The impact of climate change on the building climatology parameters used for designing the buildings and constructions in Russia

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Abstract. The data analysis results of long-term measurements of climatic parameters in Moscow and St. Petersburg is presented. The data on change in these parameters during the year over the past 10 years is exposed. The trends have been identified and represented for the following parameters: outdoor temperature, sunshine, snow depth, wind speed, humidity, etc. The duration of heating periods for each studied year and city is considered, as well as crossings through -2°C during these periods. Throughout the research, the impact of climatic changes on the parameters of building climatology, which are used in designing the buildings and constructions in Russia, was determined. The obtained climate information will allow predicting the energy efficiency of operation for various engineering systems in the construction sector, as well as for the long term perspective.

1 Introduction

The construction of modern, safe and energy-efficient buildings and constructions today is impossible without the use of standardized climatic effects when designing. Those effects are determined in accordance with the approved standard methodology and representing a typical set of climatological data – “typical climatic year”. Unfortunately, the correct climate data that could be used as a “typical climate year” in Russia is not available in the current regulatory documents. Engineers still use regulatory documents on building climatology, which were compiled according to climatological databases of the second half of the 20th century. Obviously, these documents do not take into account the climate changes that have occurred in the past decade. As a result, billions in losses are included in the project budgets for the future overstated heating period duration, estimated outdoor temperatures in the coldest five-day period, soil freezing depths, lowered estimated outdoor temperatures in the summer. Furthermore, this is the reason why we the air conditioning systems in are not installed in mass housing today, although it is already obviously necessary. The most displeasing matter is the absence of the hourly calculated values of climatic parameters in

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our regulatory documents on building climatology, primarily regarding the outdoor temperatures. All European standards regarding energy efficiency are based on the use of hourly values of outdoor temperatures, and in our standards it is monthly average. The designer is simply not able to obtain the average hourly calculated temperature values, statistically processed and representing the "typical climatic year" with sufficient reliability. Obviously, it is useless to speak about any reliable control of the achieved energy efficiency indicators without solving the problem of radically updating the regulatory base in the field of building climatology. The lack of standardized hourly values of climatic parameters does not allow designing buildings and structures at a modern level and practically excludes the possibility of using BIM-modeling of HVAC systems (heating, ventilating and air-conditioning).

2 Research methods

All measurements were carried out at the Meteorological observatory of MSU in accordance with accepted international and domestic standards established by WMO and Roshydromet. Measurements of air temperature in an instrument screen installed at a height of 2 meters above the earth’s surface were made using a standard set consisting of station hygrometer, minimum and maximum thermometers TM-1 and TM-2. Continuous monitoring of the diurnal variation was carried out using the daily thermograph M-16. [1] The values of wind speed and direction were obtained at a height of 15 meters, measured using the M63 anemorumbometer. Humidity was measured in an instrument screen using a hair hygrometer, and was also calculated according to a psychrometric installation. The relative humidity was also monitored on a daily scale in continuous mode using a daily M-21M hygrograph. [1] Snow depth was measured by three standard snow stakes in the cold season. Density is measured using a stational ramsonde. [1]

3 Typical climatic year regarding the average daily outdoor temperature in St. Petersburg

In order to represent the climatic state of St. Petersburg over the past 10 years, the illustrative and tabular data on meteorological parameters are presented. The RIHMI-WDC data for 2009-2018 was used for calculations, including information on the timing of air temperature, relative humidity, wind direction and speed; data on the snow depth per day and the sunshine duration per month. [2-5]

3.1 Daily average air temperature

Table 1. Typical climatic year (in degrees Celsius – °C)

	January	February	March	April	May	June	July	August	September	October	November	December
1	-3.5	-5.0	-2.8	1.7	7.7	16.7	18.1	19.5	14.9	9.0	3.7	-2.0
2	-4.6	-3.6	-2.3	2.5	7.7	15.5	18.6	19.2	14.7	8.8	4.3	-1.8
3	-5.3	-3.7	-2.0	2.9	8.1	15.4	19.2	20.1	14.9	9.0	4.9	-1.3
4	-5.4	-4.6	-2.4	3.3	9.0	15.5	18.0	20.3	14.6	8.7	5.2	-1.0
5	-6.3	-5.2	-2.5	4.6	8.7	14.2	17.5	19.9	14.7	8.8	4.2	-0.2
6	-6.5	-6.8	-2.7	4.7	9.8	14.6	17.6	20.7	14.5	7.8	2.5	-0.9
7	-7.8	-5.9	-3.3	2.8	10.7	15.0	18.4	20.8	14.3	8.0	2.3	-0.5
8	-6.9	-3.8	-1.5	3.0	10.5	14.5	19.6	20.7	14.7	7.4	2.8	-0.5
9	-5.0	-4.4	-0.3	4.0	11.8	15.0	19.3	20.6	14.6	7.8	2.3	-0.9
10	-3.3	-4.5	-0.6	4.3	12.3	15.7	19.1	20.0	14.6	7.9	2.5	-1.6
11	-3.8	-4.3	0.2	5.1	11.6	16.0	19.4	18.7	14.7	7.2	2.6	-1.0
12	-4.6	-4.6	-0.5	5.2	11.7	15.7	20.0	18.2	15.5	6.3	2.9	-0.8
13	-4.0	-4.1	-1.0	6.2	13.0	15.5	20.1	17.8	14.4	6.0	3.0	-1.6
14	-4.1	-4.3	-0.3	4.9	12.9	16.0	19.9	17.9	13.9	5.8	2.7	-2.2
15	-5.8	-6.2	-2.0	4.2	13.2	15.8	20.2	17.9	13.9	6.2	2.5	-3.4
16	-6.9	-6.7	-2.3	4.9	13.2	15.9	19.7	17.4	13.3	6.4	2.5	-3.3

