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Heat and Electric Power Plants Outside Cities in the Power Supply of Cities

by V. I. Veyts and V. Ya. Khasilev

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HEAT AND ELECTRIC POWER PLANTS OUTSIDE CITIES IN THE POWER SUPPLY OF CITIES

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The great structures of communism mark a new stage in the development of all branches of power engineering in the USSR, particularly in the development of urban power engineering and electrification.

The tasks of reconstructing the power systems of the cities of the USSR during the period of the transition from socialism to communism take on an ever-increasing significance. One of the very substantial factors in the further improvement of the material and cultural conditions of life for the population is an increase in the level at which its power requirements are supplied. The reconstruction of the power systems of the cities is directly linked with the improvement of the power balance as a whole for the principal regions of the country, in the direction of raising the efficiency of the power installations, economizing fuel, replacing long-haul fuel by local fuel, and improving the utilization of power equipment.

The dominant tendency in the socialist reconstruction and development of the power systems of cities is the combination of electric, gas and heating service. This combination of centralized sources of urban power supply will radically solve the fundamental questions both of the power economy itself (the shift to a mineral fuel balance, the introduction of local fuel, the increase of the efficiency, the coordinated utilization of fuel resources) as well as those connected with the level of power supply to the general public.

The urban power engineering of the USSR has already traversed a considerable distance in its development. During the years of Soviet power, the per capita consumption of electric energy for communal and living requirements has increased more than seven times and now considerably exceeds the average level in the cities of the capitalist countries. The USSR holds first place in the world in the level of development of its heating-and-power stations (TETs) and the district heating systems of its cities; in this respect the urban power systems of the USSR vividly demonstrate their superiority to the urban power systems of the capitalist countries. Urban gas systems have also expanded considerably, especially since the war, and mainly on the basis of natural gas, though coke-oven gas is also used. In the present phase, however, the development of urban power engineering brings up new problems in the fields of heating and gas service.

During the further development of heating service in cities with difficult conditions of fuel supply, other questions must also be considered besides the problem of fuel economy. These other questions involve the increase of fuel deliveries and the deterioration of sanitary conditions in connection with the location of the TETs within the city limits and with the use of local high-ash fuels, often having a relatively high sulfur content as well. For each 1000 kilowatts capacity of a heating TETs burning brown coals (of the

Moscow-Basin type), 10000 to 12000 tons of coal a year must be brought into the city, and 2100 to 2700 tons of ashes hauled out of it; while 120-140 tons of ash settle on the city area from the air.

The difficulties involved in finding building sites for a TETs within the city limits, and in providing water supply for it, also constitute limiting factors in the development of urban TETs. All these determine the choice of a TETs capacity, for a city location, according to the heat graph with a relatively low value of coefficient α_{TETs} (α TETs = Q_T/Q_{TETs} where Q_T is the maximum hourly discharge of heat from the turbines, and Q_{TETs} is the aggregate hourly output of heat from the TETs). In consequence fuel economy (in passing from α TETs = 0.75 to 0.85 to α TETs = 0.45 to 0.50 for cities located in the II climatic zone, the economy of fuel on account of the heating service is diminished by 20-25 percent) is reduced, with unchanged coefficient of heating-service coverage, while the relative capital costs per kilowatt capacity and the relative operating costs per kilowatt-hour of output both rise sharply. (Primarily in connection with the reduction in the electric capacity of the station).

A radical solution of these contradictions in the present development of the provision of heating service for a number of cities may be assured by the location of the TETs beyond the city limits and beyond its green-belt, and selection of a building site that is also convenient with respect to conditions of fuel and water supply.

A new power engineering scheme of heat service based on the construction of suburban TETs will sharply improve urban sanitary conditions by freeing the cities from pollution of the air by sulphur and ash. It will allow optimum loading of the TETs from the point of view of the efficiency, as shown by the indices α TET_s. In a number of cases it will be possible to choose a capacity not only according to the heating graph but according to the electricity graph as well, by also taking into account the structure of the electric power system in which the TETs is included, i. e. to pass over to higher capacities of both TETs and aggregate systems.

In the same direction -- towards the enhancement of economy manifested by suburban TETs as compared with those inside the cities -- the reduced costs of ash removal, fuel delivery and storage, and water supply will frequently also operate.

The realization of heat service schemes based on suburban TETs naturally means a transition to a longer-range heat supply, over a radius of some tens of kilometers instead of the current radius of heat transmission by hot-water systems, measured in terms of a few kilometers. This will involve additional expense for equipment and operation of long heating-mains. A heat-service scheme based on suburban TETs requires review firstly of the fundamental technical questions of planning, construction and operation of long heating-mains (the system and parameters of the heating network, the thermal and hydraulic regimes, etc.) and secondly of the conditions under which a suburban TETs becomes as economical as, or more economical than, the city TETs it replaces.

The scheme of heating service with a suburban TETs brings up anew the fundamental questions of the choice of capacity and type of its equipment, and also of the regime of its operation. The realization of this scheme demands the solution of the urgent problem of parallel operation of different sources of heat-supply (the city and suburban TETs), i. e. of the creation of a heat-supply system by analogy to the system of electric power supply. Under these conditions parallel heating operation stands out as one of the most important factors in the further enhancement of the reliability and economy of heat-supply operation.

It has been remarked above that Soviet power engineering has also achieved considerable successes in the area of urban gas supply, mostly based on long gas pipe-lines, using natural gas and also coke-oven gas. However, the fact that no economical methods have yet been worked out for obtaining gas of high calorific value from the local fuels is a factor that seriously limits the further development of urban gas services in a good number of regions.

The existing methods of gasifying local fuels with the object of producing a gas of high thermal value, which are based on blowing ~~steam and hydrogen~~ oxygen-vapor through the fuel, including some using high pressures, or are based on low-temperature carbonization, on semi-coking, with external or internal heating of the particles, cannot, in view of economic conditions, serve as the basis for the widespread expansion of urban gas service. (Editor's note:) This proposition would appear to be controversial.) The new schemes for semi-coking of local fuels, with solid and gaseous (heat-conducting media) ~~thermophores~~, developed theoretically and experimentally by Soviet investigators, yield gas of high thermal value and tars, and are important achievements. The hot semi-coke is burned in the furnaces of the boilers of the electric power plant (the furnaces being connected with the semi-coking installation). This scheme of energetic and chemical utilization of fuel at power stations, by the ENIN (Energeticheskiy Power Eng Institute of the Academy of

Sciences] method, is destined to open up wide new prospects of further expansion of gas facilities in cities and industrial centers. (The idea of energetic and chemical utilization of fuel at power stations was developed in the works of G. M. Krzhizhanovskiy, published as early as the 20's (G. M. Krzhizhanovskiy, Collected Works, vol. 1, Electric Power Engineering, 1933).

The researches conducted on suburban TETs with long-distance heat-supply and with parallel utilization of fuel at electric-power stations to supply heat, energy and chemical constituents, allow a combined scheme to be advanced, covering electric, heating and gas service for cities, based on the establishment of suburban TETs using the new method of the semi-coking of local fuels. Under these conditions the suburban TETs will be able to stand out as a power center for supplying its city with electric power, hot water and gas.

The present article treats only of the results of the investigation into the general principles of the suburban TETs. The questions of the utilization of fuel at suburban TETs at the same time for electric, heating and gas service for cities and industrial centers require separate consideration.

I. THE DEPENDENCE OF THE FUEL-POWER INDICES OF CITIES ON THE NUMBER OF INHABITANTS

A study of the conditions for the applicability of the combined scheme requires, first of all, the reduction of the indices to the same values for electric power, gas and heat production and for the corresponding capacities, so as to make the combined and isolated power schemes comparable.

TABLE 1

Population in Thousands	Capacity of TETs in Thousand Kilowatts	Annual Consumption		Fuel Brought in, in Tons	Ash Carried Out, in Tons	Ash Pollution in Tons
		Gas in Million Cubic Meters	Heat in Thousand mkkal.			
100	8	17	132	101	21500	1190
150	12	27	257	154	32700	1800
275	24	50	380	300	63000	3500
400	50	75	578	485	103000	5700

Table 1 presents the indices of capacity of the TETs, the consumption of gas and heat (as hot water), and the amount of fuel brought in, as depending on the size of the population.

