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The variations of future heating demand in European part of Russia due to climate change

KEY WORDS: heating demand, heating period, temperature, duration, climate change, European Russia

The forecasting of energy demand for the heating purposes is one of the main parts of energy planning and management, especially in the countries lying in the moderate and high latitudes. For example in Russia about 40% of total fossil fuel consumption is going for the heating.

The forecasting of future heating demand was the subject of several studies made in Russia in the last decades basing on the modelling of the future ambient temperature conditions using general circulation and palaeo-analogue models that predict substantial change in the duration and mean temperature of the heating season (according to Russian standards [3] it's a period with the mean daily temperature below 8°C). In the present study authors use the different approach — estimating the change of the regional climatic parameters (the duration and mean temperature of the heating period) by the means of regression-analytical model developed in MEI, that allows to estimate the variation of regional mean seasonal temperatures as the function of global climatic factors — radiative forcing of greenhouse gases and aerosols, solar and volcanic activity, change of the Earth orbital factors using physical modelling and statistical methods.

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In the present work the regression-analytical climate model (RAM) [8, 9, 10] is applied developed by the authors of the given work to study changes of the regional climatic characteristics in the European part of Russia. To show the reliability of this model we compare the forecast of global temperature anomalies made in 1993 [7] with the real data of the last decade [6] (table 1). The results of this comparison demonstrate that the model is able to give satisfactory picture of a global temperature of the 1990s. That proves the scientific basis of the method applied in the present work. According to this forecast [10] based on the "historic scenario" of anthropogenic radiative forcing and authors' prediction of the natural climate factors (solar, volcanic and orbital) the global mean temperature in the nearest 50 years should increase at 0.6°C, i.e. as during all the 20th century.

TABLE 1. Comparison of the RAM forecast of global temperature anomalies [7] with the instrumental data [6] (5-years moving average 1951—1980 base)

TABELA 1. Porównanie wyników modelowania globalnych anomalii temperatury [7] z wynikami pomiarów [6] (średnie z okresów pięcioletnich z lat 1951—1980)

Year	1993	1994	1995	1996	1997	1998	1991—2000 mean
Model run [13]	0.31	0.29	0.32	0.38	0.41	0.45	0.37
Instrumental data [4]	0.30	0.28	0.34	0.41	0.41	0.43	0.36

The regional climate changes were computed by the means of RAM to establish connection of annual and seasonal temperatures with major climate factors of natural and anthropogenic origin. The algorithm of the RAM regional forecasts is described in details in [8, 9]. According to results obtained (fig. 1) in the coming decades in the European part of Russian Federation the essential warming is to be expected, which will be completely concentrated in the winter-spring period. Mean winter temperatures will increase by 2050 from 1.3°C (in comparison with norm 1951—1980) in Northwest up to 4.5°C in central and eastern parts of considered region. Trends of mean spring temperature anomalies by 2050 will reach the following values: from 1.1°C in Southwest up to 4.2°C in the East of region. For summer and autumn anomalies no substantial change by 2050 is expected.

Climatic conditions strongly determine energy demand. Our previous studies had shown, that the national total energy annual consumption per capita linearly depends on the mean annual temperature of the country [11], i.e. in general and at least in countries lying in the moderate and high latitudes the global warming leads to reduction of energy demand. This tendency is revealed in any sphere of economics — agriculture, transportation, construction industry, but most obviously it is shown in sphere of public heating, that in Russia annually consume about 40% of total fossil fuel. Reduction of duration of the heating period, and, in the even greater measure, the increase of its mean temperature results in significant economy of fuel spent for heating. Figure 2 shows change of per capita heat consumption depending on integrated difference of temperatures ΔT_{HP} during the heating period HP — product of a difference between indoor temperature T_{id} and average temperature of the heating period T_{HP} multiplied on its duration D_{HP}.