17	-6.8	-6.4	-2.2	6.0	14.5	15.4	19.4	18.1	13.0	6.3	3.4	-3.7
18	-7.3	-6.0	-1.2	5.3	14.9	15.7	19.1	18.1	13.0	6.3	2.6	-4.2
19	-6.4	-6.1	-0.3	4.7	15.1	16.3	19.6	17.7	13.3	5.0	2.6	-3.8
20	-7.1	-6.4	-0.6	5.0	15.8	15.9	19.1	16.8	13.7	4.9	1.8	-3.2
21	-8.0	-7.0	-0.6	5.8	15.7	15.7	19.7	16.4	13.3	4.2	1.7	-3.6
22	-8.6	-5.5	-1.1	5.4	15.5	16.2	19.8	16.9	13.2	3.3	1.8	-3.4
23	-10.0	-4.2	-0.8	5.5	15.0	16.8	20.5	16.8	11.4	3.3	1.3	-3.0
24	-8.3	-3.6	-1.7	5.9	14.8	17.1	20.0	17.0	11.0	5.1	1.9	-3.2
25	-6.8	-4.1	-1.0	6.6	14.8	17.6	20.1	16.2	10.6	4.0	0.6	-2.7
26	-5.9	-3.4	-0.8	8.1	15.1	17.9	22.0	16.5	10.3	3.3	0.3	-1.5
27	-6.4	-2.6	0.1	9.2	14.0	17.2	22.4	16.4	11.2	4.1	0.6	-1.6
28	-5.7	-2.3	1.4	9.9	13.8	17.0	23.0	15.9	10.5	4.6	-0.8	-2.2
29	-4.8	-3.8	1.4	8.2	15.0	17.9	22.4	15.1	9.1	4.7	-2.8	-2.8
30	-4.5		1.3	8.0	14.7	18.0	21.1	14.8	9.4	3.7	-3.0	-2.7
31	-6.1		1.1		15.1		21.1	14.7		3.3		-1.7

Fig. 1. Typical climatic year’s course of daily average temperature

The minimum value is reached in January. The maximum value is reached in late July – early August. This is due to the coastal position of the city (the sea is much more inert than air, due to differences in the heat capacity of water and air, respectively, the maximum and minimum temperatures will be shifted relative to more continental cities at the same latitude). [2]

3.2 Sunshine duration

Table 2. Duration of sunshine in St. Petersburg (hours)

	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
2009	13	15	90	224	261	194	284	222	139	52	13	4
2010	22	32	102	181	216	225	349	248	96	69	2	1
2011	8	72	121	188	248	271	276	179	105	47	17	5
2012	20	65	106	168	295	247	248	181	106	60	17	10
2013	13	21	173	167	259	272	275	244	120	71	20	6
2014	27	22	120	261	215	202	346	225	176	63	11	1
2015	13	28	132	131	205	272	221	307	102	95	13	10
2016	15	14	109	126	299	215	176	167	113	44	6	8
2017	17	42	110	137	268	223	196	185	104	18	16	3
2018	10	48	124	176	333	241	241	226	148	71	23	1
Average	15.8	35.9	118.7	175.9	259.9	236.2	261.2	218.4	120.9	59	13.8	4.9

The maximum value is reached in July. The duration of sunshine in June is reduced compared to May and July. The minimum value is reached in December. Such regularities are explained by the cloud cover throughout the year (the maximum cloud amount is usually observed in June, and the minimum, in contrast, in December) and the duration of daylight hours.

Fig. 2. Change in the duration of sunshine throughout the year

3.3 Snow depth

Table 3. Average snow depth (cm)

	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
1	12	17	21	7	0	0	0	0	0	0	1	5
2	11	18	20	6	0	0	0	0	0	0	0	6
3	12	17	20	6	0	0	0	0	0	0	0	6
4	13	18	20	4	0	0	0	0	0	0	0	6
5	13	20	20	2	0	0	0	0	0	0	0	5
6	13	20	20	2	0	0	0	0	0	0	0	6
7	14	21	20	1	0	0	0	0	0	0	1	6
8	16	20	19	1	0	0	0	0	0	0	2	6
9	15	20	19	0	0	0	0	0	0	0	3	6
10	16	20	19	0	0	0	0	0	0	0	3	8
11	15	20	19	0	0	0	0	0	0	0	3	10
12	15	19	19	0	0	0	0	0	0	0	3	10
13	15	19	19	0	0	0	0	0	0	0	3	9
14	15	19	18	1	0	0	0	0	0	0	3	8
15	16	21	18	1	0	0	0	0	0	0	2	9
16	17	21	19	0	0	0	0	0	0	0	2	8
17	16	21	18	0	0	0	0	0	0	0	2	8
18	17	21	18	0	0	0	0	0	0	0	1	8
19	17	21	17	0	0	0	0	0	0	0	0	8
20	17	21	18	0	0	0	0	0	0	0	0	7
21	17	20	17	0	0	0	0	0	0	0	0	8
22	18	21	17	0	0	0	0	0	0	0	0	9
23	18	23	16	0	0	0	0	0	0	0	0	10
24	19	24	15	0	0	0	0	0	0	0	1	12
25	19	23	15	0	0	0	0	0	0	0	2	13
26	19	22	14	0	0	0	0	0	0	0	3	14
27	19	23	14	0	0	0	0	0	0	0	3	14
28	17	22	13	0	0	0	0	0	0	0	3	13
29	17	16	11	0	0	0	0	0	0	0	3	13
30	18		10	0	0	0	0	0	0	0	4	12
31	17		9		0	0	0	0	0	1		13

