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Development of Centralized District Heating in Russia

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Abstract—Total balances of production and consumption of low-grade thermal energy in Russia up to the year 2030 are presented. It is shown that demand for thermal energy is the key problem for further development of centralized district heating in the country.

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Centralized district heating in Russia had reached an enormous scale by the beginning of the last decade of the 20th century. Centralized sources of heat in the country produced more than 8.4 billion GJ (2 billion Gcal) of thermal energy per annum. More than one-third of the fuel oil consumed in Russia was fired to generate such a quantity of heat. Almost half of the heat for centralized district heating purposes was produced at cogeneration stations (CSs) (i.e., jointly with generation of electricity), a technology due to which tens of millions tce were annually saved in the country. Development of centralized district heating allowed the difficult challenges connected with reliable supply of heat (and electricity) to the rapidly growing industry, fundamental improvement of labor productivity in power engineering (by closing a great number of low-efficient boiler houses operating on solid fuel), and improvement of the situation with environment in settlements where low-grade solid fuels were used to be met in the most efficient way.

Undoubtedly, the system of centralized heat supply that has been created in the country for many decades is its national property. However, the conditions for operation and development of centralized district heating systems, as well as those for competition between the separate and the combined methods for generating thermal energy, have altered essentially as a transition was made in Russia to a market economy, as the share of natural gas increased considerably in the fuel balance, and as new high-efficient technologies that usl small sources of heat emerged.

It is important to note that the notion of "centralized district heating" is, in a sense, a conditional one and depends in many respects on the content of information available. The problem is that data on generation, distribution, and consumption of heat energy that are gathered in the country and reflected in specialized forms for statistical observation (11-TER, 1-TEP, 6-TP, 4-TER, 22-ZhKKh, and 1-natura) are often incompatible due to differences in the composition of economic entities covered by them, and in defining the parameters being observed. These forms were developed at different times, by different teams, and for different purposes. Small enterprises do not present "energy" statistical report forms at all. There is also a lack of definiteness in how to reflect some new types of heat sources, e.g., mini CSs built around internal combustion engines, in the existing forms used for statistical observation. Thus, any quantitative estimates relating to development of centralized district heating systems contain certain elements of ambiguity from the very beginning, which can manifest themselves especially strongly under market economy conditions. Indeed, the composition of heat sources included in various forms of statistical reports can vary significantly as different companies merge with and absorb other companies. This is why considerable differences are observed in assessments of the amount and structure of generation and consumption of thermal energy in the country made by different authors.

According to the approach that has been commonly used by Russian experts specializing in power engineering, they distinguish centralized, decentralized, and independent (individual) supply of thermal energy to consumers [1, 2]. Such classification is convenient in that respective sources of heat are characterized by fundamentally different compositions of equipment. All CSs, industrial and production boiler houses, different types of industrial heat-generating installations (including hear-recovery ones and others), as well as heating boiler houses with a capacity of 23.3 MW (20 Gcal/h) or more, are traditionally related to the category of centralized heat sources. If heat is supplied to consumers (usually, nonindustrial ones) from boiler houses with a capacity of less than 23.3 MW (20 Gcal/h), such supply is considered as decentralized. If heat is supplied to consumers (usually, households) by means of individual heat generators, including stoves, this supply is called independent. However, it should be noted that a great number of individual heat generators are used in both production and nonproduction sectors of economy that should also be related to independent heat supply sources. Then, taking the total quantity of thermal energy generated by the above-mentioned heat sources into account, one can make up the income side of the

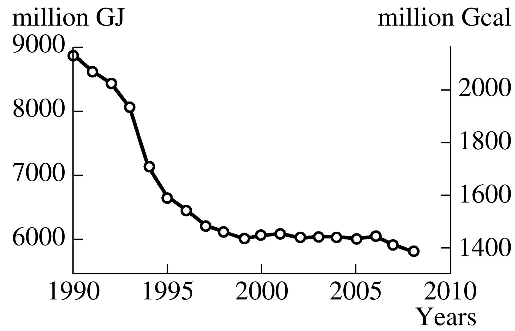

Fig. 1. Production of heat from centralized sources in Russia for the period from 1990 to 2008.

balance of low-grade thermal energy (hot water and steam) in the country.

If we proceed from the statistical information gathered in Russia in terms of its completeness and quality, the proposed classification of methods of heat supply turns out to be quite sufficient and very convenient for solving many problems important for practical purposes, in particular, those related to developing a system of fuel-and-energy balances (FEBs) for Russia and its regions. In this case, if we wish to estimate the quantities in which heat from centralized sources is produced in the country, it is advisable to use data from the forms of state statistical reports that correlate generation and consumption of heat, as well as expenditures of fuel, which makes it possible to verify the available information (these are the forms 11-TER, 6–TP, and 4-TER). Taken together, they reflect the supplies of thermal energy to consumers from the following sources:

all CSs, including nuclear ones;

all industrial–production and district boiler houses;

heating boiler houses with a unit capacity of 23.3 MW (20 Gcal/h) or higher or a combination of such boiler houses with a total capacity of 23.3 MW (20 Gcal/h) or higher;

rural boiler houses and electrical boiler houses; and

heat recovery and other industrial heat-generating installations.

Of course, information from other forms of statistical reports (primarily, from the forms 1-TEP and 22-ZhKKh) should also be used for analyzing district heating systems and making up heat balances. The quantities of heat generated by decentralized and independent sources are determined from so-called direct expenditure of fuel by consumers. Such an approach for making up an FEB is so far the most correct one, since reliable statistical information that would correlate the production of heat by decentralized and independent sources with the corresponding expenditures of fuel, and all the more so by its types, is lacking. For this reason, the thermal energy produced by individual heat generators is often included in decentralized heat supply [3].

