

CENTRAL VERSUS DECENTRAL ENERGY SUPPLY STRATEGIES FOR  
INDUSTRIALIZED COUNTRIES - SOFT OR HARD ENERGY STRATEGIES?

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INTRODUCTION AND OBJECTIVES

Of late, the discussion about alternative ways of securing our future energy supply has received a new impulse by the introduction of the catchphrase "soft energy". This catchphrase is exemplary for widely-applied socio-political criticism of the general development of technology towards industrialized technology and for the pursuit of alternative life styles signified by decentralized, comprehensible technology. With reference to the field of energy, this is to be interpreted as the concept of an energy supply in which power is produced by a number of smaller plants at the point of consumption, and which for the main part makes use of regenerative energy sources, such as sun and wind and biomass.

The technical difference between a "decentralized energy supply" and a "centralized energy supply" is shown in Fig. 1.

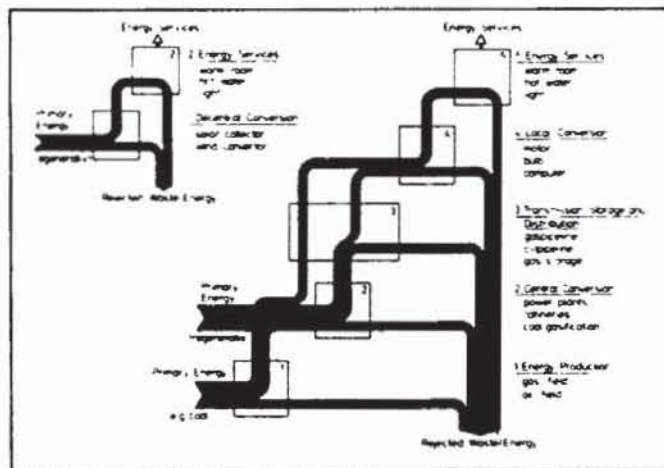


Fig. 1. Centralized and decentralized energy supply systems

The final energy demand in the FRG amounted in 1977 to approximately 7305 PJ (249 · 10<sup>6</sup> t SKE). This included about 45% for the private households and commercial sector, 35% for industry, about 20% for transportation. The following study

concentrates on the private households and commercial sector, because this sector offers favourable conditions for the applications and operation of decentralized energy supply systems by reason of the relatively low temperature level ( $< 100^{\circ}\text{C}$ ) of the basic energy demand. Because of the structure of consumption on this sector - about 90% is required for domestic heating and hot water supplies (see Fig. 2) - the potential analysed thereby amounts to about 40% of the final energy demand of the FRG.

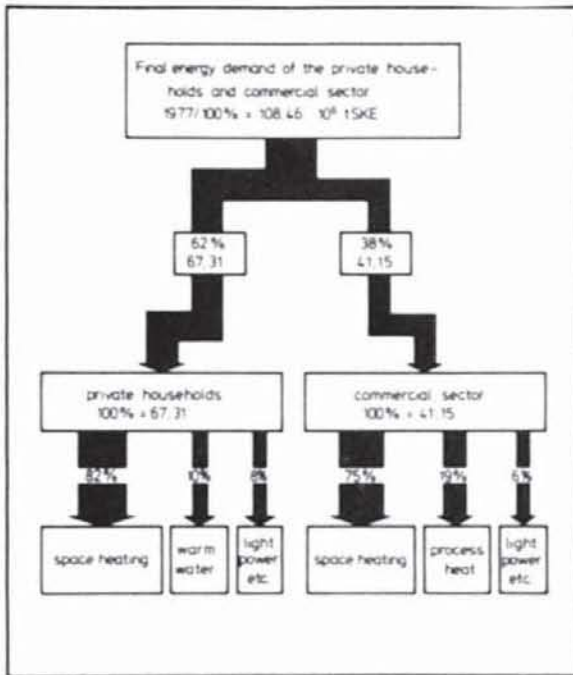


Fig. 2. Structure of the final energy demand in the private households and commercial sector

The technological, economic and ecological comparison of the heating systems to be assessed ensued on the basis of thermal density distribution in community networks, since the density of calorific demand, i.e. thermal output which must be provided per unit of built-up area, is of particular importance for the implementation of energy supply systems.

