Evaluation of Urban Microclimate Parameters as Indicators of Pedestrian Ways Environmental Comfort

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Abstract. A variant of the methodology for quantitatively assessing the availability, comfort and environmental safety of residential areas was proposed by the authors. The principles of creating a biosphere-compatible city, without conflict with the environment and developing a person, were taken as a basis. According to the main provisions of this concept, the degree of implementation of the city's functions is determined by the level of accessibility of these functions for all of its residents, regardless of the characteristics of their health and age. It is proposed to introduce the parameter of time to meet human needs into the system of indicators of master plans as one of the parameters of a comfortable and safe urban environment. It is supposed that socially significant objects of everyday service of residents, as well as open spaces for recreation, should be located on the territory of residential buildings within walking distance at a comfortable distance from the places of residence. At the same time, pedestrian communications in residential areas, in particular those leading from places of residence to the objects under consideration, must comply with environmental safety requirements, as well as open urban spaces for recreation, games, and sport. To assess these parameters an integral indicator, one of the components of which is the predicted level of thermal comfort, was proposed in the work. To determine it, it is proposed to use the bioclimatic index, that is the physiological equivalent temperature (PET). In this work, based on the example of a new residential area in the city of Orel, the corresponding integral indicators were determined in terms of assessing the availability of educational facilities and open green urban spaces, including some points of pedestrian communications. The calculation results showed that when planning a new micro-district, the values of the levels of implementation of city functions in terms of the accessibility of socially significant objects, as well as the levels of comfort and environmental safety of pedestrian communications and open urban spaces, differ significantly from the maximum possible. It is noted that when designing a micro-district and arranging pedestrian communications and open spaces, no attention was paid to ensuring a comfortable climatic regime. Conclusions about the influence of built environment on the temperature regime in the territories of the considered locations are made. It is supposed that expanding the range of indicators for assessing territorial planning projects for analyzing accessibility by time parameter, as well as for assessing the level of environmental safety and comfort, will increase the efficiency of the use of urban planning methods in the planning and development of residential micro-districts in order to create an urban environment that contributes to the preservation of health of residents.
1. Introduction
One of the key tasks of urban planning activities at the present stage is to ensure a high quality of the spatial living environment, determined by the degree of its safety and comfort [1-3]. One of the paradigms that can form the basis for the transformation of the city may be the concept of a city that is biosphere compatible and helps human development [2, 4]. This concept was proposed by the Russian Academy of Architecture and Construction Sciences. A number of fundamental principles are introduced here regarding overcoming degradation processes in the life of modern cities. The implementation of these principles will help to increase the intellectual, physical and social potential of modern cities, improve the health of residents, and will also allow a scientifically grounded balance of anthropogenic activities and increase the life potential of the Biosphere.

The basis for solving the set of tasks is to ensure the maximum availability of city functions for various groups of the population with a high quality of functional organization, safety and comfort of travel routes and open spaces. At the same time, due to the limited composition of the normative indicators of master plans adopted in Russia, the development of a methodology for their quantitative assessment is of particular scientific and practical interest.

In general, according to [2], a quantitative analysis of the quality of the urban environment should be based on the regulation and systemic management of safety and public comfort parameters. In turn, the availability of public facilities (educational, cultural, entertainment, shopping and medical institutions) to all categories of the population is currently considered in many countries among the priorities of urban development and within the concept of healthy urban planning [5].

Within this task, indicators for assessing territorial planning projects are of interest, for example, those developed within the project San Francisco Indicator, that are a district-level data system that measures healthy community development and social equity in eight directions [6]. In the assessment of certain types of indicators, the parameters of the availability of facilities (for example, educational institutions, open urban spaces, etc.) are also involved. However, the system of such indicators does not focus on specific distances between the considered objects and places of residence. Despite the fact that in Russia such distances are regulated by the relevant regulatory documents, they do not adequately determine the degree of accessibility of socially significant objects and open spaces for population groups, depending on their health and movement capabilities.