Besides, an extended interpretation of the notion of "centralized district heating," according to which the heat produced by all boiler plants is taken into account irrespective of their capacity, has become popular in recent years. In fact, we are witnessing a unification of the notions of centralized district and decentralized heating by means of supplying thermal energy to consumers by a network of pipelines in the form of hot water and steam ("network heat"), irrespective of the type of a heat source. This extended interpretation of centralized district heating is used, in particular, in very informative paper [4]. Attempts to extend the notion "centralized district heating" and make up balances of total low-grade heat should be recognized as fruitful ones in solving a wide range of problems, e.g., those related to substantiating technical policy in the field of heat supply, selecting a rational share of heat supply to concrete inhabited localities, etc. However, statistical data on heat generation and consumption must be used very carefully in this case in order to avoid the possibility of making their "double-entry" records.

Estimating how much thermal energy is consumed by households for space heating and hot water supply (HWS) is the most complicated task, because the composition of statistical information gathered in the country does not allow this to be done unambiguously. Quantitative data on the thermal efficiency of the existing dwelling stock are characterized by high degree of uncertainty. It is difficult to use the official data on the level of its comfort. The Federal Service for State Statistics (Rosstat) gives information on the extent to which the dwelling stock is furnished with district heating and HWS systems. Space heating is considered irrespective of a heat source, be it a CS, an industrial boiler house, a block, group, or a local boiler house, an independent HWS system, an individual prefabricated boiler or a boiler built into a heating stove, or other heat sources, with the exception of stove heating [5]. According to Rosstat formulation, HWS means hot water supplied through special water supply lines to living apartments for domestic needs of population either from centralized sources or from local water heaters [5]. Thus, there is obvious mixing of different methods for obtaining thermal energy. It should be emphasized that, in this study, the traditional understanding of district heating is used.

An analysis of retrospective information showed that the country's transition to a market economy was accompanied by a sharp decline in the quantity of heat generated by centralized sources (Fig. 1). From 1990 to 1998, the consumption of heat in the country dropped by 1.5 times, which was caused primarily by a decline in the industrial production and restructuring of the economy (during which the share of less energy-intense branches increased in it). The fraction of the production sector in the total consumption of heat decreased from 76 to 63% for this period of time. After 1998, there came rather a long period of stable heat consumption. In 1999–2006, the annual production of heat generated

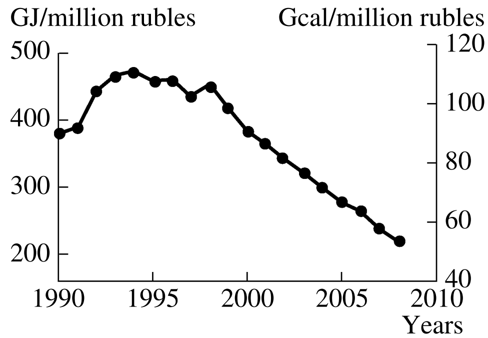

Fig. 2. Heat intensity of Russia's GDP (with respect to heat from centralized sources for the period from 1990 to 2008).

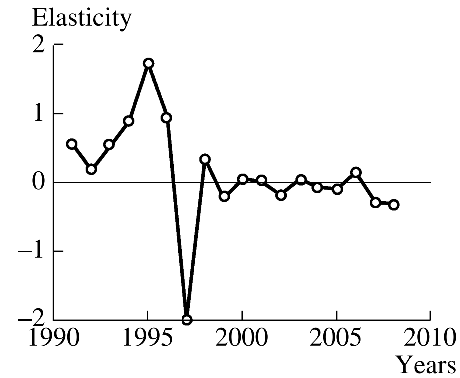

Fig. 3. Elasticity of heat consumption with respect to GDP.

in the country by centralized sources fluctuated within a narrow range from 5987 to 6072 million GJ (1430–1450 million Gcal) despite the rapid economic growth. From 2006 onward, the demand for heat supplied from centralized sources began to decline again.

Since 1998, monotonic but fairly rapid reduction in the heat intensity (with respect to heat from centralized sources) of the country's GDP has been observed (Fig. 2). Nonetheless, the 1990 level of GDP thermal efficiency was reached only in 2001. In 2008, the heat intensity of the country's GDP was already about 59% of its value in 1990. It should be noted that, here and henceforth, the heat intensity of GDP and any other macroeconomic parameter is understood to mean the ratio of the consumed thermal energy to the value of a given parameter measured in constant prices (in the present study, in 2005 prices).

Along with the structural reorganization of economy, energy conservation activities play an important role in reducing the energy intensity of the country's GDP. This can be seen from data on the elasticity of heat consumption for GDP (Fig. 3). After 1997, this indicator did not increase higher than 0.4 (its value was below 0.65 even with the GDP corrected taking into account external prices for exported hydrocarbon fuels [6]). In some years, this indicator fell into the region of negative values. By and large, the elasticity of heat consumption for GDP over the period 2000–2008 was negative (–0.07).

Proceeding from the available statistical information, the total consumption of low-grade heat in Russia (including all heat losses in networks) in 2007 can be estimated at 8256 million GJ (1972 million Gcal) (Table 1). If we exclude the heat losses in trunk networks [477 million GJ (114 million Gcal)] recorded by statistics, the actual consumption heat will be equal to 7779 million GJ (1858 million Gcal), including heat losses in intrafactory and intrablock networks, which are not recorded by statistics. Independent (individual) sources of heat supply to households account for 20% of this quantity (Table 2) or 1558 million GJ (372 million Gcal). The remaining 80% of this quantity equal to 6222 million GJ (1486 million Gcal) is delivered to consumers via pipeline networks in the form of hot water and steam supplied from centralized and decentralized heat sources. From the data on the fuel balances for different kinds of economic activity, the additional quantity of low-grade heat produced (and consumed) in 2007 by individual heat generators in different sectors of economy, primarily in the services sector, can be estimated at approximately 377–461 million GJ (90–110 million Gcal).

The list of major consumers of "network" heat includes households, processing kinds of production enterprises, and other kinds of economic activity represented mainly by the services sector. Taking together, they account for 74% of the thermal energy consumed in the country. A tendency toward a gradual increase in the fraction of the nonproduction sector (from 60.4% in 2000 to 61.5% in 2007) still remains in the structure of heat consumption (see Table 2). A large fraction of the nonproduction sector and its continuing growth are the most important features of heat supply in Russia, including district heating, that in many respects determine its future development. Households account for 55% of heat consumption in the nonproduction sector (supplies of heat from external sources). Seventy percent of thermal energy delivered to the household sector from outside is consumed for space heating and the remaining 30%, for HWS. In the production sphere, processing production facilities are the absolute leader in consumption of thermal energy. Chemical industry, metallurgy, petroleum refining, and food industry are the main heat consumers in this category (Table 3).