The calculations are based on the following assumed normative data: dwelling space, 6 square meters per person, assumed base temperature of outside air, 30° C. (As in text: 30° C.; [This does not seem to make sense, even if the dash is intended in this case to be a minus sign], hot water supply takes 15% of the total maximum heat load. The industrial low-temperature consumption (as hot water) is about 30% of the total heat consumption of the city (industrial and communal-dwelling). The annual consumption of gas (Q^p_h = 4000 calories per cubic meter) is 260 cubic meters per capita; two-thirds of this amount is used for cooking and one-third for heating water. There are two TETs systems; systems with individual capacity up to 12000 kilowatts at medium pressure; 25000 kilowatts and above at high pressure. The coefficient of heating-system coverage is 0.4, that of the gas system is 0.7.

In determining the amount of fuel brought in, the mean annual fuel consumption per unit of output has been taken on the basis of the power characteristics of the turbines and with α_{TET} = 0.5; the annual number of hours use of the installed ~~electric~~ capacity of the TETs is 5500. The table also gives data on the amount of ashes hauled away and the amount of ash pollution in the city. The ash indices were determined on the basis of the average qualitative indices of Moscow Basin coals. The coefficient of dust elimination has been taken at 0.95. The table gives round numbers and shows only the order of magnitudes.

2. LONG-DISTANCE HEAT SUPPLY AND PARALLEL HEATING OPERATIONS OF TETs

The power-engineering scheme based on the suburban TETs includes long heating-mains as a supplementary link.

The questions of long-distance heat supply and of the establishment of heat-supply systems with parallel operation for heat were first raised in the USSR during the thirties, specifically in connection with the development of the general plan for establishing a heating service in Moscow [3, 4]. The transmission of heat over long distance is accomplished, in the present condition of heat-supply technology, by means of superheated water. The hydraulic and thermal regimes of a long two-pipe heating-main were studied in the work of the Academy of Communal Economy (1934) on the technology of long-distance transmission of heat. The limitations on the range of heat transmission are primarily those imposed by technical and economic factors.

The studies of the range of heat transmission made in the thirties were devoted to finding the basis of the "economic R_{ec} and the "limiting R_1 radii of heating service. These researches aimed to discover the optimum capacity for a TETs located in a region with higher or lower density of heating service. Increases in the extent of the heating-system network were considered together with the corresponding increases in the thermal capacity of the TETs. The economic solution of the problem took into account the fact that as the radius of heating service increases, the unit capital investment and operating expense increases for the heating network. From this, then, the value of the "economic" radius R_{ec} of heat transmission, corresponding to the minimum aggregate annual operating expense was determined; at the same time

R_{ec} corresponded to the optimum capacity of a TETs in a region with a given density of heating service and configuration. The "limiting radius" R_l of heating service was determined by equating the annual cost of transmitting the heat and the fuel economy resulting from the heating service. In both cases -- for both R_{ec} and R_L -- it was assumed that the heating network would be laid out in an inhabited region and that the TETs would be located in the center of that region or at its periphery.

The divergences in the numerical values of the optimum radius of heating service [1-4] was mainly explained by the varying estimates of the variation in the unit technical and economic indices as functions of the capacity of the station and the installed aggregates.

V. B. Pakshver [5] advanced the idea of a super-long-distance transmission of heat over 150-200 kilometers by a single-pipe heating-main. The 1949-1950 investigations of ENIN (V.I. Veyts and V. Ya. Khasilev, L. A. Melent'yev and I. A. Agrachev) developed a composite power engineering scheme based on suburban TETs and investigated the separate questions of the power efficiency, schemes and regimes of parallel heating operation of more than one TETs.

The distinction of the new formulation of the question of the economics of long-distance transmission of heat in connection with suburban TETs consists in the fact that the influence of transmission distance and of the productivity of the heat-supply system is evaluated independently of the density of heat service throughout the region, inasmuch as for the transit heat-main, unit costs fall with increasing capacity of the suburban TETs instead of rising with it.

The selection of the scheme and parameters for a long heat-main is important. Comparison of the two-pipe and one-pipe schems shows that at distances not over 25-30 kilometers, even when there is a direct water connection from the city network for dwelling needs, and the suburban TETs is favorably located, with respect to water supply, it is still expedient, in many cases, to retain the ordinary two-pipe scheme of water heat-mains. The use of a direct water connection is justified on the whole by the quality of the feedwater, and requires two to three stage preheating in condensers, regulated and unregulated turbine bleeders, just as with an open, single-pipe scheme [6]. At this stage of the investigation it is expedient to start out from the characteristics of a scheme and parameters less favorable to the power engineering scheme with the suburban TETs, that is being advanced. Therefore a two-pipe scheme of an arterial heat-main was taken as the point of departure. Regardless of whether an open or closed scheme of hot-water supply was adopted, the return arterial main was figured in the same way as the delivery main, namely, at full consumption.

The rated temperature of the water in the delivery main of the heat-main was taken as 150° C. The temperature of 150° was confirmed by repeated technical and economic calculations and studies, for city networks with elevator consumer connection, at the heat-service coefficient $\alpha_{\text{TETs}} = 0.5$ that is characteristic for city TETs. For long heat-mains with length of order 15-20 kilometers and above, and with the same heat-service coefficients for the suburban TETs, the most advantageous temperature in the transit line is increased to 170-180°. However, taking into consideration the assumption adopted in the present work of higher values of the heat-service coefficients at suburban TETs, of the order of 0.7 to 0.8

instead, we have kept the calculated water temperature for a long heat-main at 150°. It is not proposed to reduce this temperature at the point of junction with the city network by means of mixing or heat exchange.

In selecting the cross-section for long transit arterial mains, the decisive elements to be considered are: (a) assurance of the allowable pressures in the pipes and in the consumer's lines, and (b) rational location of the booster pumping substations. With this as a rule we must reconcile ourselves to the reduced values of the unit losses of heat as compared to the most advantageous values determined by the technical and economic analysis (taking into consideration, in this connection, both the indices of operating costs and capital charges).

In constructing the graphs of the piezometric lines determining the pipe cross-sections, we assumed that: (a) the optimum unit loss of hea~~t~~d in the city distributing network varied, according to the capacity of the TETs, within a range of 6 to 8 millimeters of water column per line~~r~~ar meter; and arbitrarily took the length of the city arterial main at 5 kilometers; (b) that the maximum pressure in the heat main, pursuant to the GOST, on the pipes being used, should not exceed 20 atmospheres, nor should it exceed 4.5 atmospheres on the consumers' premises.

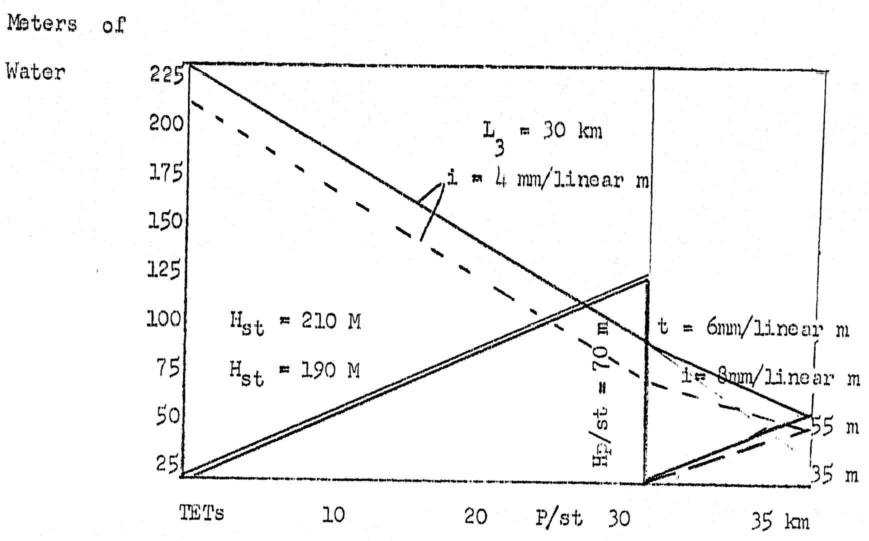
Figure 1 presents the data on the unit losses of heat, as applied to four length variants, for TETs capacities ranging from 12000 to 100000 kilowatts.

