Determining the duration of the heating season in Tomsk

O V Nosyreva, N K Barashkova and L I Kizhner

National Research Tomsk State University, 36 Lenin Avenue, Tomsk, 634050, Russia

Abstract. To solve problems of energy saving and reduce the cost of services that are essential for human comfort in buildings, the calendar duration of the heating season (HS) in Tomsk has been estimated on the basis of an analysis of temperature characteristics of the environment at the HS start and end. Monthly data of meteorological observations for the cold periods in 2011-2018 and existing methods (Ped's and SNiP) for determining the dates of the stable transition of the daily mean temperature through 8 °C are used in addition to the dates of actual heating supply in Tomsk. As an indicator of human comfort, along with the usual daily mean temperature, the index of radiation-equivalent-effective temperature (REET) is used. It has been revealed that using Ped's method for determining the duration of the heating season, which leads to less discomfort from heat or cold for the population, is economically feasible. The calculated characteristic of heating of degree-days (HDDs) is equal to 5800, which confirms a previously revealed tendency to climate warming in the study region.

1. Introduction

In the modern world in the climatic conditions of the Russian Federation, as in other countries, the problem of energy saving, reducing costs and making a comfortable stay in premises [1, 2–7] is becoming ever more urgent. This is due both to recreation facilities and workplaces, since the proportion of those who work outdoors is steadily declining, and this trend will only increase in the digital economy. In addition, it is necessary to take into account an increase in the proportion of the population composed of children and elderly, which places high demands on the thermal conditions of the premises. The construction “landscape” is being changed as well; a large variety of construction projects (often with individual architectural solutions) replace the panel and masonry buildings.

The period of the year when additional warmth is needed to the whole interior of a building (or a portion of a building in certain premises) is called the heating season (HS). Its time frame is considered to be the dates of a stable transition of the daily mean temperature of the external air through +8 °C in fall and spring. In meteorological practice, the dates of a stable transition of the air temperature through certain values are determined by a method proposed by Ped D A [8]. The day of a stable transition of the air temperature through a certain threshold is the day after which there is no reverse transition, and if it was, then short periods were related to a cold snap in spring and warming-up in fall. Some climatic indicators of the heating season in the territory of Tomsk region are given in [9], where a reduction of its duration is also noted.

The municipal services of settlements according to the Construction Regulations and rules of the Russian Federation briefly named SNiP [10] must authorize to shut off and turn up the heating systems, they are also guided by a temperature value of +8 °C, namely, after five days when the daily mean temperature does not exceed this value. In this study the method will be referred to as the SNiP method. At the same time, situations with uncomfortable temperature conditions at the beginning of autumn repeat almost every year, and heat begins to flow into the residential, public, and working premises only after insistent demands of the population. Why does it happen? Perhaps, the reaction of
the population is explained by a different set of accompanying weather conditions during the mid-seasons. The definition “period” indicates that during a certain period of time the daily mean air temperature can fluctuate both below and above 8 °C. In our opinion, there are no clear arguments for using the criterion of +8 °C for the start (end) of the heating season.

The goal of the authors is to clarify the peculiarities of the weather patterns at the heating start-of-season and end-of-season in Tomsk and to verify the economic feasibility of using one of the two existing methods for determining the date of temperature transition through 8 °C.

2. Methodology

It is well known that the main purpose of heating is to provide thermal comfort for the population. The thermal comfort of a man arises when there develop such meteorological conditions in which the thermoregulatory system of the organism has the least stress, i.e. there is physiological rest and the average skin-surface temperature (tk) is 31-33 °C [11].

Since many factors contribute to the thermal comfort, the general model of human thermal comfort (in particular, in the city of Tomsk) is extremely complex. However, in one of its obligatory blocks, the effect of the meteorological pattern on providing a comfortable human environment should be presented. To date, separate bioclimatic studies of the working outdoor conditions and sanatorium-and-spa treatment have been carried out [12]. A complete “man-building coupling” model, in addition to the meteorological factor, also includes the social and psychological ones. In our opinion, it is vital to develop a model of thermal comfort for a resident of Tomsk. In this paper, the characteristics are presented and analyzed, which belong to properties of the meteorological block of thermal comfort model by the example of Tomsk.

As initial data, the daily temperature and humidity, wind speed during the cold periods of 2011-2018 were used. On the basis of synoptic observations, the weather characteristics have been analyzed during the periods from the first date to the date of the final transition of a daily mean temperature through 8 °C. Based on D.A. Ped's method [13], the dates of a stable transition of the daily mean temperature through 8 °C were calculated. The dates of actual heating supply in Tomsk are published in an open source [14].

