Selection of Outdoor Climate Parameters for Designing of Ventilation and Air Conditioning Systems

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Abstract. The correct selection of the outdoor climate parameters for the design of ventilation and air conditioning systems in buildings allows saving initial costs and reducing energy consumption during operation. The article presents a method of statistical processing of long-term data of measurements of meteorological parameters and the results of calculations for various regions of Russian Federation. The required outdoor climate parameters such as air temperature, specific enthalpy and absolute moisture content, are presented in the form of tables, BIN diagrams and a climate map of a city.

1. Introduction
The ventilation, cooling and air conditioning systems provide optimal microclimate conditions for public and industrial buildings, such as shopping, office, multifunctional centers, transport infrastructure buildings - airports and train stations, sports facilities, medical centers, industrial and warehouse complexes and other facilities. The cooling capacity of the systems can reach several thousand kilowatts, and this influences on the required consumption energy for buildings and can cost tens millions rubles. The correct selection of the outdoor climate parameters when designing cooling systems allows saving initial costs, as well as reducing energy consumption during operation by 15-25%.

2. Regulations
The specified indoor climate parameters should be ensured in residential, public, administrative and industrial buildings at the maximum design parameters of the outside air for the corresponding regions, regulated by national standards SP 131.13330 and SP 60.13330 [1,2]:
parameters A - for ventilation during the warm season;
parameters B - for heating, ventilation and cooling systems in the cold season, as well as for air conditioning systems in the warm and cold periods of the year.

According to SP 131.13330 [1], the parameters of temperature and enthalpy for ventilation and air conditioning systems in the warm period of the year are determined as parameters B. The temperature in this case corresponds to column 4 in Table 4.1, which corresponds to the availability of 98%, and the enthalpy is determined from Figure A.5 and has a spread of parameters from low to high values. Considering that the spread of enthalpy parameters strongly affects the selection of equipment for...
ventilation and air conditioning systems, it was decided to analyze climatic data for the last 5-20 years for large cities and representative regions of the Russian Federation and compile a table with data on temperature, enthalpy and absolute moisture content of air.

3. Research methodology
To select the design parameters of the outdoor climate (temperature, enthalpy and moisture content), we used data from the website meteo.ru and website «Reliable Prognosis», which presents archived weather data with a measurement interval of 3 hours. The data for the entire observation period are sorted by the selected boundary parameters. The boundary parameters are taken with a reliability of 98%, i.e. inreliability - less than 175 hours / year. The boundary value was determined for the entire observation period, and then the sorting was performed in descending order. For example, if the observation period is 11 years, the margin of failure is 11 * 175 = 1925 hours.

Taking into account the temperature and humidity data of recent years, which are available in the form of measured parameters recorded every 3 hours, we calculated the specific enthalpy and absolute moisture content.

To calculate the enthalpy and moisture content, formulas [3,4] were used.

3.1. *Specific enthalpy, h, kJ / kg, is determined by the formula:*

\[ h = 1.006T + d / 1000 \times (2501 + 1.806 \times T), \]

where T is the temperature in °C, d is the moisture content in g / kg.

3.2. *Absolute moisture content, d, g / kg, is determined by the formula:*

\[ d = 622 \times \frac{P_s}{(P_0 - P_s)}, \]

where Ps is the partial pressure in kPa, Po is the barometric pressure in kPa.

3.3. *The partial pressure of water vapor Ps, kPa, is determined by the formula:*

\[ Ps = e^{(16.57 \times T - 115.72) / (233.77 + 0.997 \times T)} \times \frac{U}{100}, \]

where U is relative humidity, %.

The data on the absolute moisture content, which are necessary for calculating the processes of air dehumidification during ventilation of swimming pools [5] and similar objects, were independently calculated for the reliability of 98%.

When selecting equipment, it is advisable to take into account the values with the specified reliability. Possible excess of these values is less than 175 hours per year and occurs, as a rule, several hours during the day, which does not significantly affect the microclimate of the room due to thermal inertia and heat storage capacity of outer and inner building shells. One of the design errors is the oversizing of the equipment when it is calculated for higher outside parameters, which negatively affects the economic and energy characteristics, as well as the costs for the supplying excess of electrical power.