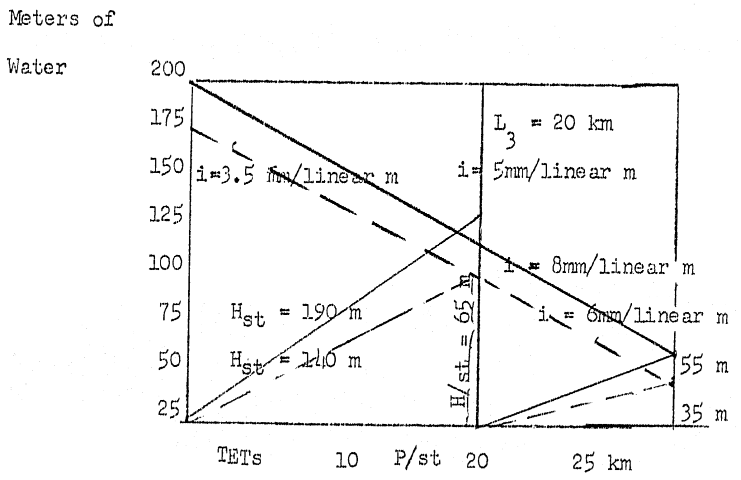
It is clear from the piezometric graphs (Figure 1), that when the heat-main is longer than 5 kilometers, the system of pumping the water through requires booster pumping substations besides the main groups of network pumps at the TETs. However, with lengths running up to 30 kilometers, a single substation will do, located on the boundary of the city, at the end of the heat-main, at its junction with the city's distributing networks. Such a solution appears justified not so much by economic considerations (the relative cost of the booster substations is small as compared with the total costs) as by considerations of convenience of control during operation.

[See Figure 1 on next page]

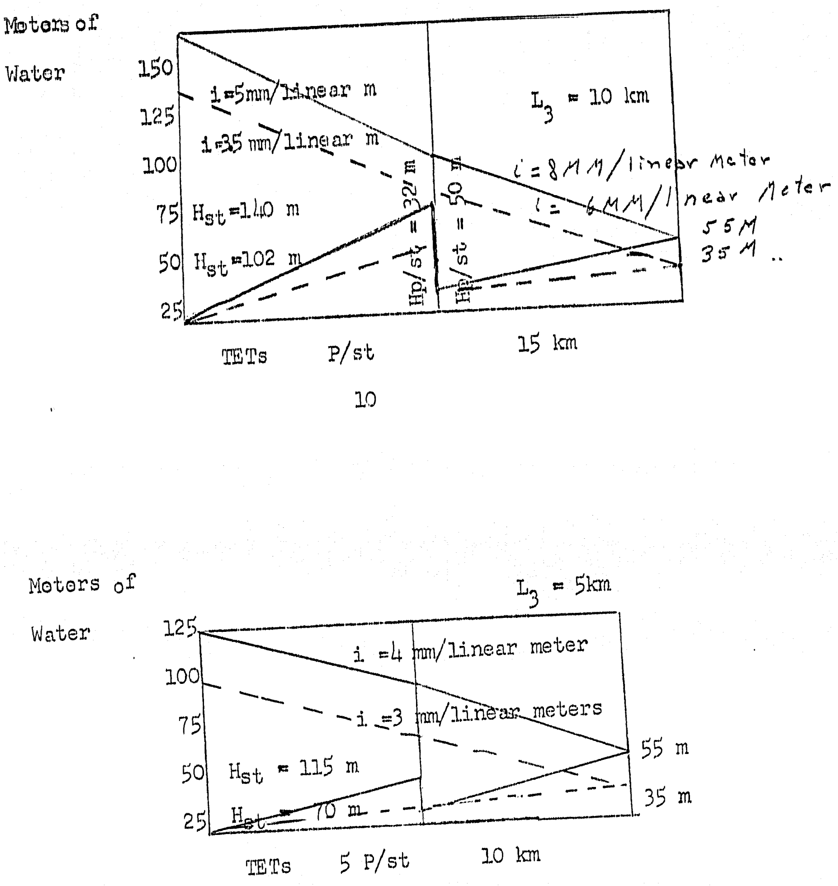
In evaluating the efficiency of a long-distance heat-supply system, the annual expenditure of energy for pumping purposes and the thermal losses in the arterial lines of the heat-main are important elements. The relative amounts of electric power used for pumping water, at capacities of suburban TETs over 25000 kilowatts, depends largely on the distance of heat transmission. Calculations show that the consumption of fuel used to generate electric power for the network pumps ranges from 1.5% to 6.5% of the total amount of fuel used to produce the heat. The unit thermal losses depend to a large extent on the capacity of the suburban TETs; and fall sharply with increasing capacity of the latter.

The fall in the temperature of the water is small for heat-mains of 30 kilometers and longer. Thus for insulation that, when installed, has the entirely realistic coefficient of thermal conductivity ~~transmission~~ of the order of 0.08 - 0.09 kilocalories/m °C. hour, the rough values of the unit temperature drop $\frac{\Delta t}{l}$ (in °C per kilometer) are shown in Table 2.





[Figure 1 continues on next page]



---------N_{TETs} = 100,000 cubic meters

________N_{TETs} = 12,000 cubic meters

Figure 1. Graphs of the piezometric lines in long heat-mains of varying length, with the calculated temperature in the arterial delivery main taken as 150°.

(P/ST means pumping station)

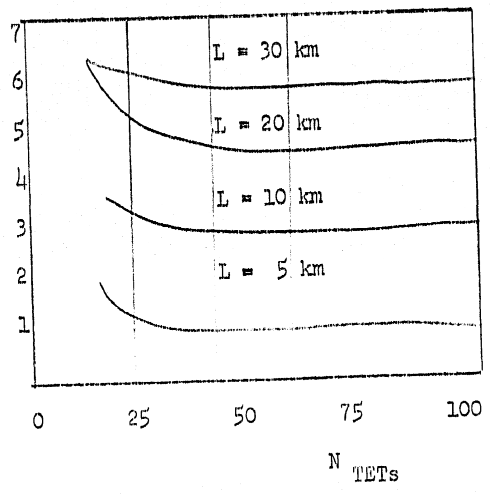


Figure 2. Consumption of fuel for pumping, in percent of the fuel used for heat production.

The amount of the heat losses should be evaluated according to the quality of the insulating construction used after it has been in service for a long time. The composite decision on the type and construction of the covering of heat mains (including the questions of thermal insulation and hydraulic protection) as well as on the compensation of longitudinal thermal expansion in large-diameter pipes, is a major technical problem in the practical realization of long-distance heating-supply systems.

TABLE 2

Capacity of TETs in thousand kilowatts	12	24	50	100
$\frac{\Delta t}{l}$	0.4	0.25	0.15	0.1

The heat losses and temperature fall were computed on the assumption that reinforced foamy cement, which has already become generally accepted, and non-conduit packing would be used. The reliability and economy of long heat-mains can be increased by the use of glass-wool for the insulating construction.

The efficiency of suburban TETs is sharply increased when their operation is parallel to that of urban sources of heat (city TETs, area boilers, etc.), on the common heat-service networks and according to a common thermal graph.

The parallel operation of suburban and urban TETs on a common heating-load graph leaves room for adjustment and maneuver in the sequence of their loads. In cases where the suburban TETs takes over the basic off-peak portion of the load graph, the unit costs and the costs of long-distance heat transmission are substantially lowered.

The accomplishment of parallel heating operation of TETs, under the conditions of long distance heat-supply, is assured in the simplest way when the suburban TETs is included in the system of the city distributing networks by means of a long heat main. Important in this connection is the "transit character" of the long heat main, without substantial branching under way. This will allow regulation to be assured at its point of junction with the city distributing networks.

The combined use of various sources of heat for parallel operation on a common network creates a number of important advantages for a heat-supply system [7]; it increases the reliability of service, reduces the required reserve of boiler capacity, increases the capacity of the boilers, load efficiency, redistributes the load among the various types of TETs, etc.

We have shown in a previous work [8] that economy of fuel may be attained not only by the joint use of heat-generating installations of different degrees of fuel economy but also by parallel working of TETs equipped with aggregates on the same level of fuel economy. Under the latter circumstances the load of the turbine bleeders may be increased on an annual basis, by the amount of the so-called "redistribution effect" Δ Q, and the direct ouput of heat from the boilers correspondingly reduced. This effect vanishes when the coefficients α TETs of the united stations are the same, and increases with increasing difference between them.

The values of Δ Q may be calculated by use of a planimeter on the heating load graphs, but the study is more convenient with a previously prepared approximate expression [8].

