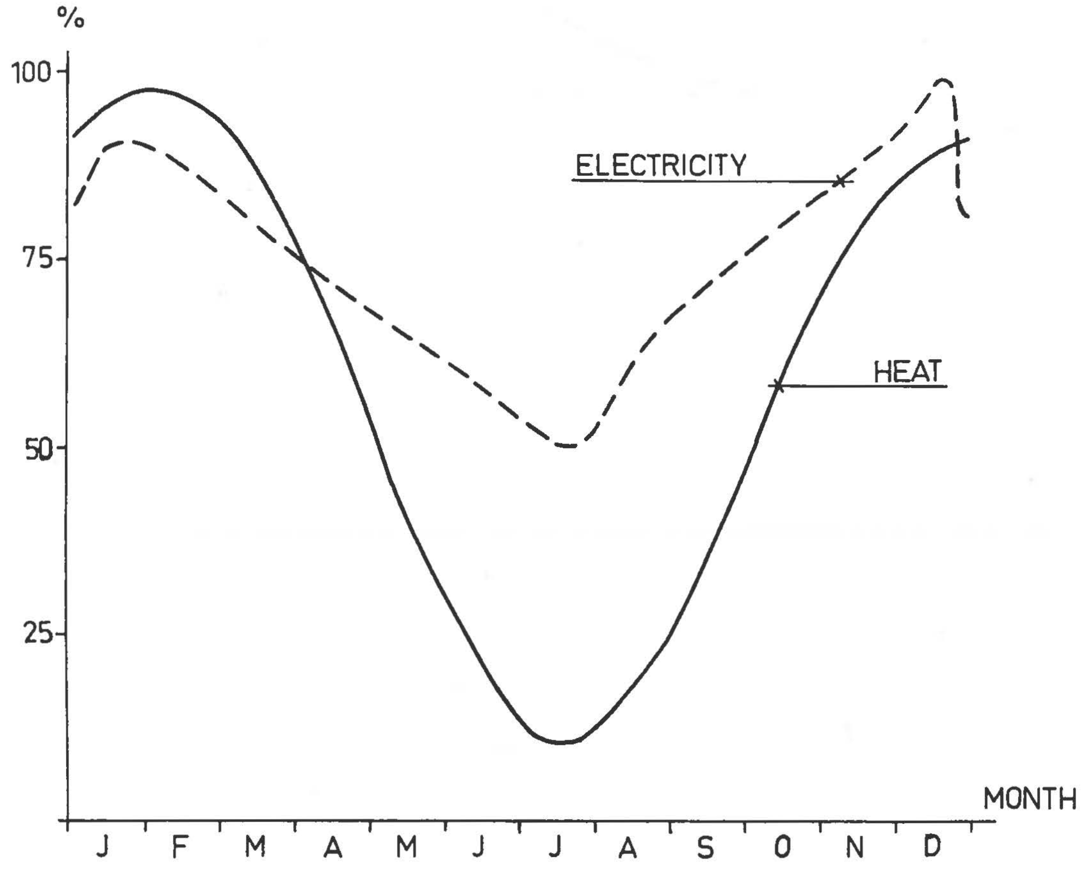

Fig. 4:2

HEAT LOAD DURATION CURVE

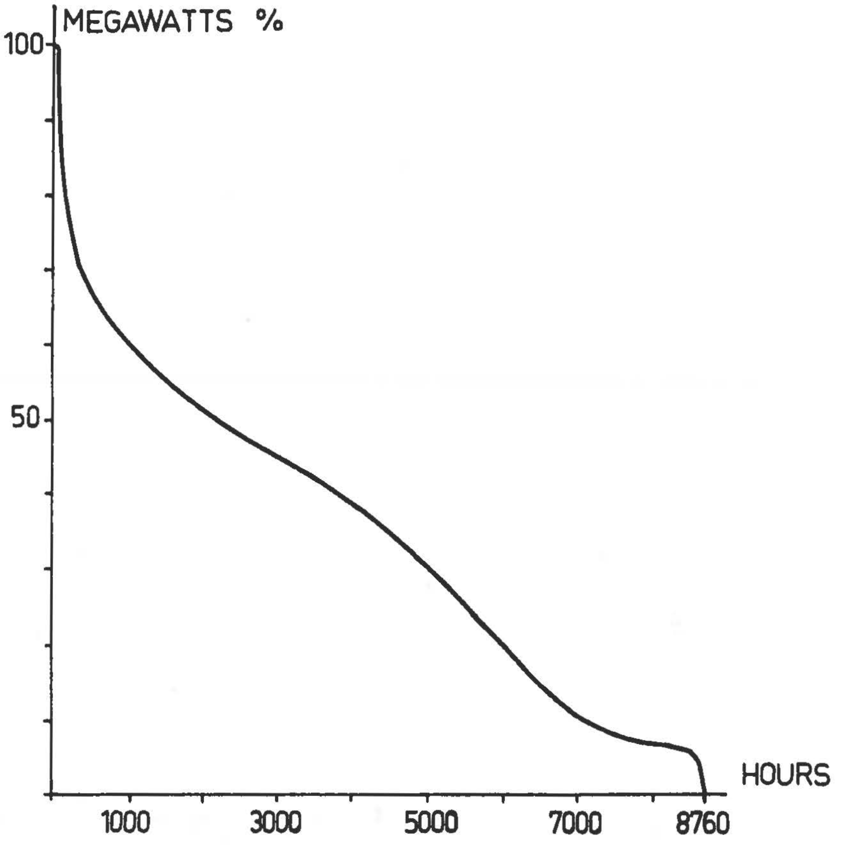

Fig. 4:3

in a condensing power station and a district heating station respectively. It is the total marginal benefit which is presented, i.e. the value of the electric power as well as the heat generated. For calculation reasons, the combined generation profit is allocated to electric power generation, although in a following paragraph, an interesting method is presented for distributing the combined generation costs onto electric power and district heating.

Fixed annual cost for the district heating power station	The investment cost is assumed to be 450$ /kW e or $112.5 million based on a rating of 250 MW. At an interest on capital of 10%, a write-off time of 25 years and allowances for fixed operating and maintenance costs, the annual cost will be $13.8 million per year.
Annual cost for interconnecting pipes.	To create a sufficiently large thermal load for the unit, it has been necessary to interconnect local distribution networks by large-bore mains. In this calculation, the investment cost is estimated to be $10 million or $1.2 million per year.

The sum of the total annual costs is thus $15.0 million.

Valuation of the heat output.	The thermal output of the plant is assumed to have the same monetary value as the corresponding output of hot water boilers, i.e. $50 per kW installed. However, the 330 MW of thermal power delivered by the unit is the largest block in the system. Since our

stand-by policy is that stand-by must always be available for the largest unit, the extra power does not have a full value. The district heating system so far incorporates hot water boilers only, the largest being rated at 150 MW. The back-pressure unit therefore only increases the prime power * by 150 MW. The value of this additional power, on the basis of the above conditions, amounts to $0.9 million per year.

Valuation of thermal energy

For calculation reasons, the combined generation gain is assigned to the electric power generation. The variable costs of heating the district heating water in the district heating power station is assumed to be exactly the same as the alternative heat generation which it supersedes, provided that the cost of fuel is the same. The price difference between the alternatives is therefore $0 million per year.

Valuation of electric power

In this marginal cost calculation, the electric power generated by the combined plant has a value which roughly corresponds to that generated by a gas turbine. The value of the power generated by a gas turbine can be taken to be $200 per kW e. Under the above condi-

*) Prime power = Total installed power minus the stand-by, i.e. the largest unit.

