Influence of urban development on change in microclimatic parameters of urbanized area

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Abstract. The expediency of quantitative analysis of safety and comfort of the spatial environment when creating master plans of cities was shown by the authors. Predictable thermal comfort should be considered here as one of the significant indicators of the environmental safety of the routes from places of residence to socially significant facilities and recreational zones. It is suggested to use thermal indexes adapted for the conditions of open urban spaces to consider the influence of climatic variables totality on the person’s thermal sensation. The physiologically effective temperature (PET) is one such index. This model takes visceral temperature, perspiration rate, the moisture of the skin, and on the other hand the meteorological parameters, including the influence of urban area conditions on them. Criteria values of PET for the middle zone of Russia are determined on the basis of bioclimatic estimation of the territory according to air temperature, cloudiness and wind speed. The authors determined experimentally the parameters of the urban microclimate.

1. Introduction
The main task is the creation of a safe and comfortable urban environment that is being solved by urban planning. At the same time, the security of an urbanized territory is determined not only by the safety of its elements for human life and health, but also by the capacity for self-sustaining development [1]. The requirements for environmental comfort in their turn are based on a complex combination of physiological, psychological and sociocultural responses of individuals and their groups to the state and changes in the spatial environment [2].

The signs of urban microclimate are the indicators of the state of environmental safety and comfort systems built environment as well as the hygienic condition of atmospheric air, insolation, acoustic and vibration pollution.

Global warming and the formation of Urban Heat Islands over densely populated areas and industrial centers make it necessary to revise the policy of long-term urban planning, for example, in accordance with the concept of biosphere-compatible cities that are developing human beings [1, 3].

In the last decades with the purpose of mitigating the climate, ensuring the thermal comfort in open spaces and increasing the energy efficiency of operated buildings, more attention is being paid to the study of the influence of building parameters, planting of greenery and improvement elements on the temperature-humidity and aeration regimes [4-16].

Urban morphology information is an important indicator in urban planning, information management, and urban climatic applications. Some most widely used urban morphological parameters
- building coverage ratio, building height, building volume density and roughness length are employed to generate an Urban Climatic Maps of several cities. The urban microclimate is also influenced by the parameters of planting of greenery, the presence of water objects and sun protection facilities. Thus, for regions with a hot climate, shading of streets and provision of aeration mode is of primary importance, and for regions with continental and mesothermal types of climate, along with ensuring temperature comfort in the summer and winter months, a sufficient level of insolation [17].

The need to mitigate abnormal climatic regimes to ensure environmental safety of habitats in urban areas should become one of the priority tasks of prospective urban planning. However, at the present time, as a rule, from the entire list of climatic and sanitary-hygienic factors in Russian normative documents, priority is given to insolation and wind protection. Normative documents practically do not contain instructions on providing temperature comfort in open urban spaces. Nevertheless, the influence on the urban microclimate of building morphology is significant not only in regions with a hot climate, but also in conditions of a temperate climatic zone [18, 19].

To assess the effect on the combination of climatic parameters of human heat, it is proposed to use universal thermal indexes adapted for the conditions of open urban spaces.

One of the most representative thermal indexes used to assess temperature comfort in open urban spaces is the physiologically effective temperature (PET) [20, 21]. This index is based on the Munich model of the energy balance of the human body, which takes into account the temperature of internal organs, the intensity of sweating, and the moisture of the skin. The thermal index PET was chosen to quantify the human-thermal biometeorological conditions. PET is calculated by RayMan [22, 23] on the basis of the human energy balance and takes the integral thermo-physiological effect of the meteorological parameters air temperature, air humidity, wind velocity and radiation fluxes into account.

The range of comfort PET values can be determined using the Predicted Mean Vote PMV and for the countries of Western and Central Europe it is 18...23°C [23], Taiwan - 26...30°C, Beijing - 22..28°C [12], for conditions of hot dry climate (Negev, Israel) - 21..33°C [24]. In the central (European) part of Russia, on the basis of the results of the bioclimatic assessment of the territory [25], climatic parameters are proposed to be considered comfortable at PET = 19.0..36.1°C [26], which corresponds to the levels "warm", "slightly warm" and "comfortable" in the scale of human perception in Western and Central Europe [13].

