Current trends of climatically driven minimal heat demand for residential buildings

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Abstract. Heating-related energy consumption depends on climatic conditions and is prone to changes in warming climate. Shortening of heating season is one of the expected effects of climate change. Since the further development and modernization of energy and heat supply systems is influenced by expectations of the climate change, studying the regional climate trends is certainly important. In this article, the authors analyzed historical changes in minimal heating-related energy demand from several Russian and European cities and show that global expectations may do not meet reality at some locations.

1. Introduction
The heat demand is currently the largest among the types of energy demands [1]. About a third of global energy consumption is used by households [2], and, in the countries with a temperate climate, about half of energy consumed by households are used for heating [2].

Heating-related energy consumption depends on climatic conditions [3] and is prone to changes in warming climate [4]. The internal temperature of a building is determined by the air temperature outside the building and by the energy spent for heating. In most climatic regions, thermally comfortable conditions cannot be maintained without heating when monthly air temperature is below 14°C. Hence, the monthly air temperature serves as a trigger for starting heating season.

Shortening of heating season is one of the expected effects of climate change. According to van Ruijven [4] heating-related energy demand in Europe would decrease by 9-14% by the end of 21st century. Since the further development and modernization of energy and heat supply systems is influenced by expectations of the climate change, studying the regional climate trends is certainly important.

In this article, the authors quantify the effect of the current climate changes in the minimal energy demand from district and individual heating in several Russian and European megalopolises located in different climatic zones.

2. Methods
According to Russian federal law № 384 “Technical regulation on the safety of buildings and structures” from 30.12.2009 [5], temperature inside residential buildings must be about 20°C during the heating season. This temperature cannot be maintained without heating during the cold season – that is, when monthly air temperature is below the threshold corresponding to comfortable indoor temperature without heating [6].
The air temperature outside the building is the most important driver for the energy demand for heating needed to maintain the legally binding threshold for the indoor temperature. Another factor affecting the energy demand is building insulation which is parameterized by the required monthly amount of energy per 1 square meter per 1°C difference between outdoor and indoor temperature. Combining the effects of these two factors gives the following equation for estimating climatically driven minimal of energy demand from heating one square meter of a residential building -- specific heat demand (SHD):

\[
SHD = \sum_{m=1}^{12} h \times \max(T_0 - T_m, 0)
\]

where \(T_m\) is the monthly average temperature, \(T_0\) is the temperature of starting or ending of heating period \((T_0 = 14^\circ C)\), \(h\) is the required monthly amount of energy per 1 square meter per 1°C difference between outdoor and indoor temperature \((h=1.8 \text{ kWh (m}^2\text{C})^{-1})\) [7]. \(T_0\) is set at 14°C based on the study of thermal comfort in free-running buildings [6] assuming that heating is needed when indoor temperature is below 20°C.

Climatic data needed to examine the current changes in SHD were taken from the Global Historical Climatology Network (GHCN-M) [8].

3. Results

During the period of 1951-2018, the Moscow’s SHD varied from 163 to 253 kWh m\(^{-2}\), the Saint-Petersburg’s SHD from 153 to 248 kWh m\(^{-2}\), the London’s SHD from 58 to 113 kWh m\(^{-2}\), and the Oslo’s SHD from 32 to 91 kWh m\(^{-2}\). In average, the Moscow’s SHD was three times higher than Oslo’s SHD and more than two times higher than London’s SHD (Table 1).

|          | Maximum monthly average temperature \(^\circ C\) | Minimum monthly average temperature \(^\circ C\) | Average SHD \(\text{kWh m}^2\) | Trendline slope | Correlation coefficient* |
|----------|-----------------------------------------------|-----------------------------------------------|-------------------------------|-----------------|-------------------------|
| Moscow   | 20.2                                          | -18.5                                         | 206.41                        | -0.63           | 0.63                    |
| Saint-Petersburg | 24.4                           | -17.9                                         | 202.02                        | -0.7            | 0.62                    |
| London   | 28.3                                          | -4.6                                          | 86.41                         | -0.45           | 0.70                    |
| Oslo     | 21.2                                          | -14.1                                         | 66.45                         | -0.13           | 0.24                    |

* i.e. the correlation coefficient between SHD and its linear trendline.

The Saint-Petersburg’s SHD show the steepest downward trend: 0.7 kWh m\(^{-2}\) y\(^{-1}\). The average SHD in 1951-1980 (216 kWh m\(^{-2}\)) higher than the average SHD in 1981-2010 (195 kWh m\(^{-2}\)) by 10%. In the last decade (2009-2018), the average SHD (182 kWh m\(^{-2}\)) decreased by 16% comparing to the 1951-1980 period.

The gentlest downward trend, 0.13 kWh m\(^{-2}\) y\(^{-1}\), is detected in Oslo’s SHD time series. In the last decade, the average Oslo’s SHD (67 kWh m\(^{-2}\)) decreased only by 6% comparing to the 1951-1980 period (71 kWh m\(^{-2}\)).

