The effects of modern temperature fluctuations on building heating modes in the Republic of Sakha (Yakutia)

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Abstract. The article characterizes trends in duration, mean temperature, and fuel consumption index for the heating periods of 1991-2018 based on the observations at several meteorological stations in Republic of Sakha (Yakutia) – Verkhoyansk, Yakutsk, and Lensk. It has been show that despite recent climate variation, the heating period remains long due to low temperatures across the territory. A downward trend in the duration of the heating period was observed at the Lensk station, and an increase in the mean temperature was recorded at the Yakutsk station. In recent decades (1991-2018), temperature fluctuations contributed to variation in the fuel consumption index: +7/-11% from the multi-year average in Verkhoyansk, +9/-9% in Yakutsk, and +11/-9% in Lensk. Comparison of the variation in heating fuel consumption index across different time intervals revealed its strong dependence on the number of years and the time period selected for the analysis. A minor increase (2-7%) was found for 1965-2015 vs 1881-1960 data. Analysis of shorter periods - 1991-2018 vs 1965-2015 – shows a more pronounced decrease in fuel consumption index (9-11%), mainly due to more frequent anomalies in year-to-year temperature variation. The ongoing climate change increases temperature variation year to year and associated risks for urban heat supply. In order to facilitate safety of human population in Northern territories, a long-term strategy is required to adapt heating energy systems to rapid climate fluctuations.

1. Introduction
Recent temperature fluctuations cause a lot of debate about climate change and its possible socio-economic impact [1, 2]. Cold continental climate necessitates thorough management of energy supply to industrial and residential customers, and emphasizes the role of regional governments in planning and development of reliable and sustainable energy systems.

In regions where the seasonal heating period is long, the recent trend towards increasing mean annual temperatures may have a positive effect due to reduced consumption of energy for heating. Recent data indicate that fuel consumption has decreased by 3-5% [3]. By mid-21st century, energy expenditures for heating are expected to continue to decrease [4-6]. Climate projections indicate that the mean temperature for the heating period in Northern territories of Asian Russia might increase by 2-3°C or more. The duration of the heating period could decrease by ~5 days or less in the Northern parts of the region, and by 5-10 days in the South. The projected change in heating period parameters could reduce energy demand for heating by 10-15%. Reduced fuel consumption and the associated emissions to the atmosphere could significantly improve environmental and economic conditions in Northern cities, because the majority of heat generating power plants in the region are coal-fired.
Almost the entire territory of the Republic of Sakha (Yakutia), except for its northern limit, lies in the most severe climatic region in Russia, with an absolute temperature minimum of \(-68^\circ C\) [7]. During the coldest five day periods, the air temperature in some areas drops to \(-60^\circ C\). Reliability of the heat supply systems is vital for the human population in these conditions.

Heat supply management considerations must include fluctuations in the duration of the heating period (HP), along with engineering, technical, and economic issues.

In Asian parts of Russia with severe climatic conditions, among other HP characteristics there is a pronounced trend of increasing mean temperatures during the heating period (up to +1.5°C in 20 years) [8].

2. Objects, data and methods
Our work presents an analysis of key HP characteristics based on the data from three weather stations located in the Southern (Lensk), Central (Yakutsk) and Northern (Verkhoyansk) parts of the Republic Sakha.

Analysis of fluctuations in the HP duration, average temperature, and estimated fuel consumption index for the heating seasons from 1991-1992 to 2017-2018 was conducted, based on meteorological data with daily and monthly resolution. Meteorological data were provided by the Russian Institute of Hydro-meteorological Information (http://www.meteo.ru/data).

According to regulatory documents [7], heating period is defined as the period of time which begins and ends when the average temperature for 24 hour period remains below (or above) 8°C for 5 consecutive days. The average temperature of the heating period was defined as the average outdoor temperature for all months of the heating period. Fuel consumption index is calculated as the difference between the outside temperature and indoors temperature (18°C), multiplied by the duration of the heating period. It characterizes the heat deficit that must be compensated for in order to maintain comfortable indoor temperature, and is measured in heating degree-days – HDD, °C day [9, 10]. The standards adopted for calculating the heat supply of premises in different countries mainly depend on the duration of the heating period and its average temperature. However, the methods for calculating the duration of the heating period differ.

Comparative analysis of changes in these parameters was conducted using historical multi-year records (1881-1960) [11] and more recent data 1965-2015 [7] and 1991-2018.

Year-over-year variations in heating season characteristics were analyzed for the period 1991-2018. Potential anomalies were identified when the values deviated from the series average by 1 standard deviation or more. Trends were estimated using regression analysis with 95% confidence interval.