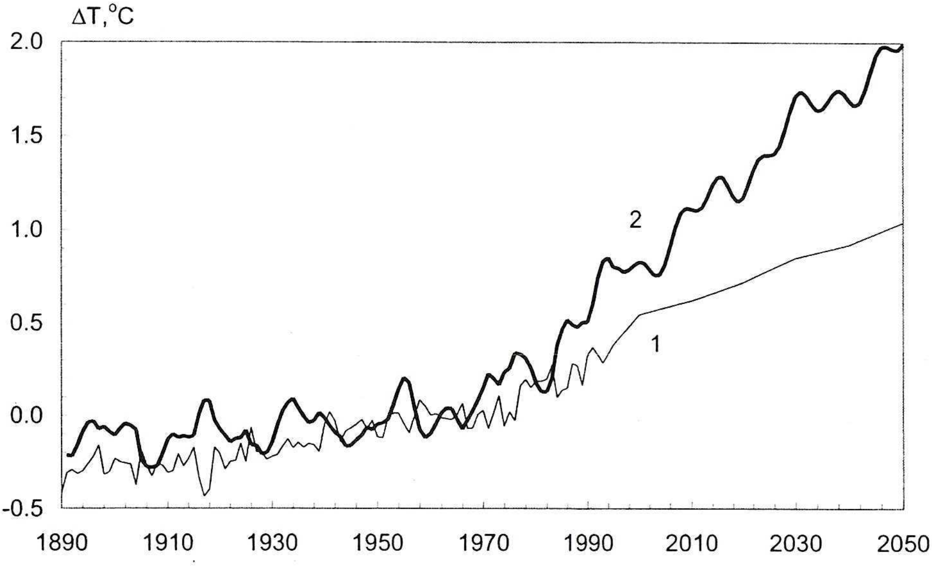

Fig. 1. Change of the mean annual temperatures ΔT as compared with 1951—1980 norm: 1 — global [10]; 2 — at the center of the European part of Russia

Rys. 1. Zmiana średniej rocznej temperatury w porównaniu do normy z lat 1951—1980 1 — globalna [10]; 2 — w środku europejskiej części Rosji

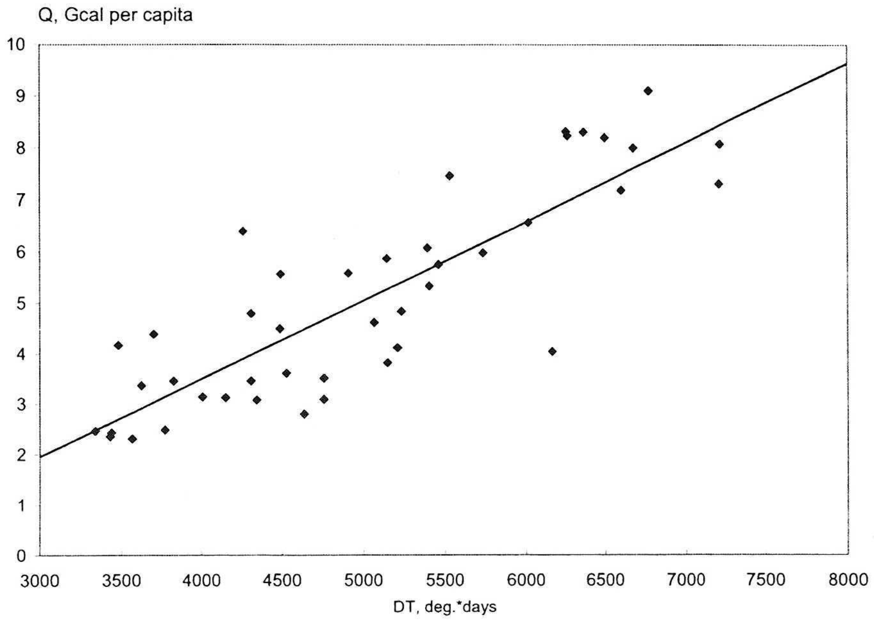

Fig. 2. Annual per capita heat consumption Q. Data of the public heating companies [14]

Rys. 2. Roczna konsumpcja ciepła na 1 mieszkańca — Q. Dane publicznych przedsiębiorstw ciepłowniczych [14]

Studies of influence of the climatic characteristics on a thermal mode of buildings are conducted in Russia for more than hundred years.

