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MICROCLIMATIC ZONING AS A BASIS FOR BIOCLIMATIC DESIGN OF LOW-RISE URBAN HOUSING IN SOUTH-EASTERN KAZAKHSTAN

Abstract. ***Purpose.*** The study develops a microclimatic zoning approach for low-rise urban housing in South-Eastern Kazakhstan that links regional climatic assessment with early-stage architectural decisions. ***Methods***. The research combines comparative climatic analysis of Almaty, Konaev and Taldykorgan with graphic-analytical interpretation of urban morphology, ventilation potential, solar exposure, green-blue infrastructure and topography. Climatic background data and spatial layers were synthesized through common criteria to identify dominant microclimatic conditions. Results. The analysis shows that a broadly comparable sharply continental climate produces different local patterns because each city has a distinct combination of terrain, development intensity, openness, vegetation, water influence and airflow. Five recurrent analytical conditions were identified: wind-exposed, moderately protected, stagnant-air/heat-accumulation, green-cooling and terrain-dominated areas. Their value lies not in prescribing fixed architectural forms but in diagnosing the environmental priorities of a site. The proposed sequence translates climatic and spatial information into microclimatic zoning and then into early-stage design priorities concerning protection, permeability, solar control, landscape integration and terrain response. The comparative application to three cities demonstrates that the method preserves local climatic specificity while maintaining a common analytical sequence for cross-case interpretation. ***Conclusions***. Microclimatic zoning can function as an intermediate architectural-climatic layer between generalized regional climate data and detailed building-level simulation. The method is context-sensitive and transferable as an analytical sequence, while the spatial zoning itself remains city-specific and requires subsequent validation through field measurements and numerical modelling.

Key words: microclimatic zoning, bioclimatic design, low-rise housing, urban morphology, South-Eastern Kazakhstan, climate-responsive architecture.

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МІКРОКЛІМАТИЧНЕ ЗОНУВАННЯ ЯК ОСНОВА БІОКЛІМАТИЧНОГО ПРОЄКТУВАННЯ МАЛОПОВЕРХОВОГО МІСЬКОГО ЖИТЛА ПІВДЕННО-СХІДНОГО КАЗАХСТАНУ

Анотація. ***Мета дослідження*** – розробити підхід до мікрокліматичного зонування малоповерхового міського житла Південно-Східного Казахстану, який поєднує регіональну кліматичну оцінку з рішеннями ранньої стадії архітектурного проєктування. ***Методи***. Дослідження поєднує порівняльний кліматичний аналіз Алмати, Конаєва і Талдикоргана з графоаналітичною інтерпретацією міської морфології, потенціалу вентиляції, сонячної експозиції, зелено-блакитної інфраструктури та рельєфу. Просторові шари інтерпретовано за єдиною системою критеріїв для виявлення домінантних мікрокліматичних умов. ***Результати***. Встановлено, що подібний різко континентальний клімат формує різні локальні просторові прояви через відмінності рельєфу, щільності й відкритості забудови, рослинності, впливу водних об'єктів та повітрообміну. Визначено п'ять повторюваних аналітичних станів: вітровідкриті, помірно захищені, застійні/теплоакумулюючі, зони зеленого охолодження та території з домінуючим впливом рельєфу. Їхнє призначення полягає не у встановленні фіксованої архітектурної форми, а в діагностиці пріоритетних екологічних умов ділянки. Запропонована послідовність дає змогу переводити кліматичні й просторові характеристики у ранні проєктні пріоритети щодо захисту від вітру, проникності забудови, сонцезахисту, інтеграції озеленення та врахування рельєфу. ***Висновки***. Мікрокліматичне зонування може бути проміжним архітектурно-кліматичним рівнем між узагальненими регіональними даними та детальним моделюванням будівлі. Методологічна послідовність може бути адаптована до інших міст, однак конкретна просторова структура зон залишається контекстною та потребує подальшої верифікації натурними вимірюваннями й чисельним моделюванням.

Ключові слова: мікрокліматичне зонування, біокліматичне проєктування, малоповерхове житло, міська морфологія, Південно-Східний Казахстан, кліматично адаптивна архітектура.

Statement of the Problem and Its Relation to Important Scientific and Practical Tasks. Bioclimatic design requires climatic information to be translated into decisions made at the scale of a particular site. Regional data describe temperature, solar exposure, humidity and prevailing winds, but the built environment modifies these conditions through density, building height, street orientation, surface cover, vegetation, relief and open-space structure [1, p. 4185; 2, p. 5605]. Urban climatic mapping and Local Climate Zone research therefore demonstrate the need to represent intra-urban climatic differentiation spatially rather than treat a city as a homogeneous climatic unit [3, pp. 2213–2214; 4, p. 1879].