One of the most essential characteristics of the thermal mode taken into account in designing of the enclosing structures is heating degree-days (HDD). This indicator presents the total specific heat consumption of buildings considering the application conditions of buildings, and it is used in calculations not only for enclosing structures, but when choosing a type of buildings, heating, ventilation, air conditioning, and fuel reserves. The heating degree-days are:

\[
\text{HDD} = (T_i - T_h)h,
\]

where HDD is the number of heating degree-days during the heating season, the start-of-season and end-of-season are determined using Ped's method; Ti is the indoor temperature equal to 18 °C; T is the daily mean temperature of the HS, °C; h is the number of days of the HS. A value of 18 °C was chosen due to the fact that the thermal sensation at 18 °C is identical to that experienced by a person in a room where the air temperature is 18 °C, the relative humidity is about 100%, and the air velocity is about 0.1 ms-1 (that is equivalent to the speed of the air flow caused by convection over the surface of a warm body only).

According to [15], Tomsk Oblast refers to climatic zoning area 5b of the CIS territory for dwelling classification, which is characterized by cold, cool, and comfortable weather with a repeatability above the critical one; while designing dwelling projectors one orients to a value of 7500 HDD and more [11]. The territory belongs to the radiation-climatic zone III.

The calculated HDD values for the city of Tomsk are presented in Table 1, from which it follows that there is a rather large scatter in the years of all analyzed characteristics. The sum of temperatures (this value is negative) ranges from -832 (2013/14) to -1898 (2012/13), the duration of the HS varies within 217 – 269 days.

The HDD computed with the methods of Ped and SNiP is less than the number given in [15], which may be a consequence of the noted climatic changes in the region [9, 16].
Table 1. Main temperature indicators for heating seasons (HS) in Tomsk.

| Year of heating season | 2011/12 | 2012/13 | 2013/14 | 2014/15 | 2015/16 | 2016/17 | 2017/18 |
|------------------------|---------|---------|---------|---------|---------|---------|---------|
| Temperature sum in HS, °C | -1661 | -1898 | -832 | -1340 | -1071 | -1550 | -1602.4 |
| Length of HS, days | 217 | 250 | 269 | 231 | 251 | 238 | 249 |
| Daily mean temperature in HS, °C | -7.66 | -7.59 | -3.09 | -5.80 | -4.27 | -6.41 | -6.4 |
| HDD | 5567 | 6398 | 5674 | 5498 | 5589 | 5834 | 6084.4 |
| Temperature sum in HS, °C | -1787.1 | -2224 | -1100.8 | -1424.7 | -1296.6 | -1758.8 | -1618.2 |
| Length of HS, days | 197 | 200 | 228 | 215 | 215 | 210 | 233 |
| Daily mean temperature in HS, °C | -9.1 | -11.1 | -4.8 | -6.6 | -6.0 | -8.4 | -6.9 |
| HDD | 5333 | 5824 | 5205 | 5295 | 5167 | 5539 | 5812 |

Indicators of indoor environmental comfort. It is known that the primary part of the heat lack is the losses arising due to the cooling effect of the air temperature. Wind and radiation reduce or increase the heat loss on average by 10-30% [17].

Effective temperature (ET) indexes can be used as an indicator of the radiant field around a person in the living room [18–21]. The ET (expressed in degrees) is determined by the temperature and relative humidity combinations at which the effect of heat transfer and thermal sensation is the same. Different types of effective temperatures are also widely used in the practice of assessing thermal loads, comfort or discomfort in the environment: the equivalent effective temperature (EET); the radiation-equivalent effective temperature (REET), etc. [11].

The equivalent-effective temperature is a combination of meteorological values that give the same thermal effect as stationary air at a relative humidity of 100% and a certain temperature computed using Missenard's formula:

\[
EET = 37 - \left(\frac{37-T}{(0.68 - 0.0014RH + 1/(1.76 + 1.4v^{0.75}))) - 0.29T (1-RH/100)}{37}\right),
\]

where \(T\) is the temperature, °C; RH is the relative humidity, %; \(v\) is the wind speed, ms-1.