In this regard, in our country, as well as in foreign countries [7, 8], tasks aimed at developing an expanded set of indicators that allow qualitatively and quantitatively assessing urban planning solutions from different positions do not lose their relevance. At the same time, the set of indicators for master plans and territorial planning projects should reflect the time to meet rational human needs, determined by the level of development of the city's infrastructure, taking into account the characteristics of human health.

One of the indicators in this case can be an integral relative quantitative indicator, reflecting the level of implementation of city functions, in the form of indicators of the availability of urbanized territories [9]. At the same time, such a set should include indicators of the level of comfort and environmental safety of travel routes and open urban spaces.

2. Methods
Availability of socially significant facilities and open urban spaces
The following are taken as indicators of the availability of urbanized territories:

- personal availability ($D_i$);
- territorial (pedestrian) accessibility ($\xi_{i,j}$);
- territorial-personal availability ($\xi_j$).

**Personal availability ($D_i$)** shows the share of the population who have the opportunity to receive services in the institution in question ($F_i$) (when implementing $i$ city functions) in the total number of residents of the considered micro-district in need of this service ($P_i$):
\[ D_i = \frac{F_i}{P_i} \]  

(1)

If \( F_i > P_i \), then \( D_i = 1 \) is taken.

**Territorial (pedestrian) accessibility** \( (\xi_{i,j}) \) determines the ratio of the time that a pedestrian living in the \( j \) site could spend on overcoming the maximum comfortable distance from the place of residence to the object that implements the \( i \) city function \( (t_{n,i}) \) to the time that the pedestrian spends on overcoming the actual distance \( (t_f) \):

\[ \xi_{i,j} = \frac{t_{n,i}}{t_{i,j}} \]  

(2)

or

\[ \xi_{i,j} = \frac{S_{n,i}}{S_{i,j}} = \frac{R_{n,i}}{R_{i,j}} \]  

(3)

where \( S_{n,i} \) and \( R_{n,i} \) are comfortable distance from the place of residence to the object that implements \( i \) city function, taking into account and without taking into account non-linearity of pedestrian connection respectively;

\( S_{i,j} \) and \( R_{i,j} \) are actual distance from the place of residence in the \( j \) site to the object that implements \( i \) city function, taking into account and without taking into account the non-linearity of pedestrian connection respectively;

herewith:

\[ R_{i,j} = S_{i,j} \cdot K, \]  

(4)

\[ R_{n,i} = S_{n,i} \cdot K, \]  

(5)

where \( K \) is the nonlinearity coefficient of the pedestrian connection (in the first approximation, it can be neglected in the calculations, assuming \( K = 1 \)).

The values of comfortable distances for different categories of the population, depending on their age and health status, can be determined based on studies of the average speed of pedestrians.

The indicator of territorial (pedestrian) accessibility \( \xi_{i,j} \) is the indicator of the implementation of the city function for residents of the considered \( j \) site. So the values \( \xi_{i,j} \) can be equal:

- within pedestrian accessibility radius and sufficient capacity of the facility \( \xi_{i,j} = 1 \);
- in the territory located outside pedestrian accessibility radius and limited capacity of the facility \( 0 < \xi_{i,j} < 1 \);
- in other cases \( \xi_{i,j} = 0 \).

**Territorial-personal availability** \( (\xi_i) \) is a measure for assessing the time of service provision (when the \( i \) city function is being implemented) for various groups of its users, taking into account the remoteness of residence and the size of the served population.

The integral value of the availability indicator under consideration can be calculated using the following formula:

\[ \xi_i = \sum_{j=1}^{\hat{m}} n_j \xi_{i,j} \]  

(6)

where \( n_j \) is the number of residents served in the microdistrict under consideration and living in its \( j \) accessibility zone; \( m \) is the number of accessibility zones, limited by the depletion of the actual capacity of the object.
The indicator of territorial-personal availability $\xi$ allows you to assess the level of implementation of $i$ city function by residents of the considered territorial entity, taking into account the population size of the sites (accessibility zones), which are characterized by different values $\xi_{i,j}$.

