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SELECTION OF THE CLIMATE PARAMETERS FOR A BUILDING ENVELOPES AND INDOOR CLIMATE SYSTEMS DESIGN

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Abstract. The current research considers the principles of selection of the climate information needed for the building envelope and indoor climate design and adopted in Russia and some European countries. Special reference has been made to the shortcoming of methodologies that include the notion of a typical year, and the advantages of climate data sets generated via software-based designs, using pseudo-random number generators. The results of the average temperature of the coldest five-day period with various supplies were calculated using the numerical Monte-Carlo simulations, as well as the current climate data. It has been shown that there is a fundamental overlap between the statistical distribution of temperatures of both instances and the possibility of implementation a probabilistic-statistical method principle in the development of certain climate data, relative to envelopes and thermal conditions of a building. The calculated values were combined with the analytic expression of the normal law of random distribution and the correlations needed for the main parameter selection.

Keywords: building, envelopes, heating system, indoor climate, design parameters.

Introduction

The issue of determining the heating system load is a matter of balancing consumers' needs against the price. On one hand, consumers expect the heating system to maintain an internal temperature of the building that is necessary for their health and comfort. On the other hand, the demand for a very high heating load is rare, usually arising in cases when meteorological extremities occur. Designing heating systems for rare extremities might not be economical since it might lead to high capital cost and reduce the operational efficiency of the system.

From the practical point of view, a rarely occurring but not extreme value of the external air temperature is usually selected as the basis for determining the designed heating system load. This means that the heating needs of a building might exceed the capacity of the heating system, thus the internal temperature might be lower than expected or additional heating might be required (e. g. internal heaters).

The same method of determining the designed weather parameters was valid in the former USSR and is still in force in Lithuania. It is based on processing large amounts of meteorological data, which raises doubts whether such time intensive calculations were actually carried out back when computers were scarce or if the interpolation method was applied, using data from several cities.

The methods of determining the designed external air temperature

The method currently applied in Lithuania

The method (RSN 156–94) of determining the designed temperature, used in the former USSR, has been adopted in Lithuania. Its purpose is to find the average external air temperature of several consecutive days which factor of safety (integral recurrence) is either 0.98 or 0.92. This means that in the first case, the temperature lower or equal to the selected value usually occurs twice in 100 years (or once in 50 years) and in the second case it occurs 8 times in 100 years (or 4 times in 50 years). When designing heating systems for buildings of medium and high thermal inertia, which are prevalent in Lithuania, the average temperature of 5 consecutive days (the coldest five-day period) with the factor of safety of 0.92 is applied.

The temperature of the coldest five-day period is calculated based on the external air temperature monitoring for

50 years (from 1925 to 1975). The data is retrieved from monthly meteorological monitoring tables and monthly meteorological journals. The temperatures of the coldest five-day period are selected based on the temperatures of rolling five-day periods.

The selected data is listed in chronological order and then in descending order (in terms of the absolute value) by assigning a sequence number to each value. Each temperature of the coldest five-day period is rounded off to 0.5 °C and every interval is assigned a sequence number.

The integral recurrence is calculated using the following equation:

$$P = \left(1 - \frac{m_v \cdot 0,3}{n + 0,4}\right) \cdot 100\% . \quad (1)$$

where: P – the integral recurrence of the relevant term of the sample set; m_v – the average sequence number in the sequence; n – the number of years in the sample set.

Then integrated air temperature distribution curves for the coldest five-day period are plotted in the asymmetric grid: the logarithmic scale of the air temperature is depicted on the y-axis (ordinate) and the double logarithmic scale of the integral recurrence is depicted on the x-axis (abscissa).

Using the plotted curves, the temperatures of the coldest five-day period of the needed integral recurrence are determined.

The ASHRAE method

The purpose of this method (ASHRAE) is to find the highest temperature limit of the external air temperature that is observed in the studied area for a certain period of time in the season. There are three values of this period of time determined: 0.4%, 1%, and 2% of the season. There are 8760 hours in a year, so 35 hours, 88 hours, and 175 hours correspond with the previous percentage values. The usage of annual percentiles to determine the designed conditions guarantees a similar probability of recurrence for any climate, regardless of seasonal extremities. When using this method, heating systems are usually designed following the 1% condition.