Fig. 3. Average snow depth (cm)

The maximum snow depths are reached around mid-February, as snow manages to accumulate during the winter. A sharp decrease in the average snow depth in March is explained by frequent thaws. In autumn and in December, the snow cover is still unstable.

This is represented by large amplitudes of average snow depth in the histogram.

3.4 Wind speed and direction

Table 4. Average wind speeds (m/s)

	Januar y	Februar y	Marc h	Apri l	Ma y	Jun e	Jul y	August t	Sept.	Oct .	Nov.	Dec.
1	2.1	2.3	1.9	2.0	2.1	1.9	1.7	1.9	1.6	2.0	2.3	2.1
2	2.3	2.6	2.0	2.1	2.2	1.9	1.7	1.7	1.5	1.9	2.2	2.5
3	2.1	1.9	2.1	2.0	2.2	2.0	1.8	1.6	1.6	1.6	2.0	2.8
4	1.9	1.8	2.0	1.9	1.7	2.2	1.6	1.8	1.7	2.0	2.4	2.1
5	2.1	1.7	1.8	2.1	1.8	2.1	1.9	1.5	1.5	2.5	2.3	2.9
6	2.3	2.0	1.9	2.4	2.0	1.5	1.5	1.8	1.5	2.1	1.9	3.0
7	2.3	1.8	2.2	1.7	1.8	1.8	1.5	1.8	1.3	2.2	2.3	2.6
8	1.9	2.3	2.4	1.9	1.7	1.8	1.6	2.0	1.5	2.1	2.1	2.3
9	1.8	1.8	2.3	2.1	1.9	1.6	1.8	2.1	1.4	2.0	2.0	2.4
10	2.0	1.5	2.1	2.3	1.7	1.6	1.5	2.1	1.1	2.0	2.2	2.5
11	2.6	1.6	2.2	1.9	1.7	2.0	1.4	1.7	1.2	1.7	2.1	2.2
12	2.5	2.0	1.8	1.7	1.9	1.9	1.6	1.9	1.8	1.6	2.2	2.3
13	2.7	2.0	1.9	1.9	2.1	1.9	1.6	2.0	1.8	1.6	2.5	3.0
14	2.0	1.8	2.2	1.8	2.2	1.9	1.8	2.0	1.9	1.7	2.0	2.2
15	1.4	1.6	2.0	2.4	1.9	2.1	1.7	1.9	2.2	1.7	2.2	2.5
16	1.8	1.5	2.3	1.7	1.6	2.1	1.9	1.7	2.0	1.8	2.4	2.2
17	1.9	1.7	2.0	2.3	1.5	2.4	2.1	1.7	1.9	1.9	2.7	2.2
18	1.9	1.9	1.8	2.8	1.7	2.8	1.6	1.7	1.9	2.5	2.3	2.5
19	1.8	2.1	1.9	2.3	1.6	2.4	2.1	2.0	2.2	2.6	2.3	2.3
20	1.7	2.0	2.2	2.1	1.5	2.3	1.8	1.5	1.6	1.6	2.2	2.7
21	1.5	2.0	2.4	2.1	1.5	2.0	1.6	1.5	1.5	1.7	2.1	2.3
22	1.5	2.2	2.3	1.4	1.7	1.7	1.7	1.7	2.1	2.0	2.2	2.3
23	1.8	2.3	2.4	2.0	1.8	1.6	1.7	1.7	2.1	2.1	1.8	2.5
24	1.8	2.6	2.2	2.2	1.7	1.6	1.7	1.6	1.9	2.1	2.5	2.6
25	2.2	1.8	2.0	2.2	1.6	1.6	1.6	1.5	1.9	2.3	2.0	2.6
26	2.2	1.8	1.9	2.0	1.5	1.3	1.4	1.5	1.7	2.0	2.4	3.0
27	1.8	1.7	1.9	1.9	1.7	1.9	1.3	2.0	2.1	2.1	2.9	2.4
28	2.2	1.8	2.3	1.9	1.5	2.1	1.2	1.5	2.1	2.4	3.0	2.1
29	2.4	1.6	1.9	2.1	1.5	1.3	1.5	1.7	2.0	2.8	2.3	2.3
30	2.5		1.9	2.1	1.9	1.5	1.5	1.6	2.5	2.2	2.2	2.4
31	2.1		1.9		1.5		1.7	1.5		2.4		2.0
Average	2.0	1.9	2.1	2.0	1.7	1.9	1.6	1.7	1.8	2.0	2.3	2.4

Fig. 4. Average wind speed (annual course)

Wind speeds reach their maximum values in December, which is explained by active cyclonic activity in the winter period. Minimum speeds are observed in the summer (especially in July), cyclonic activity is weakened during this period.