The figures on heat consumption in different sectors of economy presented in Table 1 were obtained by processing the Rosstat data with correcting them based on the results from an analysis of constructed dynamic series reflecting the consumption of thermal energy by the types of economic activity in entities of the Russian Federation taking into account the appropriate economic information (on the goods and services yielded from these kinds of economic activities). That great changes toward more efficient use of heat are taking place in the economy of Russia can be seen from the data on a fairly rapid reduction of the heat intensity of

Table 1. Consumption of low-grade heat in Russia

Economy sector	2000	2001	2002	2003	2004	2005	2006	2007
Consumption, total*	**7976/1905**	**7947/1898**	**7888/1884**	**7892/1885**	**7855/1876**	**7834/1871**	**7901/1886**	**7779/1858**
Mining industries	205/49	205/49	209/50	209/50	201/48	197/47	201/48	193/46
Processing industries	2006/479	1985/474	1939/463	1939/463	1930/461	1947/465	1951/466	1909/456
Construction	50/12	50/12	46/11	42/10	42/10	38/9	38/9	38/9
Agriculture	176/42	163/39	151/36	138/33	126/30	121/29	121/29	121/29
Transport and communications	147/35	147/35	142/34	142/34	138/33	134/32	138/33	134/32
Other kinds of economic activity	1900/453	1880/449	1851/442	1842/440	1809/432	1763/421	1767/422	1717/410
Households	3500/835	3517/840	3551/848	3580/855	3609/862	3634/868	3685/880	3668/876
heat supply from external sources	2047/489	2060/492	2081/497	2102/502	2119/506	2110/504	2148/513	2106/503
including:								
space heating	1352/323	1378/329	1419/339	1428/341	1449/346	1457/348	1507/360	1474/352
hot water supply	695/166	682/163	662/158	674/161	666/159	653/156	641/153	632/151
independent heat supply	1448/346	1461/349	1470/351	1482/354	1495/357	1524/364	1537/367	1558/372
Losses in trunk heat networks	461/110	461/110	469/112	473/113	477/114	486/116	502/120	477/114
Total	**8437/2015**	**8408/2008**	**8357/1996**	**8365/1998**	**8332/1990**	**8320/1987**	**8403/2007**	**8256/1972**

Notes: Figures in the numerator are in millions of GJ/yr, and those in the denominator, in millions of Gcal/yr.
* Including heat losses in intrafactory and intrablock networks.

the main kinds of economic activities (Table 4). At present, processing industries remain the most heat intensive ones. Unlike the majority of foreign countries, the services sector is very heat intensive in Russia, which is to a large degree due to the climatic conditions.

According to statistical data, an increase of heat losses in trunk heat networks was observed in 2000–2006: from 461 million GJ (110 million Gcal) in 2000 to 502 million GJ (120 million Gcal) in 2006 (see Table 1), or from 6.6 to 7.1% of the heat produced. Note that this occurred as the conditions of heat consumption were stabilizing and the length of the heat networks for general use in Russia was shrinking. The period 2000–2007 saw the length of heat supply networks for general use (i.e., without networks belonging to enterprises) decrease by 13 500 km, mainly due to the share of small diameter pipelines (Table 5). A growth in the number of worn-out pipelines seems to be the main factor due to which heat losses increased in the networks. For 2000–2007, the fraction of networks that needed to be replaced increased from 16.2 to 25.9%, despite the fact that they were repaired and replaced in significantly larger volumes. It can also be supposed that the improved quality of measuring the quantity of thermal energy delivered to consumers as a result of furnishing heat supply systems with instrumentation is another reason why growth occurred in the heat losses in networks recorded by statistical observations.

Table 2. Sectoral structure of the consumption of low-grade heat, %

Economy sector	2000	2001	2002	2003	2004	2005	2006	2007
Mining and quarrying	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.5
Processing industries	25.2	25.0	24.6	24.6	24.6	24.8	24.7	24.6
Construction	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5
Agriculture	2.2	2.1	1.9	1.7	1.6	1.5	1.5	1.5
Transport and communications	1.8	1.8	1.8	1.8	1.8	1.7	1.7	1.7
Other kinds of economic activity	23.8	23.7	23.5	23.3	23.0	22.7	22.4	22.1
Households:	43.8	44.2	45.0	45.4	45.9	46.3	46.7	47.1
heat supply from external sources	25.7	25.8	26.4	26.6	26.9	26.9	27.2	27.1
independent heat supply	18.1	18.4	18.6	18.8	19.0	19.4	19.5	20.0
Total	100	100	100	100	100	100	100	100

It is important to note that centralized heat sources (Table 6), which account for more than 72% of total low-grade thermal energy produced in the country (Table 7), make up the basis of heat supply in Russia. Decentralized heat sources occupy less than 10% of the market of heat. The remaining heat is generated by individual (independent) heat sources immediately at consumers (in households).

The structure of centralized heat sources that has been formed in the country remains fairly stable for already one and half decades (Fig. 4). Cogeneration stations and boiler houses are the main producers of centralized heat supply in Russia. However, the amounts of thermal energy they produce gradually decrease and are replaced by heat generated by heat-recovery installations and other industrial heat sources, in particular, those using various industrial wastes. Over the last 10 years, the share of CSs in the structure of centralized production of heat in Russia was around 44%, and that of boiler houses, around 49%. The ratio between CSs and centralized boiler houses also remained stable. Since 1999, the share of CSs in the total amount of heat generated by centralized boiler houses and CSs varied in a very narrow range from 47 to 48%. However, a trend towards a decrease of this share has become evident in recent years. After 2000, with the rise of tariffs for electricity, a stable trend toward a decrease in the quantity of heat generated by electric boiler houses and reduction of their share in the structure of heat production has emerged.

