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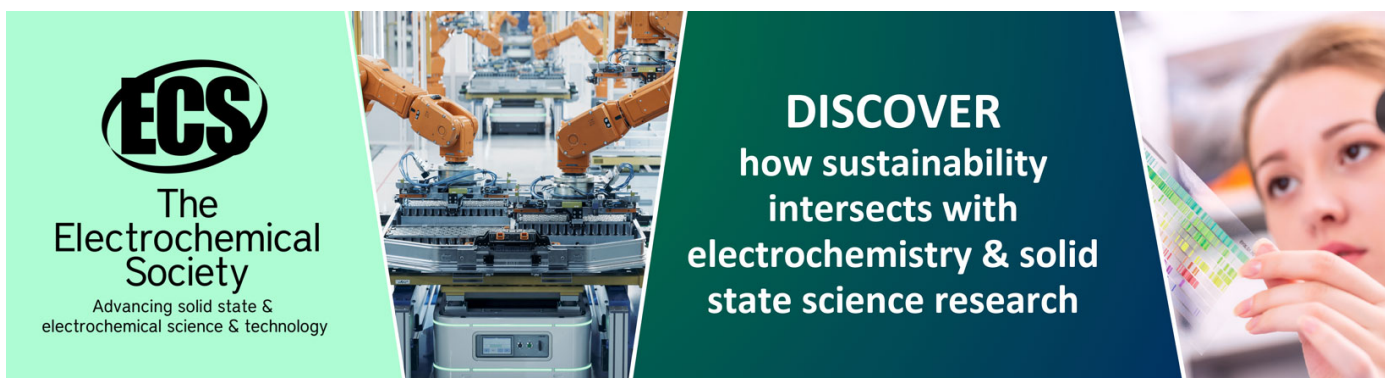
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The impact of the warm spells on reliability of the regional energy systems in Russia

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Abstract. The paper states the problem of the influence of extreme warm weather conditions on the Russian power system in a changing climate. The meteorological air temperature data of the warm seasons of 1945-2018 for the territory of Russia are analysed. The effects of summer warming of the Russian power systems are estimated using the relations between air temperatures and electric loads. Temperature load coefficients are calculated for four power systems of the European part of Russia. The effect on North-West, Siberian and Far East power systems was found to be negligible.

1. Introduction

Climate change effects on Russian energy systems has been shown to be quite significant during winter seasons. A significant decrease of heating demand along with lowering of cold spells frequency and intensity have still resulted in a noticeable shift of power and heating systems operation across the country. Effects of the climate change on the Russian energy system during summer are less evident at the moment. That is related to the specific regional climate change pattern with a winter warming rate being three to four times higher as compared with the summer ones [1]. However, the summer warming is also progressing and very likely to persist during the whole twenty-first century even if moderate climate scenarios are considered [2].

The influence of such summer manifestation of the climate change is still evident in some regions of the world and is known to have the most serious impact on reliability of the power systems [3][7]. This kind of the climate change effects to the authors' best knowledge has not been studied yet for Russia, although there is still some evidence in power systems operation.

Our work is aimed to contribute in filling this gap. We have used meteorological observations combined with statistic data related to the Russian power systems to study operation of these systems during summer taking into account the climate change.

2. Climate change evidence

Original Roshydromet [8] observation data were used to assess climate change manifestation across Russia during the warm period (May – September).

Fig. 1 demonstrates the change of cooling degree-days (CDD), heat waves duration (days) and total number of days in a year with mean air temperature above +25°C.