#### THERMAL DENSITY PROFILE OF THE FEDERAL REPUBLIC OF GERMANY

The level of calorific consumption for the private households and commercial sector correlates closely with the building structure in the community networks. Calorific demand for domestic heating is influenced by building construction, climate, type of use, as well as standard of comfort provided. Varying building structures result in zones with different thermal densities in community networks.

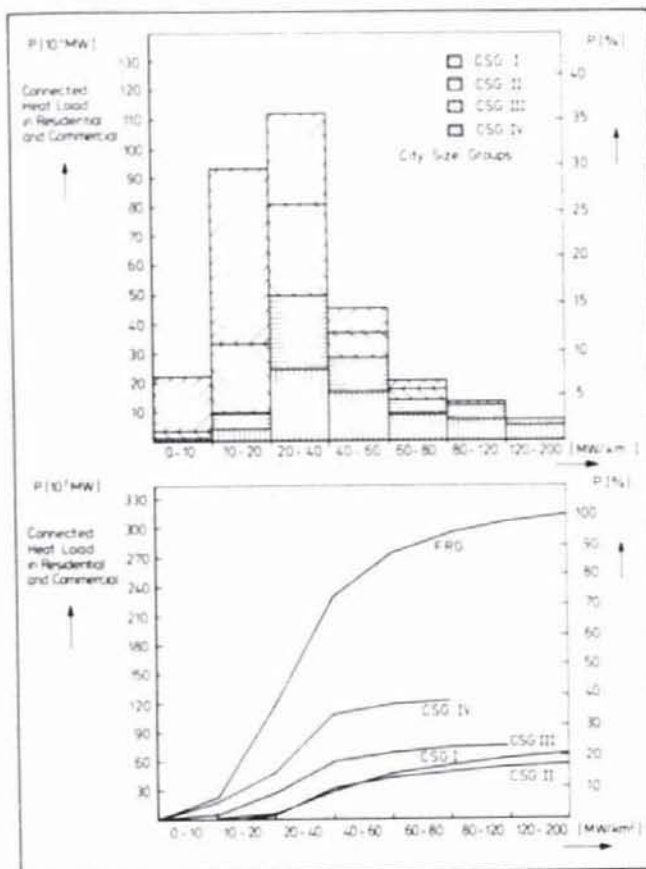
In the core area there is concentrated commercial demand with high power density. In the ring zone around the core area, a mixture between private households and commercial demand with medium power densities is to be found, whilst on the periphery, mainly occupied by private households, the level is determined by a high proportion of low-rise development with a low power density.

If power consumption and its distribution is analysed by thermal density classes, the result is the thermal density profile for the FRG shown in Fig. 3.

The upper part of the diagram shows the connected heat load in relation to typical thermal density classes. Within in thermal density class the potentials are broken down into city size groups. These city size groups are defined as follows:

City size groups (CSG)	Population	Frequency
CSG I	> 500 000	13
CSG II	100 000-500 000	56
CSG III	20 000-100 000	394
CSG IV	0 - 20 000	10 460

According to the structure of the building development in community networks, the loading in the individual thermal density classes is at varying levels. The lower part of the diagram in Fig. 3 shows the cumulative frequency curves for each CSG and the FRG as a total (private households and commercial sector only).



A concentration in the distribution of the thermal density profile of the Federal Republic lies clearly in the range of 10 - 40 MW/km<sup>2</sup>, in other words in the ring and peripheral zones of cities. The share of this range amounts to approximately 65% of the thermal loading of the Federal Republic.