3.5 Wind direction

It can be noted that the prevailing winds in St. Petersburg are of the western directions (western, southwest), both regarding the whole year and also for particular months, which is due to the Atlantic effect. Also, northern (mainly in late summer and early autumn) and southeastern winds (mainly in winter) are often observed.

Fig. 5. Wind rose in St. Petersburg (2009-2018)

Table 5. Relative air humidity (%)

	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
1	86	83	83	71	68	55	74	71	77	81	85	85
2	86	82	82	77	69	68	70	73	80	78	86	87
3	86	86	78	78	58	68	65	68	80	80	89	85
4	85	85	80	66	62	58	73	72	79	81	87	87
5	83	85	78	69	66	61	71	72	78	76	83	88
6	85	83	75	71	61	58	67	69	78	77	87	88
7	83	85	75	75	58	60	71	70	85	77	90	85
8	85	86	78	70	62	63	72	70	80	80	89	85
9	89	85	73	63	59	63	71	68	77	82	84	86
10	90	87	81	60	63	66	68	69	80	82	87	86
11	85	86	85	62	69	69	67	71	81	82	87	89
12	88	85	81	65	62	75	67	72	81	85	85	87
13	90	84	79	67	57	70	68	74	79	86	85	83
14	88	81	74	73	54	65	66	75	78	83	86	81
15	87	83	72	67	52	64	70	75	77	84	87	84
16	84	83	69	65	58	68	72	74	80	79	87	86
17	85	82	72	69	63	67	72	71	80	79	85	84
18	85	84	66	62	64	67	72	73	78	78	87	85
19	86	84	71	64	64	66	69	74	78	77	87	85
20	83	83	74	66	63	69	75	76	81	81	85	86
21	84	81	71	70	62	73	73	74	81	80	87	86
22	86	83	72	71	61	67	75	73	81	78	86	85
23	86	84	74	69	62	64	75	77	83	81	88	86
24	85	82	72	69	60	68	75	76	78	83	87	83
25	86	83	69	71	64	71	73	78	77	81	89	85
26	86	84	66	69	68	70	68	78	83	81	87	84
27	86	83	68	67	65	71	67	75	79	84	87	85
28	85	83	71	64	68	73	64	75	80	85	82	84
29	85	88	71	71	64	65	72	78	79	81	82	87
30	82		67	69	64	68	73	79	82	83	85	86
31	82		67		60		70	75		85		86

Fig. 6. Relative air humidity (%)

The annual course of relative air humidity is the opposite of the temperature one. Maximum values are reached in winter and late autumn, air temperature decreases and western winds prevail (see Figure 7), bringing humid air from the sea.

It can be seen that in spring and summer the fluctuation amplitude of the relative humidity is greatest. This is due to the fact that the air temperature is constantly quite high during this period (at least much higher than in winter). Thus, there may be more water vapor in the air,

therefore the relative humidity is less than in winter, and its values fluctuate due to the humid air influx from the Atlantic. In winter, the air temperature is low, so humidity in the air is kept worse, and the influx from the Atlantic side does not affect the relative humidity (since it is high already). [6]

3.6 The heating period duration in St. Petersburg.

Table 6. Heating period duration (days)

Period	Start	Finish	Duration (days)
2009-2010	01.10.2009	07.05.2010	218
2010-2011	10.10.2010	07.05.2011	209
2011-2012	11.10.2011	04.05.2012	206
2012-2013	10.10.2012	03.05.2013	205
2013-2014	25.09.2013	09.05.2014	226
2014-2015	02.10.2014	19.05.2015	229
2015-2016	07.10.2015	06.05.2016	212
2016-2017	20.09.2016	19.05.2017	241
2017-2018	04.10.2017	10.05.2018	218

The heating period begins after a stable average daily temperature of 8°C settled (usually, if the temperature does not exceed 8°C during five days, the heating period starts).

3.7 The number of degree-hours during the heating period

Table 7. Degree-hours during the heating period

Period	Avg. heating period temperature	Basic temperature	Duration (days)	The number of degree-days	The number of degree-hours
2009-2010	-1.70	-2	218	66	1574
2010-2011	-2.34	-2	209	71	1698
2011-2012	-0.02	-2	206	-409	-9804
2012-2013	-1.78	-2	205	-44	-1060
2013-2014	2.25	-2	226	-959	-23026
2014-2015	2.10	-2	229	-939	-22534
2015-2016	1.05	-2	212	-646	-15505
2016-2017	0.98	-2	241	-717	-17216
2017-2018	0.34	-2	218	-510	-12230

It is noticeable that the number of degree-days in the heating season depends mainly on the average period duration, and not on the average outdoor temperature.

Table 8. Crossings through -2°C.