The indicator of the openness of the sky - Sky View Factor (SVF) is one of the important factors affecting the thermal sensation of a person who is in open spaces. SVF is a dimensionless parameterization of the quantity of visible sky at a certain location. In open terrain, the SVF value will be close to 1, while in densely built-up or near-tree conditions, SVF will proportionally decrease [27].

2. Methods of research

To assess the urban microclimate from the standpoint of the influence on it of the parameters of building and improvement, the actual values of temperature, air humidity and wind speed in different points of the city were measured. Based on the experimental data obtained, the indicators of the temperature comfort of pedestrians were determined. Studies were carried out in the city of Orel, one of the major cities of the European part of Russia.

The objectives of this study were as:
- experimental determination of urban microclimate parameters (actual air temperature, air humidity and wind speed at various points) in the spring and summer;
- determination of physiologically equivalent temperature at the points of measurement;
- analysis of research results.

Measurements of temperature, humidity and air velocity were carried out using an anemometer-hygrometer Testo 410 with a range of measurements of 0.4-20 m/s, -10 - 50 ° C, 0-100% RH. Measurement mode - Hold Avg - calculation of time-averaged values (average time of measurement - 2 minutes). The height of the device above the earth's surface is 1 m (it is chosen to take into account
the influence of various factors on climatic parameters: albedo of surfaces, heat losses through building envelopes, presence of exhaust gases of motor vehicles, etc.).

3. Case of studies
Orel - a city in Russia, the administrative center of the Oryol region, with a population of about 320 thousand people. It is located 368 km southwest of Moscow, on the Central Russian Upland in the European part of Russia, along both banks of the Oka River and its tributary Orlik (figure 1).

![Figure 1. Geographical location of the city of Orel.](image)

3.1. Climate of Orel
The climate of Orel is characterized as moderately continental. The yearly mean temperature is 6.2°C and the yearly average amount of precipitation is 601 mm. The winter is mild, the summer with alternating periods of intense heat and cooler weather (figure 2).

![Figure 2. Air temperature during the summer 2015 at 15:00 (data from Meteorological Station, airport).](image)

To study the parameters of the urban microclimate in the spring (08/04/2015) and summer (03/07/2015) period was chosen route from the 1-st Posadskaya Street to the MOPR's Street in the city of Orel. The measurements were carried out on two parallel streets: Str. Komsomolskaya and Str.
Karachevskaya, at five points on each street (figure 3). At each point, three measurements were taken at a distance of 2 m from the buildings facades.

![Site maps and existing conditions in some points.](image)

Figure 3. Site maps and existing conditions in some points.

The SVF values are different at the selected waypoints (Figure 4).

![Sky View Factor.](image)

Figure 4. Sky View Factor.

4. Discussion
The averaged measurement results are given in the form of diagrams (figure 5). In this diagram, you can see significant differences between the values of the air temperature measured at a meteorological station located outside the city and measured in the city. This confirms the presence of Urban Heat Island near the measuring points (with a difference of up to 5°C).

The calculation of the physiologically equivalent temperature based on the measurement results was made using the program RayMan [21, 22] for the average pedestrian (a healthy man aged 35 years,
weight 75 kg, height 175 cm). The values of the calculated PET index are given for each route point (figure 6).

![Air temperature at measuring points.](image)

**Figure 5.** Air temperature at measuring points.

![The values of Air Temperature and PET along the Komsomolskaya Street and Karachevskaya Street, corresponding to the route of measurements in the spring and summer periods.](image)

**Figure 6.** The values of Air Temperature and PET along the Komsomolskaya Street and Karachevskaya Street, corresponding to the route of measurements in the spring and summer periods.

### 5. Results

The greatest differences between the temperature in the city and at the meteorological station for the spring period are observed for points 6 and 9. This is due to the location of point 6 near the busy intersection, and points 9 - in close proximity to the dilapidated house and significant heat loss through the facade.