For the assessment of thermal supply systems, it can thus be maintained that the systems which are optimal in this thermal density range have the greatest market potential.

Fig. 3. Distribution of the connected heat load in the FRG (1974) by density classes

#### TECHNICAL DESCRIPTION OF THE SYSTEMS ANALYSED

For satisfying the calorific requirements detailed above for the private households and commercial sector, the systems shown in Fig. 4 will be referred to.

According to the definitions made in the introduction, the following systems can be regarded as centralized:

- District heating,
- Oil and gas central heating,
- Off-peak electric heating (night storage heating).

All these centralized systems, with the exception of night storage heating, are conceived as pumped hot water heating, i.e. the effective heat is conveyed by means of the medium water via pipes from the point of heat generation (e.g. boiler) to the room heating surfaces. A design temperature of 90°C for flow and 70°C for return, with a minimum external temperature of -15°C was chosen.

System	Energy	Operation	Operation Temperature
1 District Heating	Water (fossil energy carrier)		90/70
2 Oil Heating	Oil		90/70
3 Gas Heating	Gas		90/70
4 Storage Heating	Electricity		
5 Electric Heat Pump and Oil Boiler	Electricity, oil, air	bivalent, alternative	90/70 60/50
6 Heat Pump and Diesel Motor	Diesel, air	monovalent	60/50
7 Heat Pump with Diesel Motor and oil boiler	Diesel, air	bivalent, parallel	60/50
8 Solar Collector with Oil boiler	Oil, solar radiation	bivalent, parallel	45/35
9 Total Energy System	Fossil carrier	bivalent, parallel	90/70

Fig. 4. Analysed heating systems

The decentralized systems comprise 3 heat pump units with various configurations, a solar system and a total energy system.

The bivalent electrical heat pump with additional oil boiler utilizes as a source of energy besides electricity and oil the surrounding atmosphere with the heat pump. It is bivalently and alternatively operated, i.e. as long as the heating output of the heat pump is sufficient, e.g. up to  $+3^{\circ}\text{C}$ , the heat pump operates alone. Below this temperature, the heat pump is switched off and the boiler takes over the further supply of heat. By this method of operation, the heat pump attains a share of 60 - 70% of the annual thermal volume. In order to achieve this, its capacity must amount to about 50% of the maximum heating capacity. The maximum operating temperatures are: heat pump operation  $60/50^{\circ}\text{C}$ , boiler operation  $90/70^{\circ}\text{C}$ .

A further heat pump system as a basis for comparison is a monovalent heat pump with diesel motor drive. The system is designed so that alone the condenser capacity and utilization of the waste heat from the motor are always sufficient for the supply of heat, i.e. an additional boiler is not necessary.

Since the investment costs for a monovalent designed heat pump are very high, the bivalent diesel motor-driven heat pump was chosen as a further alternative. In this case the heat pump is operated parallel to the boiler if the heat output of the heat pump alone no longer suffices for the requirements of the household. With a share of the output amounting to about 50% of the design capacity, the heat pump attains approximately a 90% share of the annual thermal volume.

The solar system with oil boiler analysed comprises solar collectors, a hot water storage tank and an oil-fired auxiliary heating system. The oil heating takes over when the energy yielded by the collectors and storage tank is exhausted. In this system the proportion of energy originating from solar sources should amount to 50%. In order to provide favourable operating conditions for the solar system, a maximum temperature for the hot water system was chosen at  $45/35^{\circ}\text{C}$ .

The total energy system with peak demand boiler utilizes the power-heat coupling for heat and electricity generation. It works on the same principle as district heating, although the heating capacity is considerably less. It is designed for heating individual houses. The thermal capacity of the motor-driven generator is about 50% of the total heating capacity. In parallel operation with boiler heating it attains a share of about 90% of the annual thermal volume. By reason of the high temperature level of the engine cooling water and waste gas, the unit can be operated with the usual average hot water temperatures of  $90/70^{\circ}\text{C}$ .