Heating period	Number of crossing through -2°C
2009-2010	8
2010-2011	14
2011-2012	14
2012-2013	16
2013-2014	14
2014-2015	20
2015-2016	10
2016-2017	30
2017-2018	16

Fig. 7. Crossings through -2°C throughout the heating periods in St. Petersburg.

The greatest number of -2°C crossings (30) was observed during the heating season 2016-2017. The minimum number of such crossings (8) was observed during the heating season 2009-2010, and a low number (10) was observed during the heating season 2015-2016.

Table 9. Periods with temperatures exceeding -2°C.

Heating season	Average duration	Total number of periods during the season	Average number of degree-days per period
2009-2010	24	5	147
2010-2011	14	7	83
2011-2012	18	8	96
2012-2013	10	9	60
2013-2014	22	8	144
2014-2015	16	11	95
2015-2016	27	6	159
2016-2017	10	16	57
2017-2018	16	9	90

Fig. 8. The number and average duration of periods of the heating season with a temperature exceeding -2°C.

In general, it is noticeable that changes in the number of periods with a temperature exceeding -2°C are inversely proportional to changes in the average duration of such periods.

The maximum number of such periods (16) was observed during the heating season 2016-2017, however, their average duration (10 days) was one of the lowest for 2009-2018.

On the contrary, the minimum number of periods with a temperature exceeding -2°C, which is 5 periods, was observed during the heating season 2009-2010. The average duration of periods during the heating season 2009-2010 is 24 days.

Table 10. Periods with temperature not exceeding -2°C.

Heating season	Average duration	Total number of periods during the season	Average number of degree-days per period
2009-2010	22	4	-170

Fig. 9. The number and average duration of periods of the heating season with a temperature not exceeding -2°C .

According to the Figure 10, the changes in the number of periods with a temperature not exceeding -2°C are inversely proportional to changes in the average duration of such periods. The maximum number of periods, as in the previous case, is observed during the heating season 2016-2017 (according to it Table 7, it is the longest of all along with the 2009-2010season). The average duration of such periods is small, 4 days at average. The longest average period duration (22 days) was observed during the heating season 2009-2010. In the same season, the number of periods was minimal (4). [6]

Table 11. Periods with an average daily relative humidity above 60% at a temperature between $+5^{\circ}\text{C}$ and -3°C .

Heating season	Average period duration	Total number of periods
2009-2010	6	11
2010-2011	4	15
2011-2012	7	14
2012-2013	5	13
2013-2014	6	14
2014-2015	7	17
2015-2016	6	16
2016-2017	6	21
2017-2018	10	9

The greatest number of periods with an average daily relative humidity above 60% was observed during the heating season 2016-2017.

The smallest amount (9) was observed in the 2017-2018 season, while the greatest duration of the periods was observed (10 days on average). The shortest duration was observed during the heating season of 2010-2011. On average, the average daily relative humidity was above 60% at temperatures between $+5^{\circ}\text{C}$ and -3°C lasted 4 days.

Fig. 10. The number and average duration of periods with an average daily relative humidity above 60% at temperatures between + 5°C and -3°C during the heating period.

4 Typical climatic year’s annual course of the average daily outdoor temperature in Moscow

In order to represent the climatic state of Moscow over the past 10 years, illustrative and tabular data on meteorological parameters are exposed. The RIHMI-WDC data for 2009-2018 was used for calculations, such as data on the air temperature timing, relative humidity, wind direction and speed, data on the snow depth per day and the sunshine duration per month. [6-7]

4.1 Daily average air temperature

Fig. 11. Typical climatic year’s temperature course

Table 12. Typical climatic year’s temperature course

Day/month	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
01	-3.6	-8.0	-3.0	1.7	12.6	16.5	20.8	21.8	13.6	7.8	2.2	-4.5
02	-4.3	-6.4	-2.9	2.8	13.5	17.5	20.9	21.2	15.2	7.3	2.5	-3.1
03	-5.9	-5.2	-3.0	3.0	13.0	17.8	19.8	20.8	14.9	7.8	3.6	-3.0
04	-6.7	-6.0	-2.3	3.1	12.6	17.1	20.1	20.8	13.9	7.8	4.4	-1.4
05	-7.2	-6.7	-2.8	3.2	13.2	15.4	19.3	21.0	13.6	8.5	2.8	-1.5
06	-9.1	-8.2	-3.5	5.5	12.6	14.9	19.3	21.4	13.8	7.5	2.5	-2.6
07	-8.8	-8.2	-3.0	4.8	12.6	15.1	19.0	21.3	13.6	7.4	2.2	-3.3
08	-8.5	-6.8	-3.3	4.7	14.3	16.9	18.5	20.2	13.3	8.0	2.6	-3.5
09	-8.0	-5.0	-1.2	4.5	14.5	16.0	19.6	20.5	13.5	7.3	3.0	-3.1
10	-7.3	-5.9	-0.6	5.4	14.1	16.1	19.3	20.5	13.3	6.9	2.7	-2.4
11	-6.9	-5.5	0.0	5.3	14.7	17.0	19.2	20.5	14.1	7.0	2.8	-2.9
12	-5.8	-5.7	-0.6	5.6	15.7	18.0	20.9	20.4	15.1	6.7	1.6	-4.2
13	-4.6	-6.7	0.1	5.8	14.9	17.5	21.0	19.9	14.3	6.9	2.1	-2.7