3. Results and discussion
The contributing factors of the harsh continental subarctic climate of Republic Sakha (Yakutia) are the significant North-South span of its territory, openness towards the Arctic basin, and terrain features. The Republic’s population living conditions are characterized by long-term disruptions in day/night regime and extended periods of low temperatures. The sum of negative temperatures varies from 3700°C in the South of the region to 7669°C in mountain valleys (Oymyakon). The duration of the period with average daily temperatures below -30°C is up to 120 days. In Yakutia, seasonal heating period is long, and its duration varies from 252 days in Southern parts of the region to 365 days at its Northern limits. Mean temperatures for the heating period also vary: from -13.6°C in Lensk to -22°C in Verkhoyansk [11]. In such conditions, a person’s stay in the open air is limited and is accompanied by a violation of the body’s heat exchange with the external environment, a sharp increase in the risk of frostbite. For optimal functioning of its vital activity, clothing with adequate thermal insulation, high-quality and high-calorie food, as well as warm residential and industrial premises are required.

In recent decades (1991-2018), daily variation in air temperatures has increased considerably. For example, in Verkhoyansk, in some years the period when mean temperature over 5 days remained below 8°C started in August and ended in mid-June. There was considerable variation in duration of
the heating period (table 1). The difference between the shortest and longest heating period varied from 42 days in Yakutsk to 59 days in Verkhoyansk.

Based on the 1991-2018 observations, the duration of the heating period shows a downward trend at all three monitoring stations, but only at the Lensk station these changes were statistically significant, -0.5 days/year, $R^2 = 0.11$.

| Meteorological stations | Duration, days | Temperature, °C |
|-------------------------|----------------|-----------------|
|                         | Average        | Min             | Max             | Average | Min | Max |
| Verkhoyansk             | 268            | 244             | 303             | -21.4   | -25.4 | -16.1 |
| Yakutsk                 | 249            | 225             | 267             | -17.1   | -19.2 | -14.2 |
| Lensk                   | 253            | 224             | 272             | -12.3   | -15.4 | -9.9  |

Mean temperature for the heating period increases from North to South (table 1). Mean temperatures for the heating period varied by 9.3°C in Verkhoyansk, 5.0°C in Yakutsk, and 5.5°C in Lensk. Over the observation period (1991-2018), mean temperatures increased in Verkhoyansk and Yakutsk, but only the latter shows statistically significant changes (0.07°C per year, $R^2=0.19$). The changes were negligible at the Lensk station.

The analysis of mean HP temperature dynamics has revealed abnormally low (>1 standard deviation) values recorded 3 times in Verkhoyansk, 4 times in Yakutsk, and 6 times in Lensk, and abnormally high values 4 times at each station.

Based on multi-year data (1991-2018), the fuel consumption index (HDD) varied +7/-11% from the multi-year average in Verkhoyansk, +9/-9% in Yakutsk, and +11/-9% in Lensk.

This drastic variation indicates that during abnormally cold winters there may be an increasing risk of fuel shortages, heat supply limits and disruptions. An excess of fuel supply during warm winters may result in economic impacts due to degradation of fuel quality during prolonged storage.

The asynchronous nature of variation in heating period parameters [2] matters. At the country-wide scale, when the mean temperature and the duration of the heating period change in opposite directions, fuel consumption (demand) is approximately 1/3 lower than if these two parameters were changing in the same direction.

At the same time, factual heat energy consumption in the city of Yakutsk remained nearly constant (~2.6 million gigacalories) for the period from 2014 to 2018, with minor increases (-0.7/+3.0%) [12].

Comparative analysis of the heating period parameters for 1991-2018 vs. historical records (1881-1960) and more recent data (1965-2015) indicated that the degree of variation strongly depends on the number of years and the time period selected for the analysis (table 2).

Table 1 Heating period parameters (1991-2018).

| Meteorological stations | Duration, days | Temperature, °C |
|-------------------------|----------------|-----------------|
|                         | Average        | Min             | Max             | Average | Min | Max |
| Verkhoyansk             | 268            | 244             | 303             | -21.4   | -25.4 | -16.1 |
| Yakutsk                 | 249            | 225             | 267             | -17.1   | -19.2 | -14.2 |
| Lensk                   | 253            | 224             | 272             | -12.3   | -15.4 | -9.9  |

Table 2 Variation in heating period characteristics in Sakha (Yakutia) over different time intervals.

| Meteorological stations | $\Delta T_a$, °C | $\Delta H P_b$, % | $\Delta H D D_c$, days | $\Delta T$, °C | $\Delta H P$, % | $\Delta H D D$, days | $\Delta T$, °C | $\Delta H P$, % | $\Delta H D D$, days |
|-------------------------|------------------|------------------|-----------------------|----------------|------------------|---------------------|----------------|------------------|---------------------|
| Verkhoyansk             | 3.5              | -4               | -10                   | 0.6            | -4               | -3                  | -2.9           | 0                | 7                   |
| Yakutsk                 | 3.5              | -3               | -11                   | 2.4            | -5               | -8                  | -1.1           | -2               | 2                   |
| Lensk                   | 2.0              | -4               | -9                    | 1.3            | -5               | -6                  | -0.7           | -1               | 2                   |

$^a$ $\Delta T$ – variation average temperature of the heating period.
$^b$ $\Delta H P$ – variation duration of the heating period.
$^c$ $\Delta H D D$ – variation fuel consumption index.