This problem is particularly relevant to Almaty, Konaev and Taldykorgan. The cities share a sharply continental regional setting but differ in topography, urban morphology, vegetation, water influence and exposure to airflow. For low-rise housing, these differences directly affect courtyards, pedestrian spaces, ground surfaces and the relationship between buildings and landscape. The same planning strategy may therefore have opposite effects: openness can improve ventilation where air exchange is restricted but increase wind discomfort in exposed areas, while compactness can provide protection yet intensify stagnation.

The scientific and practical gap lies between generalized regional climatic assessment and the spatial

scale at which early architectural decisions are made. This study addresses that gap by treating microclimatic zoning as an additional architectural-climatic layer that does not replace regulatory zoning or detailed simulation, but organizes climatic and spatial information before the architectural concept is fixed.

Analysis of Recent Research and Publications. Urban-climate research has progressively moved from description toward spatial classification and planning application. Urban Climatic Maps integrate thermal load, ventilation, topography, land use, vegetation and morphology and translate them into planning information [3, pp. 2213–2214]. Earlier work demonstrated that climatic assessment can be spatially classified for urban and regional planning objectives [1, p. 4185; 2, p. 5605], while applications in high-density cities confirmed the value of climatic mapping as a bridge between environmental analysis and planning decisions [5, p. 1].

Subsequent studies expanded LCZ mapping through GIS, remote sensing and machine learning [6, p. 3835; 7, p. 1]. LCZ is relevant here as evidence that urban climatic conditions can be differentiated spatially, but it is not equivalent to the present method: standardized LCZ classes support comparative climate research, whereas architectural design requires interpretation of the environmental priorities of a particular site.

A parallel body of research shows that density, massing, orientation, street geometry and open-space configuration modify temperature, radiation and airflow [8, p. 1; 9, p. 1]. Ventilation studies further demonstrate that roughness, building arrangement and continuity of open spaces influence ventilation paths [10, p. 198]. Contemporary research increasingly uses field measurements, CFD, remote sensing and data-driven methods for detailed evaluation [11, p. 1]. These tools provide quantitative resolution but generally require inputs that may not exist when fundamental decisions on orientation, openness, massing and landscape structure are first made.

The reviewed literature therefore reveals an intermediate methodological need. Urban climatic maps operate primarily at planning scale, LCZ provides standardized morphological-climatic classification, and numerical simulation evaluates specific processes at high resolution. The present study focuses on the scale between them: a context-specific zoning procedure that identifies dominant microclimatic priorities before detailed architectural geometry is established. This scale remains insufficiently developed for low-rise housing in South-Eastern Kazakhstan.

Purpose of the Article. The purpose of the article is to develop and demonstrate a microclimatic zoning approach for low-rise urban housing in South-Eastern Kazakhstan by integrating regional climatic conditions with local morphological and environmental modifiers. Using Almaty, Konaev and Taldykorgan as case studies, the study: (1) systematizes climatic, morphological and environmental factors contributing to local differentiation; (2) establishes criteria for translating these factors into microclimatic zones; and (3) determines how zoning information can support early-stage bioclimatic design. The method is positioned as an intermediate analytical layer rather than a substitute for standardized classification, field measurement or numerical simulation.

Presentation of the Main Research Material. ***Climatic and Spatial Context of the Study Area.*** The underlying research compared temperature patterns, solar radiation, wind conditions and humidity in Almaty, Konaev and Taldykorgan and interpreted these data together with urban morphology, relief, vegetation, water bodies and open-space structure. The Olgyay chart and Mahoney tables supported climatic interpretation, while graphic-analytical mapping was used to relate the regional background to local spatial modifiers. The analysis showed that regional similarity does not produce local uniformity: Almaty is strongly affected by foothill relief, heterogeneous density and ventilation structure; Konaev by openness, wind exposure and the Kapchagay Reservoir; and Taldykorgan by comparatively open morphology, vegetation, terrain and local airflow.

Criteria and Sequence of Microclimatic Zoning. The zoning procedure moves from climatic background to spatial diagnosis. First, regional climatic conditions are established. Second, morphology is assessed through development intensity, street structure and openness. Third, environmental modifiers – relief, vegetation, water and surface structure – are interpreted together with ventilation and solar exposure. Fourth, these layers are synthesized graphically to identify dominant combinations of exposure, protection, stagnation, thermal moderation and terrain influence. Finally, common criteria are applied to classify territories into analytical microclimatic zones.

Five recurrent conditions were identified: wind-exposed areas, moderately protected areas, stagnant-air/heat-accumulation areas, green-cooling areas and terrain-dominated areas. They are analytical categories rather than regulatory boundaries; their value lies in translating a complex spatial condition into a legible climatic diagnosis. The integrated classification logic is summarized in the proposed framework (Fig. 1).