ENERGY CONSUMPTION AND EMISSIONS OF THE SYSTEMS

Within the energy consumption of the systems analysed an assessment is to be made on the one hand on the basis of final energy, and on the other hand corresponding values on the basis of primary energy. With regard to the effects on the environment, emission of the harmful substances  $SO_2$ ,  $NO_x$ ,  $CO$ ,  $C_mH_n$  and dust particles is to be analysed.

Final Energy Consumption

A comparison of the systems is carried out on the basis of the final energy consumption necessary for generating one unit of basic heat. The results for the systems analysed are shown in Fig. 5.

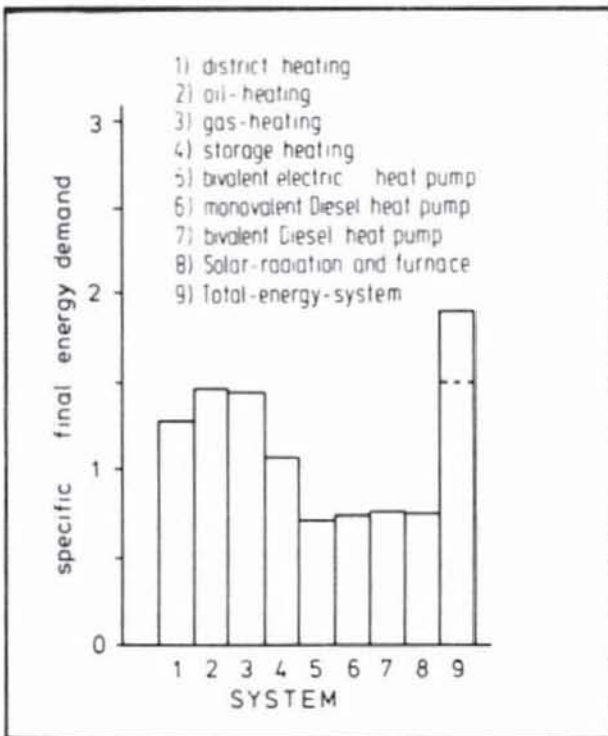


Fig. 5. Specific final energy demand, based on net energy demand of various heating systems

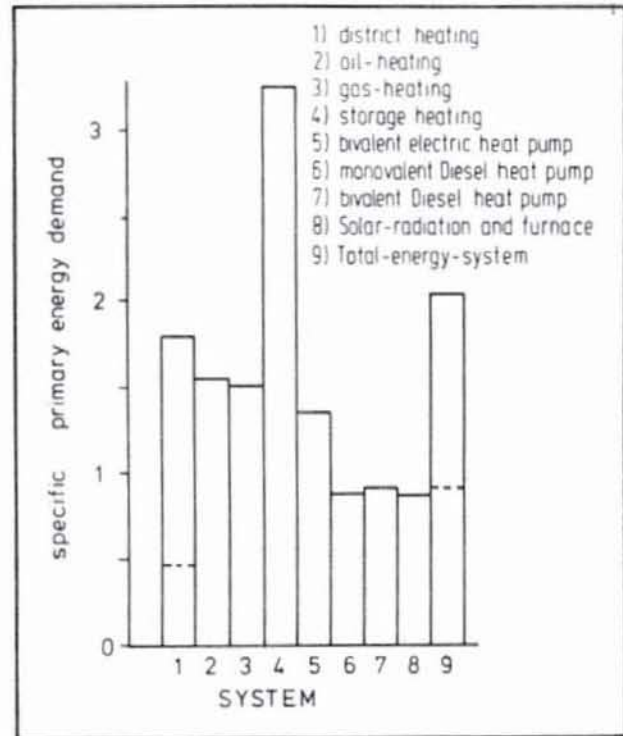


Fig. 6. Specific primary energy demand on the basis of net energy demand for various heating systems

From these it is apparent that all 4 central heating systems have specific final energy consumption levels which are greater than 1. On the other hand, in energy terms all 3 heat pump systems as well as the solar system showed considerable advantages.