tions (10% interest on capital, write-off time of 25 years and rating of 250 MW), the value of the power generated by the district heating power station can be taken to be $7.5 million per year, including operation and maintenance.

Valuation of the electrical energy

Electric power is normally valued in accordance with the methods employed by the power utilities, i.e. the variable cost applicable on any occasion for generating the last kilowatt-hour on the Swedish grid. In this generalised example, the variable marginal cost of the electrical system for the additional generation is taken to be an average of about 20 mills/kWh, which corresponds to the production-related price of oil-fired condensing power at a fuel-oil price of 83 $\$/m^3$. The marginal cost of electric power generation in the district heating power station is only half, i.e. 10 mills/kWh, as a result of the better energy utilisation. As outlined above, this particular back-pressure plant delivers about 90% of the heat generated, and the availability is assumed to be 85%. The electrical energy generated thus amounts to 970 GWh. As outlined above, the net gain is taken to be 10 mills/kWh or $9.7 million per year.

The sum of the power and energy gains will thus be $18.1 million per year, and the net result will be a saving of 18.1 - 15.0 = $3.1 million per year as a result of combined generation.

Distribution of combined generation profit between the electric power utility and the district heating utility

The allocation of the combined generation profit onto the two utilities may appear to be merely of academic interest, since they both have the same owner. However, when the tariffs are set, it is important to know the generation cost of the district heating sector, for instance, particularly since the product is sold on the open market and the producer has economic responsibility for the product. At Stockholms Energiverk, we have therefore worked out a distribution principle known as the "equal discount method", with the following contents. The alternative cost of generating the electric power and heat in the relevant quantities is calculated, and it is then assumed that generation takes place separately and in an optimum manner, i.e. in a condensing power station and a district heating station respectively. The actual costs of combined generation in the district heating power station are then divided in relation to the alternative costs, and the district heating network integration costs, etc. are then also taken into account. The method can be regarded as the result of negotiations between two equal parties and is illustrated below, based on the conditions outlined in the preceding section.