According to regulatory documentation for heating energy consumption based on climate data for 1965-2015 [7] a significant reduction of heating period in Republic of Sakha (Yakutia) is not
warranted. The heating period remains long (from 252 days in Yakutsk to 272 days in Verkhoyansk), and with low mean temperatures (-14.3°C in Lensk, -24.9°C in Verkhoyansk).

Comparing two multi-year periods 1881-1960 and 1965-2015, the latter shows an increase in HDD (2-7%), mainly due to a decrease in the air temperature. HP duration decreased only by 1-2 days, mean temperature decreased by -0.7°C in Lensk to -2.9°C in Verkhoyansk.

The decrease in fuel consumption index (HDD) during the 1991-2018 time frames was more pronounced compared to long-term data (1965-2015): 9% in Lensk, 11% in Yakutsk, and 10% in Verkhoyansk, primarily due to increasing mean temperature during the heating period (table 2).

For the period 1991 to 2018, a decrease of 4-5 days in the duration of the heating period was found in comparison to long-term observation records (1881-1960), along with an increase in the mean temperature: +0.6°C in Verkhoyansk, +1.3°C in Lensk, and +2.4°C in Yakutsk. The combined effect of the shorter heating period and higher temperatures results in a decrease in the calculated fuel consumption index by 3-8% in the recent decades in comparison with the pre-1960 period.

4. Conclusion
Our results indicate that modern climate change significantly increases variability in air temperature, which increases the risks for urban heat supply systems.

Comparison of the fuel consumption index (HDD) variation across different time intervals revealed its strong dependence on the number of years and the time period selected for the analysis. A minor HDD increase (2-7%) was found for 1965-2015 vs 1881-1960 data. Analysis of shorter periods – 1991-2018 vs 1965-2015 – shows a more pronounced decrease in HDD (9-11%), mainly due to more frequent anomalies in year-to-year temperature variation. In abnormally cold winters there may be an increasing risk of fuel shortages, heat supply limits and disruptions. An excess of fuel supply during warm winters may result in economic impacts due to degradation of fuel quality during prolonged storage.

At the same time, variation in climate parameters in 1991-2018 shows any directionality only for some parameters and at some locations, e.g. a decrease in heating period duration at the Lensk station and an increase in temperature at the Yakutsk station.

Therefore, despite the recent (1991-2018) trend towards decreasing fuel consumption index (HDD), a balanced approach is warranted when forecasting energy demands in cold weather due to significant temperature variation year to year. Fuel consumption index forecasts may underestimate future energy demands for heating, although there was no de facto decrease in heat consumption observed in the city of Yakutsk.

In order to facilitate safety of human population in Northern territories and ensure their sustainable development, a long-term strategy is required to adapt heating energy systems to rapid climate fluctuations.

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References
[1] Kattsov V M and Porfiriev B N 2017 Adaptation of Russia to climate change: the concept of the National plan Proc. of the Voeikov Main Geophysical Observatory 586 7-20
[2] Zorkaltsev V I 2017 Long-Term Temperature Variations and Their Impact on the Economy and Energy (Novosibirsk: Geo) p 178
[3] Sherstyukov B G 2007 Climatic conditions of heating period in Russia in 19 and 21 centuries Proc. of VNIIGMI-MCD 173 163-70
[4] Ginzburg A S, Reshetar O A and Belova I N 2016 Effects of climate factors on energy consumption during heating season Teploenergetika 9 20-7
[5] Klimenko V V, Tereshin A G, Beznosova D S, Mikushina O V and Andreychenko T N 2004 Variation of the parameters of heating period in Asian territory of Russia as the result of global warming Izvestia RAN Energetika 4 135-45

[6] Khlebnikova E I and Sall I A 2013 Climatic factors of energy consumption in Russia: trends, variability, and uncertainty of estimates Proc. of the Voeikov Main Geophysical Observatory 569 7-19

[7] SP 131.13330.2018 Building Climatology 2018 (Moscow: Ministry of Construction Industry Housing and Utilities Sector of Russian Federation) p 107

[8] Second Evaluative Report of Rosgidromet on Climate Change and Its Consequences on the Territory of Russian Federation 2014 (Moscow: Federal Service for Hydrometeorology and Environmental Monitoring of Russia) p 1009

[9] Efimova N A, Baykova I M and Laperrier V S 1992 Influence of climate warming on the heating regime of buildings Meteorology and Hydrology 12 95-8

[10] Belser D B, Scott M J and Sands R D 1996 Climate change impacts on US commercial building energy consumption: An analysis using sample survey data Energy Sources 2 177-201

[11] Handbook of the Climate of the USSR 1966 vol 24(2) (Leningrad: Gidrometeoizdat) p 398

[12] On the Scheme and Program for Development of the Electricity Systems in Republic of Sakha (Yakutia) for 2019-2023 2019 (Yakutsk: Decree of the Head of the Republic of Sakha (Yakutia)) (in Russian) Income accessed online on 05th of March 2020 via http://docs.cntd.ru/document/553273832