The European standard EN ISO15927–5 method

Using this method (EN ISO 15927–5:2004), the acceptable balance of the risk of insufficient power and the price is determined using a method that is essentially analogous to the one that is valid in Lithuania, i.e. by determining the recurrence period of a certain average temperature of several consecutive days. The number of consecutive days can be 1, 2, 3 or 4 (there are no instructions when to use which value). The expected recurrence period is one year. This means that over, for example, 20 years the average temperature of the selected period of time has to recur 20 times. The average external air temperature for several days is determined using the average temperatures for each day. The latter might be determined in several ways, depending on the available recorded data. It is recommended to determine the designed temperature using the climatologic data for 20 consecutive years.

The DIN 4710 method

German standards (DIN 4710) define the designed external air temperature as the coldest average for two consecutive days that recurs 10 times in 20 years. However, when determining the final designed air temperature, corrections are made that depend on the thermal accumulation properties of the external partition (dynamism). This correction of temperature might change the designed external air temperatures by up to 4 degrees.

Consequently, the designed external air temperatures were calculated for the three largest Lithuanian cities following the requirements of the four methods. The results are presented in Tables 1 and 2.

Table 1. The design heating temperatures, *calculated* using the average external air temperature data for year 1976 to 1990

Method / City	Vilnius	Kaunas	Klaipėda
RSN	–24.2	–22.5	–21.4
EN ISO15927–5			
1 day	–21.6	–20.4	–18.0
2 days	–22.0	–20.5	–17.7
3 days	–21.4	–20.6	–17.6
4 days	–21.1	–20.1	–17.0
Din 4710	–22.8	–22.1	–19.6
ASHRAE			
0.4%	–21.65		–17.1
1%	–18.35		–14.83
2%	–15.25		–12.76

The ASHRAE handbook defines two designed winter temperatures for Lithuanian cities that correspond with the 0.4% and 1% limits. These temperatures are higher than the standards valid in Lithuania.

Table 2. The designed heating temperatures, *defined* in regulation and handbooks

Method / City	Vilnius	Kaunas	Klaipėda
RSN	–23	–22	–20
ASHRAE – 0,4%	–20	–19.3	–16.2
ASHRAE – 1%	–16.8	–15.9	–12.4

The highest designed temperatures (the least strict requirements) are calculated following the ASHRAE method. When determining the designed external air temperature following this method, the heating system load, compared to the one that is set in regulation now, might be reduced about 14% (considering that the room temperature is at 20 °C).

The probabilistic-statistical modelling in the selection of design parameters of the external climate

Currently, the normative documents legislated in the Russian Federation, namely, The Code nr. 131.13330.2012 titled 'SNIP (Russian Construction Codes and Regulations) 23–01–99 "Building Climatology" (further – The Code 131)', as well as calculated parameters of the outdoor climate used for the construction of envelope building and indoor climate systems are denoted with certain provision (Gagarin *et al.* 2013; Malyavina, Ivanov 2014). The provision defined by the holdings ratio $k_{h,}$ means that the probability of an actual value of the parameter considered in the process of exploitation of the building will not go beyond specified limit, i.e. neither exceeds the limit during warm months, nor gets reduced during the cold seasons. This ratio might be expressed as follows:

$$k_h = 1 - \frac{\Delta N}{N}, \text{ or } k_h = 1 - \frac{\Delta z}{z}. \quad (2)$$

where N is the number of total observation instances, ΔN is the number of instances, when the parameter goes beyond the given limit, z is the overall length of the period of observation, and Δz is the amount of time interval when the parameter goes beyond limit value. The first option is used to evaluate the k_h ratio of discrete events, e.g. the coldest five-day period, whereas the second option defines the level of climate parameters overall – over warm or cold periods. These are the known parameters 'A' and 'B' for the warm and 'A' for the cold periods, whose values are also given in The Code 131.

Nonetheless, in a number of cases, the given k_h ratio, which is different from those meanings in the source, requires different parameters. This includes instances of highly important targets, when the client needs not only increased reliability but also the k_h value. In order to find a scientifically valid level of climate parameters, the probabilistic-statistical model of outer climate is required. It is based upon the representation of terminal temperature of the external air and a correlatively associated enthalpy as random value, characterized by a specific expected value and a standard deviation, which is equally spread by the normal distribution law. It might be shown that, in spite of two main factors affecting the formation of the parameters, namely, the natural trend and its fluctuations that are very close to being random, such model describes the main correlations between different parameters fairly well (Kryuchkova 2013; Samarin 2014).