In assessing the total energy system it must be mentioned that here the overall final energy consumption for heat as well as electricity generation were taken into account. The broken line shows the final energy consumption of this system after subtracting the electricity generated. Judged on the basis of final energy this system assumes the bottom position.

The order of precedence changes if not the final energy consumption is compared with the primary energy consumption.

Primary Energy Consumption

Primary energy consumption can be determined from final energy consumption taking into account the levels of efficiency in the conversion range. The following levels of efficiency were taken as a basis for calculations:

	District heating systems Combined heat and power plant	Heating plant	Natural gas	Electricity	Fuel oil
Generation	3.45	0.8	-	0.365	-
Distribution	0.9	0.9	0.96	0.9	0.94
Final energy/ primary energy	3.105	0.72	0.96	0.33	0.94

Within the analysis the assessment of district heating in power-heat coupling, as well as heat generation from motor-driven generators (total energy systems), requires particular attention with regard to the consumption of primary energy. Only the additional energy consumption as compared with pure electricity generation is subtracted in the case of district heat from combined heat and power plants. In the analysis of the motor-driven generator, the electricity generated was in energy terms assessed with a level of efficiency in conversion of 33%, and as a bonus point this was subtracted from the overall energy consumption of this system.

A comparison of the systems analysed as shown in Fig. 6 demonstrates that the centralized systems have the highest specific primary energy consumption, whereby district heating occupies a special position. Here, the primary energy consumption is particularly low when the heat is generated in combined heat and power plants (broken line in the bar chart of system 1 in Fig. 6). The highest level of consumption of primary energy is reached by night storage heating. It is about twice as high as the primary energy consumption of oil and gas boiler heating.

Of the heat pumps, systems with diesel motor drive emerge with the best results. The primary energy consumption amounts to about 60% of that of boiler heating systems. The bivalent electric heat pump lies between the boiler heating systems and the diesel heat pumps. The primary energy consumption of the solar system lies in the same range as that of the diesel heat pump. In consideration of the primary energy allowance for the electricity generated, the motor-driven generator (total energy system) has reduced primary energy demand (broken line in Fig. 6) which is comparable with that of the diesel heat pumps.

Emissions

A greater part of the emissions in the Federal Republic are caused by energy conversion on the private households and commercial sector. The share of immissions is even greater, for the emissions come from a large number of energy conversion units with low flues.

Based on the specific emissions occurring by energy conversion the specific emissions arising at the point of effective heat utilization and in the central conversion ranges were calculated for the systems. For  $\text{SO}_2$ ,  $\text{NO}_x$  and dust, Fig. 7 gives a summary of the emissions based on one unit of effective heat. Gas boiler heating has the lowest overall emissions. The highest level of emissions is reached by night storage heating. Whilst in the case of boiler heating systems the emissions occur for the main part locally, the emissions of the electrical systems are produced centrally and are more readily eliminated by means of filtering devices and higher chimneys. Systems with an internal combustion engine are typified by their high level of nitric oxide emissions, which occur mainly decentrally. A reduction

in these values appears to be necessary for the utilization of such systems.

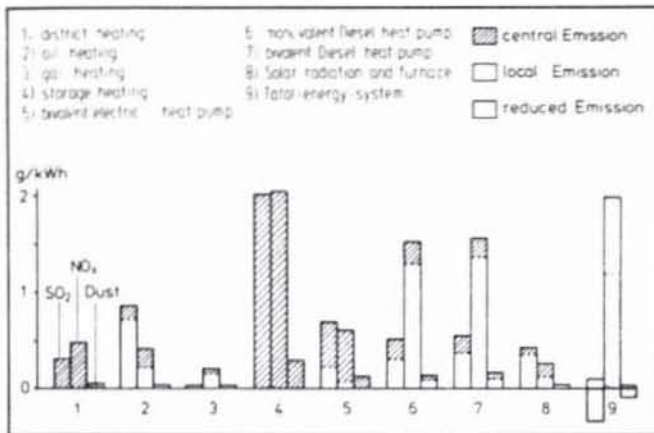


Fig. 7. Specific emissions of heating systems based on basic energy (g/kWh), subdivided into localized and centralized emissions as well as total emissions.

