Biometeorological characteristics as energy consumption estimates in large Russian cities

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Abstract. We have conducted a comparative analysis of the climatic and biometeorological characteristics of the regions with the largest Russian cities and have laid the basis for constructing maps of the heating season climatic characteristics for the territory of Russia. For the effective ambient temperature range of 17.2 to 21.7°C (comfort zone), we have calculated changes in the comfort zone for Moscow, St. Petersburg, Krasnodar, Novosibirsk, and Vladivostok according to data from 1959 to the present. Despite all climate differences between regions with selected cities, allowance for wind speed leads to a decrease in the number of days with temperature within the comfort zone.

1. Introduction

To estimate the energy amount needed to heat indoor living and public spaces, the heating degree day (HDD) parameter is applied. This is the most common climatic indicator of energy consumption for the building heating, which is calculated for a certain period of the year by summing the absolute deviations of the average daily ambient temperature from the selected base temperature [1]. However, human biometeorological sensitivity is based not only on the ambient temperature, but on a combination of temperature, humidity, and wind speed.

According to Mexican researches, short cold periods do not affect human health as destructively as long periods with temperatures below minimum mortality temperature (MMT). Especially the group of the 65+ generation suffers, whose health can be not as strong as before [2]. The risk of health deterioration for older people during prolonged moderate colds is quite high [3]. It requires special attention to the problem of sufficient heating of living accommodation, especially for socially disadvantaged groups. In [3] there are discussed results for the following countries: Australia, Brazil, Canada, China, Italy, Japan, South Korea, Spain, Sweden, Taiwan, Thailand, UK, and the USA. Due to the difficulty of obtaining heating season data and other relevant statistics, the mentioned study does not have results for countries such as Russia, Mongolia, Norway, Finland, and Sweden, where historically long-term periods of cold are annual events. In Russia, for example, preparing for the winter heating season is carried out at the state level, and the Moscow city district heating system is the largest in the world.

The effective temperature is used as one of the main methods to assess the state of the human body under the influence of a combination of meteorological factors. We mention in passing that
bioclimatic indices are used in agriculture [4], for example, in vineyards, to predict changes in existing vineyards in addition to the development of new vineyards at potential areas with suitable varieties of grapes [4]. Bioclimatic comfort zones are also used in urban development, rural planning, tourism purposes, urban area residential area planning, and landscape architecture.

To estimate completeness of existing data on annual temperatures, we have created a database and constructed 145 maps of average annual temperatures for the period 1874–2017 for the territory of Russia for different climatic zones (for the Soviet era, calculations were carried out for the territory of the USSR). These long-term average annual data were obtained from the Federal Service for Hydrometeorology and Environmental Monitoring – World Data Center. Figure 1 presents an example of such a map for 2017.

Figure 1. The map of average annual temperatures for the Russian territory (2017 yr.). Blue dots are geographical points with insufficient data for calculations (data are present for less than 80% of the days in a year).

2. Methods and objects
To further obtaining more accurate estimates of energy consumption, we consider not only the temperature of the air itself but also the equivalent-effective temperature $ET$, °C [5], calculated according to the formulas of A. Missenard [6]:

a) as a function of ambient temperature $T$, °C, and relative humidity $f$, %:

$$ET_1 = T - 0.4(T - 10)\left(1 - \frac{f}{100}\right);$$

b) as a function of ambient temperature $T$, °C, relative humidity $f$, %, and wind velocity at a height of 1.5 m $v$, m s$^{-1}$:

$$ET_2 = 37 - \frac{37 - T}{0.68 - 0.0014f + \frac{1}{1.76 + 1.4v^{0.75}}} - 0.29T\left(1 - \frac{f}{100}\right).$$

This parameter characterizes the heat-sensing of the person in the shade. We have chosen the $ET$ parameter among other existing bioclimatic parameters ($PET$ and $UTCI$ [7]) as the simplest and most suitable for our statistical data. Since we have quite limited data, this parameter recommended by the Russian Federal Service for Hydrometeorology and Environmental Monitoring seems to us quite reliable and correctly interpreted. There are several ways to determine the boundaries of comfort zones, where a person experiences optimal heat sensation. We have chosen the $ET$ range from 17.2 to 21.7°C according to [6].
We have calculated $ET$ using data from 1959 to the present [8] for the following cities in Russia: Moscow, St. Petersburg, Krasnodar, Novosibirsk, and Vladivostok (Figure 2). These megacities are examples of cities located in regions with different climate features.