It thus becomes possible to use the aforementioned model for predicting the changes in normative values depending on the desired level of k_h. This could be demonstrated by calculating the average external air temperature of the coldest five-day period t_{e5} as one of the most important temperatures, which is used for thermal protection of the enclosing structures and calculation of thermal power of the heating and ventilation systems. Due to the fact, that a five-day period is related to discrete events, the direct application of the analytical expression for the probability density function of a normally distributed random value with parameters that characterize a year in tote would be difficult because such expression would describe the temperature behaviour of a continuous time interval (Šliogerienė *et al.* 2009; Wang *et al.* 2011). Consequently, numerical simulation using software that generates daily temperatures with sensors of pseudorandom values is required. The aforementioned procedure is one of the Monte-Carlo method options, which has a number of advantages as compared with a local and foreign approach, which is based upon the notion of a standard year (Ecevit *et al.* 2002; Masson 2000). This approach means that great bulk of climate information is being researched, stored and analyzed in terms of its representativeness (Uzsilaityte, Martinaitis 2008; Zukowski *et al.* 2011). Moreover, the implementation of Monte-Carlo method is not time-consuming in terms of uploading large sets of raw data in the already existing or newly developed software. The data generation was produced for a 400-year period, whereby five coldest days of a year were sorted and average temperatures t_{e5} were calculated, (the latter were ranked in ascending order). As a result, it became possible to construct a curve $t_{e5} = f(k_h)$.

Figure 1 shows the results of climate conditions in Moscow. Hence, the expected value (+5.4 °C) was represented by an average annual temperature in accordance with The Code 131, whereas the standard deviation was realized as a value, which is close to semi-amplitude of an annual variation for average monthly temperatures. The latter comprises $A_{te}/2 = (18.7 + 7.8)/2 = 13.25$ °C, but for a better match of t_{e5} value at $k_h = 0.92$, i.e. ground level presented as parameters 'B' for the cold period of year along with The Code 131 data (–25 °C) matches the standard level, which was revealed by cut-and-try method and was equal 12.6 °C. Thus, an analogous procedure should be performed when other regions of construction are calculated so that the specific ratio between the annual amplitude and standard level may be obtained.

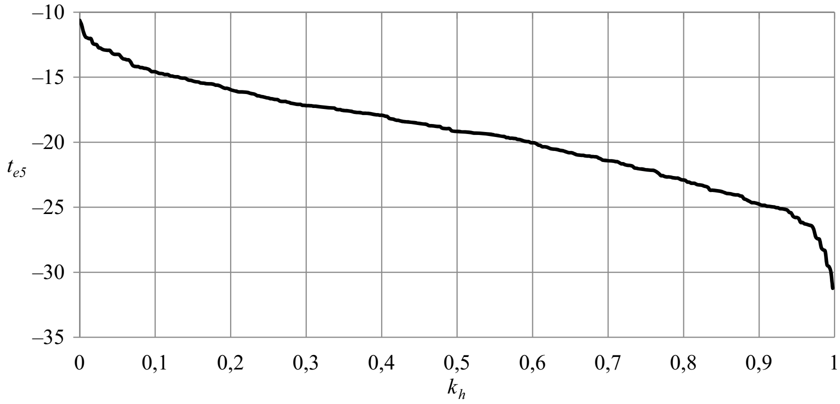

Fig. 1. $t_{e5} = f(k_h)$ calculated dependency for Moscow

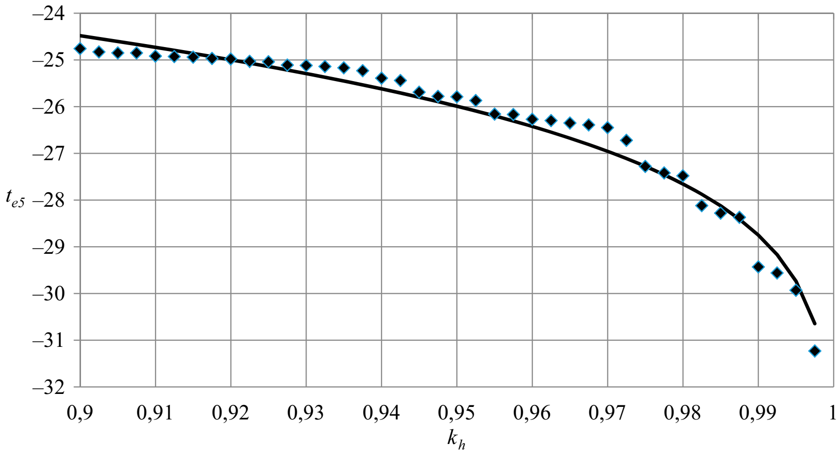

Fig. 2. $t_{e5} = f(k_h)$ calculated dependency for great values k_h in Moscow

The value of interest in Figure 1, i.e. the right part of a diagram, is given in a larger scale (0,9–1) in Figure 2. Here, points show the results of the calculations, while the continuous line represents an approximating dependence, which is also obtained using probabilistic-statistical models with the parameters related to the distribution of the coldest five-day temperature. These parameters are selected for the maximal coincidence of approximating curve with nominal design points. General view of this dependence might be depicted by the following formula:

$$t_{e5} = M\left(t_{e5}\right) - \sigma_{e5}\sqrt{-1.592\ln\left[1-\left(1-2k_h\right)^2\right]} \quad . (3)$$

Here, $M(t_{e5})$ and σ_{e5} are a mathematical expectation of examined value t_{e5} and its standard value respectively. The formula is comprised by an approximate expression of the error function for great argument values.

Since $M(t_{e5})$ corresponds to provision t_{e5} equal 0.5, its estimated value in Figure 1 might be –19 °C, whereas the value of σ_{e5} is selected 4.3 °C. It is evident that the aforementioned parameters are not linked to the mathematical expectation of terminal temperature annually or its standard deviation, thus the parameters should be defined only after the numerical modelling. However, they allow calculating the level of t_{e5} with any random $k_h > 0.9$ via correlation (3). The aforementioned problem may be additionally simplified and shown as the following dependency:

$$t_{e5} = M\left(t_{e5}\right) - \sigma_{e5}C \quad \text{and} \quad C = \sqrt{-1.592\ln\left[1-\left(1-2k_h\right)^2\right]} . (4)$$

Hence, calculate the coefficient C is related to the values of k_h and may be independently calculated in advance. The results are given in the following Table 3, which is valid for any region of construction.

Table 3. C and k_h relation

k_h	0.9	0.91	0.93	0.94	0.95	0.96	0.97	0.99	0.995
C	1.275	1.333	1.464	1.54	1.626	1.727	1.85	2.267	2.497

Within underlying range $k_h = 0.92 \ldots 0.995$, the data of this table is approximated with reasonable accuracy:

$$C = 1 + \frac{0.045}{1.025 - k_h} \cdot \quad (5)$$

It should be noticed that since The Code 131 leads to the value of t_{e5} for two different $k_h = 0.92$ and 0.98 ($t_{0.92} - t_{0.98}$ accordingly), $M(t_{e5})$ and σ_{e5} may be approximately defined without software calculations, placing t_{e5} and k_h in (3) and solving a consequent system of equations, which looks like:

$$M\left(t_{e5}\right) = t_{0.92} + 2.26\left(t_{0.92} - t_{0.98}\right); \sigma_{e5} = 1.616\left(t_{0.92} - t_{0.98}\right). \quad (6)$$

Formally, it is $M(t_{e5}) = -16$ °C and $\sigma_{e5} = 6.5$ °C in Moscow. Bearing in mind the expression (4), the value t_{e5}, takes the form (along with an arbitrary probability) of the weighted average between $t_{0.92}$ and $t_{0.98}$:

$$t_{e5} = C_{0.92} t_{0.92} + C_{0.98} t_{0.98} \,. \quad (7)$$

Here, the weight ratios $C_{0.92}$ and $C_{0.98}$ take the forms (Table 4).

Drawing from (4), when $k_h = 0.92 \ldots 0.995$, it is thus:

$$C_{0.92} = 1.644 - \frac{0.073}{1.025 - k_h} \quad C_{0.98} = \frac{0.073}{1.025 - k_h} - 0.644 \cdot \quad (8)$$

Figure 3 demonstrates data comparison of software generation (points) with the values, which were received by the process management of climate observations at the weather station in Moscow (solid line) for the period time until 2000.

At the same time, the calculation was performed under the input data, which satisfies the parameters of The Code 131, i.e. with the average annual temperature equal +4.1 °C and a standard deviation = +13.3 °C, at $A_{te}/2 = (18.1 + 10.2)/2 = 14.15$ °C. It should be noticed, that the standard deviation ratio to A_{te} equals 0.94 and does not differ from the condition of the previous calculation, whereby it is 0.95, which is suggestive of certain regularity. Is might be clearly seen that within the span varying from 0.9 to 0.99 the discrepancy does not exceed 0.5 °C, whereas within higher probability the software calculation provides a somewhat understated value of t_{e5}, which may be considered as a reserve.