In the beginning of 1970s the experts of State Hydrological Institute developed a technique [1], allowing to compute thermal balance of objects taking into account such climatic factors as ambient temperature, solar radiation and wind velocity. Further the influence of climatic conditions on parameters of the heating period were repeatedly undertaken for various regions of the former USSR [15] and some cities of Russia [5, 13] for optimisation of work of the heating systems. All these studies were based on the analysis of the long (more then 100 years) time-series of HP duration and its mean temperature. Authors of all the specified works mark large inter-annual variability of these parameters that lead to significant deviations (15—30%)of the heating demand from technological norms [15], and also offer methods of the long-term (about 1 year ahead) forecasting of these parameters with the accuracy up to 70% [5].

Studies [2, 12, 4] make future estimates of the specified parameters for all the territory of Russia by different methods (palaeo-analogue, GCMs and expert approach). Changes of the mean duration ΔP_{HP}, temperature ΔT_{HP} and integrated temperature difference ΔDT_{HP} for the European part of Russia according to different estimates are submitted in the table 2.

TABLE 2. Changes (from the 1951—1980 norm) of the mean duration ΔP_{HP}, temperature ΔT_{HP} and integrated temperature difference ΔDT_{HP} for the European part of Russia according to different estimates (ΔT_{glob} — respective change of the mean global temperature)

TABELA 2. Odchylenia (od normy z lat 1951—1980) średniego okresu trwania ΔP_{HP}, temperatury ΔT_{HP} i zintegrowanych różnic temperatury ΔDT_{HP} w europejskiej części Rosji według różnych oszacowań (ΔT_{glob} — względne zmiany średniej globalnej temperatury)

Reference	Approach	Year of forecast	ΔT_{glob}	ΔP_{HP} [days]	ΔT_{HP}	ΔDT_{HP} [%]
[4]	palaeoclimate analogue	2010	1	10—30		10—15
		2050	3—4	20—50		20—25
[2]	GCM ECHAM1-A	2050	1	10—30	2—2.5	20—25
[12]	expert estimate	2010	2,5			10—25

Table 2 shows significant difference in the assumptions of the future global climate change as well as different results of the modelling that do not allow to use them in energy planning. To eliminate these lacks the authors of present work studied by means of correlation and regression analysis the variations of the HP parameters as statistically connected with respectively well predictable climatic characteristics — mean seasonal temperatures with the purpose of construction of the long-term forecast.

Using projected seasonal temperatures as predictors in linear regression models of the HP parameters we estimate (with the determination rate of 30—70%) the change of mean duration and temperatures of HP for 90 available stations. These results are submitted in a figures 3—4.