![Figure 2. The geographical location of the selected cities (©Google Earth).](image)

- The climate of Moscow is humid continental with warm summers and cold long-lasting winters.
- Novosibirsk is the largest Siberian megalopolis. As well, it is located on the same latitude as Moscow and has a continental climate (more continental than Moscow’s one) with severe winters.
- St. Petersburg is located northward of Moscow; it has a moderate transitional from the continental to the marine climate.
- Vladivostok has a monsoon climate, and winter is much more comparable to that in Moscow due to Pacific Ocean influence.
- The climate of Krasnodar is transitional, from moderately continental to humid subtropical climate.

Data from the Federal Service for Hydrometeorology and Environmental Monitoring – World Data Center have some unexpected gaps, and there are almost no data on daily measurements of relative humidity and wind speed. Thus, the American database NOAA of National Centers for Environmental Information was chosen for calculating bioclimatic temperatures as more convenient.

3. Results and discussion
We have analyzed the trends of percent of days with $ET$ in a year ($ET_1$ and $ET_2$) within the boundaries of the comfort zone, and also compared with the percent of days in a year with ambient temperature at the same boundaries (Figure 3a–e). Krasnodar is the city with the maximum number of days in a year with $ET$ falling within the boundaries of the comfort zone, and St. Petersburg is the same with the minimum. In Moscow, Novosibirsk, and Vladivostok, the difference between the number of days with $ET$ within the boundaries of the comfort zone and the number of days with ambient temperature within the same boundaries is least expressed. The dynamics of the number of days with $ET$ within the comfort zone in Vladivostok and Novosibirsk accords with the geographical location of these cities in regions with monsoon and continental climate.

It was noted that for all the selected cities, the linear trend of the percent of days with bioclimatic temperature $ET_1$ within the comfort zone (with consideration to relative humidity solely) is the same as the trend of the percent of days with ambient temperature within the comfort zone. Moreover, the slope of the linear trend of the percent of days with bioclimatic temperature $ET_2$ within the boundaries
of the comfort zone (with consideration to wind speed as well), changes sign for Krasnodar and Novosibirsk, and for other cities, both trends increase.

Figure 3. Graphs of linear trends of ambient temperatures and effective temperatures calculated by the Missenard formulas.

Among the selected cities, Krasnodar is the only city in which the calculation of the effective temperature as a function of ambient temperature and relative humidity leads to an increase in the number of days with temperature within the comfort zone. This is probably due to the location of the city in the transition zone from temperate continental to humid subtropical climate.
4. Conclusion

A comparative analysis of the climatic and biometeorological characteristics of regions with the location of the largest Russian cities was conducted. Despite the fact that the selected cities are located at close latitudes, they represent a diverse climatic sample. The influence of relative humidity and wind speed on the indicator characterizing the heat sensation of a person was revealed. The calculation of changes in bioclimatic characteristics was carried out for Moscow, St. Petersburg, Krasnodar, Novosibirsk and Vladivostok according to data from 1959 to the present. Consideration for wind speed for the effective temperature calculation leads to a decrease in the number of days with temperature within the comfort zone in all the major Russian cities. Comparison of $ET_1$ and $ET_2$ trend results for Krasnodar and Novosibirsk shows the importance of taking into account wind speed when detection of comfort zones.

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References

[1] Belova I N, Ginzburg A S and Krivenok L A 2018 Energy Procedia 149 373–9
[2] Hurtado-Díaz M, Cruz J C, Texcalac-Sangrador J L, Félix-Arellano E E, Gutiérrez-Ávila I, Briseño-Pérez A A, Saavedra-Lara N, Tobias A and Riojas-Rodriguez H 2019 Int. J. Biomet. 63 1641–50
[3] Gasparrini A et al 2015 The Lancet 386 369–75
[4] Sánchez Y, Martínez-Graña A M, Santos-Francés F and Yenes M 2019 Index for the calculation of future wine areas according to climate change application to the protected designation of origin “Sierra de Salamanca” (Spain) Ecol. Ind. 107 105646
[5] Konstantinov P I, Varentsov M I and Malinina E P 2014 Urban Climate 10 563–72
[6] Kobysheva N V, Stadnik V V, Klueva M V, Poglotsina G B, Akent’eva E M, Galyuk L P, Razova E N and Semenov Yu A 2008 Guidelines for specialized economic services for climate information, products and services ed N V Kobysheva (St. Petersburg) p 336 (In Russian)
[7] Semenova A A, Konstantinov P I, Varentsov M I, and Samsonov T E 2019 IOP Conf. Ser. Earth Environ. Sci. 386 012017
[8] NOAA National Centers for Environmental Information. URL: https://www.ncdc.noaa.gov