In addition to the correct selection of design conditions for determining the maximum capacity of the equipment, it is also necessary to take into account the change in climatic parameters during the year or season. In Europe, the seasonal efficiency of refrigeration equipment, chillers and air conditioners is often rated by the seasonal energy efficiency ratio SEER which is controlled by the Eurovent Certification Company. This defines a new approach to product development that encourages manufacturers to consider the environmental benefits of a product throughout its entire life cycle.
3.4. The SEER rating of a unit is the cooling output during a typical cooling-season $Q_x$ divided by the total electric energy input during the same period $Q_{el}$:

$$\text{SEER} = \frac{Q_x}{Q_{el}}$$

To calculate seasonal indicators, the BIN method is used, which makes it possible to differentially reflect the current value of the ratio of the outside air temperature and the corresponding amount of equipment load. For the selected settlement, a BIN diagram is built of the hourly duration of outdoor temperatures (step yearly graph of temperatures). The diagram is divided into BIN intervals (cells) with a width of 1 °C. Each numbered interval corresponds to the average value of the current outside temperature (BIN temperature), the current cold consumption (equipment load), and the current value of the coefficient of performance $EER$ (energy efficiency ratio).

3.5. The integral seasonal indicator is calculated by summing the current values of all intervals according to the formula:

$$\text{SEER} = \frac{Q_x}{Q_{el}} = \frac{\sum Q_{xi} \cdot \tau_i}{\sum \tau_i \cdot [q_{xi} / EER_{bin}(i)]}$$

where $Q_x$, $Q_{el}$ - respectively, the seasonal amount of cooling output and corresponding electric energy input, kWh / season;

$$i = 1,2,3 \ldots \ldots n;$$

where $n$ is the total number of BIN intervals in the season with the $i$-th outdoor temperature (depends on the seasonal range of the outdoor temperature and the selected cell width),

$$Q_{xi} = q_{xi} \cdot \tau_i, \text{kWh};$$

where $Q_{xi}$ is the amount of cooling output generated by refrigeration equipment at the $i$-th BIN outdoor temperature, kWh;

$q_{xi}$ - current refrigerating capacity of a piece of equipment at the $i$-th BIN outdoor temperature, kW;

$\tau_i$ - the number of hours of duration of each BIN of outdoor temperature, h.

$EER_{bin}(i)$ - the current value of the coefficient of efficiency $EER$ for each BIN temperature and the corresponding value of the equipment load.

We propose a similar approach for assessing the energy efficiency and annual energy consumption for the whole refrigeration system, such as a chiller and an air conditioning system [6,7]. For various objects, the current power of the system is determined not only by the current outside temperature, but also by the current specific enthalpy and moisture content, which requires the construction of appropriate graphs (BIN diagrams).

For the convenience of designing an air conditioning system, it is advisable to draw up a real «climatic map of the city», indicating the hours or minutes of the possible duration of meteorological parameters. We use archived data from the "Reliable Prognosis" website. To determine the number of hours, first of all, we determine the measurement frequency; for example, for Moscow, measurements are taken every 3 hours (for different cities it is different). Since the archive is taken over several years, for example, over 5 years, the hours are averaged to bring the readings to 1 year. We set a number for each dimension: 3 hours / 5 years = 0.6 hours / per year. A matrix is created in which all observed temperatures are given vertically, and the values of relative humidity are shown horizontally in 5% increments. Further, for each field, according to the selected temperature and humidity range, the sum of measurements is calculated, corresponding to the observation time. The resulting matrix is transferred to the I-D diagram of humid air, creating a grid of rectangles of different colors - from light to dark. The most frequently measured parameters are highlighted in dark color, once measured - the lightest, then the color changes depending on the percentage: selected sum of measurements / maximum sum of measurements.

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4. Results

The calculated values for the outside climate parameters (specific enthalpy and moisture content of the outside air) are presented in the table below for the regions of the Russian Federation. This data shall be used for calculating of the nominal capacity of ventilation and air conditioning systems.

**Table 1.** Enthalpy and moisture content of the outside air during the warm season for calculating the nominal capacity of ventilation and air conditioning systems.