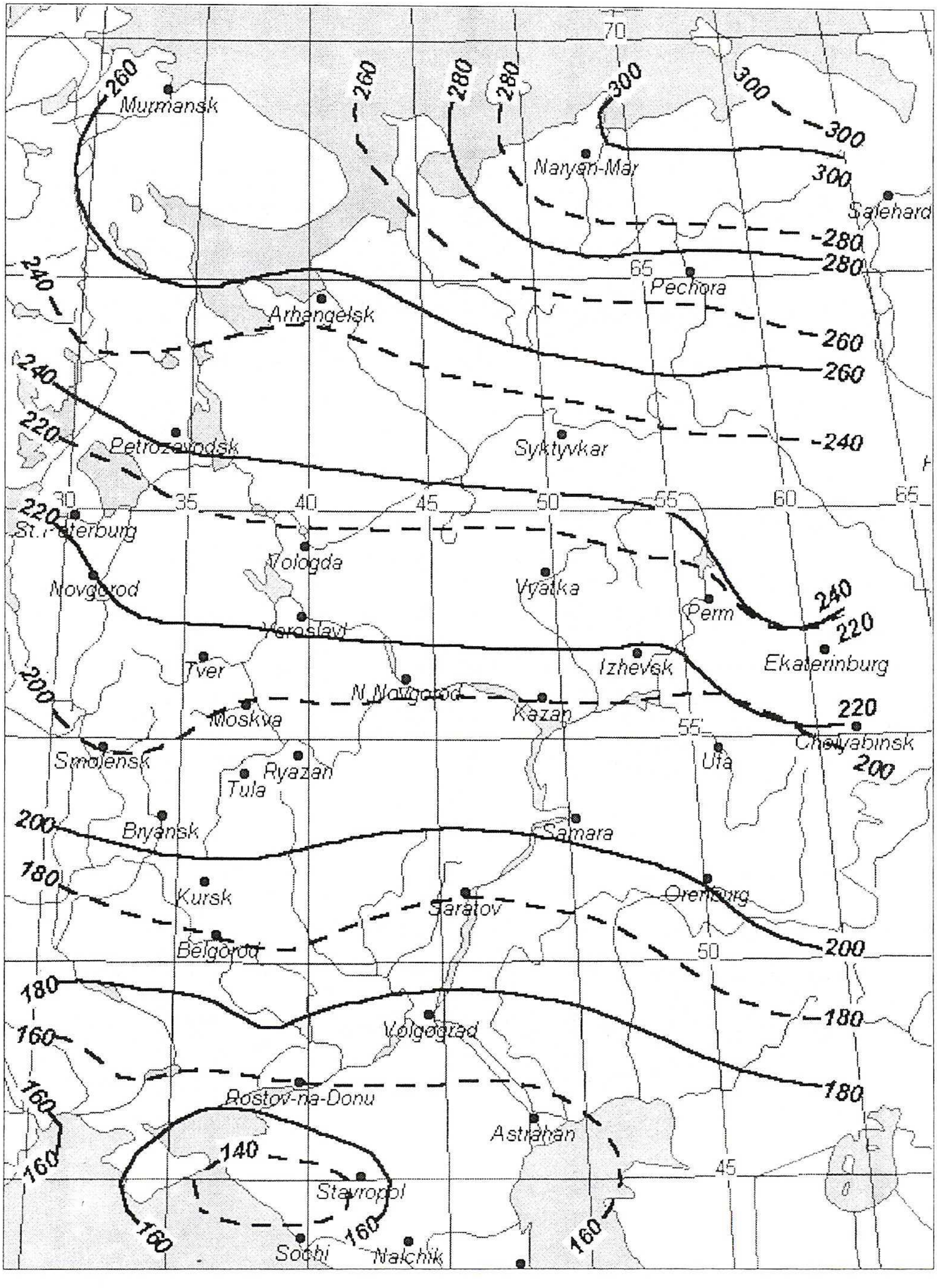

Fig. 3. Changes of mean HP duration in the European part of Russia. Forecast 2050 — solid line; norm 1951—1980 — dashed line

Rys. 3. Zmiany średniego okresu trwania sezonu grzewczego w europejskiej części Rosji. Prognoza na 2050 rok — linia ciągła; norma z lat 1951—1980 — linia przerywana