For the evaluation of conditions that are comfortable for humans, the REET index is preferable, which, in addition to the temperature, relative humidity, and wind speed, takes into account additional heating by solar radiation. Various formulas and nomograms are used to calculate the REET, but the most complete formula is proposed by V I Rusanov [22]:

\[
REET = 0.83EET + 12.0
\]

where \(T\) is the temperature, °C and RH is the relative humidity, %; \(v\) is the wind speed, ms-1; \(\beta\) is the absorption of solar radiation by the human body surface, kW m-2; \(\beta = \varepsilon (1-\alpha)\), \(\alpha\) is the skin albedo (0.28 for non-pigmented skin and 0.11 for pigmented skin), \(\varepsilon\) is the intensity of solar radiation. The application of this formula is most suitable for evaluating comfortable external conditions, i.e. outside the premises. Note that the period with "comfortable weather" is composed of a year with the subtracted duration of a really demanded heating period without considering the periods required for the cooling of residential premises.

A simpler formula is based on the EET with the addition of a constant value, namely the free term, which reflects the influence of solar radiation:

\[
REET = 0.83EET + 12.0
\]
In our research the REET was computed by formula 4 with the results derived from formula (2).

It is known that the value of REET determined with allowance for solar radiation is below the air temperature in the cold season and above in the warm season. In the transitional seasons the ratio can be different.

In the conditions of living premises the thresholds of REET for an unclothed person are 20.3–24.7 °C, and for a dressed person 19.7–23.6 °C [11].

Note that the most accurate evaluation of comfort for a person is the fulfilment of the condition of his heat balance on whose basis one can determine the temperature at which a person will feel comfortable. Accordingly, it is possible to clarify the criterion of 8 °C, which forms a basis of the decision on turning up/shutting off the heat supply to the premises.

The issue of determining other comfort criteria with the enlarged architectural and aesthetic requirements remains actual. In the next section the results of using the daily mean temperature and the REET index as the main criteria for the start and end of heating seasons are presented.

3. Results

To determine the features of start and end of the heating season, the calendar and temperature characteristics were determined and refined using the existing and practical methods that can be used to establish the dates of heating on and off. These characteristics for both periods are presented below:

**Fall period:**
- date of first decrease in the daily mean air temperature up to +8 °C (FD1);
- date of stable transition of the air temperature through 8 °C in fall according to the Ped’s method (FD2);
- start date of the HS according to SNiP (FD3);
- date of last daily mean temperature t = +8 °C (FD4);
- actual date of turning up of heating (FD5);
- number of days with daily mean temperature t > 8 °C after FD2 (FP1);
- number of days with t >8 °C after FD3 (FP2);
- duration of transition from FD1 to FD2 (FP3);
- duration of transition from FD1 to FD3 (FP4);
- duration of transition from FD1 to FD4 (FP5);
- reached in FP2 increase of the daily mean temperature value 8 °C (FW).

**Spring period:**
- date of first increase in the daily mean air temperature up to +8 °C (SD1);
- date of stable transition of the air temperature through 8 °C in spring according to the Ped’s method (SD2);
- end date of HS according SNiP (SD3);
- date of last daily mean temperature t = +8 °C (SD4);
- actual date of shutting off of heating (SD5);
- number of days with daily mean temperature t > 8 °C after SD2 (SP1);
- number of days with t >8 °C after SD3 (SP2);
- duration of transition from SD1 to SD2 (SP3);
- duration of transition from SD1 to SD3 (SP4);
- duration of transition from SD1 to SD4 (SP5);
- reached in SP2 decrease of the daily mean temperature value 8 °C (SC).

**Abbreviations:** F – fall, S – spring, D – date, P – period, W – warm, C – cold.

The same characteristics were determined using the radiation-equivalent effective temperature, the letter R (FDR2, SDR2, FPR1, SPR1, etc.) was added to the designations.

For the autumn and spring time segments of the heating season, the following short definitions are used:
- "the transition period" (FP5), (SP5).
- "the Ped's method" - FP3 and SP3.
- "the SNiP method" - FP4 and SP4.
A set of specified characteristics of the heating seasons for 2011–2018 taking into account the air temperature and radiation-equivalent-effective temperature (the REET index) is shown in Figure 1.

![Figure 1. Structure of the transition periods of heating seasons (HS).](image)

It is shown (Figure 1) that all 7 analyzed HSs have various patterns of transition periods. Thus, in the autumn transitional season the first drop of the daily mean temperature to 8 °C may be as early as August 28 (2014). At the same time, in 2016 it happened only on September 24. In this case, a stable transition through 8 °C according to the Ped's method could both coincide with the date of the first appearance of the daily mean temperature equal to 8 °C and be in a month and a half (44 days, 2011). The length of the transition periods in fall ranges from 1 to 44 days at the present temperature and from 19 to 32 days at the REET.

There is no direct connection between FD1 and FP3, although, in general, it can be noted that the earlier the FD1, the longer the transition period.