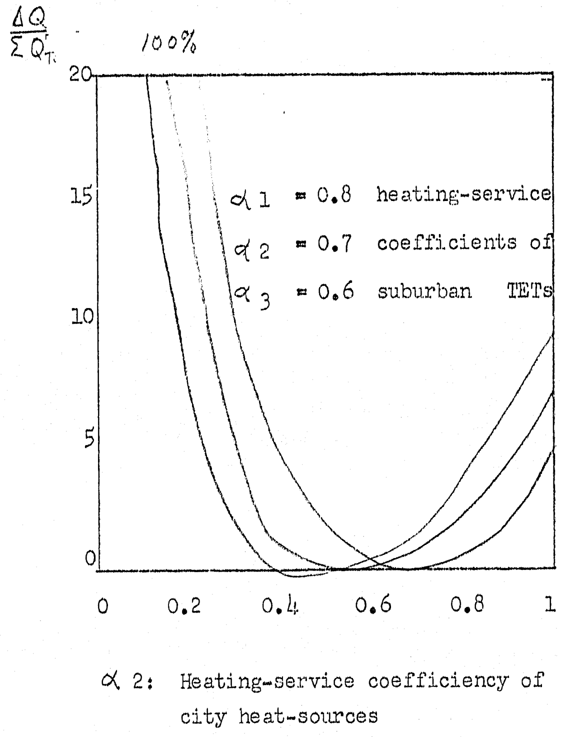


Figure 3. Relative Increase of Load on the Turbine Bleeders, in Percent, under parallel operation of suburban TETs and city heat sources.

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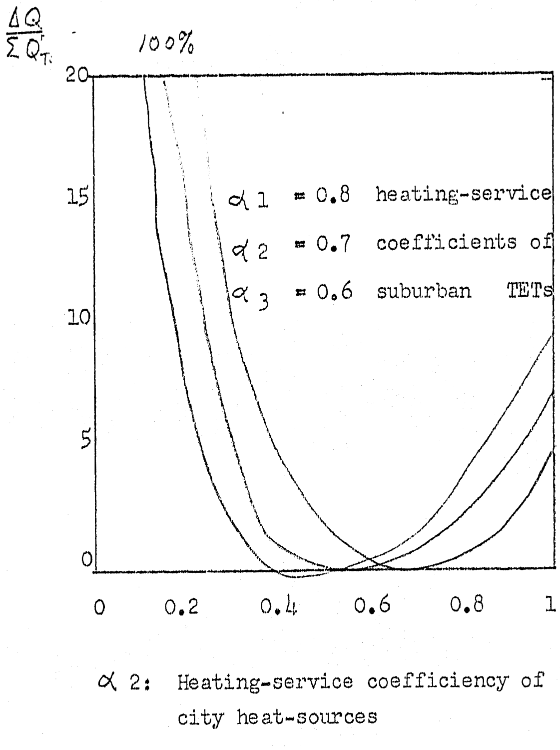


Figure 3. Relative Increase of Load on the Turbine Bleeders, in Percent, under parallel operation of suburban TETs and city heat sources.

Figure 3 shows, for one of the cities of the II climatic zone, the heating load and the relative increase of the turbine-bleeder load with parallel operation of a suburban TETs and sources of heat in the city itself, as compared with their separate operation. When the heating-service coefficients of urban and suburban TETs are 0.45 and 0.8, respectively, for instance, the supplementary bleeder load amounts to only 6%. If, however, district boilers are included in the city heat-sources and thus bring the heating-service coefficients for the city as a whole down to, say, 0.3, then the increase of the bleeder load already amounts to 14%.

It must be emphasized in this connection that the relative increase in the electric power generated during the operation of the heating service rises to larger values than the increase in the load on the turbine bleeders. The reduction in the losses that result from the changing conditions of the output of heat from the bleeders exert a substantial influence in this respect. Under the conditions of parallel operation: (a) the total length of the operation of the bleeders with the maximum rated productivity increases at the base or off-peak TETs; and this increase cuts the losses from the fluctuating operating conditions in the high-pressure part of the system, due to the fall in internal relative efficiency and the changing feedwater temperature as the input of steam to the turbine is reduced; (b) the total duration of the output of heat from the regulated bleeders at the peak-output station drops, and this consequently also cuts the power losses caused by throttling down the flow of steam to the low-pressure part of the system by using the regulator-valve in the bleeder chamber, which valve is fully open only when the turbine is operating on condensation. (The latter is an essential point for schemes in stations where steam from regulated bleeders is used only for heating-service purposes).

The most convenient way of estimating the steam losses under "a" is by using the method proposed by L. A. Melent'yev, through what is termed the "thermal component of idling operation" χ_T [7]. The losses from throttling down the steam flow under "b" may be estimated by the ratio $X_d = \frac{\Delta Q_d}{Q_T}$, where ΔQ_D is the difference between the consumption of heat during idling of the turbine KO when the bleeder valve is turned on and the consumption when it is turned off. [9]. The idling coefficient presented $X_h = X_t + X_d$. Thus, for instance, for AT-25 turbines,

$$X_T = 0.1,\ X_d = 0.045 \text{ and } X_n = 0.145.$$

An analysis shows, the fuel economy that results from the reduction of these losses under the conditions of parallel operation of TETs with monotypic turbo-aggregates may be determined by using the "reduced redistribution effect" ΔQ's which increases the "heat redistribution effect" ΔQ by an amount equivalent to the fuel economy resulting from the reduction in the total losses connected with the fluctuating conditions of turbine-bleeder load under parallel operation. The value of the reduced effect, after derivations which we shall not give here, is represented in the form of the following expression:

$$\Delta Q' \frac{\Delta Q}{1-\chi_n} + \frac{\chi_n}{1-\chi_n} \sum_{2}^{K} Q_{Ti}\, \Delta n_i \qquad (1)$$

where Δ ni is the length of operation of the TETs turbines (from the 2nd to the K-th) with the bleeders turned off.

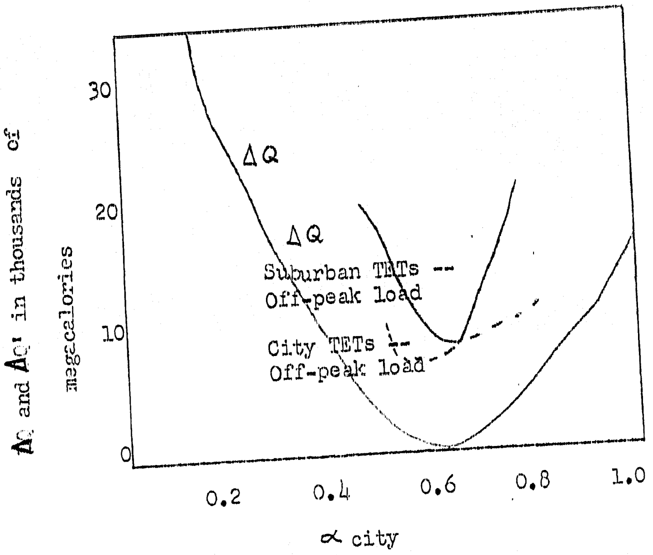


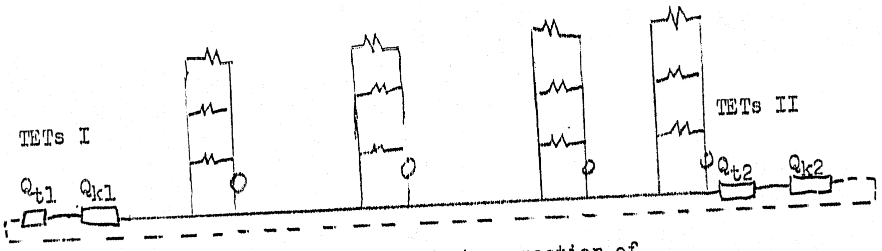
Figure 4. Influence of fluctuating remine on the efficiency of parallel operation.

[See Figure 5 on next page]

This influence of the fluctuating regime is illustrated in Figure 4 by one of the examples of parallel operation of city and suburban TETs. It is obvious that the second summand in Formula (1) is equivalent to the economy that can be attained even where the α TETs of the united sources are equivalent.