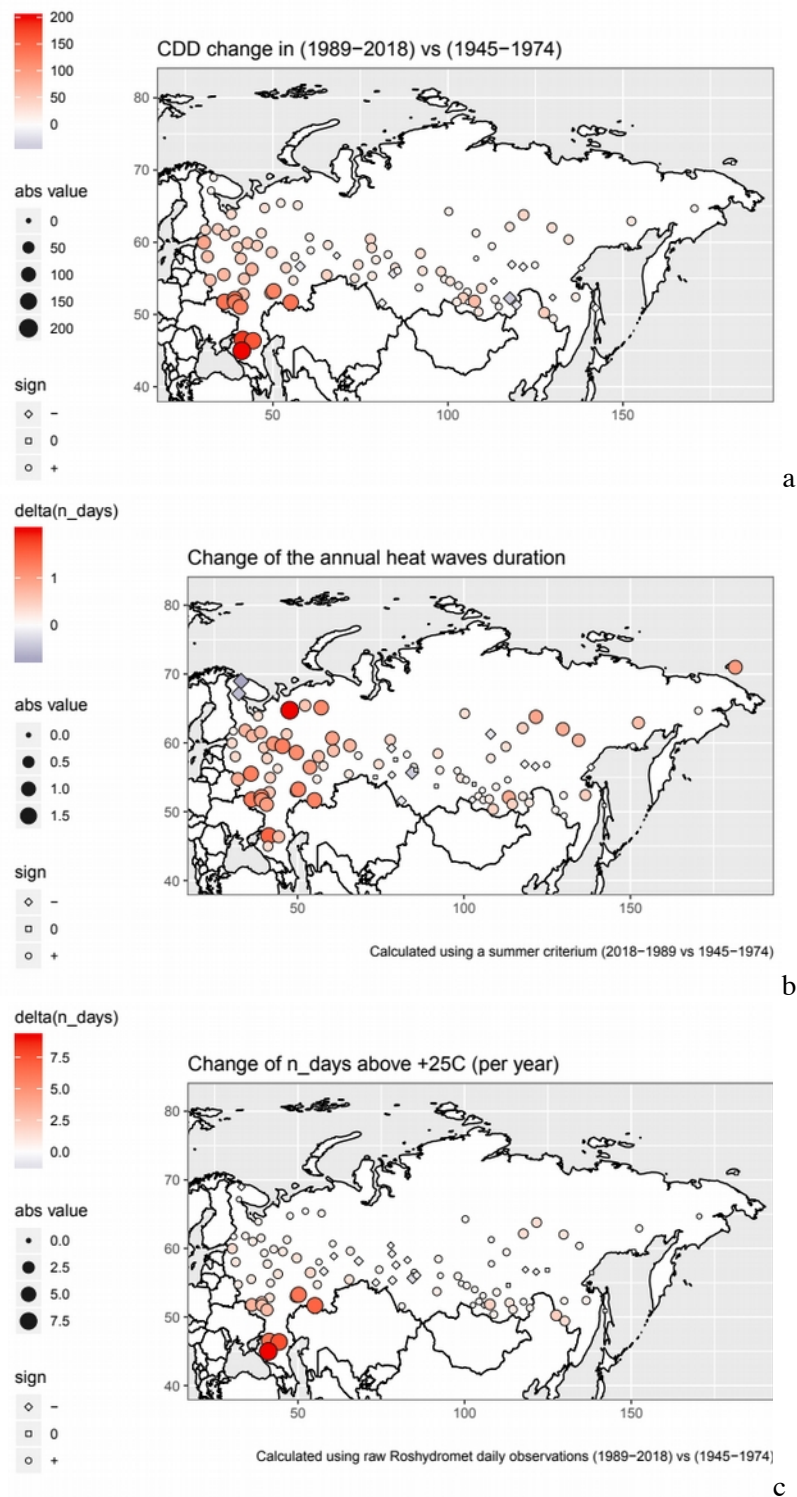


Figure 1. Change of the warm period climate features across Russia in 1989-2018 as compared with 1945-1974: a – cooling degree-days, b – annual duration of heat waves, c – annual number of the hot days (daily ambient air temperature exceeds 25°C)

3. Effects of summer warming on the Russian power systems

The ambient air temperature t_{amb} is one of the most important predictors for the daily electricity demand E_{daily} . Generally, the $E_{\text{daily}} \sim t_{\text{amb}}$ relation is described with a V-shape curve [9]. The first branch

corresponds to the demand increase when the weather is getting colder during the cold season. The second branch of the curve describes electricity demand increase related to the increase of the ambient temperature during the hot season. Such a pattern is linked with a human response to meteorological factors, in particularly with residential heating and cooling [10].