Growth in the share of individual heat generators in the structure of sources producing low-grade thermal energy is observed in the same period of time. This is connected, on the one hand, with an increase of heated spaces in low-rise buildings and an increased level of comfort in individual homes, and, on the other hand, with a drop of heat generation at CSs and boiler houses. It should be noted that the estimates of heat production by individual heat generators in households given in Table 6 are in good agreement with the estimated data obtained independently in [4]. The mismatches over the period 2001–2006 do not exceed 5%.

Obviously, under the conditions of market economy the prospects for development of district heating will be determined by demand for thermal energy purchased by consumers from centralized sources. Below, a forecast of the needs of the country and key sectors of its economy in centralized supplies of thermal energy for the period up to 2030 is presented. Calculations were carried out using the approach described in [7]. This approach has the following very important distinctive features:

(i) the demand for energy carriers is predicted on a macroeconomic basis;

(ii) the economic (production) and energy (energy intensity) variables are separated in it;

(iii) the energy intensities of different kinds of economic activities are predicted in correlation with macroeconomic factors (investments, prices for energy carriers, etc.); and

Table 3. Consumption of heat by processing industries (in 2007)

Kind of industry	Million GJ	Million Gcal	%
Food industry	206.4	49.3	10.8
Light industry	26.8	6.4	1.4
Wood-processing industry	46.5	11.1	2.4
Coke production	12.1	2.9	0.6
Manufacture of petroleum products	268.8	64.2	14.1
Chemicals industry	492.8	117.7	25.8
Manufacture of nonmetallic products	83.7	20.0	4.4
Metallurgy	300.2	71.7	15.7
Construction of machinery	181.3	43.3	9.5
Others	291.8	69.7	15.3
Total	**1910.4**	**456.3**	**100**

Table 4. Heat intensities of different kinds of economic activity for Russia as a whole

Economy sector	2000	2001	2002	2003	2004	2005	2006	2007
Mining and quarrying	85.8/20.5	83.3/19.9	80.4/19.2	73.7/17.6	67.0/16.0	64.5/15.4	63.6/15.2	57.4/13.7
Processing industries	313.2/74.8	292.3/71.0	286.4/68.4	257.9/61.6	236.6/56.5	219.4/52.4	210.2/50.2	192.6/46.0
Construction	46.9/11.2	39.4/9.4	36.0/8.6	30.1/7.2	27.2/6.5	22.6/5.4	19.3/4.6	16.7/4.0
Agriculture	136.9/32.7	118.5/28.3	107.6/25.7	96.3/23.0	86.3/20.6	80.8/19.3	77.9/18.6	75.8/18.1
Transport and communications	63.2/15.1	59.9/14.3	55.3/13.2	51.1/12.2	44.8/10.7	41.5/9.9	39.4/9.4	36.4/8.7
Other kinds of economic activity	177.9/42.5	171.2/40.9	159.5/38.1	149.1/35.6	136.9/32.7	123.9/29.6	116.4/27.8	102.6/24.5

Note: Figures in the numerator are in GJ/(million rubles), and those in the denominator, in Gcal/(million rubles).

Table 5. Characteristics of heat (water and steam) networks according to Rosstat data*

Indicator	2000	2001	2002	2003	2004	2005	2006	2007
Length of networks, thousand km	186.6	183.7	183.5	180.7	179.0	177.2	175.9	173.1
Of them, with a diameter of								
less than 200 mm	141.7	138.4	137.9	135.7	134.2	132.9	131.7	128.9
from 200 to 400 mm	29.0	29.4	29.1	28.5	28.6	28.3	28.0	27.8
from 400 to 600 mm	10.6	10.2	10.8	10.6	10.5	10.1	10.2	10.3
Length of networks that need replacement								
thousand km	30.3	32.3	33.7	33.1	34.6	44.7	44.2	44.8
%	16.2	17.6	18.4	18.3	19.3	25.2	25.1	25.9
Of them, in disrepair, thousand km	n/a	n/a	n/a	n/a	n/a	27.0	30.0	30.6
Repaired networks, thousand km	n/a	n/a	n/a	n/a	n/a	5.9	12.2	13.5
Replaced networks, thousand km	n/a	n/a	n/a	n/a	n/a	4.5	5.7	5.2
Of them, in disrepair, thousand km	n/a	n/a	n/a	n/a	n/a	n/a	4.2	3.9

* —double-pipe, n/a—data are not available.

(iv) regional and sectoral features (territorial and sectoral nonuniformities) of energy consumption, interchangeability of energy carriers, and infrastructural constraints are taken into account.

As is shown in [7], investments in the fixed capital of different kinds of economic activities, primarily the most energy-intensive ones (such as processing industries), play a decisive role in making the country's economy more energy efficient. Price factors predominantly have a stimulating effect.

In their final form, forecasts of needs for energy carriers, in particular, for heat from centralized sources, are drawn in the course of developing a mutually consistent system of federal and regional fuel-and-energy balances, i.e., as a result of striking a balance between the demanded and offered quantities of fuel-and-energy resources. The needs of Russia and its regions for fuel-and-energy resources were predicted and the system of fuel-and-energy balances was shaped using special software tools developed at the Energy Research Institute (INEI), Russian Academy of Sciences, that include a forecasting methodology, simulation and optimization mathematical models, computer facilities for implementing them, and databases. The modeling system incorporates the MENEK macroeconomic model, a model of the country's fuel-and-energy complex, specific models of its branches, and models of energy consumption in different sectors of the economy of Russia

Table 6. Production of low-grade thermal energy in Russia

Heat sources	2000	2001	2002	2003	2004	2005	2006	2007
Centralized	6063/1448	6076/1451	6016/1437	6041/1443	6024/1439	5999/1433	6062/1448	5916/1413
Including								
CSs	2692/643	2709/647	2650/633	2650/633	2638/630	2629/628	2680/640	2588/618
boiler houses	2981/712	2973/710	2969/709	2981/712	2964/708	2935/701	2943/703	2893/691
nuclear power stations	21/5	21/5	21/5	21/5	21/5	21/5	21/5	21/5
electric boiler houses	38/9	38/9	33/8	29/7	29/7	29/7	25/6	25/6
heat-recovery units (HRUs)	285/68	289/69	297/71	310/74	318/76	331/79	339/81	335/80
others	46/11	46/11	46/11	50/12	54/13	54/13	54/13	54/13
Decentralized	921/220	879/210	867/207	842/201	816/195	800/191	804/192	787/188
Individual heat generators	1449/346	1461/349	1470/351	1482/354	1495/357	1524/364	1537/367	1558/372
Total	**8433/2014**	**8416/2010**	**8353/1995**	**8365/1998**	**8335/1991**	**8323/1988**	**8403/2007**	**8261/1973**

Figures in the numerator are in millions of G7/year and thouse in denominator in millions of Gcal/year.