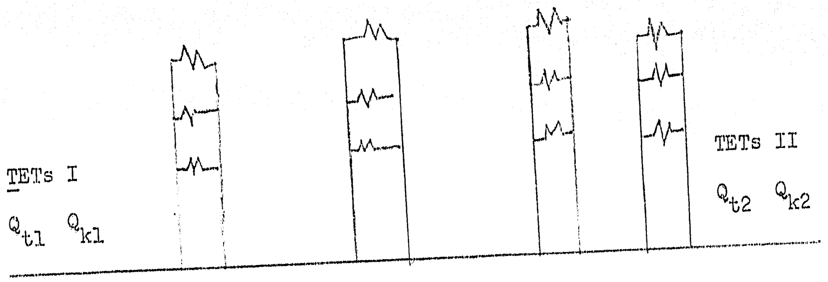
As far as maximum utilization of the productivity of the turbine bleeders is concerned -- "maximum Δ Q) -- the sequence in which the individual TETs are turned on makes no difference. However, as follows from Formula (1), the value of the "reduced redistribution effect" (and together with it, that of the supplemental output on heat-service regime) does not depend on the order in which the TETs or the individual turbines are switched into the network. This

(a)



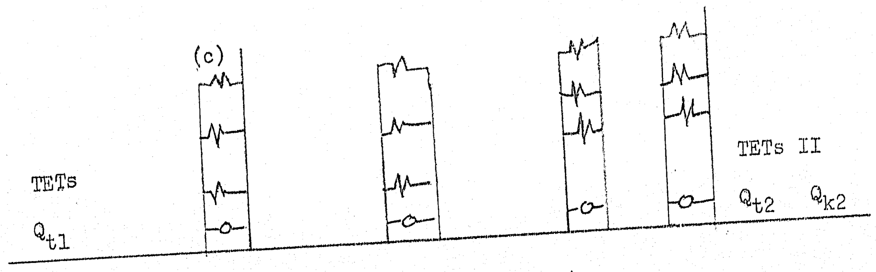
Scheme with independent connection of consumers of distributing network (Scheme II)

(b)

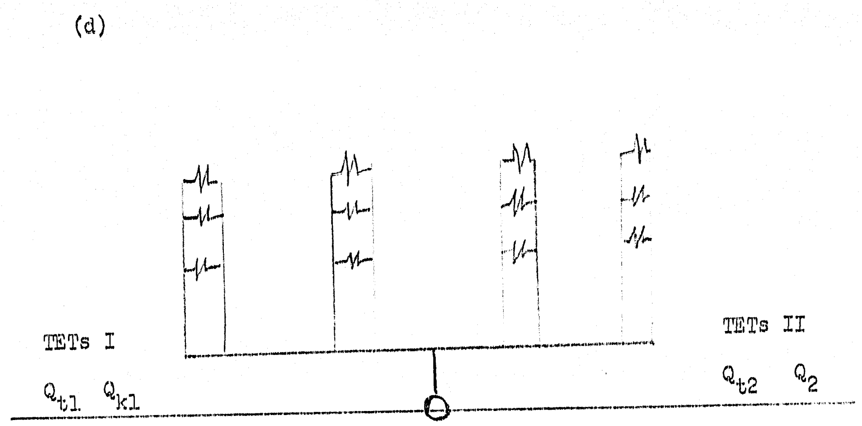


Scheme with elevator connection of consumers (Scheme II)

(c)



Scheme with booster pumping-mixing substations (Scheme II)



Point of Central Mixing

Scheme with central mixing (Scheme I)

Figure 5. Principal Schemes of Type I and II for Parallel Operation of TETs on Common Networks.

is illustrated in Figure 4 by variants in the location of the suburban and urban TETs in the base period [off-peak portion] of the load-graph.

The economy of fuel attained by parallel operation, as compared with the individual operation of the TETs, due to the reduced redistribution effect for monotypic stations, may be determined by the formula

$$\Delta B_T = \Delta Q'_y \Delta b \cdot 10^{-3} \text{ tons of coal per annum} \tag{2}$$

where y is the unit output of electric power of the TETs on heating-service operation, expressed in kilowatt-hours per megakilocalories; Δ b is the difference between the unit fuel consumption under the system of substitute working of stations and that on heating-service regime, expressed in kilograms of coal per kilowatt-hour; and Δ Q' is the reduced redistribution effect in megakilocaloires [MKKAL).

Analysis of the energetic efficiency of parallel operation of the TETs with heterotypic equipment shows that the sequence of switching the individual TETs into the system requires special calculation. It is, for instance, by no means obligatory that the high-pressure TETs should handle the base or off-peak load, while the medium-pressure TETs should take the semi-peak or peak parts of the load curve. This question will be separately considered in detail elsewhere.

Analysis of the parallel operation of TETs on a common heat-load graph allows us to draw the following conclusions, on which the choice of the regulation systems and schemes of heat-service networks should be based.

1. The energetic effect of parallel heating-operation is attained by the consecutive cutting in of the TETs into the heat-supply system, as the load increases. Thus the base TETs at the beginning of the heating season must cover the entire area of the system, and then gradually reduce the zone of its activity.

[See next page for Figure 6]

2. The heat-sources should be cut in in such an order that during the initial period bleeders of the turbine groups of all TETs -- from the first to the last -- are turned on consecutively. Subsequently, at times of peak heating load, the TETs boilers are

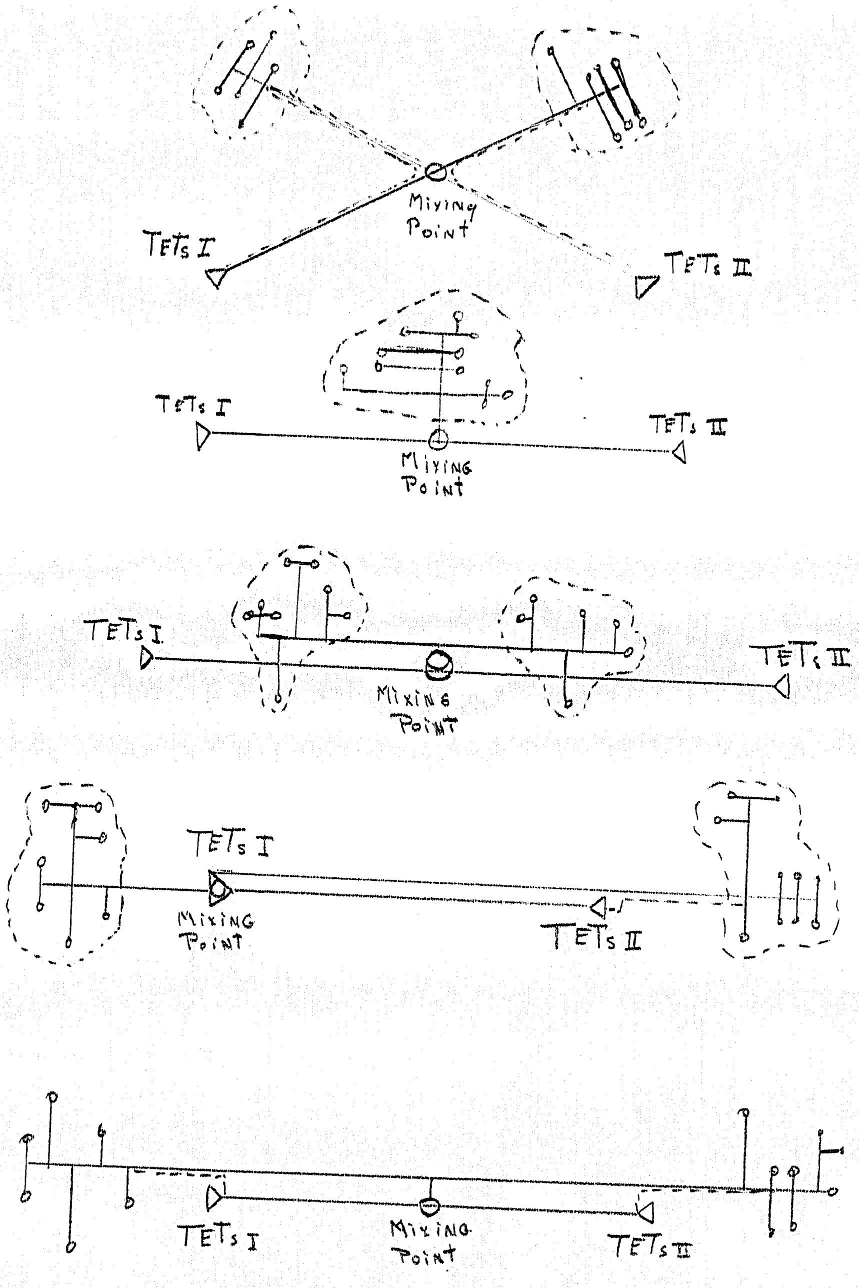


Figure 6. Variants of Schemes of I Type with Central Mixing

then turned on, but these may perhaps follow in a different sequence. (It is assumed [redacted] that the bleeders of the turbines at each individual TETs are also turned on consecutively.)