Persistent temperature transition through 8 °C according to Ped usually occurs earlier than by the SNiP method: on average, the difference is 3-10 days. The last date with a daily mean temperature of 8 °C usually corresponds to the date of the transition according to Ped.

The actual heating supply occurred in the period from September 17 (2015) to September 27 (2012).

In spring, the earliest increase in the temperature above 8 °C was observed on April 2, and the last date with a daily mean temperature of 8 °C was on June 9 in 2014 (this year is characterized by the longest transition period of 68 days). At the same time, the lasting of the transition periods of the HS was 14-68 days at the present temperature and 25-63 days at the REET. In spring a stable temperature transition through 8 °C according to Ped was noted later than by the method of SNiP (on average by 8-37 days).

The duration of start and end of the HS, as a rule, is less in autumn than in spring.
The calendar boundaries of the transition periods at the REET in fall are commonly shifted to later periods in relation to the transition periods at the present temperature. In spring, on the contrary, their boundaries are shifted to earlier periods.

A comparative analysis of the methods used to determine the dates of heating switching on/off can be made using results presented in Table 2.

**Table 2.** Parameters of the transition period (numerator – Ped's method, denominator – SNiP method), days.

| Indicators | Years of heating season | Sum of losses in days |
|------------|-------------------------|-----------------------|
|            | 2011/12 | 2012/13 | 2013/14 | 2014/15 | 2015/16 | 2016/17 | 2017/18 |
| FP3/FP4    | 44/47   | 6/16    | 22/5    | 18/23   | 0/4     | 0/4     | 14/4    |
| FP1/FP2    | 0/0     | 3/0     | 3/3     | 3/2     | 3/3     | 0/0     | 0/7     |
| FP5        | 45       | 13      | 21      | 28      | 29      | 1       | 14      |
| SP3/SP4    | 40/24   | 12/4    | 69/32   | 12/2    | 34/4    | 26/3    | 37/11   |
| SP1/SP2    | 2/6     | 0/22    | 0/24    | 0/6     | 1/20    | 1/10    | 0/23    |
| SP5        | 46       | 43      | 69      | 15      | 44      | 28      | 37      |
| EP         | 2/6     | 3/22    | 3/27    | 3/8     | 4/23    | 1/10    | 0/30    | 16/126  |
| FPR3/FPR4  | 22/26   | 22/26   | 3/7     | 6/9     | 0/5     | 0/5     | 8/12    |
| FPR1/FPR2  | 0/0     | 0/0     | 4/4     | 8/8     | 10/10   | 10/10   | 22/20   |
| FPR5       | 23       | 23      | 20      | 22      | 30      | 30      | 33      |
| SPR3/SPR4  | 48/34   | 48/34   | 48/33   | 64/36   | 45/47   | 18/10   | 53/25   |
| SPR1/SPR2  | 1/8     | 1/8     | 1/14    | 0/13    | 5/5     | 9/9     | 0/16    |
| SPR5       | 53       | 53      | 52      | 64      | 25      | 63      | 53      |
| EPR        | 1/8     | 1/8     | 5/18    | 8/21    | 15/15   | 19/19   | 22/36   | 71/125  |

|            |          |          |          |          |          |          |          |
|------------|----------|----------|----------|----------|----------|----------|----------|
| FP1 (SP1)  | number of days with daily mean temperature >8 °C after FD2 (<8 °C after SD2); |
| FP2 (SP2)  | number of days with >8 °C after FD3 (<8 °C after SD3); |
| FP3 (SP3)  | duration of transition from FD1 to FD2 (from SD1 to SD2); |
| FP4 (SP4)  | duration of transition from FD1 to FD3 (from SD1 to SD3); |
| FP5 (SP5)  | duration of transition from FD1 to FD4 (from SD1 to SD4); |
| EP         | number of days with >8 °C in fall and <8 °C in spring, i.e. cold snap (spring) and warming-up (fall). |
|            | Computed as EP = (FP1+SP1)/(FP2+FP2). |

The lasting from the first appearance of a daily mean temperature of 8 °C to the last date with such a temperature is in the range from 1 to 45 days and from 15 to 69 days in fall and spring, respectively. The values of FP3 and SP4 are also significantly different. In general, within the heating season uncomfortable conditions (cold snap in spring and warming-up in the fall) occur up to 4 days determined by the Ped's method; as for the method of SNiP, such days vary from 6 to 27 days. The use of the REET to assess the comfort index shows the inexpediency of its use in defining the calendar boundaries of the HS. In fall it is better to perform calculations at the standard daily mean temperature. The characteristics of EP and EPR characterize extra costs for heating; in other words, these are economic losses for the consumer. The duration of the transition period using the REET in fall (FPR1) is 20-30 days, in spring (SPR1) it is much longer and varies from 25 to 63 days.