Table 7. Structure of the production of low-grade thermal energy by the types of heat sources, %

Heat sources	2000	2001	2002	2003	2004	2005	2006	2007
Centralized	71.9	72.2	72.1	72.3	72.2	72.0	72.0	71.6
Including								
CSs	31.9	32.2	31.7	31.7	31.6	31.6	31.9	31.3
boiler houses	35.4	35.3	35.5	35.6	35.6	35.3	35.0	35.1
nuclear power stations	0.2	0.3	0.3	0.3	0.3	0.2	0.2	0.3
electric boiler houses	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.3
heat-recovery units	3.4	3.4	3.6	3.7	3.8	4.0	4.0	4.0
others	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6
Decentralized	10.9	10.3	10.3	10.1	9.9	9.7	9.7	9.5
Individual heat generators	17.2	17.4	17.6	17.7	17.9	18.3	18.3	18.9
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

and its regions. Forecasts of energy consumption for the country as a whole are obtained by summing the corresponding forecasts for the entities of the Russian Federation.

The forecast of heat consumption has been prepared for the crisis scenario of social and economic development of Russia (in March to April of 2009) drawn up by the Ministry of Economic Development of Russia with corrections made at INEI using the MENEK modeling system. The forecast for the number of permanent population of the country and its regions was adopted in accordance with the medium scenario of demographic

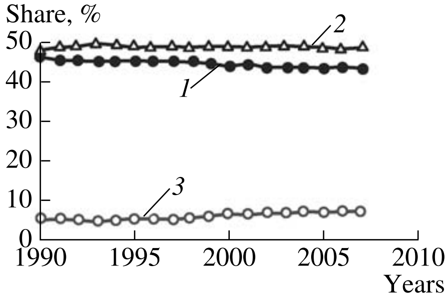

Fig. 4. Structure of heat produced by centralized sources, %; (*1*) CSs, (*2*) boiler houses, and (*3*) other sources.

forecast prepared by Rosstat in 2009 [8] taking into account the Concept of Demographic Policy of the Russian Federation for the Period up to 2030 approved by Decree of the President of the Russian Federation No. 1351 dated October 9, 2007. The main parameters of the calculated scenario are given in Table 8. The economic indicators placed in the table are given in comparable prices (2005).

Since the figures on energy efficiency of investments (rates of decrease in the energy intensity of manufactured products) contain some uncertainty, the forecasts of heat consumption by different sectors of economy have been prepared for two scenarios:

(i) the maximal scenario, which assumes pessimistic rates of decrease in the heat-intensity of manufactured products (low rates of energy conservation); and

(ii) the minimal scenario, which assumes optimistic rates of decrease in the heat intensity of manufactured products (high rates of energy conservation).

The predicted needs of households for thermal energy were determined on the basis of the following assumptions: the thermal efficiency of all newly commissioned dwelling houses is in conformity with the requirements of SNiP (Building Code) 23-03-2003: Thermal Protection of Buildings; residential buildings with the worst heat insulation properties (emergency and residential buildings) are decommissioned; no special energy conservation measures are taken in the dwelling stock that remains in service (above the scopes that are implemented under the conditions of established trends); and the climatic factors in the regions of the country correspond to their average values for many years. Thus, the prepared forecast of dwelling stock's demand for thermal energy should be considered fairly conservative.

The predicted needs of the country and the key sectors of its economy for low-grade heat for the period up to 2030 are presented in Table 9. It should be expected that a decreasing trend in the country's needs for thermal energy will remain in the years soon to come. This primarily concerns centralized heat supply. A drop in heat consumption in different sectors of the economy is the main factor behind this. However, the consumption of heat for household purposes—both supplied from centralized sources and produced by individual heat generators—will continue to grow. This growth is due to the predicted increase in the dwelling stock in the country and its becoming more comfortable. As regards the demand for heat from centralized sources for different sectors of the country's economy, we can hope that this demand will grow no sooner than in 4–5 years, but the rate of this growth will be very low.

Table 8. Key parameters of the calculated scenario of development of the Russian economy up to 2030

Indicator	2007	2008	2009	2010	2015	2020	2025	2030
Population, million pers.	142.1	141.9	141.9	141.8	141.7	141.5	140.6	139.2
Including%								
urban	103.8	103.7	103.8	103.9	104.5	104.9	104.7	104.0
rural	38.3	38.2	38.1	37.9	37.2	36.6	35.9	35.2
GDP, trillion rubles (2007)	24.9	26.3	24.9	24.5	30.3	40.3	51.6	63.4
Output of products, trillion rubles								
mining and quarrying	3.34	3.35	3.22	3.20	3.34	3.48	3.57	3.66
processing industries	9.91	10.23	9.45	9.16	10.85	14.49	17.59	20.78
construction	2.35	2.65	2.26	2.26	3.14	4.56	6.26	8.04
agriculture	1.59	1.76	1.72	1.77	2.08	2.45	2.78	3.12
transport and communications	3.71	3.74	3.50	3.51	4.20	5.36	6.71	8.10
other kinds of economic activity	16.77	18.21	17.75	17.47	20.16	25.43	31.78	38.35
Income of the population, trillion rubles	17.23	18.09	16.38	16.38	20.64	28.28	37.43	46.96
Investments in fixed capital, trillion rubles	5.29	5.83	4.77	4.78	6.82	10.09	13.97	18.03
Commissioning of dwellings, million m^2/yr	61.0	63.5	50.0	51.0	75.0	90.0	90.1	90.1
Fraction of low-rise buildings, %	42.8	40.9	41.0	41.23	42.2	43.2	44.0	44.5