In 1951-1980, there was a noticeable difference between the Oslo’s and London’s SHD. The Oslo’s SHD varied in the range from 43 to 86 kWh m\(^{-2}\), whereas London’s SHD varied in the range from 84 to 113 kWh m\(^{-2}\). This difference almost disappeared in the last decade (Fig. 1): the London’s SHD varied in the range from 58 to 100 kWh m\(^{-2}\) during this period, and Oslo’s SHD from 53 to 92 kWh m\(^{-2}\).
The peak values of Oslo’s SHD increased by 6 kWh m$^{-2}$ during the last 30 years (1989-2018) comparing to the period of 1951-1980 (from 86 to 92 kWh m$^{-2}$). The peak values of London’s SHD decreased by 13 kWh m$^{-2}$ (from 113 to 100 kWh m$^{-2}$).

Three times larger decrease occurred in the peak values of Moscow’s and Saint-Petersburg’s SHD - 38 and 34 kWh m$^{-2}$, respectively: from 253 to 215 kWh m$^{-2}$ in Moscow and from 248 to 214 kWh m$^{-2}$ in Saint-Petersburg.

**Discussion and conclusions**

The information about the trend in SHD peak value is important for understanding the directions for heating system development. The SHD peak value determines climate-based requirements to heating system capacity, and so the peak value, not the average, should be used in assessments of the climatically driven minimal energy demand from a given city.

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Time series of the Specific Heat Demand (SHD) in Moscow (WMO code: 27612), London (WMO code: 03772), Saint-Petersburg (WMO code: 26063) and Oslo (WMO code: 01384) for the period 1951-2018 (trends are shown by dotted lines).

In Moscow, the total floor area of residential buildings is estimated at 236.1 million square meters. Hence, the minimal climatically driven energy demand for heating during the last three decades (1989-2018) was 50.8 billion kWh that requires 5.9 billion cubic meters of natural gas. In a specific year the amount of natural gas needed for heating Moscow’s residential sector may be much less than this amount.

For example, in 2018, 5.3 billion cubic meters of natural gas was sufficient to satisfy the minimal climatically driven energy demand. However, the amount of natural gas really required for heating is not known at the start of the heating season, when the city purchases it. This situation may lead to an increase in indoor temperature. Thus, if the city has purchased 5.9 billion cubic meters of natural gas at the start of 2018 heating season, then indoor temperature would be higher than 20°C by 11%, that is, by 2.2°C. Since the SHD minimum during the last three decades is 32% lower than the SHD maximum, the “overheating” in some years could be as large as 6.4°C.
In fact, the amount of natural gas burnt at the Moscow’s combined heat power plants in 2018 was much higher than the minimal climatically driven energy demand for heating residential sector: 27 vs 5.9 billion cubic meters. But there is no such a big difference in the Saint-Petersburg. The total floor area of residential buildings in Saint-Petersburg estimated at 143.8 million square meters required 3 billion cubic meters of natural gas in 2018. The amount of natural gas burnt at the Saint-Petersburg’s combined heat power plants was only two times higher: 6.6 vs 3 billion cubic meters. In other words, the about half of natural gas burnt for producing heat and electricity in Saint-Petersburg was used for heating residential sector, whereas the Moscow’s residential sector consumes only 22% of the energy at combined heat power plants. Due to the lack of official data on the floor area in commercial buildings, it is not possible to assess their share in the heat-related energy demand.

It is worth mentioning here that according to Russian federal law No. 354 “On providing public utilities to owners and users of floor spaces in residential buildings” from 06.05.2011 [9], the heating season should start it autumn when the 5-day average temperature drops below 8°C and end in spring when the 5-day average temperature rises above 8°C. The average length of the heating season that matches these requirements in Moscow was equal to 214 days in the last decade [10]. According to Belova et al. [11] the average value of heating degree days (HDD) in Moscow was 4129 and was decreasing with the rate -13.55 per year during the period of 1966-2015. At Saint-Petersburg HDD was decreasing with the rate -15.26, and in Europe with the rate -7.87 during the same period. These results support our conclusion about the downward tendency in energy demands for heating in Europe.

However, the low regulates the period during which district heating should be turned on, but it does not regulate the start and the end of the individual heating. Households may use electricity for heating before and after the legally defined heating season to maintain comfortable indoor temperature. In view of the fact that combined heat power plants supply both electricity and heat they satisfy both the district and individual heating demands. The method for calculating the minimal climatically driven energy demand for heating used in this study takes into account the demands for heat supply before the start and after the end of the legally defined heating season.

This study of changes in minimal heating-related energy demand in Moscow, Saint-Petersburg, London and Oslo show that global expectations may do not meet reality at some locations. The SHD peak values reduced by 15% in Moscow and Saint-Petersburg, by 11% in London, but they increased (by 7%) in Oslo.

Such a different behaviors of SDH in investigated and some other Russian and European cities suggests that next step of research: a large-scale assessment of the historical, current and projected changes in the climatically driven minimal energy demand from the major cold climate cities.

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