Cold climate of the most part of Russian area determines dominance of the cold branch of $E_{\text{daily}} \sim t_{\text{amb}}$ relation [11]. Increase of the electricity load due to rising of the ambient temperature is nowadays clearly noticeable in the most southern part of the country only (fig. 2). However, summer warming unavoidably leads to intensifying such an effect in other regions where the hot branch of the $E_{\text{daily}} \sim t_{\text{amb}}$ curve has not formed yet.

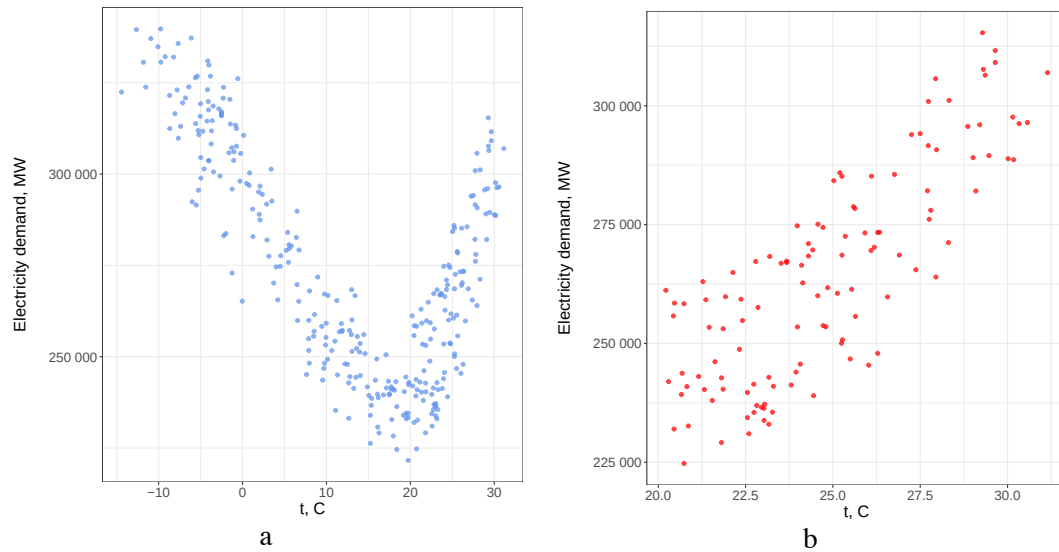


Figure 2. Dependence of the electricity demand on the daily ambient air temperature in the South energy system during 2018: a – the whole year, b – warm days. The air temperature was smoothed with 5-days moving average.

The subject of our analysis was application of the V-curve $E_{\text{daily}} \sim t_{\text{amb}}$ model for all Russian regional energy systems. The electricity demand data for all Russian regional energy systems were used. The data archive for last twenty years (2000-2019) was provided by the System operator [12]-[13]. The areas with centralized electricity supply only were taken into account. The data check was implemented basing on comparison of the daily and hourly-resoluted data.

The original daily meteorological data were spatially averaged for all the regional systems areas. Five-days smoothing with a simple moving average was applied to take into account thermal inertia.

An iteration procedure was used to find a change-point on the hot branch of the V-curve. The method used has included

- 1) assume the cut-point temperature value $t_c^{(i)}$;
- 2) build a linear regression model $E_{\text{daily}} \sim t_{\text{amb}}$ for $t_{\text{amb}} > t_c^{(i)}$.