In summer, the greatest excess of the actual temperature values over the values obtained at the weather station is primarily due to the location of the measurement points near the intersections with busy traffic.

According to the results of PET calculations, at points 1, 5, 6, 10 the pedestrian will experience thermal discomfort with a strong level of physical stress [23, 26].

It should also be noted the difference in the nature of the distribution of PET for the Komsomolskaya Street and Karachevskaya Street. It is of interest to compare PET values between neighboring measurement points (table 1).
Figure 7. Thermal facade pictures of dilapidated wooden house (near the point 9) (a) and – for comparison - the facade of the new brick building (b).

Table 1. PET difference between adjacent measurement points.

| Point spacing | Difference of values PET, °C |
|---------------|-----------------------------|
|               | Spring (08/04/2015) | Summer (07/03/2015) |
| 1-2           | 0.7                       | 13.0                  |
| 2-3           | 2.9                       | 6.4                   |
| 3-4           | 4.2                       | 6.2                   |
| 4-5           | 3.0                       | 10.2                  |
| 10-9          | 2.8                       | 5.5                   |
| 9-8           | 2.0                       | 0.6                   |
| 8-7           | 3.1                       | 1.0                   |
| 7-6           | 1.5                       | 1.6                   |

The most influential factors in PET are air temperature and humidity, as well as wind speed (figure 8, b-d). There was no clear dependence of PET on SVF (figure 8, a).

6. Conclusions
Experimentally determined indicators values of pedestrians’ thermal comfort show significant differences in microclimate parameters along one street. Increase PET in the points of selected streets contribute to the surrounding surface with a high albedo, the presence of a lively car traffic. The low number of stories along these streets and the considerable width between them reduce the impact on the PET of the build-up morphology.

At the same time, the presence of dilapidated buildings, large asphalt areas, busy highways contribute to increasing the temperature difference in the center and on the outskirts of the city.

The observed climate change at the scale of a single city, the formation of a thermal island and a particular urban microclimate is one of the problems that must be addressed at the stage of urban planning. At the same time, the creation of a safe and comfortable climate regime will not only promote the preservation of human health, but also strengthen the ability of the anthropogenic and natural environment to self-sustaining development.
Figure 8. Comparison of PET and SVF (a), Air Temperature (b), Wind Velocity (c), Humidity (d).

References
[1] Ilyichev V, Kolchunov V, Emelyanov S and Skobeleva E 2013 Algorithm for the development of programs for integrated safety and vitality of urban areas Biosphere compatibility: people, region, technology 1 pp. 44-52
[2] Kuzmin A 2011 Quality of life and quality of the spatial environment - social standards and standards in urban planning, architecture, construction, Urban Development 4 pp. 16-19
[3] Ilyichev V, Emelyanov S, Kolchunov V, Bakaeva N 2014 Innovative practices in cities and the doctrine of town planning, Biosphere compatibility: people, region, technology 3 pp. 3-18
[4] Abreu-Harbich L V, Labaki L C and Matzarakis A 2014 Thermal bioclimate in idealized urban street canyons in Campinas, Brazil. Theoretical and Applied Climatology 115 pp.333–340, DOI 10.1007/s00704-013-0886-0
[5] Sidorova V, Zhivitsa V and Mosyakin D 2019 The substantiation of architectural-planning transformations of urban public spaces with the account of the principles of biopositivity Journal of Applied Engineering Science 17 2
[6] Erell E, Perlmutter D, Boneh D and Kutiel P B 2013 Effect of high-albedo materials on pedestrian heat stress in urban street canyons. Urban climate 10 pp. 367-386
[7] Gómez F et. al. 2008 Vegetation influences on the human thermal comfort in outdoor spaces: criteria for urban planning, The Sustainable City V pp. 151-163
[8] Pilipenko O, Skobeleva E and Bulgakov A 2018 Methodology for assessing the comfort of an urban environment in terms of availability analyzing, Proceedings of the Creative Construction Conference, 30 June - 3 July 2018, Ljubljana, Slovenia, pp. 914-921. ISBN 978-615-5270-45-1 DOI: 10.3311/CCC2018-119
[9] Isaa N A, Wan Mohda W M N and Salleha S A 2017 The effects of built-up and green areas on the land surface temperature of the Kuala Lumpur city. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLII-4/W5, October 2017, Kuala Lumpur, Malaysia, pp. 107-112