Calculated alternative cost of generating 970 GWh of electric power in a condensing power station	26.9 million $/year
Calculated alternative cost of generating 1 530 GWh of heat in a district heating station	16.2 million $/year
Sum of alternative cost	43.1 million $/year
Actual costs of generating 970 GWh of electric power and 1 530 GWh of heat in the district heating power station, including district heating system interconnection costs	40 million $/year

Combined generation profit: 43.1 - 40.0 = 3.1 million $/year

Discount: $100 \times \frac{3.1}{43.1} = 7.2\%$

Cost share of the electric power utility:

26.9 million $/year - 7% = 25.0 million $/year

Cost share of the district heating utility:

16.2 million $/year - 7% = 15 million $/year

Proportion of power-generating heat in the Stockholm system

The installed district heating power in Stockholm at present amounts to 1 650 MW thermal, of which 520 MW is generated in district heating power stations. Installed electric power of the back-pressure turbines amounts to 320 MW electrical, which represents about 25% of the power available to Stockholm. During 1977, about 65% of the distributed district heating energy was generated in back-pressure turbines. At the same time, 775 GWh of electrical energy was generated, and this corresponds to 20% of the total electrical energy consumed by the municipality during the year.

Future expansion plans are entirely dependent on the State energy policy. If further expansion of nuclear power is banned, construction of fossil-fired district heating power stations will be necessary. As far as Stockholm is concerned, three district heating power stations for base-load generation will then probably be built, and the total thermal rating of these stations will be approx. 800 MW, with a corresponding electric power rating of approx. 500 MW. Together with the existing district heating power stations, about 50% of the installed electric power in Stockholm will then consist of district heating turbines by the mid-1990's. Most of the necessary thermal and electrical energy will then be generated in these district heating power stations.

On the other hand, if further expansion of nuclear power will be permitted in the future, long-distance transmission of hot water from a nuclear district heating power station will probably be an alternative to the above fossil-based expansion of the generation capacity in the municipality. Full stand-by in the form of hot water boilers will obviously have to be available within the distribution area.

5. The economics of district heating

This economic analysis of the district heating activities is based on a depreciation on the purchase value of 4% for buildings, 5 % for mechanical equipment in the production plants and an average of about 3.5% for the distribution plant. In addition, the interest paid on loans from the municipality or external financiers has been deducted from the earnings. The dollar rate of exchange has been assumed to be $1 = Skr 5.

The district heating operations started in 1954. The activities were initially of a local nature, and customers were supplied with heat from temporary minor hot water stations. At the same time, the construction of a more extensive distribution network was started. During the first year, the investment amounted to about $1 000 000, and the turnover was approx. $140 000. Thus in the initial stages, large investments in relation to the turnover were made, although the rate of expansion was far too careful to achieve optimum development of the operations. This was primarily due to the uncertainty regarding the future market for district heating. The plants were not utilised to their full capacities, although the business was obliged to meet full depreciation and interest. As a result, the operations suffered a loss during a number of years.

District heating basically showed a loss up to 1973 inclusive, when the accumulated loss, including interest paid, amounted to $3.6 million. But the operations produced a profit from 1974 onwards, and all earlier losses were recovered by 1976. The turnover was then $37 million and a total of about $100 million had been invested in production and distribution plants.

At the present structure of tariffs, which provides compensation for increases in the cost of fuel as well as for anticipated cost developments, and at the present rate of capacity utilisation in the plants, the future holds the promise of very favourable development. It may be of interest to note that the district heating tariff during 1977 was entirely competitive as compared to other forms of heating.

Profitability

In this particular case, the profitability has been defined as the yield (profit + interest on loans + extra depreciation) in relation to the capital invested.

In 1972, the yield on the capital invested amounted to approx. 3%, which should be compared with the yield expected by the lenders which, during 1972, amounted to approx. 7%. By 1976, the yield had increased to 11%, which exceeded the interest paid on loans by about 3%. The estimated yield according to the present five-year plan is expected to be approx. 20% in 1982.

Degree of self-financing

The relationship between the funds generated by the activities in the form of profits and depreciation made and the capital invested each year amounted to an average of about 25% per year during the period between 1954 and 1976. In 1977, the degree of self-financing amounted to 40% and, according to the present five-year plan, it is estimated that complete self-financing will be possible on the investment of approx. $18 million planned for 1981. In 1981, the turnover is expected to be $95 million.