Table 9. Needs for low-grade thermal energy in Russia for the period of up to 2030

Economy sector	2007	2008	2009	2010	2015	2020	2025	2030
Low rates of energy conservation								
Consumption, total	7780/1858	7687/1836	7609/1817	7562/1806	7691/1837	8237/1967	8784/2098	9257/2211
Mining and quarrying	193/46	184/44	176/42	172/41	167/40	163/39	159/38	159/38
Processing industries	1909/456	1838/439	1792/428	1767/422	1788/427	2027/484	2173/519	2299/549
Construction	38/9	42/10	38/9	33/8	33/8	42/10	46/11	46/11
Agriculture	121/29	130/31	126/30	126/30	134/32	147/35	159/38	167/40
Transport and communications	134/32	130/31	126/30	121/29	121/29	134/32	151/36	159/38
Other kinds of economic activity	1717/410	1675/400	1650/394	1629/389	1629/389	1759/420	1980/473	2169/518
Households	3668/876	3688/881	3701/884	3714/887	3819/912	3965/947	4116/983	4258/1017
Including:								
heat supply from external sources	2106/503	2114/505	2123/507	2123/507	2169/518	2227/532	2282/545	2332/557
independent heat supply	1562/373	1574/376	1578/377	1591/380	1650/394	1738/415	1834/438	1926/460
Losses in networks	477/114	465/111	456/109	456/109	452/108	477/114	490/117	498/119
Total	**8257/1972**	**8152/1947**	**8065/1926**	**8018/1915**	**8143/1945**	**8714/2081**	**9274/2215**	**9755/2330**
High rates of energy conservation								
Consumption, total	7780/1858	7646/1826	7535/1800	7489/1789	7591/1813	8038/1920	8508/2032	8910/2128
Mining and quarrying	193/46	184/44	176/42	172/41	159/38	155/37	151/36	151/36
Processing industries	1909/456	1821/435	1775/424	1750/418	1754/419	1955/467	2068/494	2156/515
Construction	38/9	42/10	33/8	33/8	29/7	29/7	29/7	29/7
Agriculture	121/29	130/31	121/29	121/29	126/30	134/32	142/34	147/35
Transport and communications	134/32	130/31	121/29	121/29	117/28	121/29	130/31	138/33
Other kinds of economic activity	1717/410	1650/394	1608/384	1578/377	1587/379	1679/401	1872/447	2031/485
Households	3668/876	3688/881	3701/884	3714/887	3819/912	3965/947	4116/983	4258/1017

Table 9. (Contd.)

Economy sector	2007	2008	2009	2010	2015	2020	2025	2030
Including:								
heat supply from external sources	2106/503	2119/506	2123/507	2123/507	2169/518	2223/531	2282/545	2332/557
independent heat supply	1562/373	1570/375	1578/377	1591/380	1650/394	1742/416	1834/438	1926/460
Losses in networks	474/114	465/111	456/109	452/108	448/107	465/111	473/113	477/114
Total	**8257/1972**	**8111/1936**	**7991/1910**	**7941/1896**	**8039/1919**	**8503/2033**	**8981/2145**	**9387/2241**

Notes: 1. Figures for 2007 are taken from reports and those for 2008 are preliminary estimates;
2. Figures in the numerator are in millions of GJ/yr, and those in the denominator, in millions of Gcal/yr.

Table 10. Saving of thermal energy in industrial sectors of the Russian economy

Economy sector	2020	2025	2030
Mining and quarrying	(38–46)/(9–11)	(12–54)/(10–13)	(50–59)/(12–14)
Processing industries	(766–837)/(183–200)	(1218–1323)/(291–316)	(1708–1851)/(408–442)
Construction	(38–50)/(9–12)	(50–71)/(12–17)	(67–92)/(16–22)
Agriculture	(38–46)/(9–11)	(63–75)/(15–18)	(92–109)/(22–26)
Transport and communications	(59–71)/(14–17)	(96–113)/(23–27)	(134–155)/(32–37)
Total	(**930–1051**)/(**224–251**)	(**1470–1633**)/(**351–390**)	(**2077–2261**)/(**489–540**)
Fraction of saved heat, %	28–29	37–38	43–44

Note: Figures in the numerator are in millions of GJ, and those in the denominator, in millions of Gcal.

According to the obtained estimates, the country's total needs for low-grade thermal energy may increase to 9387–9756 million GJ (2240–2830 million Gcal) per annum by 2030, or by 14–18% with respect to the 2007 level. Of this amount, the needs for heat supplied from centralized sources will increase to a level of 6530–6825 million GJ (1560–1630 million Gcal) per annum, i.e., by 13–18 %. In this case, almost the entire increase in heat consumption will be due to processing industries [250–400 million GJ (60–95 million Gcal)] per annum by 2030]; other kinds of economic activity, primarily the services sector [170–250 million GJ (40–60 million Gcal) per annum]; and households [210 million GJ (around 50 million Gcal) per annum].

This forecast was made on the assumption that energy conservation measures would be taken on a considerable scale in the country. The combined saving of heat from centralized sources in production sectors of the economy will total around 920–1050 million GJ (220–250 million Gcal) in 2020 and reach 2050–2260 million GJ (490–540 million Gcal) in 2030 or 28–29 and 43–44% of its consumption without energy conservation, respectively (Table 10). As was already pointed out, the forecast is conservative only with regard to heat consumption in households. Such a cautious approach was used because Russia has no state program for radically improving the thermal efficiency of the existing dwelling stock, and one can hardly expect that such a program will be developed in the near future. Moreover, desirable results from retrofitting the dwelling stock can be obtained only if corresponding measures are taken in the heat supply system to harmonize the parameters of heat generation and consumption. This circumstance is often overlooked. At the same time, it is well known that the household sector has an immense potential for heat savings (see, for example, [4]). Saving 420–630 million GJ (100–150 million Gcal) per annum seems quite realistic, but this will not be possible without targeted state support and will require enormous expenses of money and organizational efforts. However, if these measures are taken, not only may the demand of the household sector for heat supplied from centralized sources remain the same, but even decrease by 210–420 million GJ (50–100 million Gcal) by 2030 as compared with the amount of heat consumption in 2007.