**Comfort and environmental safety of pedestrian communications and open urban spaces**

The following are taken as indicators of comfort and environmental safety of residential areas:
- predictable thermal comfort ($k_t$);
- predicted level of acoustic pollution ($k_a$);
- degree of landscaping ($k_g$).

**Predictable thermal comfort ($k_t$)** is defined using adapted to the conditions of open urban spaces bioclimatic index, which shows the features of human thermal perception and is named the physiological equivalent temperature (PET) [10, 11], as the ratio of the average comfort value (PET$_k$) to the predicted actual value (PET):

$$k_t = \frac{\text{PET}_k}{\text{PET}}. \quad (7)$$

In this case, the predicted value of PET is determined taking into account the peculiarities of building and landscaping for various combinations of climatic parameters that are the most typical for different seasons.

The PET index is universal and allows you to take into account the complete heat balance equation of the human body, the temperature of internal organs, the intensity of sweating, skin moisture, and meteorological parameters. The calculation of the indicator involves such parameters as air temperature and humidity, wind speed, cloudiness and openness of the sky, the albedo of the surrounding surfaces, the degree of closure of the human body by clothing, and some others.

Calculation models of integral temperature indices used in determining the energy balance of the human body when analyzing the comfort level of an urban microclimate are based on determining the average radiation temperature $T_{mrt}$, which is the most important meteorological parameter affecting the energy balance of a person during sunny weather conditions [12]. For calculation $T_{mrt}$ the surface of the human body is divided into n isothermal surfaces with temperature $T_i$ and emissivity $\varepsilon_i$:

$$T_{mrt} = \frac{1}{2} \sum_{i=1}^{n} \left( E_i + \alpha_k \frac{D_i}{\varepsilon_p} \right) F_i \right)^{0.25}, \quad (8)$$

where $\sigma=5.67 \times 10^{-8} \text{ W/(m}^2\text{K}^4)\)$ is the Stefan-Boltzmann constant, $\varepsilon_p$ is the human body emissivity (it is taken equal 0.97), $D_i$ includes diffuse solar radiation and diffusely reflected global radiation, $a_k$ is absorption coefficient of the irradiated surface of the body of short-wave radiation, $E_i$ is the value of long-wave radiation, that is calculated as $E_i=E_i; \sigma \cdot T_i^4$, $F_i$ is the level of covered area of the human body (the presence of clothing).

The proposed classification of physiological temperature stress of human, developed for various climatic conditions, makes it possible to assess the PET indicator and establish criteria for a comfortable (neutral) temperature [13]. So, for the countries of Western and Central Europe, it averages are 18-23°C [10-12]. Researches [14], carried out by bioclimatic assessment of the territory, for the conditions of the Central and European parts of Russia have established a satisfactory comparability of the PET values corresponding to comfortable weather with the scale of human temperature perception in Western and Central Europe.

**Predictable level of acoustic pollution ($k_a$)** is determined by the ratio of the average comfortable value ($N_\xi$) to the predicted actual value ($N$):

$$k_N = \frac{N_\xi}{N}. \quad (9)$$
It takes into account the noise from city roads and roads of intra-quarter significance, enterprises, playgrounds and other objects, depending on the distance of the point in question from noise sources.

According to the Set of the Rules 51.13330.2011 «Sound protection» on the territory of a residential micro-district the sound level, that is considered as comfortable, should not be higher 55 dBA, maximum allowable is 70 dBA.

**Degree of landscaping** ($k_g$) of pedestrian communications is characterized by the share of the greened parts of the path, and for open urban spaces by the percentage of landscaping:

$$k_g = \frac{S_g}{S}.$$  \hspace{1cm} (10)

We take $S=90\text{-}100\%$.