6. Environmental aspects

As in other large cities, air pollution in Stockholm increased substantially during the period between World War II and 1968, when firing with low-sulphur fuel oil with a maximum of 1% sulphur was stipulated. At the same time, the large resources devoted by the municipal authorities to district heating started to bear fruit in the form of reduced SO_2 emission. Prior to this date, the SO_2 content often exceeded the limit of 5 pphm (150 $\mu g/m^3$) then specified by the Swedish environment protection authorities as the mean value for the six months of the winter season.

Conditions have gradually improved during the past ten-year period. The reason for this improvement is primarily the concentration of heat generation to district heating stations in which combustion is efficient, dust collection is employed and the plants are equipped with tall stacks. However, the demands of the environment protection authorities have concurrently become more stringent. The mean value of the SO_2 content during the six months of the winter season should not exceed 100 $\mu g/m^3$ (3.3 pphm), and the value of 60 $\mu g/m^3$ (2.0 pphm) has been proposed as a planning target.

The air pollution situation in Stockholm during various expansion stages of the district heating networks is illustrated by a sequence of four pictures (Figs. 6:1, 6:2, 6:3 and 6:4). A dispersion model designed by the Swedish Meteorological and Hydrological Institute has been used for the calculations. (The dispersion model is presented in Atmospheric Environment, vol. 8, pp 131 - 148, 1974: A numerical air pollution dispersion model for the Stockholm region.) The calculation model takes into account all major point emissions and the scattered emissions known as surface sources. The assumptions made in the calculation were that heavy fuel oil with a maximum sulphur content of 1% is used at the point sources and that light oil with a maximum content of 0.6% is used at the surface sources. The calculations comprised the entire Outer Stockholm region, although the report deals only with the central parts of the city.

The following four planning stages were studied:

Fig.6:1 Reference case. The SO_2 immission in 1970. District heating only expanded to approx. 10%.

Fig.6:2 The SO_2 immission in 1980. District heating expanded to approx. 33%. Oil-firing used in the entire heating sector.

Fig.6:3 The SO_2 immission when the district heating system is expanded to the whole of the central part of the city, and with some suburban areas included. About 60% is covered by district heating. Oil-firing is used for the entire heating sector. The probable date is 1990.

Fig.6:4 The SO_2 immission in a hypothetical final stage when all buildings within the municipality are connected to large oil-fired district heating stations.

A comparison between the reference case and the measured values indicates that the model overestimates the concentration somewhat, but that the correlation is good on comparison with the