#### COST ANALYSIS WITH ECONOMIC COMPARISON

In order to provide a basis for an objective economic comparison all costs must be considered which are incurred for installation and running of the heating system. This means that the whole process of generation and distribution, including installation of the heating system by the final consumer must be taken into consideration. For the decentralized heating systems a calculation is made for the heat generation, distribution and storage costs, including costs arising from partial utilization of the centralized systems. When an addition is made of all costs of the individual heating systems, the result is a figure for the total costs, which can be incorporated into the economic comparison.

#### Transport and Distribution Costs

The transport and distribution costs are for the main part determined by the loading density. Demands made on mains energy sources are in the case of varying loading densities of considerable economic importance. In zones with a lower loading density the lesser degree of loading must be seen in relation to the necessity for a branched mains system. As is demonstrated in Fig. 8 this leads to high specific costs.

In the case of mains energy carriers growing loading density is accompanied by considerable cost depression. For non-mains energy sources such as oil and coal there can be no such development, i.e. there is only a limited potential for a depression of costs.

As is to be expected the distribution costs for district heating are the highest. For a 100% supply coverage the costs for electricity and gas lie in the same range. The distribution costs for fuel oil are lowest in the whole loading density range.

However, it is only possible to draw conclusions after combining the distribution costs with the remaining cost factors.

#### Costs of the Domestic System

For the purposes of the analysis a summary was made of costs for systems in single-family, two-family and multiple dwelling houses as well as in larger apartment houses.

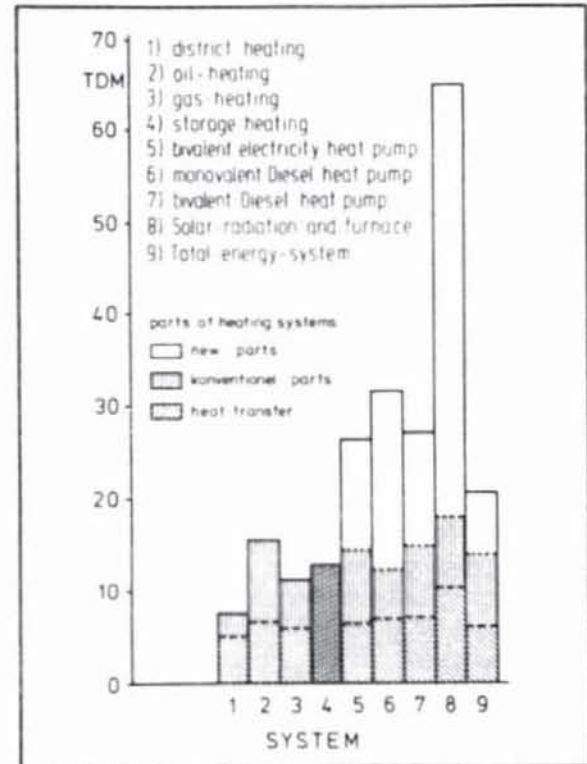
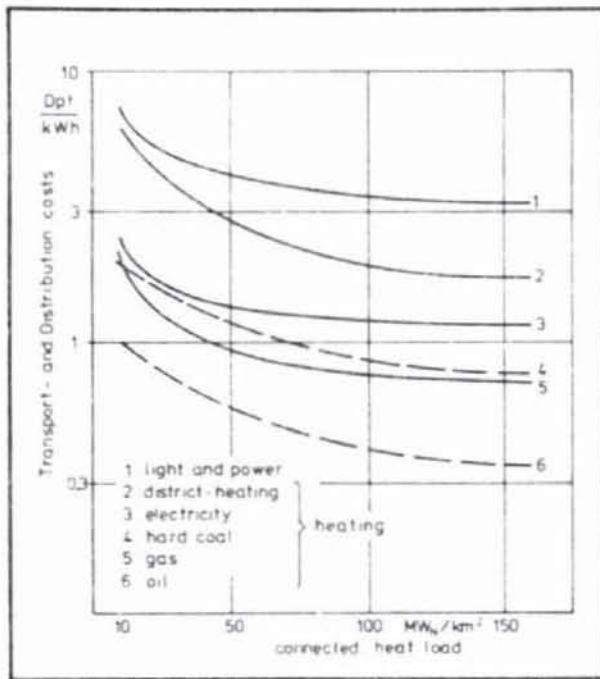