The model with the highest determination coefficient R^2 satisfying a condition of more than ten points used in the regression was assumed to be an optimal one. The corresponding cut-point temperature was taken as the best-guess for the change-point temperature. The procedure was applied for each year of the all regional datasets. Indeed, valid results could be obtained only if the year was hot enough in the given region to make evident electricity demand increase during hot days, with the mean may-august temperature higher than 18°C as a rough estimation. Averaging by the years was applied to obtain the final value of the change point and regression coefficient dE/dt .

The calculations results are presented in the table 1. Four of seven regional energy systems demonstrate a noticeable correlation between E_{daily} and t_{amb} , although this relation persists during all considered years for the warmest South system region only. The change points is about 20°C for all the considered areas, the regression coefficient is of order 1..2% points per 1°C.

Thus, the ambient air temperature still has a quite considerable impact on the electricity load in the most part of Russian regional power systems.

Table 1. Mean 10-years (T_m) and threshold (T_h) daily ambient air temperature of the warm period and power load relation (dE/dt) for Russian regional power systems

Power system	T_m , deg. C	T_h , deg. C	Years used in T_h estimation	dE/dt , kWh/ deg. C	dE/dt , %/ deg. C
Noth-West	13.9	—	—	—	—
Center	18.1	20	2010, 2013, 2016, 2018	5500	1
Middle Volga	18.3	21	2010, 2012, 2013, 2016	10500	0.5
South	23.6	20	2009-2018	5100	2.4
Urals	18.5	22	2012, 2015, 2016	3400	0.5
Siberia	15.8	—	—	—	—
East	15.5	—	—	—	—

The electricity load profiles was analyzed for all the regional systems during the hottest days during 1950-2018. It has been found that there are some statistically significant difference as compared with typical moderate-conditions days (fig. 3).

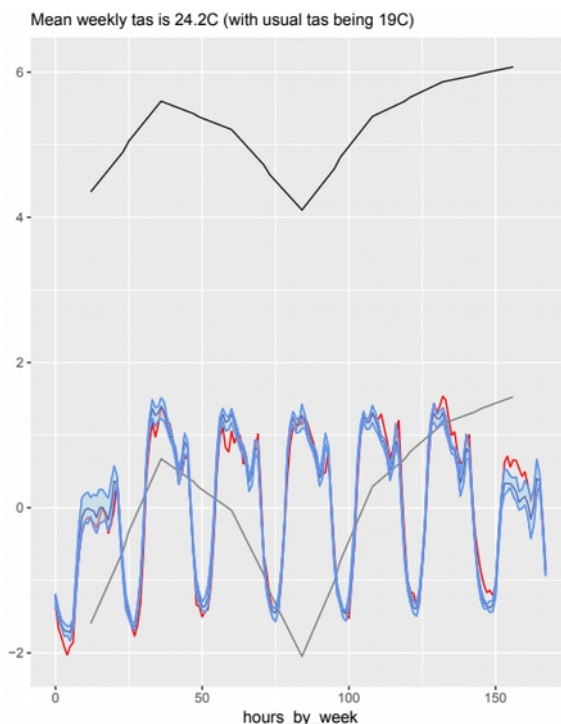


Figure 3. Power load profiles during one of the hottest weeks in August 2012 on the Urals regional power system area as compared with typical power profiles in Urals regional energy system: black and gray lines – ambient air temperature anomaly [°C] and normalized anomaly, blue lines – average normalized load profiles in August (median, 67% and 33% quantiles), red line – the hot week load profile.

This effect to the authors' best knowledge has not been yet quantified. That means that heat waves will lead to a considerable and poorly predictable shift in the profile of the energy demand. Thus, the energy systems need an additional balancing power reserve to cover possible load peaks.

4. Summary

The summer warming still has some noticeable manifestations across Russia, especially in the southern part of European Russia.

Impact of the summer warming is getting evident in the electricity demand on the daily and monthly scale across the country. The daily electricity demand is rising on 1..2 percent points per 1 °C air daily temperature increase.

The temperature projections should be included in the energy systems modeling to account for modification of the load profiles to maintain the reliability of the regional energy systems in Russia in a changing climate.

5. Acknowledgements

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