14	-4.2	-5.8	0.1	6.5	13.7	16.6	21.0	19.3	13.3	6.4	1.5	-4.6
15	-5.1	-5.2	-0.6	7.3	13.6	16.7	21.7	19.2	13.7	6.2	1.3	-6.5
16	-6.3	-6.3	-1.5	6.9	14.2	16.8	22.5	18.3	13.2	5.8	0.3	-7.7
17	-7.5	-6.6	-2.1	7.6	14.1	16.8	21.2	18.4	12.5	5.6	0.7	-6.3
18	-9.2	-6.3	-2.1	7.3	15.3	16.7	20.4	19.1	13.0	5.5	0.4	-6.3
19	-9.7	-6.1	-1.4	7.0	15.3	17.3	20.3	18.9	12.6	4.7	0.4	-4.5
20	-9.6	-5.4	-0.9	7.1	16.4	18.7	20.3	17.7	13.0	4.1	0.1	-4.9
21	-10.3	-6.9	-0.4	7.9	16.4	18.0	19.5	17.2	13.1	3.8	-0.5	-3.7
22	-11.4	-7.1	-0.2	7.8	16.3	18.5	19.3	17.5	12.2	2.7	-0.4	-4.2
23	-9.8	-5.5	-0.6	7.3	16.2	18.8	20.1	17.4	11.6	2.0	-1.4	-4.4
24	-9.3	-4.1	-0.3	7.5	15.7	19.0	20.7	16.0	10.8	2.6	-0.7	-4.1
25	-10.7	-4.1	-0.2	8.9	16.1	18.7	21.4	16.0	9.7	2.9	-0.1	-4.4
26	-11.6	-4.1	-0.1	10.4	15.6	20.6	22.6	16.1	10.0	3.3	-1.0	-2.4
27	-9.9	-3.3	-0.4	11.4	16.6	20.4	22.8	16.3	10.2	3.5	-1.3	-1.5
28	-8.1	-3.3	-0.3	12.6	16.2	19.1	22.8	16.1	10.8	3.8	-2.3	-2.7
29	-7.5		0.2	13.6	17.4	19.6	22.8	16.1	8.3	3.3	-5.0	-4.5
30	-7.3		1.1	12.9	18.6	20.1	22.4	15.6	7.8	2.9	-5.7	-4.1
31	-8.2		1.5		17.1		21.8	14.3		2.1		-4.6

4.2 Sunshine duration

Table 13. Sunshine duration of in Moscow (hours)

Year/ month	Jan.	Febr.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	
2010	75.3	61.7	160.8	230.1	255.7	286.1	396	193.4	171.6	111.7	14.9	25.9	1983.6
2011	46.3	61.7	150.9	199.4	292.6	340.1	338.2	294.8	131.1	58.4	39.7	10.5	1964
2012	54	54.7	119.7	175.1	285	286.9	312.4	225.6	163.2	39.6	16.5	44.3	1777
2013	31.7	64.2	136.2	204.1	255.2	337.7	235.5	266.2	60.5	78.7	23.7	13.5	1707
2014	73.2	48.1	168.5	258.4	307.9	271.7	411.2	275.1	203.8	91	44.7	14.2	2168
2015	27.6	60.3	163.3	169.7	259.7	291.7	304	324.9	157.7	95.9	27.4	17.2	1899
2016	29	49.4	139.8	176.6	278.8	298.8	289.2	295.8	91.1	37	28	22.9	1736
2017	36.1	54.5	136.7	165.2	267.9	235.6	257.6	282.4	171.6	32	21.1	0.1	1661
Average	46.7	56.8	147.0	197.3	275.4	293.6	318.0	269.8	143.8	68.0	27.0	18.6	1862.0
Poss. Max.	190	237	333	351	462	362	396	448	505	178	132	42	3818

Fig. 12. Annual course of the sunshine duration in Moscow (hours)

4.3 Snow depth

Table 14. Average snow depth (cm)

Day\ Month	Jan.	Febr.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
01	14.3	30.3	34	21.9	0	0	0	0	0	0	1.2	5.1
02	13.7	30	36	19	0	0	0	0	0	0	0.9	5.6
03	13.9	29.9	34.5	16.5	0	0	0	0	0	0	0.8	5.5
04	14.3	31.4	34.1	15.2	0	0	0	0	0	0	0.7	6.9
05	15.7	34.4	34.9	14.2	0	0	0	0	0	0	0.9	6.1
06	15.4	33.8	34.3	12	0	0	0	0	0	0	0.7	7.1
07	14.7	33.3	33.9	10.3	0	0	0	0	0	0	1.7	7.9
08	14.8	33	33.1	9.2	0	0	0	0	0	0	0.7	10.8
09	16.1	33	32.2	9.2	0	0	0	0	0	0.1	0.5	10.8
10	17.5	33.3	31.1	7.5	0	0	0	0	0	0.1	0.6	10.3
11	17.6	33.1	30.5	6.6	0	0	0	0	0	0	0.4	11
12	18.1	33.3	30.2	6	0	0	0	0	0	0	0.9	10.7