3. The increase in the output of heat at each new stage should be handled in such a way as to hold the output of heat constant during all the preceding stages. If this principle cannot be fully observed under the conditions of the temperature graph of the hot-water heating network, within the limits of regulation of the bleeder pressures, then at any rate the resulting reduction in the productivity of the bleeders at the peak-service TETs should not exceed the corresponding reduction of bleeder productivity for isolated operation. (It is assumed that the water temperature in the delivery mains is the same for isolated operation as for parallel).

4. The order in which the TETs are turned on into the heat-supply system is determined in accordance with the electrical capacity of the TETs, their parameters - both initial and in the bleeders - and their boiler efficiency, as well as on their assumed operating temperatures. (Assuming the same conditions of fuel and water supply). Thus, while in parallel operation of thermal electric-power stations on a single grid, the order in which the several stations are switched into the system is determined exclusively by the relative operating costs of the stations - the off-peak portion of the electric load curve being handled by the stations that produce power at the lowest unit cost - this criterion is not the only one to be considered in parallel heating operations of TETs. It is entirely probable that less-economical TETs will be put on the off-peak section of the heating-load graph. Each individual case demands special consideration.

5. When the boiler-installation efficiency varies between the different TETs, its value determines not only the order in which the boilers are fired, but also that in which the bleeders of the individual turbines are turned on.

6. The scheme under which the TETs are arranged in blocks for the heating networks should simultaneously assure the possibility of section arrangement in cases of station breakdowns or other conditions, and of parallel operation on a joint heating-load graph under the conditions of the normal regime.

It must be emphasized that the simultaneous satisfaction of all these demands is not always possible or expedient in practice. But only an analysis that starts out from these general assumptions allows establishment of the actual limiting conditions. And if it should in any given case prove impossible to set up an "ideal" parallel operation on a joint load graph, that ideal should still be approximated as closely as possible.

As has been pointed out above, all forms of the energy gain from parallel heating-operation of TETs are achieved by consecutively (in time) turning on the turbine bleeders into the heating-supply system. To achieve the maximum gain with this, the scheme should assure constant heat-output from all the sources previously turned on during the period in which case the productivity of each successive source will increase. The attainment of this objective with respect to a two-pipe hot-water heating networks is possible in two directions: (a) by the establishment of Type I schemes with central mixing, (Type I schemes with central mixing were propsed in a 1949 work of the ENIN), in which case the streams of thermophore [heat-carrier] from all of the TETs are mixed at one or more central points, from which all consumers are directly supplied; (b) by the establishment of Type II schemes with variable streams of water distribution in the main-line networks, in which case the zones of action of the several TETs change in accordance with the variations in the outside temperature.

Figure 5 given the principal schemes for the parallel operation of TETs on joint heating networks.

Type II schemes are as follows: (a) with independent connection of the consumers or of the distributing networks, through water-preheaters; under this scheme constant circulation is maintained in the local systems, while redistribution of the load among the TETs is accomplished by means of redistribution of the water streams in the main-line networks; a detailed analysis of this scheme has ben given in an earlier paper [10]; (b) with elevator connections and installation of automatic regulators on the consumers' premises to hold the discharge (head) at constant levels; (c) with booster-mixer pumping substantions to maintain a constant circulation in the consumers' lines or in the distributing networks, with varying discharge-rates in the main lines.

Of the Type II schemes, scheme a officers the greatest possibilities for satisfaction of the requirements of parallel operation on a joint heating-load graph.

Type I schemes require the laying of feeders between the separate TETs and the central mixing points. The role of these mixing points can of course also be assumed by separate TETs, according to the lay-out of the heat-mains. The latter is most probable under the conditions of long-distance heating supply, and immediate connection of consumers with feeders of Type I schemes should not as a rule be made. Type I schemes are mainly characterized by the fact that they allow parallel heating operations of TETs under a stable hydraulic regime in the network throughout the entire heating season. Regulation is assured by changing the temperature of the water streams arriving at the mixing points from the various TETs. According to the relative positions of the heating districts and the sources, Type I schemes are designed and executed in a number of variants, examples of which are given in Figure 6. Comparative analysis and the technical and economic comparison of these schemes will be presented in a separate paper.

3. The Technical and Economic Principles of Suburban TETs.

A decisive factor in the construction of suburban TETs is the solution of the problem of improving the sanitary conditions involved in the necessity for burning fuels with sulfur and high-ash content in a good many cities.

An energy scheme of electric and heating service, based on a suburban TETs, involves additional capital and operating charges for the arterial heat-main and for the generating capacity required to service the operating needs of long-distance heat transmission.

However, under certain conditions, a suburban TETs does afford a number of economic advantages in comparison with an energy scheme based on a TETs in the city itself.

The construction of a suburban TETs allows transition to a higher capacity equipment (and station), inasmuch as the above discussed limitations imposed on the capacity of a TETs within the city limits no longer obtain.

The determination of the most advantageous capacity of a suburban TETs relies both on the characteristics of the heating load and their satisfaction by the various types of turbines as boilers, (the standards of the boilers and the selection of their number here play an essential role.), and on the indices of the structure of the electric power system in which the suburban TETs is to be included. The factor of the district energy balance is very important, and in many cases is of decisive significance. The theoretical principles of the solution of this problem will be the subject of a special work. There is sufficient reason for assuming, as a first approximation, that the proper electrical capacity of a suburban TETs and of its single aggregates will be double that of a TETs located in the city itself. (Except for a suburban TETs of 12000 kilowatts capacity, replacing a city TETs of 8000 kilowatts, which has been adopted in view of the standards for heating-service turbines. The number and productivity of the boilers at each station are based on the balance of steam for generating electric power and heat, taking account of the need for a local reserve of steam capacity. The calculations assume isolated heating operation of the suburban TETs.)

In fact, as shown by the preliminary data of the investigation into this question, relatively higher ratios between the capacities of the suburban TETs and the city TETs they replace must be expected in individual districts, if we take into account the possibility of expanding the coverage of the heating service for a suburban TETs by way of increasing the rated value of α TETs.

The index α_{TETs} reaches its optimum value for fuel economy at suburban TETs. The transition to more powerful units also works in the direction of fuel economy. All these factors assure the economy of capital charges and of operating costs for fuel.

At suburban TETs, under certain conditions, the cost of fuel supply, water supply, ash removal, and ash and sulfur suppression in the discharged smoke, are all less than in a city TETs.

Finally, the increase in the electrical capacity of a suburban TETs cuts or eliminates the cost of high-tension network from the condensation electric power stations, located at fuel bases which are considerably further from the center of electric consumption than the suburban TETs.

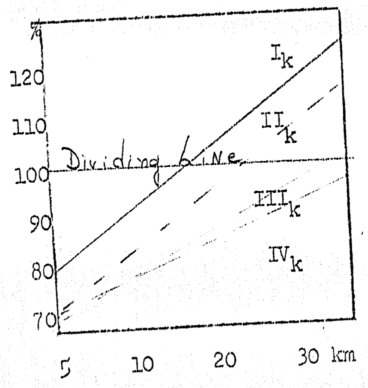


Figure 7. Relative Variation of Unit Capital Investment in Electric Power and Heat Facilities in Dependence on the distance of Heating-Service, for Suburban TETs of Varying Capacities.

[See next page for Legnd on Figures 7 and 8]

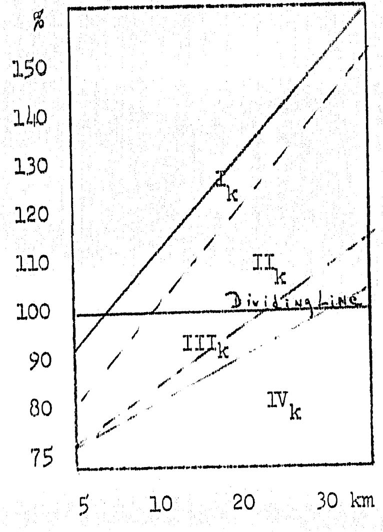


Figure 8. Influence of the Isolated output of Heat on the two Lines on the Relative Variation of Unit Capital Investment in a Suburban TETs as Compared with a City TETs.

Legend for Figures 7 and 8:

I_k : suburban TETs of 12000 kilowatts capacity;
II_k : the same, 24000 kilowatts capacity;
III_k : suburban TETs of 50000 kilowatts capacity;
IV_k : suburban TETs of 100,000 kilowatts capaity.