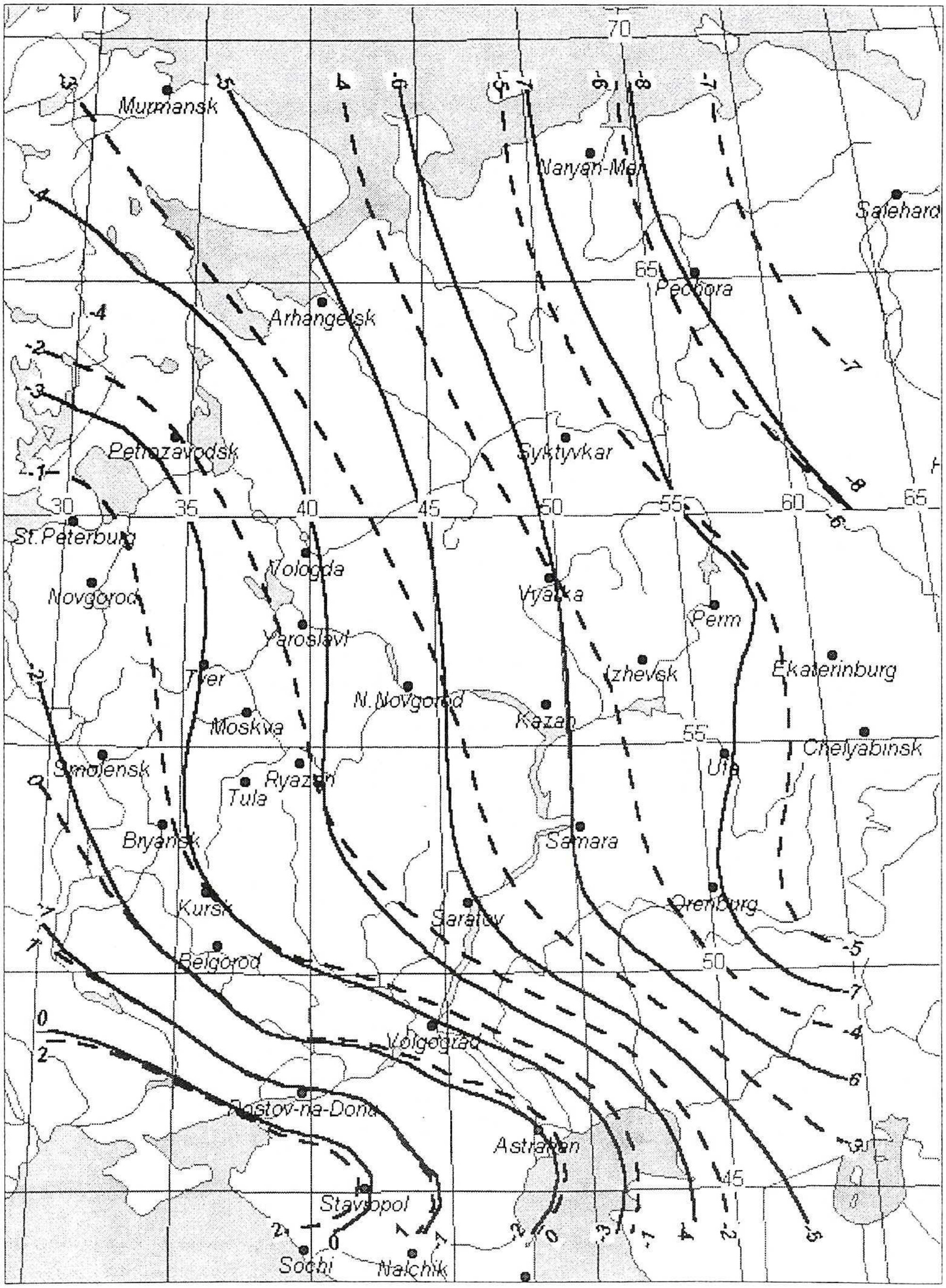

Fig. 4. Changes of mean HP temperatures in the European part of Russia. Forecast 2050 — solid line; norm 1951—1980 — dashed line

Rys. 4. Zmiana średniej temperatury w europejskiej części Rosji. Prognoza na 2050 rok — linia ciągła; norma z lat 1951—1980 — linia przerywana

As it is shown in the figure 3, the structure of spatial distribution of HP duration remains the same through the next 50 years — it increases in the north-northeast direction without any significant change in the isolines. The anomalies of this parameter (respective to 1951—1980 norms 1951—1980 appropriate to construction standards [3]) in the middle of the 21st century in the major part of the European territory of Russian Federation should be of 10—15 days, and only in Ural region the reduction of HP duration by 3 weeks is expected. The relative reduction of P_{HP} in the European part of Russia by 2050 will differ from 8% in a southwest up to 3% in northeast, and only in Karelia and Ural will reach 10—15%.

These results remarkably differ from the given estimates [2, 4]. Both specified works predict increase of anomalies of HP duration in the territory of Russia in the northern direction, that do not correspond to the observational data of the last 50 years: mean decadal decrease of HP duration for this period in Kazan has made 1.5 day, in Arkhangelsk — 0.4 day, and in Pechora only 0.1.