Fig. 13. Average snow depth (m)

4.4 Wind speed and direction

Table 15. Average wind speeds (m/s)

Day\Month	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
01	1.0	1.4	1.2	1.7	1.6	1.2	0.9	0.8	1.1	1.3	1.3	1.3
02	1.3	1.3	1.5	1.7	1.1	1.2	0.8	0.9	0.6	1.2	1.1	1.2
03	1.4	1.2	1.4	1.5	1.3	1.0	0.9	1.0	0.9	0.9	1.0	1.2
04	1.2	1.6	1.5	1.5	1.1	1.3	1.1	1.0	1.0	1.0	1.1	1.4
05	1.5	1.4	1.3	1.2	1.3	1.4	1.1	1.1	1.1	1.2	1.2	1.4
06	1.6	1.2	1.3	1.0	1.4	1.3	1.0	0.7	0.9	1.2	1.2	1.4
07	1.7	1.1	1.5	1.2	0.9	1.1	0.8	0.7	0.7	1.0	1.1	1.3
08	1.4	1.3	1.2	0.9	0.9	1.1	1.0	0.9	0.8	1.0	1.2	1.3
09	1.1	1.8	1.3	1.2	1.4	1.2	0.8	0.8	0.7	1.1	1.2	1.2
10	1.0	2.0	1.2	1.5	1.1	0.7	1.0	0.6	0.8	0.9	1.4	1.5
11	0.9	1.6	1.2	1.4	0.9	1.1	0.9	0.7	0.7	1.0	1.5	1.2
12	1.3	1.5	1.3	1.0	1.2	1.1	1.1	0.8	0.7	0.9	1.4	1.3
13	1.5	1.4	1.4	1.0	1.2	1.0	1.0	0.8	0.7	1.1	1.2	1.4
14	1.3	1.7	1.2	1.0	1.1	0.8	0.7	1.0	0.9	0.9	1.4	1.4
15	0.9	1.4	1.3	0.9	1.0	1.0	0.8	1.0	0.9	1.2	1.2	1.1
16	1.0	1.3	1.2	1.3	1.2	0.9	0.8	0.9	0.8	1.1	1.1	1.1
17	1.3	1.5	1.3	0.8	1.5	1.1	0.9	1.1	0.8	1.0	1.2	1.4
18	1.1	1.1	1.4	1.5	1.2	0.9	1.0	1.0	0.8	1.0	1.4	1.4
19	1.3	1.0	1.3	2.0	1.0	0.9	1.0	0.8	0.7	1.0	1.3	1.2
20	1.2	1.2	1.1	1.7	0.9	1.2	1.0	1.0	0.6	0.9	1.3	1.2
21	1.1	1.0	1.2	1.8	0.9	1.1	1.0	1.3	0.9	1.0	1.3	1.3
22	1.2	1.3	1.5	1.6	0.9	1.3	0.9	1.1	0.9	1.3	1.3	1.0
23	1.3	1.1	1.5	1.5	1.0	1.0	1.0	1.1	1.1	1.3	1.0	1.1
24	1.2	1.2	1.7	1.5	1.1	0.7	0.9	0.9	1.1	1.1	1.1	1.4
25	1.3	1.3	1.7	1.4	1.1	0.8	0.9	0.8	1.0	1.2	1.1	1.2
26	0.9	1.2	1.8	1.5	0.9	1.0	1.0	0.9	1.2	1.2	1.4	1.3
27	0.7	1.3	1.5	1.0	1.4	1.1	0.9	0.6	0.9	1.3	1.3	1.1
28	1.0	1.4	1.8	1.2	1.0	1.3	0.8	0.7	0.9	1.2	1.4	1.2
29	1.4		1.7	1.3	0.9	1.1	1.0	1.1	1.1	1.5	1.5	1.7
30	1.4		1.6	1.3	1.2	1.1	0.8	1.2	1.2	1.5	1.4	1.4
31	1.5		1.5		1.2		0.8	1.0		1.4		1.1

Fig. 14. Average wind speed (annual course)

Fig. 15. Wind rose in Moscow (2009-2018)

Table 16. Relative air humidity (%)

Day\ Month	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
01	87	81	79	77	57	60	62	67	79	77	81	86
02	88	82	82	77	57	60	68	68	79	80	80	87
03	85	84	80	76	60	63	68	68	80	79	88	84
04	86	83	80	66	62	62	66	68	81	82	85	88
05	85	79	82	71	66	63	69	67	82	82	82	87
06	85	81	77	67	67	65	65	67	83	81	84	86
07	83	81	74	73	60	68	71	69	80	81	87	85
08	84	83	76	67	62	66	74	69	79	83	89	86
09	85	85	72	64	58	70	76	66	80	82	88	88
10	86	83	68	62	61	72	77	70	79	79	88	89
11	88	83	70	59	60	73	73	72	81	78	87	87
12	87	81	73	59	61	69	67	70	77	84	85	87
13	84	83	70	64	60	71	71	68	77	83	83	87
14	84	84	68	66	59	71	69	72	80	81	85	84
15	87	83	70	64	66	73	69	74	76	84	82	87
16	86	82	74	72	72	74	66	75	79	81	82	89
17	86	79	71	66	75	68	68	73	79	82	84	88
18	86	80	70	68	71	62	71	71	77	79	82	87
19	82	82	76	56	70	69	72	70	76	79	88	88
20	83	82	76	60	67	65	76	74	79	80	85	86
21	85	83	77	61	65	69	75	71	79	82	86	87
22	85	81	72	64	69	67	73	72	80	76	82	85
23	84	81	66	61	74	68	66	74	82	79	82	89
24	85	82	66	58	72	68	67	75	84	81	88	85
25	81	75	65	61	68	72	67	75	83	77	87	88
26	80	71	59	60	66	68	66	73	76	76	88	89
27	83	73	57	66	67	69	68	75	75	81	86	86
28	84	74	58	62	72	66	70	77	82	84	87	85
29	83	77	60	52	73	62	66	76	83	78	85	86
30	83		66	58	65	64	68	76	79	76	85	88
31	83		77		62		67	78		82		84