SO_2- IMMISSION $\mu g/m^3$ 1970

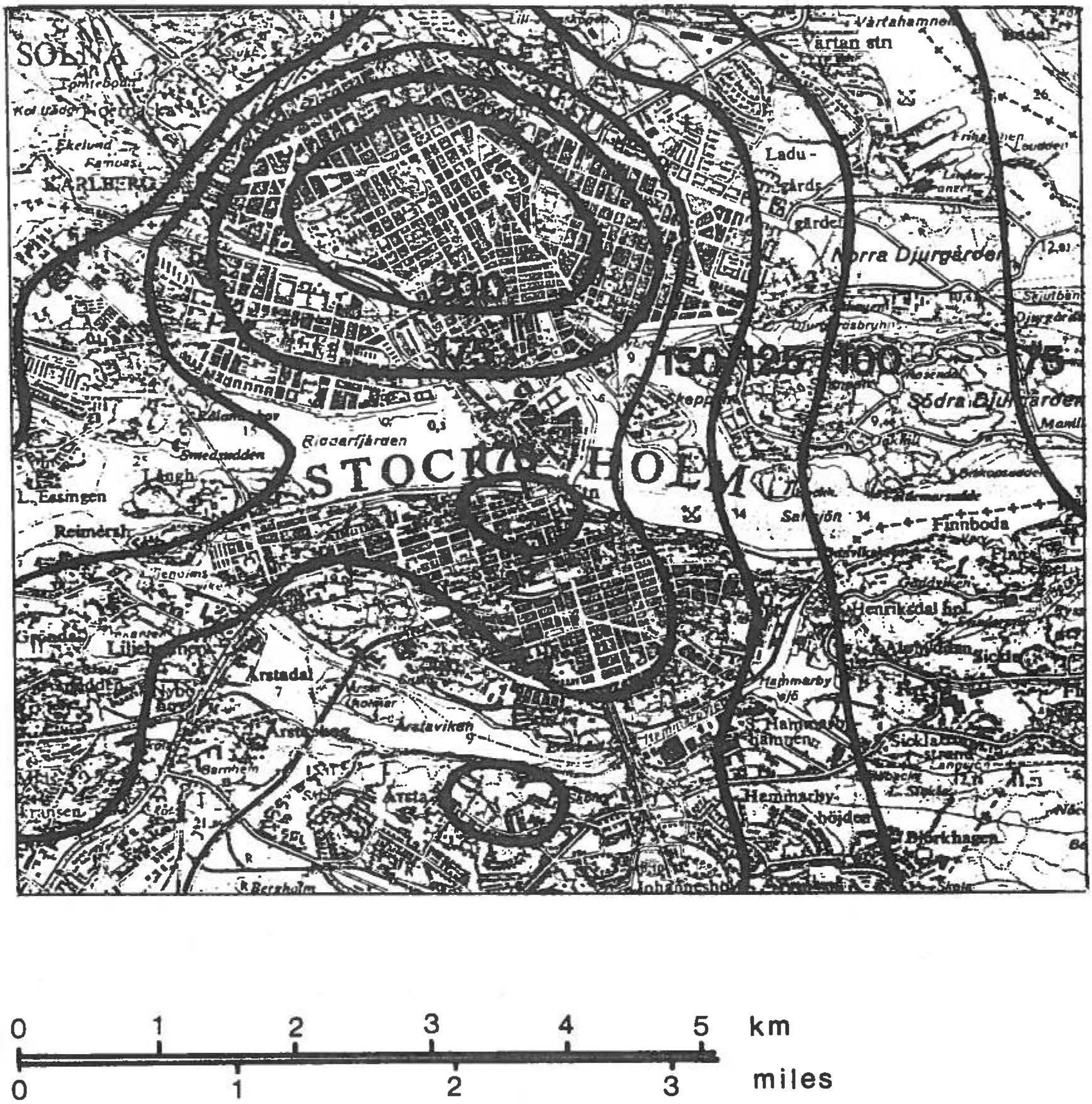

Fig 6:1

SO_2 - IMMISSION $\mu g/m^3$ 1980

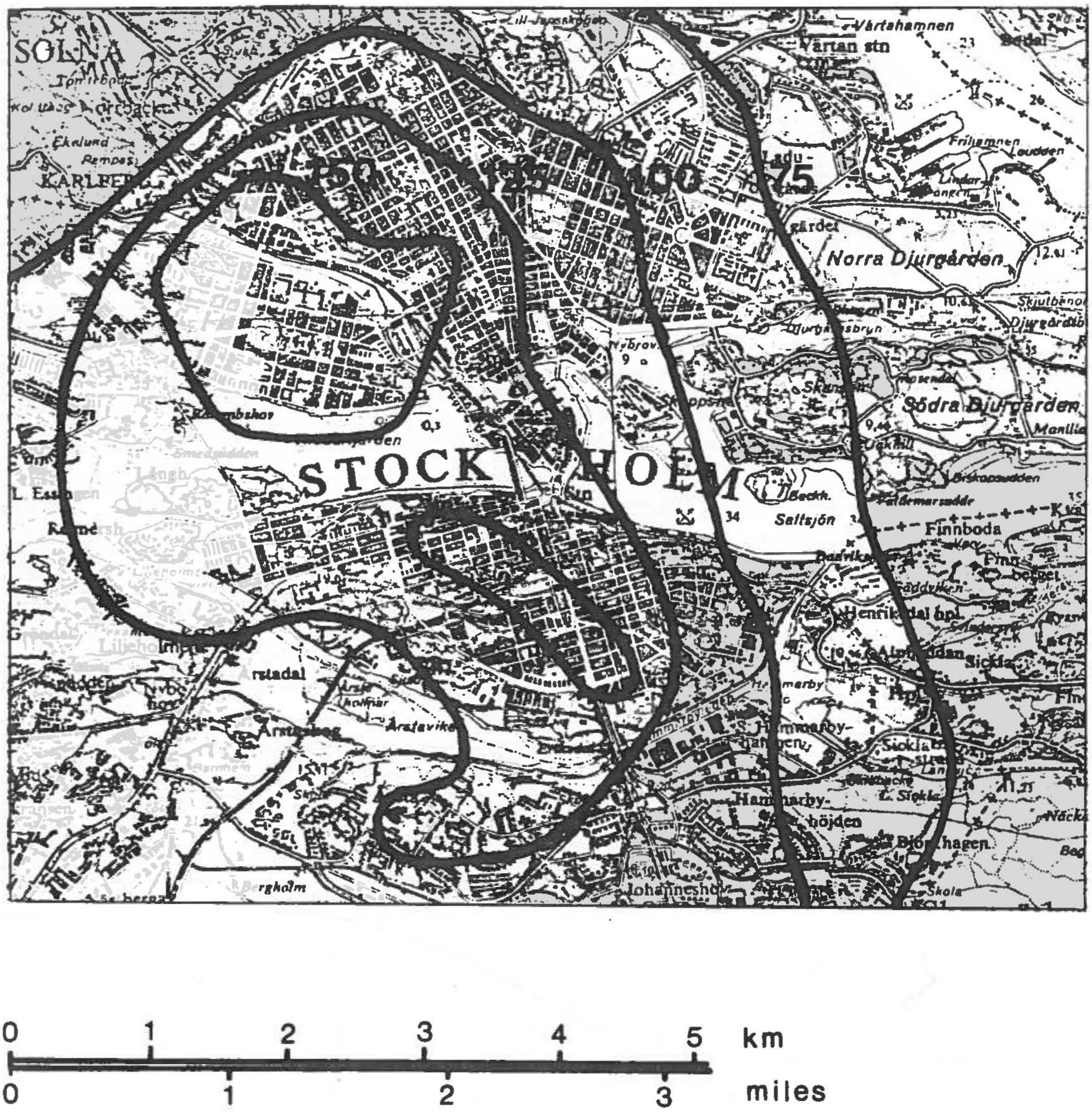

Fig 6:2

SO_2 - IMMISSION $\mu g/m^3$ 1990

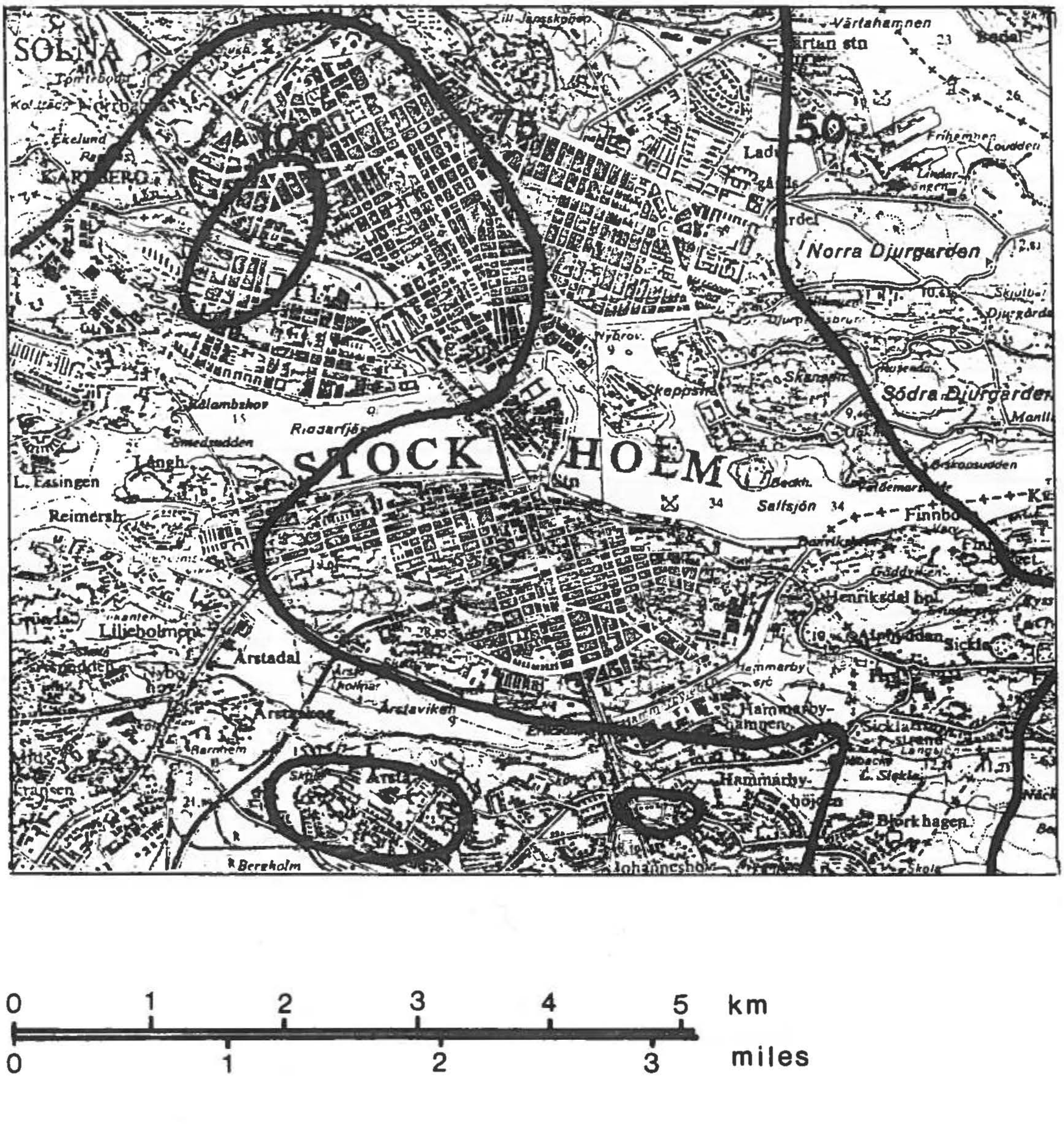

Fig 6:3

SO_2- IMMISSION $\mu g/m^3$ 2000