The specified divergences has also resulted in absolute values of expected anomalies. Using scenario of the global warming by 1 degree (that approximately corresponds to our forecast for 2050) in the central Russia both works predict the same decrease of HP duration by 10—15 days, though in the northern areas the model of general circulation [2] calculates reduction of this parameter by 15—30, and palaeo-analogue scenario [4] — even by 30—60 days! Nowadays when the mean global temperature anomaly is coming near to 0.5°C there is no sign of such essential decrease of HP duration in the northern areas. It gives the basis to conclude, that methods used in [2, 4], are inapplicable for forecasting the regional climatic characteristics for the practical purposes.

Figure 4 shows that the spatial distribution of mean HP temperatures differs radically from that of HP duration. According to our model results, by 2050 the significant changes of mean HP temperatures for all the region are expected with their spatial structure to be saved. Their increase in comparison with 1951—1980 norm will differ from 2.5°C in Low Volga and Southern Ural to 1.5°C in Northwest of Russia, following the growth of winter and spring temperatures. That means that in the middle of current century in Central Russia the temperature conditions of the cold period will correspond to the present conditions of Kiev and Kharkov, and in Vorkuta mean HP temperature will be the same as now in the Kirov area or Udmurtiya.

The work [1] stated that the major part of thermal losses of buildings and hence most of their heating demand is determined by the difference between ambient and indoor temperatures: total additional thermal flows connected with solar radiation and air convection in the studied region do not exceed 10% and in the present work are assumed to be independent on climate changes. The integrated sum of these temperature differences for all the heating period is obviously equal to the difference of the mean HP temperature and indoor temperature multiplied by HP duration. Figure 2 demonstrates linear dependence of specific heat consumption per capita of urban population supplied by the public heating companies on integrated temperature difference DT_{HP}. Reduction of DT_{HP} by each 1000 degree·days results in reduction of annual heating demand by 1.5 Gcal per capita. As the companies of RAO "EES Rossii" provide approximately 35% of the total heating supply in the country [14], and the share of the urban population in the studied region makes about 70% of the total population of 105 millions, reduction of the total consumption of heat per each 1000 degree·days is 3 Gcal per capita. As losses in heating networks are of approximately 10 % and average fuel consumption in the heating plants is 0.15 tce/Gcal [14] the annual economy of fossil fuel makes about 0,5 tce per capita for each 1000 degree·days.

Figure 5 shows the spatial distribution of changes to 2050 of integrated temperature differences respective to 1951—1980 norms for the European part of Russia which vary from 3000 degree·days in the southern part of Russian Federation up to 7000—8000 degree·days in northeastern region. According to our forecast in the middle of 21[st] century spatial distribution of DT_{HP} in the territory of European Russia will not change and its reduction in comparison with 1951—1980 norms will make approximately 700—950 degree·days that should lead to the appropriate annual economy of fossil fuel of about 40 Mtce.

The maximal relative reduction of fuel demand for heating in 2050 should be expected in Ural and Northern Caucasus, where it will make 15—20% from present norms. In northern areas the reduction will be not as large, approximately 10—15% from modern values. Comparison of relative change of HP duration (5—10%) and integrated temperature differences shows that the major part of expected economy of fuel due to global warming is caused by the change of the mean HP temperatures. This conclusion agree with these of all cited works [2, 4, 5, 12, 13, 15].

In general estimates of decrease of the heat demand obtained in the present work agree with results of [2], despite of the marked above differences in the forecasts of P_{HP} change. According to the model results [7] expected decrease of DT_{HP} to the middle of 21st century due to global warming by 1 degree will make 15—25% of modern norm in the Central and Northwest regions of Russia and 10—15% — in the area of Polar Ural. An estimated in [12] economy of fuel for heating due to the possible increase of mean global temperature on 2,5°C (i.e. 2,5 times higher than the forecast of the present work) as only of 10% for Central Russia and 25 % for Ural seems to be strongly underestimated. Opposite to it, overestimated, at least for northern areas, are estimates of 15—20% reduction of heating demand in high latitudes based on the palaeoanalogue scenario [4] of global temperature increase of 1°C.