Fig. 8. Transport and distribution costs for energy supply to private households and commercial sector

Fig. 9. Costs of installation for a single-family house (20 kW peak load)

Figure 9 shows the breakdown of costs in the house in the example of a single-family house.

Here the centralized heating systems exhibit the lowest level of costs. From the centralized systems, oil boiler heating incurs the greatest costs.

The decentralized heating systems, on the other hand, give rise to considerable costs. Thus, the solar system of the chosen design reaches a cost level which is 4-5 times as high as that of oil-fired boiler heating. Even the costs for heat pump systems are double those of oil-fired boiler heating. On the other hand, the total energy system emerges with a relatively positive result as regards costs.

Import Prices and Energy Production Costs

Figure 10 shows that the import price for light fuel oil is almost twice as high as that of natural gas. For electricity the prices for off-peak power (operating costs only) and the total costs are given. Of the mains energy carriers natural gas exhibits the lowest costs.

Light oil	Import price: 277,25 DM/t	2,40 DPf/kWh	Price basis: 1977
Gas	Import price: 11,27 Dpf/m <sup>3</sup>	1,16 DPf/kWh	
Electricity (operating costs)		4,00 Dpf/kWh	1 ¢ ≅ 2.00 DM
Electricity (total costs)		8,40 DPf/kWh	
District heat;	5,00 DM/GJ	1,8 DPf/kWh	100 DPf = 1 DM

Fig. 10. Import prices and average production costs of final energy carriers

Economic Comparison

In the discussion about regional energy distribution it became clear that in the FRG there are large variations in the energy densities and maximum loads.

After outlining the most significant factors of influence and final consumer costs, Figs. 11 and 12 show the specific final consumer costs in relation to the loading density.

Fig. 11 shows the final consumer costs at 1976/77 price levels. However, for assessing the future economics fields of implementation, the future and not the current cost level is of significance. For this reason Fig. 12 shows a comparison of costs under the aspect of possible energy price increases.

The main conclusions to be drawn from the economic comparison shown in Fig. 12 are as follows:

The centralized energy supply systems are the cheapest at all loading densities. Oil-fired central heating is cheapest at almost all loading densities.

With increasing loading density in built-up and urban core areas, oil-fired central heating loses its cost advantage to gas-fired central heating and district heating. It can be established that in areas with lower loading density night storage heating becomes economically viable. However, this only applies for the case where it is utilized exclusively for exploiting the off-peak tariff, since only combustible material costs (variable costs) arise and there are no fixed costs for the power plant and electricity distribution.

District heating and total energy systems are in the case of low loading densities outside the range of economic viability. With increasing loading density, district heating exhibits greater cost advantages than total energy systems.

In comparison with diesel-powered heat pumps, the electrically powered heat pump (including fuel oil boiler) exhibits cost advantages. The reason lies in particular in the low house investment costs of the electric heat pump and the fact that only the variable electricity generating costs were taken into consideration.