[10] Konarska J, Holmer B, Lindberg F and Thorsson S 2015 Influence of vegetation and building geometry on the spatial variations of air temperature and cooling rates in a high-latitude city, International Journal of Climatology DOI: 10.1002/joc.4502

[11] Zvyagintseva M, Skripkina J and Fedorchenko N 2019 Principles and examples of design of rehabilitation centers in Russia and abroad, Journal of Applied Engineering Science 17 4, 646, 567 - 570 doi:10.5937/jaes17-23722

[12] Lin T P and Matzarakis A 2008 Tourism climate and thermal comfort in Sun Moon Lake, Taiwan Int. J. Biometeorology 52 pp. 281–290

[13] Martins T, Adolphe L and Krause C 2012 Microclimate Effects of Urban Geometry on Outdoor Thermal Comfort in the Brazilian Tropical Semi-arid Climate, PLEA2012 - 28th Conference, Opportunities, Limits & Needs Towards an environmentally responsible architecture Lima, Perú 7-9 November

[14] Moser A, Uhl E, Rötzer T, Biber P, Dahlhausen J, Lefer B and Pretzsch H 2017 Effects of Climate and the Urban Heat Island Effect on Urban Tree Growth, Houston Open Journal of Forestry 7, pp. 428-445

[15] Shashua-Bar L, Pearlmutter D and Erell E 2011 The influence of trees and grass on outdoor thermal comfort in a hot-arid environment, International Journal of Climatology 31, pp. 1498–1506

[16] Yang C, He X, Lingxue Y, Yang J, Yan F, Bu K, Chang L and Zhang S 2017 The Cooling Effect of Urban Parks and Its Monthly Variations in a Snow Climate City, Remote Sens. 9, pp. 1066

[17] Skobeleva E 2015 Analysis of proposals for assessing the microclimate environmentally safe and comfortable urban environment, Construction and reconstruction, 4, pp. 123-132

[18] Ketterer C and Matzarakis A 2014 Comparison of different methods for the assessment of the urban heat island in Stuttgart, Germany, Int. J. Biometeorology, 59, pp. 1299-1309.

[19] Höppe P 1999 The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment Int. J. Biometeorology 43 pp. 71-75

[20] Matzarakis A and Mayer H 1996 Another kind of environmental stress: thermal stress, WHO Collaborating Centre for Air Quality Management and Air Pollution Control, 18, pp. 7-10

[21] Matzarakis A, Rutz F and Mayer H 2010 Modelling radiation fluxes in simple and complex environments: basics of the RayMan model, International Journal of Biometeorology, No. 54 (2), pp. 131–139

[22] Matzarakis A and Rutz F 2007 Rayman: a tool for tourism and applied climatology, Developments in Tourism Climatology, pp. 129-138

[23] Matzarakis A, Mayer H and Iziomon M G 1999 Heat stress in Greece. Applications of a universal thermal index: physiological equivalent temperature International Journal of Biometeorology, 43 pp. 76–84

[24] Pearlmutter D J and Garb Y 2014 The relationship between bioclimatic thermal stress and subjective thermal sensation in pedestrian spaces International Journal of Biometeorology, No. 8 10, pp. 2111-27

[25] Danilova N 1980 Climate and rest in our country, Moscow, 155 p

[26] Pilipenko O and Skobeleva E 2016 Determination of Thermal Comfort Criteria Person as Indicators of Environmental Safety of Open Urban Space. Biosphere Compatibility: Human, Region Technologies 1, pp.12-21

[27] Svenson M 2004 Sky view factor analysis - implications for urban air temperature differences, Meteorological Applications 11, pp. 201-211