Conclusions

1. The most probable increase of global temperature at the middle of the current century is to be moderate and make approximately 1°C in comparison with 1951—1980 norm. Respective warming in the moderate and high latitudes, in particular, in the European Russia, is expected to be more radical. The annual temperatures anomalies (concentrated, basically, in the winter-spring period) should make by 2050 approximately 1.1 to 4.5°C.

2. Warming expected in the first half of a century should result in the substantial changes of the basic climatic parameters of the heating period in Russia. By 2050 its duration will decrease in comparison with the present level by 10—20 days, and its average temperatures will increase by 1,5—3°C with the maximal anomalies achieved in the east areas of European Russia. Expected reduction of heating demand and respective economy of fuel in the region will make 10—15% of the modern norms in northern and 15—20% — in central and southern areas, that in the whole region will provide total decrease of annual fossil fuel consumption of approximately 40 Mtce.

3. Palaeoanalogue scenarios and GCM modelling do not describe the observed tendencies in change of the HP climatic characteristics and, at least in their modern state, can not be used for

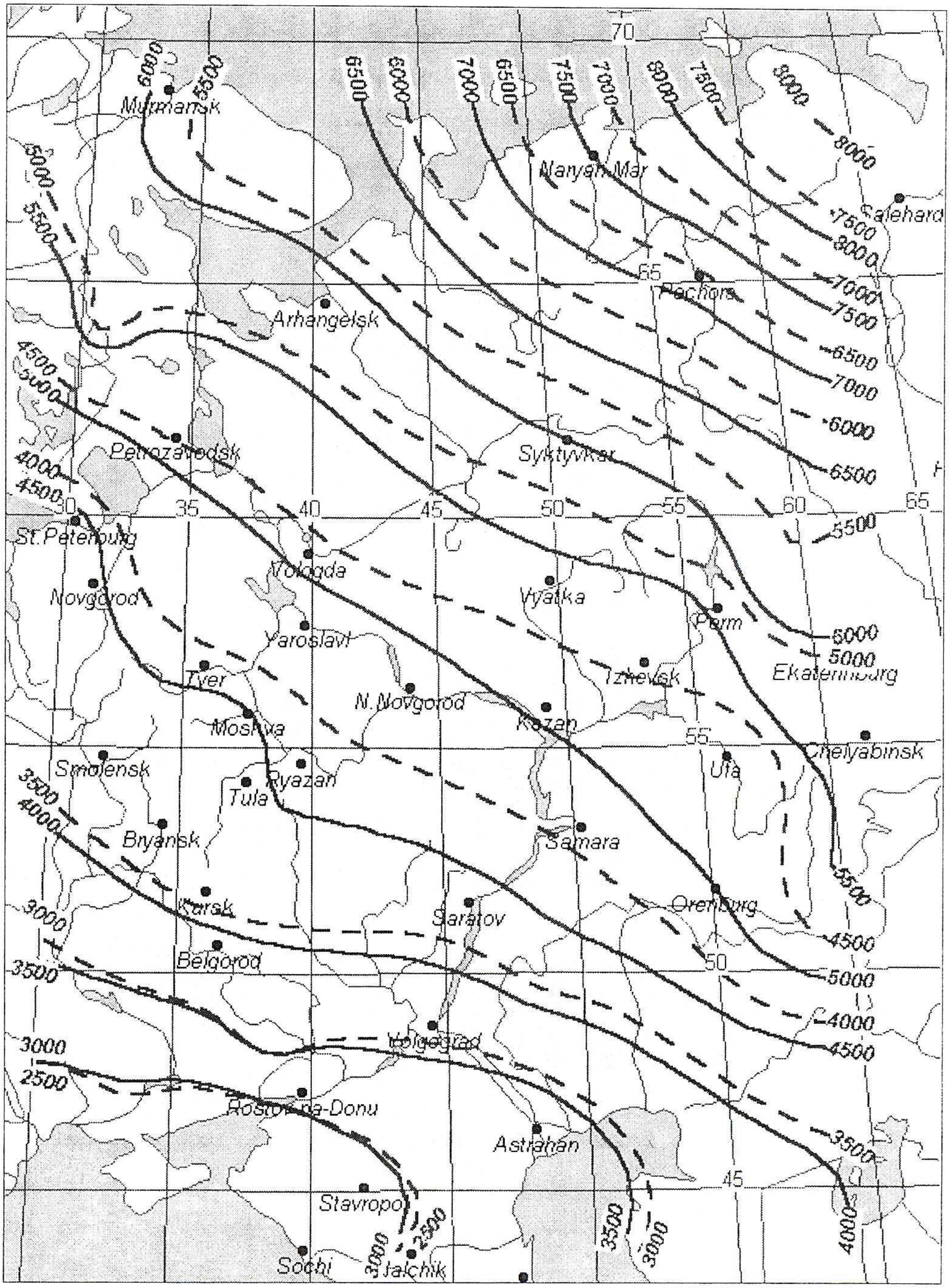

Fig. 5. Integrated temperature differences in the European part of Russia. Forecast 2050 — solid line; 1951—1980 norms — dashed line

Rys. 5. Zintegrowane zmiany temperatur w europejskiej części Rosji . Prognoza na 2050 rok — linia ciągła; norma z lat 1951—1980 — linia przerywana practical needs. Combined model — statistical approach realised in RAM climate model allows to forecast various regional climatic characteristics with proper spatial and temporary resolution. Its results correspond well to the observed data of last decades.

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Abstract

Paper presents the results of climatic studies for the purpose of energy planning in the Northern latitudes. Authors estimate the change of the regional climatic parameters (seasonal temperatures and the duration and mean temperature of the heating period) by the means of regression-analytical model developed in MEI as the function of global climatic factors using combined physical modelling and statistical methods.