For the solar system with fuel oil boiler, which is only capable of generating an adequate supply of energy in areas with low demand, the costs are 3 times as high as those for centralized heating systems.

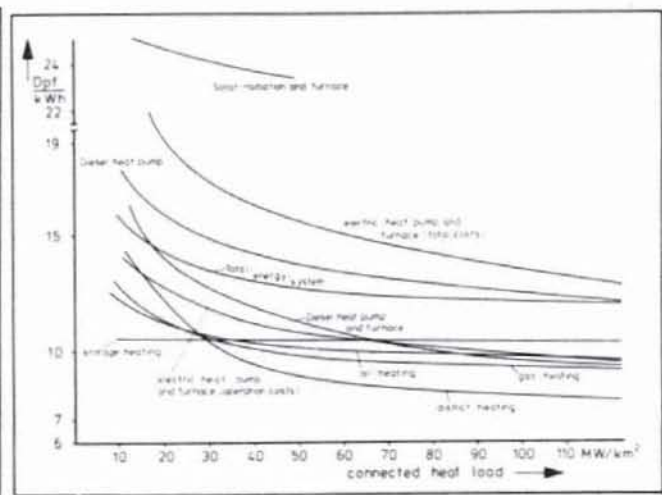
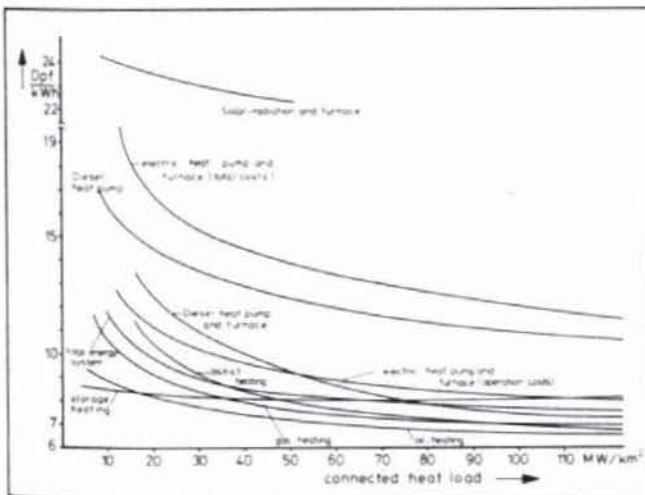


Fig. 11. Overall costs of heating systems (1977 basis)

Fig. 12. Overall costs of heating systems taking into account possible price increases

The price increase for fossile energy carriers assumed in Fig. 12 (fuel oil and natural gas +100%, district heating and electricity generating costs +50%, since in

the case of these secondary energy carriers an increase in the price of fossile energy carriers of +100% only influences the generating costs by about 50%) leads to the conclusion that district heating and gas-fired central heating are cheaper than oil-fired central heating. However, the electrically powered heat pump also comes within the range of economic viability. The solar system remains uneconomical.

Despite the uncertainties which influence the economic calculations, these results show that the centralized heating systems offer cost advantages when compared with decentralized heating systems, even assuming high increases in the price of energy. Changes may only be anticipated when the price of energy sources increases by over 100% and/or as a result of intensified research and development the technical/economic marginal conditions can be shifted in favour of the decentralized energy supply systems.

#### FUTURE PROSPECTS

Heating systems which utilize regenerative energy sources, such as heat pumps and solar systems, as well as systems which function decentrally according to the principle of combined heat and power production will in future offer the conventional systems an ever-increasing level of competition. If one assesses the future energy supply systems against the criteria economy of operation, energy consumption as well as emission of harmful substances, it can be anticipated that of the decentralized systems heat pumps will make the greatest impact on the market. The solution to the energy supply problem should thereby not be regarded as centralized versus decentralized, but it should rather take the form of an optimal strategy for both.

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