The isolated energy schemes work with the city TETs. The Unit capital investments in the power schemes with the city TETs, as compared to the capital investments for the suburban TETs, are taken at 100%.

[redacted]

Figure 7 gives the characteristics of the relative changes in the capital investment per unit of electric power and heat for suburban and city TETs, in dependence on the distance of heating supply (the length of the main-line heating-service network from the TETs to the junction with the distributing network) and on the capacity of the TETs.

The indices of capital investment for the energy schemes from the suburban TETs include the cost of the TETs and the main-line heating network, (the costs for the arterial heating-main in Figure 7 are given for a single two-pipe line. The influence of the variant with two two-pipe lines (and isolated working of the TETs) is shown in Figure 8. These capital costs should be reduced by increasing the water temperature and providing for parallel heating operation between suburban TETs and city heat-generating sources) taking account of the cost of providing electric generating capacity to compensate for the electric power used in pumping water, as the capital costs for the extracting of fuel.

The corresponding indices for the power scheme using the city TETs take account of the construction of the TETs and of the supplementary electrical generating capacity located at a large-scale electric power station; (the supplementary generating capacity is equal to the difference between that of the suburban station and the city station it supplants; in determining the economic indices a regional power station of 100000 to 200000 kilowatts was assumed) and the cost of transmitting the current to the city and the corresponding capital costs connected with extraction of fuel are also figured in. (The capital costs for rail transport of fuel to the suburban TETs and to the city TETs make up an insignificant proportion of the total capital costs, and are roughly equal. They can therefore be omitted in a comparative analysis.

The curves in Figures 7 and 8 are given for the conditions of using Moscow Basin coals. The graphs show the decisive influence of TETs capacity on the relative indices of unit capital investment for the power schemes compared.

For suburban TETs of 50000 kilowatts capacity and upwards, the unit capital investment per unit of generating capacity is 7-16 percent lower than for the power schemes with a city TETs, even when the suburban TETs is 30 kilometers away. At 25000 kilowatts capacity for the suburban station, both variants are equally economical in capital investment for lengths of the arterial heat-main not over roughly 22 kilometers, and for not over 10 kilometers for a 12000 kilowatts suburban TETs. The location of a suburban station at a greater distance (in Figure 7, the zones to the right of the critical points for curves I_k and II_k) requires a steadily increasing supplementary capital investment by comparison with the city TETs.

[See next page for Figure 9]

Figure 9 gives the structure of the capital investment for the respective energy schemes of electric and heating service being compared. The factor of concentration stands out in the foreground in the reduced cost of the suburban TETs.

What consequences does the new suburban TETs energy scheme involve in the field of fuel costs?

Figure 10 gives the variation in the indices of annual fuel

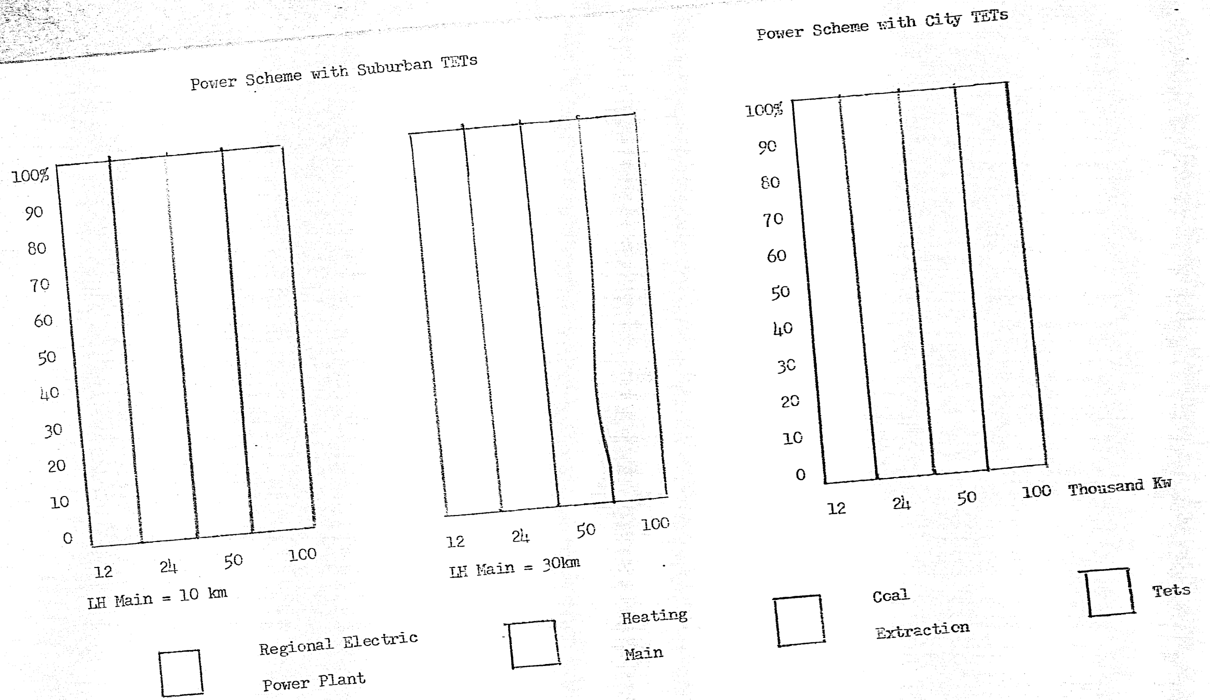


Figure 9. Relative Structure of Adjusted Unit Capital Investment In Power Schemes with Suburban and City TETs

consumption for electric power generated and heat produced for service. These indices realte to 1 kw. generating capacity of the suburban TETs and are given in dependence on the distance of heat transmission for various TETs capacities.

The new power scheme with a suburban TETs affords an economy in fuel consumption only for capacities of over 50000 kilowatts.

The following are the factors that determine the variations in the unit fuel consumption:

1. The index α_{TETs} is increased when we pass to the suburban TETs. At city TETs it is 0.5, while for suburban TETs it is about 0.8; this increases the output of electric power during the generation of heat for the service.

2. Transition to the suburban TETs is accompanied by an increase in electrical capacity. This factor acts, consequently, in the opposite direction: at the same annual number of hours of utilization of the installed electrical capacity (5500 hours), the value of X_{TETs} ($X_{TETs} = \frac{W_t}{W}$, where W_t is the amount of electric power generated in the course of heat-service generation, and W is the total electric power generated (heat-service and condensation)), for suburban TETs becomes appreciably lower than for city TETs. This appreciable reduction in the value of X^{City}_{TETs} (by 15-25 percent), results in increasing the mean annualunit fuel consumption for generating electric power, since the unit fuel consumption per kilowatt-hour generated in the condensation regime amounts (in kilograms of standard fuel) (the calculations were based on the power characteristics of the corresponding types of turbines. The first figure is for a TETs of medium pressure, and the second for one of high pressure. For a

city TETs it is 0.535 and 0.450 kilograms/kilowatt hours respectively. The somewhat higher unit costs for city TETs result mainly from the conditions of water supply), to 0.525-0.43.

3. The share of the electric power generated at the Regional Power Station (RES), replacing the supplemental power generated at the suburban TETs, in connection with the increased power of the latter, also exerts an influence on the mean annual fuel consumption in the scheme of the city TETs (for the RES operates with high-power units having high initial parameters). This circumstance increases such mean annual fuel consumption and thereby increases the relative efficiency of the suburban TETs scheme.

[See next page for Figure 10]

4. The fuel consumption absorbed by the long-distance transmission of heat (the consumption of electric power at the booster substantions, plus the heat losses) increases the total fuel consumption in the suburban TETs scheme as compared to the city TETs.

The factors we have enumerated, which act in opposite directions, determine the resultant indices of fuel consumption for generating electric power and heat in the energy schemes under comparison.

The propositions set forth above are likewise characterized by Figure 11, on which are plotted the curves of the relative indices of fuel consumption in dependence on TETs capacity at the two levels of heat-transmission distance, 10 and 30 kilometers.

The dependences shown on Figure 11 are accurate for the assummed indices of structure, parameters and regimes of the suburban and city TETs power schemes under comparison.