It is expected that specific losses of thermal energy in trunk heat networks will decrease with respect to its production from 7.1% in 2007 to 6.4% in 2030, or by approximately 42 million GJ (10 million Gcal). However, it is small-diameter distribution networks, which account for about 75% of the total length of heat networks in the country (see Table 5), that must become the key target for reducing the losses of thermal energy in heat networks (through insulation and with leaks). An approach commonly used in the absence of means for measuring heat losses consists of shifting the corresponding losses to consumers. It is realistic to expect that 125–165 million GJ (30–40 million Gcal) of thermal energy can be saved in distribution networks by 2030.

For the forecast presented above, the heat intensity of GDP (with respect to heat from centralized sources) will decrease down to 150–155 GJ/(million rubles) [36–37 Gcal/million rubles)] by 2020 and down to 105–110 GJ/(million rubles) [25–26 Gcal/(million rubles)] by 2030. With respect to the 2007 level, this decrease will be equal to 36–37 and 55–56%, respectively. Thus, for the conditions of this forecast (the predicted levels of investments into the fixed capital of economy sectors), the requirement of Decree of the President of the Russian Federation No. 889 dated June 4, 2008, demanding that the energy intensity of GDP should be decreased by no less than 40% by 2020 as compared with the 2007 level, will, regretfully, not be fulfilled for heat consumption. In order to fulfill the requirements of this decree, effort by the state is needed, primarily in the sphere of centralized supply of heat to residential and commercial buildings. These efforts are fairly diverse in nature. The following of them should be pointed out as the most important ones: the requirements specified in the appropriate normative documents for the level of thermal efficiency of newly constructed buildings should be made more stringent; a state program for retrofitting the existing stock of residential and commercial buildings to improve their thermal protection properties should be developed and implemented; a legislative framework encouraging consumers (and enforcing budgetary ones) to save heat should be created; and favorable conditions for attraction of advanced foreign technologies into the country should be provided. In addition, there is a need for a target state program (possibly, on the basis of partnership between state-owned and private sectors) for radically modernizing the utility heat supply networks that are in operation.

Centralized heat sources will remain dominating ones in meeting the needs of the country for thermal energy in the period covered by the forecast (Table 11). However, the share of these sources in the overall generation of low-grade heat will somewhat decrease: from the present 72 to 70% by 2030. This is mainly due to an increase in the share of individual heat sources. As before, CSs and boiler houses will predominate in the production of heat supplied in a centralized manner. Their total share will remain at the level of today's indices equal to around 93%. It should be noted that the possible future ratio between CSs and boiler houses remains very uncertain, because there are factors due to which a change is likely to occur in this ratio. The forecasts were prepared under the assumption that this ratio will slightly change in favor of CSs: from 47.2% in 2007 to 48.3% by 2030. The fact that there are real possibilities for extending district systems on the basis of CSs by connecting new consumers (because idle heat-generating capacities are available) and displacing small low-efficiency boiler houses was used as a background in making the forecast. The latter assumption relates to a greater degree to regions with large-scale use of solid fuel, in which displacement of low-efficient coal-fired boiler houses makes it possible to obtain considerable economic and environmental gains.

However, a more substantial increase in the share of CSs can be obtained by launching mass-scale retrofitting of large boiler houses, primarily gas-fired ones, to construct mini CSs on their basis. Studies have shown that, if such boiler houses were equipped with gas turbine installations provided that they cover the loads of hot water supply, the potential amounts of increase in the production of thermal energy at CSs could be grown by 380–960 million GJ (90–230 million Gcal) per annum (the lower value relates to covering daily average load and the upper one, to the maximal load of hot water supply). In this case, the share of CSs would increase to 54–64%.

Under conditions in which there are no well-grounded hopes that the demand for thermal energy will increase considerably, the prospects for development of district heating systems in the country will be determined mainly by their technical and economical ability to compete with decentralized and individual heat sources. As has been pointed out in many papers (see, for example, [9, 10]), great possibilities for reduction of costs are available in Russian district heating systems. Different versions of using advanced gas-turbine and combined-cycle technologies in them have been substantiated [11]. High economic gains from development of district heating cogeneration on the basis of constructing gas-turbine units at the sites of existing gas-fired boiler houses have been shown [12]. The possibilities of making the traditional cogeneration equipment more efficient are still far from being exhausted [13]. Positive experience with achieving considerable reduction of losses in heat networks through the use of new materials and new technologies is available [14]. Considerable saving is achieved by taking measures on adjusting hydraulic operating conditions of heat networks and improving water treatment facilities [4]. Large-scale introduction of proposed technical solutions for practical applications is presently the top-priority task; however, it cannot be solved without appropriate legislative and administrative support.

Otherwise, if district heating systems lose their competitiveness, the most economically well-to-do consumers will abandon them giving more and more preference to construction of their own heat sources,

Table 11. Forecasts for production of low-grade thermal energy in Russia for the period of up to 2030

Heat sources	2007	2008	2009	2010	2015	2020	2025	2030
Low rates of energy conservation								
Centralized	5915/1413	5814/1389	5731/1369	5685/1358	5751/1374	6171/1474	6531/1560	6840/1634
Including:								
CSs	2587/618	2507/599	2474/591	2457/587	2486/594	2692/643	2888/690	3060/731
boiler houses	2893/691	2893/691	2851/681	2826/675	2838/678	3022/722	3165/756	3273/782
nuclear power stations	21/5	17/4	17/4	17/4	17/4	25/6	38/9	54/13
electric boiler houses	25/6	21/5	21/5	21/5	17/4	17/4	13/3	13/3
heat-recovery units	335/80	322/77	318/76	314/75	339/81	356/85	368/88	381/91
others	54/13	54/13	50/12	50/12	54/13	59/14	59/14	59/14
Decentralized	787/188	766/183	753/180	745/178	745/178	894/12	908/217	992/237
Individual heat generators	1557/372	1570/375	1578/377	1591/380	1649/394	1741/416	1833/438	1926/460
Total	**8259/1973**	**8150/1947**	**8062/1926**	**8021/1916**	**8145/1946**	**8716/2082**	**9272/2215**	**9785/2331**
High rates of energy conservation								
Centralized	5915/1413	5780/1381	5681/1357	5626/1344	5660/1352	5981/1434	6292/1503	6533/1560
Including								
CSs	2587/618	2507/599	2470/590	2453/586	2470/590	2675/639	2859/683	3022/722
boiler houses	2893/691	2859/683	2805/670	2771/662	2763/660	2872/686	2955/706	3001/717
nuclear power stations	21/5	17/4	17/4	17/4	17/4	25/6	38/9	54/13
electric boiler houses	25/6	21/5	21/5	21/5	17/4	17/4	13/3	13/3
heat-recovery units	335/80	322/77	318/76	314/75	399/81	356/85	368/88	381/91
others	54/13	54/13	50/12	50/12	54/13	59/14	59/14	59/14
Decentralized	787/188	753/180	737/176	720/172	724/173	770/184	858/205	929/222
Individual heat generators	1557/372	1570/375	1578/377	1591/380	1649/394	1741/416	1833/438	1926/460
Total	**8259/1973**	**8103/1936**	**7996/1910**	**7937/1896**	**8033/1919**	**8492/2034**	**8983/2146**	**9391/2242**