The forecast for the European part of Russia for the period until 2050 based on the authors' scenarios of the major climate factors evolution predicts that the mean annual temperature in the region should rise by 2°C as compared to the norm of the 1951—1980 (corresponding to the global change of 1°C). That warming should increase mean temperature of the heating period (a period with the mean daily temperature below 8°C) by 2—3°C and decrease its duration by 10—20 days. That would result in the future decrease in the heating demand in the region by 10—15% of its present values. Calculations based on the data of Russian public heating companies show that annual economy of fuel resources will reach about 40 Mtce at 2050.

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Wahania zapotrzebowania na ciepło w europejskiej części Rosji z powodu zmian klimatycznych

SŁOWA KLUCZOWE: zapotrzebowanie na ciepło, temperatura, okres grzewczy, czas trwania, zmiany klimatyczne, europejska część Rosji

Streszczenie

Artykuł przedstawia wyniki badań klimatycznych prowadzonych do celów planowania zużycia energii w północnych szerokościach geograficznych. Za pomocą regresywnego modelu analitycznego opracowanego w Moskiewskim Instytucie Energetycznym (MEI), wykorzystującego modelowanie fizyczne oraz metody statystyczne, autorzy szacują zmiany regionalnych parametrów klimatycznych (sezonowość temperatur, jak również czas trwania i średnią temperaturę w sezonie grzewczym) w funkcji globalnych czynników klimatycznych.

Prognoza dla europejskiej części Rosji do roku 2050 wykonana w oparciu o scenariusze autorów w zakresie zmian głównych czynników klimatycznych przewiduje, że średnia roczna temperatura w regionie wzrośnie o 2°C w porównaniu do normy z lat 1951—1980 (przy globalnej zmianie o 1°C). To ocieplenie powinno podnieść średnią temperaturę w sezonie grzewczym (okres o średniej dziennej temperaturze poniżej 8°C) o 2—3°C oraz obniżyć jego czas trwania o 10—20 dni. Spowoduje to obniżenie zapotrzebowania na ciepło w regionie o 10—15%. Obliczenie oparte na danych z rosyjskich publicznych przedsiębiorstw grzewczych wskazują, że osiągną one 40 Mtce w roku 2050