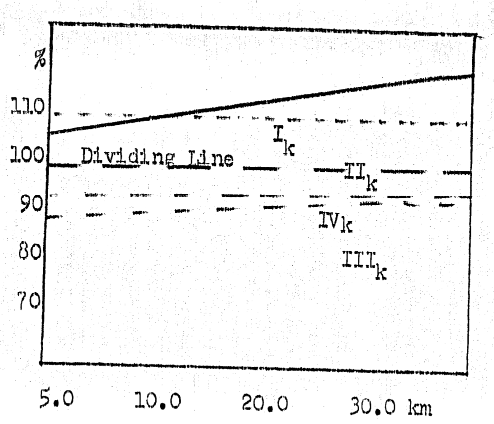


Figure 10. Relative Variations in the Indices of Fuel Consumption for Generating Electric Power and Heat.

I_k , II_k, III_k , and IV_k are the indices of fuel consumption in the energy scheme using a suburban TETs of 12000, 24000, 50000 and 100000 Kilowatts respectively. The indices of fuel consumption in the power scheme using a city TETs are taken as 100 percent.

The effectuation of parallel operation between the suburban TETs and urban heat-sources sharply increases the economy of the suburban stations with respect to fuel consumption, since in the latter case the suburban stations carry the base or off-peak load of the heating graph, while the city stations come in at the peak and semi-peak of the graph.

The conclusion may be drawn that under certain conditions the power scheme using a suburban TETs may even assure fuel economy as compared to an energy scheme with a city TETs. At the same time the existence of the suburban TETs reduces the carriage of fuel into the city. The annual haulage of fuel (Moscow basin coals, peat) into the city is cut by more than 500,000 tons for a TETs of 100,000 kilowatts.

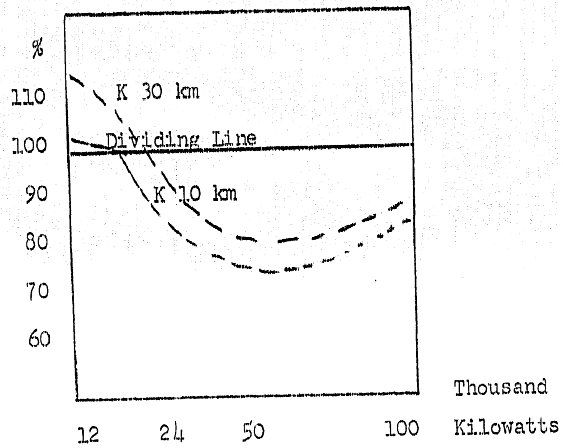


Figure 11. Relative Variation of Indices of Fuel Consumption for Generating Electric Power and Heat, in Dependence of the Capacity for the TETs.

K30 and K10 are the power schemes with suburban TETs supplying heat over a distance of 30 and 10 kilometers respectively. The indices of fuel-consumption for the power scheme using the city TETs have been taken at 100.

It is finally, necessary to determine the influence of the new energy scheme using a suburban TETs on the synthesizing indices of production cost that cover both electric power and heat generation. Calculations and analyses have been made on the operation of a TETs with Moscow Basin coal and with peat. As with other characteristics, the energy schemes to be compared are here also presented in comparative form.

Figure 12 gives the composite indices of the capital costs for power and heat installations per kilowatt of electric generating capacity, in relation to the distance of heat transmission, for TETs of varying power.

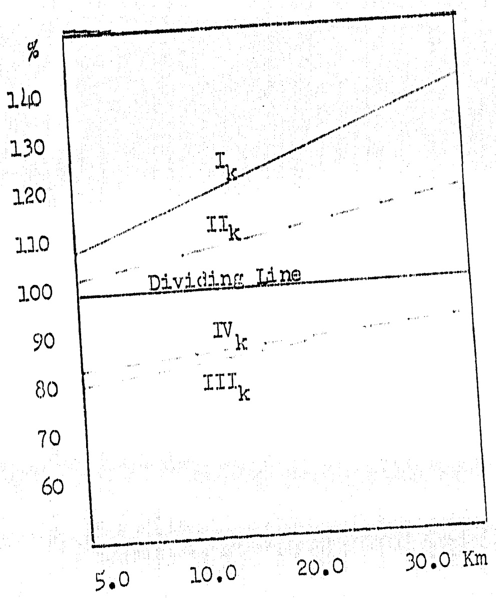


Figure 12. Relative Variation of indices of Operating Costs for Electric Power and Heat in Power Schemes with Suburban and City TETs (Burning Moscow Basin Coal).

I : suburban TETs of 12000 kilowatts capacity;
II : suburban TETs of 2400 kilowatts capacity ;
III : suburban TETs of 50000 kilowatts capacity;
IV : suburban TETs of 100,000 kilowatts capacity.

Analysis of the curves allows the following to be established: the factor of the capacity of the suburban TETs, as followed from the consideration of the characteristics of the unit capital investment and of the fuel consumption, plays the dominating role in the economics of the new scheme and in the indices of production cost of electric power and heat.

The operating costs for the long-distance transporation of heat, for 1 megakilocalorie [MKKAL] of heat and 1 kilowatt of generating capacity, which increase the cost of the power scheme with a suburban TETs, increase with increasing length of the network and sharply fall with increasing capacity of the suburban; this is shown by the data of TABLE 3.

For a low-pwer TETs, the expense of operating a heating main 30 kilometers long roughly, more than doubles the production cost of 1 megakilocalorie of heat, while for high-power stations that cost is increased by less than 1.5 times.

The indices of unit fuel consumption exert as substantial influence on the relative economy of energy schemes with suburban and urban TETs, with respect to the operating costs.

We have already considered the factors that determine the variation of this index for energy schemes with TETs of varying power and with various regimes for generating electric power and heat at varying distance of heat-supply. The same factors also determine the variations in the fuel component of the generating cost of electric energy and heat.

Variation in the fuel component is the principal cause for the "jump" in the reduction of the total operating costs of suburban TETs of 50000 kilowatts capacity (conversion to high pressure, increase of α TETs, etc.)

[See Table 3 on next page]

The reduction in labor costs in connection with the reduction in the number of personnel employed at a TETs of 1000 kilowatts power

TABLE 3

DISTANCE OF HEATING SUPPLY IN KILOMETERS

Power of Suburban TETs in Thousand Kilowatts	TETs of 12000 kw = 100%	Length of Heating Main 10 Km=100%	TETs of 12000 kw = 100%	Length of Heating Main 10 km =100 %	TETs of 12000kw = 100%	Length of Heating Main 10 km =100%
12	100%	100%	100%	189%	100%	280%
24	71.4	100	67.6	179	67.4	264
50	50.3	100	47.1	177	44.5	248
100	42.2	100	40.5	181	39.0	258
		100				

plays a substantial role in the increase in the economy of TETs as their power is increased.

In the transition to a large suburban TETs, however, the influence of this factor is levelled off by the increased role played by the high-power RES in the power schemes with the city TETs, to compensate for the supplementary electrical capacity of the suburban TETs.

CONCLUSIONS

The construction of suburban TETs of 50000-100000 kilowatts capacity and above, with a range of heating supply of the order of 20-30 kilometers, affords economic advantages, under certain conditions, in comparison to low-power TETs in the city. The improvement of sanitary conditions in cities where high-ash and sulfur-content fuel must be burned is of decisive importance. The economy of suburban TETs is considerably improved at capacities of 150000 and 200000 kilowatts.

It is necessary to continue studying the questions of selecting the capacity, type of equipment and operating regime of suburban TETs under the conditions of parallel heating operation with city sources of heat, and also under the conditions of gas being obtained from the operations as well; and likewise the question of the scheme and parameter for the arterial heating-mains and the system of parallel heating operation, with wide application of non-linear electrical models of heating-supply systems. The power-engineering peculiarities of the separate types of cities and the structure of the electric power systems should be taken into consideration in the course of such studies. The planning and survey work in this direction must be energetically prosecuted in a good number of USSR cities.

The production of gas by the ENIN method at suburban TETs makes it possible to provide electric, heating and gas service for cities at operating and capital costs considerably lower than those required by the existing isolated power-engineering scheme.

Our power-systems are the first in the world to be converted into integrated power systems with combined generation of electric power, heat and gas, with an intimate connection between the graphs of production and distribution of the various forms of energy. The erection of the mighty structures of communism, and the impending transmission of large quantities of electric power from huge hydro-electric plants to powerful power systems generating electric power, heat and gas simultaneously, raises anew the questions as to the structure and regime of such systems. These new questions on the operation of power systems of complex structure should already constitute the subject of profound investigations.

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