| Item No. | City name             | Specific enthalpy of outside air, kJ / kg | Specific moisture content of outside air, g / kg |
|----------|-----------------------|------------------------------------------|-----------------------------------------------|
| 1        | Astrakhan             | 63.6                                     | 11.7                                          |
| 2        | Blagoveshchensk       | 64.1                                     | 11.9                                          |
| 3        | Vladivostok           | 62.1                                     | 15.2                                          |
| 4        | Vladikavkaz           | 61.8                                     | 13.1                                          |
| 5        | Volgograd             | 56.2                                     | 9.4                                           |
| 6        | Voronezh              | 58.0                                     | 11.4                                          |
| 7        | Grozny                | 65.1                                     | 13.1                                          |
| 8        | Yekaterinburg         | 53.5                                     | 10.1                                          |
| 9        | Irkutsk               | 53.9                                     | 10.9                                          |
| 10       | Kazan                 | 57.0                                     | 11.5                                          |
| 11       | Kaliningrad           | 55.0                                     | 11.7                                          |
| 12       | Krasnodar             | 64.6                                     | 12.6                                          |
| 13       | Krasnoyarsk           | 54.7                                     | 11.3                                          |
| 14       | Mineralnye vody       | 62.1                                     | 11.9                                          |
| 15       | Moscow                | 57.8                                     | 12.2                                          |
| 16       | Nizhny Novgorod       | 57.0                                     | 11.9                                          |
| 17       | Novosibirsk           | 54.6                                     | 10.9                                          |
| 18       | Omsk                  | 54.3                                     | 10.7                                          |
| 19       | Orenburg              | 56.1                                     | 9.6                                           |
| 20       | Perm                  | 54.8                                     | 11.2                                          |
| 21       | Petropavlovsk-Kamchatsky | 41.2                             | 9.0                                           |
| 22       | Rostov-on-don         | 60.6                                     | 11.5                                          |
| 23       | Saint-Petersburg      | 56.5                                     | 12.8                                          |
| 24       | Saratov               | 56.6                                     | 10.4                                          |
| 25       | Sevastopol            | 67.3                                     | 15.5                                          |
| 26       | Simferopol            | 56.3                                     | 11.0                                          |
| 27       | Sochi                 | 73.8                                     | 17.6                                          |
| 28       | Stavropol             | 58.8                                     | 11.1                                          |
| 29       | Tyumen                | 55.1                                     | 11.2                                          |
| 30       | Ufa                   | 56.9                                     | 11.2                                          |
| 31       | Feodosiya             | 65.9                                     | 14.0                                          |
| 32       | Khabarovsk            | 64.0                                     | 14.5                                          |
| 33       | Chelyabinsk           | 52.5                                     | 10.1                                          |
| 34       | Elista                | 61.9                                     | 11.3                                          |
| 35       | Yuzhno-Sakhalinsk     | 56.0                                     | 13.0                                          |
| 36       | Yalta                 | 65.2                                     | 14.2                                          |
Figures 1, 2, 3 show the graphs of the values of temperature, enthalpy and absolute moisture content (BIN diagrams) with the display of the number of hours of their duration, for the warm season in Vladivostok.

**Figure 1.** The number of hours with the certain outside temperature for the warm season for Vladivostok.

**Figure 2.** The number of hours with the certain enthalpy for the warm season for Vladivostok.

**Figure 3.** The number of hours with the certain absolute moisture content for the warm season for Vladivostok.
Figures 4 and 5 show the graphical data of the number of hours with the values of enthalpy and moisture content, and also indicate the boundary values of the parameters with the 98% coverage.

**Figure 4.** The comparison graphs of the number of hours with the certain enthalpy for the warm period of the year in Moscow and Vladivostok, indicating the boundary values with the reliability of 98%.

**Figure 5.** The comparison graphs of the number of hours with the certain moisture content for the warm period of the year in Moscow and Vladivostok, indicating the boundary values with the reliability of 98%.

Figure 6 shows the I-D diagram with plotted averaged meteorological data over the number of minutes with a certain temperature and humidity during the year for Moscow («climatic map of the city»).
Figure 6. The I-D-diagram represents the number of minutes with a certain temperature and humidity during the year for Moscow.
5. Conclusions
The value of the specific enthalpy and absolute moisture content of the outside air in the warm season should be taken according to the table given in the article (for the cities presented).

The using of the real climate data allows us to make the calculations of operating costs throughout the year and estimate the savings when using equipment with energy recovery. It is also possible to compare equipment that has different heat recovery rates and efficient cooling capabilities. For example, the operating costs during the warm period can be reduced several times due to the use in the ventilation equipment a cooling tower with indirect adiabatic cooling, which allows to cool the outside air by 10-12 °C, without changing its moisture content, and without using the compressor of the refrigerating unit.

Thus, the data obtained, shell help to optimize the selection of refrigeration and ventilation equipment, reduce its cost and energy consumption. The estimating of the annual operating costs for different climate regions give us the possibility for determining the economic efficiency by using the energy-saving equipment and solutions, and this tool can be widely applied in the practice for the selecting the equipment with the lowest energy consumption.

6. References
[1] National Standard: SP 131.13330.2020 "Construction climatology"
[2] National Standard: SP 60.13330.2016 "Heating, ventilation and air conditioning"
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