Fig. 16. Relative air humidity (%)

4.5 The heating period duration in Moscow.

Table 17. Heating period duration of the (days)

Period	Start	Finish	Add.period (Start)	Add.period (Finish)	Duration (days)
2009-2010	29.09.2009	01.05.2010	-	-	214
2010-2011	28.09.2010	28.04.2011	-	-	212
2011-2012	28.09.2011	22.04.2012	-	-	207
2012-2013	06.10.2012	30.04.2013	-	-	206
2013-2014	21.09.2013	30.04.2014	-	-	221
2014-2015	25.09.2014	30.04.2015	-	-	217
2015-2016	04.10.2015	03.05.2016	-	-	212
2016-2017	20.09.2016	01.05.2017	09.05.2017	18.05.2017	232
2017-2018	28.09.2017	29.04.2018	-	-	213

4.6 The number of degree-hours throughout the heating period (HP).

Table 18. Degree-hours throughout the heating period.

Period	Av.heating period temperature, °C	Duration, days	The number of degree-days	The number of degree-hours
2009-2010	-1.8	214	42.8	1027.2
2010-2011	-2.1	212	-21.2	-508.8
2011-2012	-1.4	207	124.2	2980.8
2012-2013	-2.2	206	-41.2	-988.8
2013-2014	1.4	221	751.4	18033.6
2014-2015	0.2	217	477.4	11457.6
2015-2016	0.5	212	530	12720
2016-2017	0.1	232	487.2	11692.8
2017-2018	-0.7	213	276.9	6645.6
average	-0.7	214.9	291.9	7006.7

4.7 Crossings through -2 °C.

Table 19. The number of periods with an average daily temperature above -2°C during the heating seasons

Heating season	Number of seasons	Degree-days	Degree-hours	Duration, days
2009-2010	8	595.2	14284.8	124
2010-2011	11	478.8	11491.2	84
2011-2012	14	673.1	16154.4	127
2012-2013	14	605	14520	110

2013-2014	13	1089.9	26157.6	173
2014-2015	14	480.6	11534.4	89
2015-2016	9	826.8	19843.2	156
2016-2017	19	742.4	17817.6	128
2017-2018	10	694.4	16665.6	124
Total	112	6186.2	148468.7	1115
Average per year	12	687.4	16496.5	124

Table 20. The number of periods with an average daily temperature below -2 °C during the heating seasons

Heating season	Number of periods	Duration, days
2009-2010	7	90
2010-2011	10	128
2011-2012	13	80
2012-2013	13	96
2013-2014	12	48
2014-2015	13	128
2015-2016	8	56
2016-2017	17	104
2017-2018	9	89
Total	102	819
Average per year	11	91

Table 21. The number of periods with an average daily temperature below 5°C and above -3°C, and with a relative air humidity of more than 60% during the heating seasons

Season	Number of periods	Duration, days
2009-2010	19	65
2010-2011	16	88
2011-2012	16	105
2012-2013	18	77
2013-2014	18	104
2014-2015	19	199
2015-2016	19	99
2016-2017	26	87
2017-2018	16	87
Total	167	911
Average per year	19	101

5 Conclusion

The data on average daily outdoor temperatures, sunshine duration, snow depth, wind speed, etc. are presented. The number of hours and degrees-hours of the heating season with temperatures exceeding minus 2°C is determined, as well as the ratio of periods (degrees-hours) with temperatures above and below minus 2°C.

The data of a typical climatic year by region showed the following: the maximum monthly average values in St. Petersburg are observed in July-August (23°C), the minimum are in January (-10°C). In Moscow, the maximum values in July are 22.8°C, -11.6°C in January.

The data on relative humidity above 60% and the moisture content of atmospheric air in two regions are also presented in the research. Periods with an average daily relative humidity above 60% at a temperature between +5°C and -3°C during the heating season (the number of such periods) are represented as well. It was established that the maximum number of days of such periods in Moscow during the heating season was observed in 2014-2015, and the minimum in 2009-2010. For St. Petersburg, the greatest value was observed during the heating season 2016-2017, the smallest was for 2017-2018. [8-9]

Acknowledgement

The research was conducted by JSC "INSOLAR-INVEST" with the financial support of the Ministry of Education and Science of Russian Federation. Unique identifier of the project RFMEFI57918X0159.

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