More indicative for comparing the both methods are the data presented in Table 3.

It is clear that the use of the SNiP method leads to considerable discomfort from "heat", i.e. there is inefficient use of heating, and Ped's method indicates to discomfort of "cold", however, in a much fewer days. Thus, in fall Ped's method gives the most reliable date for the temperature transition through 8 °C, FP1 does not exceed 3 days. The air temperature noted in the above-mentioned 3 days was in the range of 10.8-12.3 °C, which practically did not affect the conditions of thermal comfort of a human.
In spring, SP1 is 1-2 days, in half of the cases, 0 days. The use of the REET gives the following result: FPR1 and SPR1 do not exceed 10 and 9 days, respectively, and in most cases the last indicated parameter does not exceed 1 day; the difference of the REET changes from 0 to 22 (2017/2018).

**Table 3.** Dates of deviation of actual turning up (in fall), shutting off (in spring) of heating from dates of transition of daily mean temperature through 8 °C (numerator), radiation-equivalent-effective temperature (REET) (denominator) in accordance with Ped and SNiP methods: «-» – earlier, «+» – later, days.

| Heating season | 2011/12 | 2012/13 | 2013/14 | 2014/15 | 2015/16 | 2016/17 | 2017/18 | Sum of losses in days |
|----------------|---------|---------|---------|---------|---------|---------|---------|-----------------------|
| Fall Ped       | -25/26  | -1/12   | 5/4     | 8/5     | 6/7     | 2/16    | 0/-1    |                      |
| SNiP           | -29/-29 | -12/-15 | 0/-1    | 3/1     | 0/0     | -2/10   | 11/-5   |                      |
| Spring Ped     | -6/7    | 22/7    | -30/-15 | 8/-23   | -16/-18 | -10/26  | 3/3     |                      |
| SNiP           | 10/10   | 30/21   | 8/3     | 18/7    | 14/-18  | 13/35   | 30/29   |                      |
| Discomfort caused by cold (heat undersupply) Ped | 6/7 | 0/0 | 35/19 | 8/28 | 22/25 | 12/16 | 0/0 | 83/95 |
| SNiP           | 0/0     | 0/0     | 0/0     | 3/1     | 0/18    | 0/10    | 11/0    | 14/29               |
| Discomfort caused by heat (overheating) Ped | 25/26 | 23/19 | 0/0 | 8/0 | 0/0 | 0/26 | 3/4 | 59/75 |
| SNiP           | 39/39   | 42/36   | 8/4     | 18/7    | 14/0    | 15/35   | 30/34   | 166/155             |

Part of the characteristics for the fall of 2011, spring of 2015, 2018, all characterized by a long duration of transition periods of the HS, is shown in Figure 2.
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Figure 2. Dynamics of daily mean temperature and REET index:

- dates of transition through 8 °C, Ped's method,
- start/end date of heating season according to SNiP method,
- actual dates of turning up/shutting off of heating;

a – Autumn 2011;
b – Spring 2015;
c – Spring 2018.

For instance, in the spring of 2015 actual shutting off of heating happened on May, 12; at the same time, the end of the heating season (HS) using SNiP was on April 22 and 24 in accordance with the REET and present temperature. In autumn 2011, the date of actual heating supply was recorded on September 22, while the date of start of the HS (SNiP) was October 20 (both with the REET and present temperature). For the spring of 2018, the HS shutting off dates according to SNiP were April 30 and May 2 (the REET and present temperature, respectively); the end of the HS using Ped's method was on May 29, whereas actual heating closed on June 1.

4. Conclusions
In conclusion, we note the principal points of the study. The duration of the heating season in Tomsk varies from 217 to 269 days and is 244 days on average. The duration of the period for start and end of the heating supply, as a rule, is less in fall than in spring.

The heating of degree-days (HDD) differs from the climatic data, towards a decrease, which may be a consequence of the observed climate changes in the region.

The use of the standard (SNiP) method leads to considerable discomfort from "heat", i.e. there is inefficient use of heating, while Ped's method indicates discomfort from "cold", however, in a much less number of days. Thus, in fall Ped's method gives the most reliable dates for the temperature transition through 8 °C (FP1 does not exceed 3 days). The use of the REET index shows that the losses in days in this case exceed the losses calculated for the actual temperature.

The dates of actual heating period do not always agree with meteorological conditions that characterize comfortable human thermal conditions. In a market economy, energy and heat supply organizations are seeking for additional profits, extending the heating season by earlier beginning and later end of heat supply.

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