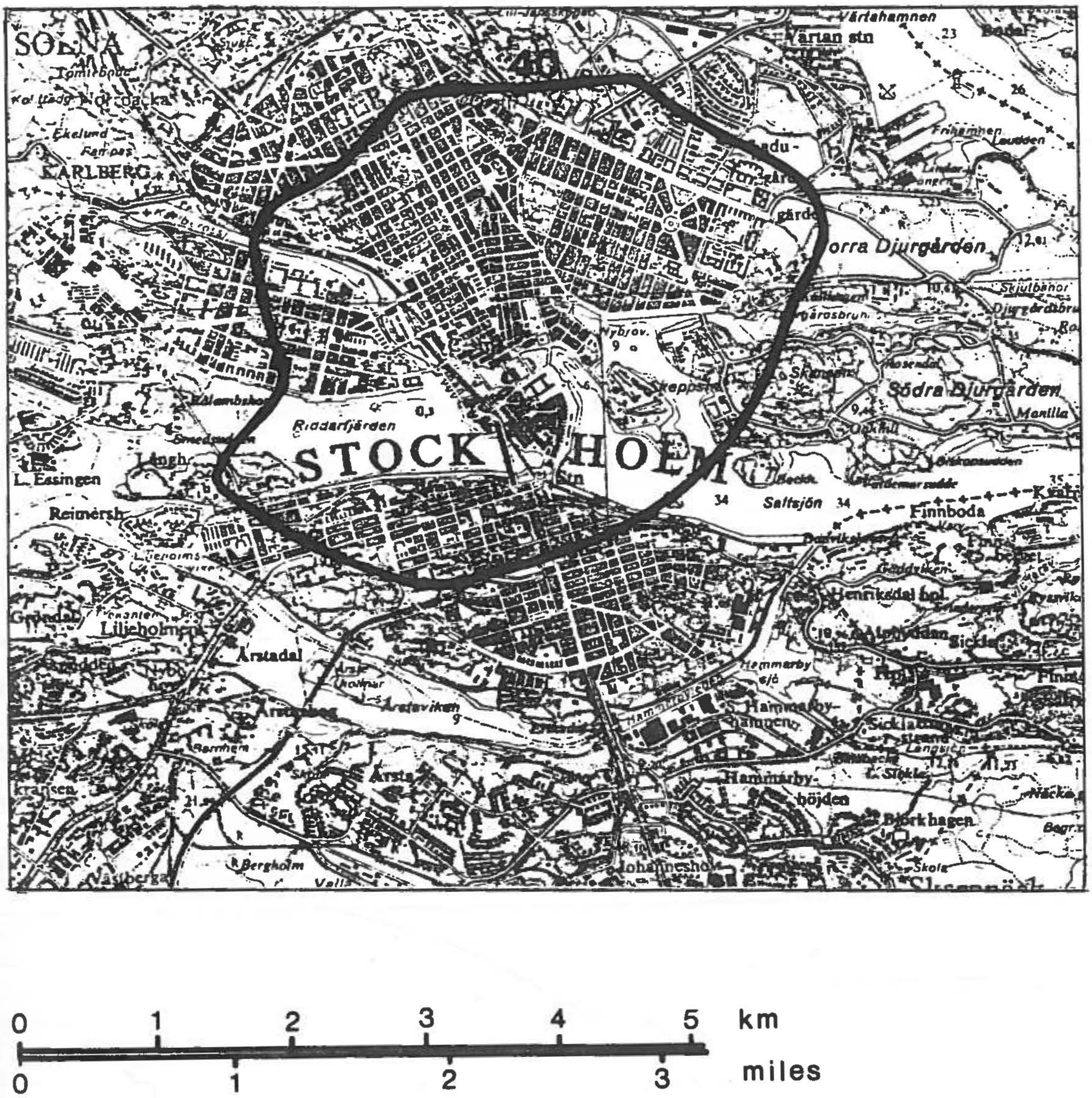

Fig 6:4

measured values. This overestimate on the occasion of verification is due to the relationship between surface sources and point sources. The model tends to overestimate the influence of the surface sources. On further expansion of the district heating network illustrated by Figs. 6:2, 6:3 and 6:4, the proportion of point sources will increase appreciably, and this will reduce the overestimate. This has been verified in other large city regions where the model has been tested.