Notes: 1. The figures for 2007 are taken from reports, and those for 2008 are preliminary estimates.
2. Figures in the numerator are in millions of GJ/yr and those in the denominator, in millions of Gcal/yr.

processes that are already observed at present. As a result, this will cause district heating systems to become still less competitive, in particular, because the expensive equipment of CSs will operate at partial loads and because its operating modes will be shifted into a nonoptimal region.

Of course, a systems approach-based comparison between different competing technologies used for generation, distribution, and consumption of low-grade heat [2] and also for determining the optimal share of district heating in the country and its regions remains an important issue. This issue is becoming increasingly more topical for new external conditions for the considered future: low demand for thermal energy, growth of prices for fuel and power engineering equipment, and considerable improvement in the technical and economic characteristics of alternative technologies.

CONCLUSIONS

(1) Demand for the thermal energy supplied by district heating systems is the key issue that will determine their further development in Russia.

(2) The technical and economic abilities of district heating systems to compete with decentralized and individual heat sources will determine the prospects for their development.

(3) Great technical possibilities for reducing the expenditure of fuel and energy are available in Russian district heating systems; large-scale implementation of these possibilities in practice is the top priority objective, which cannot be achieved without adequate legislative and administrative support, including stimulation of energy conservation and attraction of advanced foreign technologies.

(4) To fulfill the requirements outlined in Decree of the President of the Russian Federation No. 889 of June 4, 2008, on reducing the energy intensity of GDP, it is necessary to develop and implement state programs for improving the thermal protection properties of the existing stock of residential and public buildings and modernizing the existing district heating systems.

(5) It is necessary to improve the system of statistical observation over generation, distribution, and consumption of thermal energy in the country.

REFERENCES

1. L. A. Melent'ev, *Systems Investigations in Power Engineering* (Nauka, Moscow, 1983) [in Russian].
2. L. S. Belyaev, B. G. Saneev, S. P. Filippov, et al., *System Investigations of Power Engineering Problems*, Ed. by N. I. Voropai (Nauka, Novosibirsk, 2000) [in Russian].
3. L. S. Khrilev and I. A. Smirnov, "Socio-Economic Principles and Lines of Development of District Heating," Teploenergetika, No. 2, 9–17 (2005) [Therm. Eng., No. 2 (2005)].
4. A. I. Bashmakov, "An Analysis of Major Trends in Development of Heat Supply Systems in Russia," Novosti Teplosnab., No. 2, 6–10 (2008); No. 3, 12–24 (2008).
5. *Housing and Consumer Services for Population in Russia. Statistical Reports* (Rosstat, Moscow, 2007) [in Russian].
6. V. A. Malakhov, "Approaches for Predicting Demand for Electric Energy in Russia," Probl. Prognozir., No. 2, 57–62 (2009).
7. S. P. Filippov, "An Integrated Approach for Predicting the Needs of Russia and Its Regions for Energy Carriers for Long-Term Future," Vestn. Saratov. Gos. Tekhn. Univ., No. 1 (31), 11–27 (2008).
8. *A Tentative Size of Population in the Russian Federation up to 2030: A Statistical Bulletin* (Rosstat, Moscow, 2009) [in Russian].
9. Ya. A. Kovylyanskii, "The Development of District Heating in Russia," Teploenergetika, No. 12, 7–10 (2000) [Therm. Eng., No. 12 (2000)].
10. I. A. Smirnov and L. S. Khrilev, "The Main Lines for Improving the Efficiency of Cogeneration Stations under the Conditions of a Free Market," Teploenergetika, No. 4, 50–57 (2004) [Therm. Eng., No. 4 (2004)].
11. V. I. Dlugosel'skii and A. S. Zemtsov, "The Efficiency of Using Gas-Turbine and Combined-Cycle Technologies in Cogeneration," Teploenergetika, No. 12, 3–6 (2000) [Therm. Eng., No. 12 (2000)].
12. A. I. Smirnov and L. S. Khrilev, "Determining the Efficiency of Commissioning Gas-Turbine Units at the Sites of Operating Boiler Houses," Teploenergetika, No. 12, 16–21 (2000) [Therm. Eng., No. 12 (2000)].
13. V. F. Gutorov, L. L. Simoyu, E. I. Efros, and S. I. Panferov, "Ways to Enhance Performance of Cogeneration Turbines," Teploenergetika, No. 12, 25–34 (2000) [Therm. Eng., No. 12 (2000)].
14. V. I. Kashinskii, V. M. Lipovskikh, and Ya. G. Rotmistrov, "Experience Gained from the Use of Polyurethane Foam-Insulated Pipelines at OAO Moscow Heating-Network Company," Teploenergetika, No. 7, 28–30 (2007) [Therm. Eng., No. 7 (2007)].
15. A. Bogdanov, "Ubiquitous Use of Boiler Houses in Russia is a Nation-Wide Disaster," Energorynok, No. 3, 50–58 (2006); No. 6, 46–50 (2006); No. 9, 52–57 (2006).