Conclusions

1. Based on the data for 1976 to 1990, the calculated designed external air temperature for three Lithuanian cities varies from 1 °C (the RSN and ASHRAE 0.4% methods) to 2 °C (ASHRAE: 1%) lower than the officially stated designed external air temperatures of these cities.
2. The difference between the room temperature in the building (it was considered in this paper that it is at 20 °C) and the designed external air temperature, laid down in different sources which determines the thermal

Table 4. $C_{0.92}$, $C_{0.98}$ and k_h relation

k_h	0.9	0.91	0.93	0.94	0.95	0.96	0.97	0.99	0.995
$C_{0.92}$	1.2	1.1	0.9	0.77	0.63	0.47	0.27	–0.4	–0.78
$C_{0.98}$	–0.2	–0.1	0.1	0.23	0.37	0.53	0.73	1.4	1.78

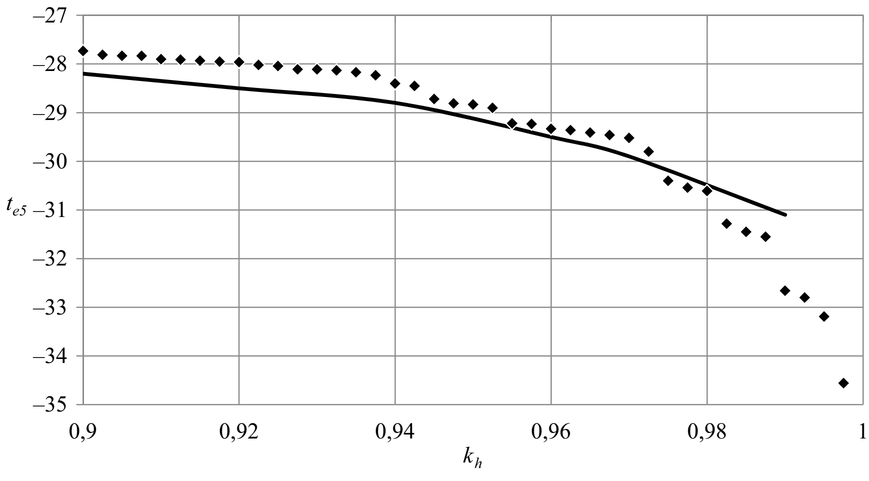

Fig. 3. Comparison of software generation (points) with the values, which were received by the process management of climate observations at the weather station in Moscow (solid line)

losses of a building is 14%. This shows that it is possible to increase the designed external air temperatures laid down in current Lithuanian regulations. This would allow reducing the initial investments into heating system installation and the seasonal efficiency coefficient, at the same time cutting maintenance costs.

3. It has been confirmed that there is a possibility of the probabilistic-statistical modelling for array design of the climate data once certain calculations have been performed. The latter are linked to the thermal conditions of buildings and building envelopes as well as the choice of calculation parameters of the outdoor climate with the required supply. The results may be presented as an engineering report along with the basic values, given in The Code 131, and may also be available for engineering design practice.

Disclosure statement

Authors declare that they have no competing financial, professional, or personal interests from other parties.

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KLIMATO PARAMETRŲ, SKIRTŲ PASTATŲ ATITVARŲ IR MIKROKLIMATO SISTEMOMS PROJEKTUOTI, PARINKIMAS

O. Samarin, S. Paulauskaitė, K. Valančius, K. Čiuprinskas

Santrauka

Straipsnyje nagrinėjami informacijos apie išorės sąlygas atrankos principai, reikalingi pastato patalpų mikroklimatui sukurti remiantis Europos šalių (ir Rusijos) patirtimi. Dėmesys atkreiptinas į metodikų trūkumą, kuriose vartojama „tipinių metų“ sąvoka, ir į klimato duomenų rinkinių, įtrauktų į programinę įrangą, privalumus. Vidutinė šalčiausių penkių dienų temperatūra buvo apskaičiuota taikant skaitmeninius Monte Carlo modelius ir dabartinius klimato duomenis. Buvo įrodyta, kad abiem atvejais temperatūros statistinis pasiskirstymas iš esmės sutampa ir yra tinkamas pastatų atitvaroms ir mikroklimato sistemoms projektuoti. Apskaičiuotos vertės buvo įvertintos atsitiktinio pasiskirstymo metodo analitine raiška ir pagrindiniam parametrų pasirinkimui reikalingomis koreliacijomis.

Reikšminiai žodžiai: pastatas, atitvaros, šildymo sistema, mikroklimatas, projektinės vertės.