The gradual improvements illustrated by the sequence of pictures is largely real and provides a good illustration of the benefits of district heating in improving the quality of atmospheric air.

From 1970 and up to the date when the intentions of the heating plan have been fully implemented, the SO_2 emissions will decrease to one-fifth in the central regions of Stockholm city. The limits for SO_2 in atmospheric air recommended by the Swedish environment protection authorities are already satisfied, and no difficulties should be experienced in attaining the planning target of 60 $\mu g/m^3$. Finally, it should be pointed out that the SO_2 emission will decrease by about 20 000 tons per year if nuclear heat is used instead of fuel oil in an integrated district heating network.

7. Future energy sources

The heat generated today for district heating is predominantly oil-based and the boilers are designed for oil-firing only, although conversion to gas-firing by means of natural gas or coal gasification is relatively simple. The base-load generation plants now in the planning stage will also include provision for coal-firing as well as firing with domestic emergency fuels.

Municipal refuse incineration and the recovery of industrial waste heat will also be of some significance. It can therefore be claimed without exaggeration that no other heating alternative offers as large a degree of flexibility in the choice of energy raw materials as district heating.

But the keenest interest is shown in nuclear energy. In relation to her size, Sweden has very large uranium deposits. According to a recently published investigation, Sweden is claimed to have between 15 and 20% of the world's known workable uranium deposits. Even if this figure is considered to be optimistic, Sweden has sufficient uranium to reduce radically her dependence on oil for electric power generation and for heating. A very comprehensive study has been made into the possibility of transmitting about 2 000 MW of heat of a base-load nature from a nuclear district heating power station in Forsmark, 80 miles north of Stockholm. The load district covers all of Outer Stockholm. This would save about 1.5 million tons of fossil fuel annually in the Outer Stockholm region.

A new energy policy decision due to be made this fall may possibly clear the way for the nuclear district heating power station project.

The storage capacities of the district heating networks should also be suitable in the future for renewable types of energy, such as large-scale solar energy.

8. Summary

The energy supply of Stockholm is highly dependent on petroleum products, primarily fuel oil for heating. The municipal energy policy should therefore aim at saving energy and creating the conditions necessary for reducing the oil dependence.

District heating plays a significant role in the Swedish energy debate. The dominating role of the district heating activities is due largely to the municipal and State involvement. Energy conservation, economy, flexibility and the environment are arguments which are often heard in the energy policy debate. In order to allow the municipalities to run district heating utility companies, the State has enacted a number of legislative measures and offers extensive financial support.

Stockholm municipality has recently adopted a heating plan, the ambitions of which are to guide future energy consumption in the field of heating. Various heating alternatives were compared in the investigation preceding the heating plan. The heating plan recommends water-borne district heating for all densely built-up areas. Implementation of the heating plan is expected to expand the market share of district heating from the present value of about 30% to about 90% towards the end of this century.

The generation of heat in district heating power stations offers additional benefits, and electric power generation based on district heating will therefore dominate in Stockholm. A practical example shows how the combined generation profit can be valued. The distribution of the profit between the electric power generation and the district heating activities has often presented a problem. A simple, theoretical model is described in the production section.

The expansion of district heating in Stockholm has been pursued in parallel in several districts. As a result of this very determined effort, even the working capital has been loaded by debts during the early years. The economics are now beginning to be consolidated and the accumulated deficit has been repaid. The degree of self-financing will increase in the next few years, and will rise to 100% during the 1980's. In the long run, this may result in lower costs for the inhabitants of the municipality.

The expansion of district heating plays a very important role in improving the quality of the air in Stockholm. A sequence of four pictures illustrates the expected gradual improvement, expressed as the SO_2 immission. A numerical air pollution dispersion model developed by the Swedish Meteorological and Hydrological Institute has been used in the calculations.

The heat generated today for district heating is primarily oil-based. The plants now being planned will also include provision for firing with coal or domestic emergency fuel. Nuclear energy arouses widespred interest, particularly since Sweden has very large uranium deposits. Large-scale solar energy projects should also be applicable to the district heating network.