The integral indicator of the level of comfort and environmental safety of travel routes and open urban spaces $k$ can be defined as the arithmetic mean between the values of the proposed indicators.

### 3. Case Study

As an example, we will determine the integral indicators of accessibility, safety and comfort of socially significant facilities (for example, educational institutions), open spaces and some pedestrian communications in the “Novaya Botanica” micro-district, located in Orel city on the area between the floodplain of the river Oka and the main railway (figure 1), the area of the allotted territory within the boundaries is 40.2 hectares. Residential development is represented by apartment buildings with a height of 9 and 16 floors, next to the micro-district there are the low-rise buildings area and a city park.

There is a building of the preschool educational institution for 280 seats and a secondary school for 550 seats in the south-eastern part. In the west the micro-district borders the Park.

![Figure 1. The development scheme of the micro-district "Novaya Botanica", Orel](image)

It is proposed to determine the predicted thermal comfort for a summer day and time of day with the least favorable weather conditions, as calculation data we take the data according to the table 1.
Table 1. Initial data for determining predicted thermal comfort

| Date       | Time | T_a, °C | Rel. humidity, % | Wind velocity, m/s | Cloud cover, octas |
|------------|------|---------|------------------|--------------------|-------------------|
| 22/06/18   | 12:00| 28.1    | 10               | 4                  | 1                 |
|            | 15:00| 29.4    | 40               | 3                  | 3                 |
|            | 18:00| 26.1    | 70               | 2                  | 2                 |
| 23/06/18   | 12:00| 30.7    | 70               | 5                  | 4                 |
|            | 15:00| 32.1    | 80               | 4                  | 4                 |
|            | 18:00| 29.8    | 70               | 2                  | 4                 |
| 28/07/18   | 12:00| 29.6    | 20               | 4                  | 1                 |
|            | 15:00| 31.8    | 20               | 3                  | 1                 |
|            | 18:00| 30.7    | 30               | 3                  | 1                 |

Comfort and environmental safety indicators will be assessed for two children's playgrounds and two points of pedestrian communications (figure 2).

Figure 2. Layout of locations 1-4 in the micro-district "New Botanica".

4. Results and Discussion

According to the results of the calculation, the territory of the "New Botanika" micro-district was divided by accessibility radii into sites (figure 3). So, figure 3 graphically presents comfortable distances to the facilities for pre-school and general education and to the intra-district park for people with different moving abilities.

As can be seen from figure 4, the radii of the pedestrian accessibility of socially significant objects do not fully cover the territory of the considered micro-district. So, apartment buildings in the north-western and eastern parts of the micro-district are located from educational facilities at distances greater than comfort values. The values of the indicators of the level of implementation of the function i=2 “Entertainment and leisure” in terms of its component i=21 “Leisure in urban open green spaces”, of the function i=3 “Knowledge” in terms of its component i=31 “Pre-school educational institutions” and i=32 “Educational institutions” in the micro-district “New Botanica”, defined by Eq. 1 for various population categories [14], are given in Table 2.

The analysis shows that the design of the new microdistrict planning initially included decisions that did not allow reaching the maximum values of the indicator of the implementation of the city function "Knowledge" (for school and pre-school education: $\xi_3 = 0.74$). Moreover, due to the isolation of the micro-district “New Botanica” and its relatively low transport accessibility, insufficient provision of general education facilities will force residents to use educational institutions located at a distance of several kilometers from their places of residence [16].

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1 from the weather archive on the website https://rp5.ru
The calculation of the physiologically equivalent temperature PET at certain points (see figure 2) for selected weather conditions (see Table 1) was made using RayMan [10-11] for the average pedestrian (a healthy 35-year-old man with a weight of 75 kg and a height of 175 cm). The results of calculating PET are shown as diagrams in Figure 5.

Figure 3. The radii of the accessibility of pre-school educational institution I, secondary school II and the intra-district park III in the micro-district “Novaya Botanica”, corresponding to comfortable distances: 1 - for healthy people aged 21-25 years, 2,8 – 7-8 years, 3,7 – 3-4 years, 4 – over 70 years, 5 – for people with disorders of the musculoskeletal system, 6 - for all population groups [14].

Figure 4. PET values in locations 1-4.

As can be seen from figure 4, the highest PET value is typical for location 3, at this point it significantly exceeds the air temperature. In almost all locations, the PET value exceeds the air temperature measured at the weather station by an average of 3-6°C, this is due to the fact that the bioclimatic index also takes into account the influence of solar radiation, wind speed and humidity on human thermal comfort.

To analyze the influence of built environment and vegetation on the PET values, diagrams were built (figure 6), which allow us to make the following conclusions. In the evening, PET is close to the air temperature practically regardless of the location, while in the daytime there is a significant excess of the PET value relative to the air temperature. The existing buildings have the greatest impact on PET in locations 1, 2,
4 in the daytime. At the same time, none of the considered locations allows us to draw conclusions about a comfortable temperature regime on its territory on hot summer days in the daytime.

Figure 5. Diagrams of the distribution of air temperature values at the meteorological station and PET in locations 1-4.

Analysis of the noise level at the points under consideration showed satisfactory noise pollution, since the selected locations are located at a considerable distance from busy highways. Noise level from play activities was not assessed in the territories of playgrounds.

The results of calculations of the indicators of comfort and environmental safety for locations 1-4 are shown in Table 3.

Table 3. The results of calculations of the indicators of comfort and environmental safety for locations 1-4.

| Location 1 | Location 2 | Location 3 | Location 4 |
|------------|------------|------------|------------|
| $k_t$      | 0.65       | 0.65       | 0.62       | 0.65       |
| $k_n$      | 0.98       | 0.98       | 1.0        | 1.0        |
| $k_g$      | 0.7        | 0.6        | 0.5        | 1.0        |
| $k$        | 0.78       | 0.74       | 0.71       | 0.88       |

As can be seen from Table 3, during the design of the microdistrict and the arrangement of pedestrian communications and open urban spaces, no attention was paid to ensuring a comfortable climatic regime, insufficient landscaping is noted.

5. Conclusions

The introduction of integral indicators of the level of implementation of city functions, environmental safety and comfort of pedestrian communications and open spaces will make it possible to quantitatively assess the accessibility and comfort of the environment, including the quality of communications between places of residence, socially significant objects, areas for recreation, games and sport.

In particular, an integral indicator of the level of implementation of city functions in socially significant objects of daily service $\xi$ can serve as an indicator of the effectiveness of urban planning design solutions from the standpoint of ensuring the comfort of the spatial environment by ensuring not only its functional sufficiency, but also temporary accessibility [17-26].

In turn, the integral indicator of the comfort and environmental safety of pedestrian communications and open urban spaces will be useful in quantitative assessment of options for
planning projects of territories and master plans from the indicated positions. Since taking into account the influence of the spatial organization of the development of Russian cities on the thermal comfort of residents is currently in the staging stage, the introduction of the corresponding indicator into the calculation of the integral indicator of comfort and environmental safety is relevant. This indicator makes it possible not only to assess the adopted design decisions, but also to draw up scientifically grounded proposals for improving the climatic regime in the residential area. Thus, the recommendations for creating environmental comfort by urban planning methods in the planning of new, reconstruction and development of existing urban micro-districts will create a safe comfortable urban environment that will help preserve the health of the population.

Expanding the number of components of these integral indicators, developing methods for calculating them, accompanying monitoring studies will contribute to a more accurate assessment of urban planning solutions, will be useful in the design of pedestrian communications and the development of improvement projects, as well as in analyzing the effectiveness of strategic planning programs for the urban environment.

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