Table 1

Climatic and Spatial Characteristics Relevant to Microclimatic Differentiation

Dimension	Almaty	Konaev	Taldykorgan	Zoning relevance
Topography	Foothill/terrain influence	Open terrain; reservoir interface	Valley/foothill influence	Modifies exposure and airflow
Urban morphology	Dense and heterogeneous	More open, mainly low-rise	Comparatively open	Modifies shading, heat storage and ventilation
Wind conditions	Terrain-related circulation	High relevance of exposure	Local airflow shaped by openness/terrain	Differentiates protection and aeration
Green-blue structure	Uneven but substantial	Reservoir and open landscape	Significant green structure	Supports thermal moderation
Dominant implication	Urban intensity + terrain + ventilation	Openness + wind + water	Open morphology + green structure + terrain	Requires city-specific interpretation

Source: authors' material.

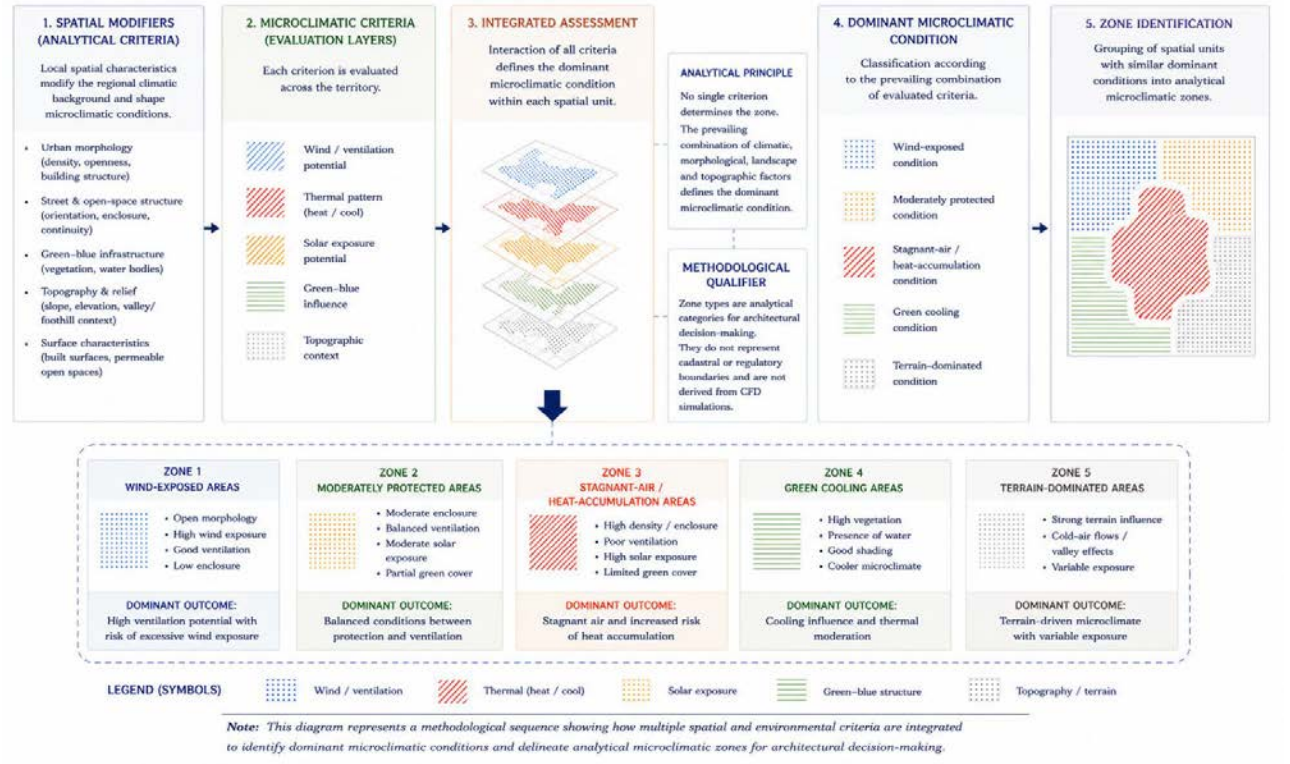


Fig. 1. Multi-Criteria Logic of Microclimatic Zone Identification. [Authors' material]

Comparative Results for the Three Cities. Application of the same criteria produced different dominant combinations of microclimatic modifiers. In Almaty, intensive urbanization interacts most strongly with terrain and ventilation structure; in Konaev, openness, wind exposure and reservoir influence are more pronounced; in Taldykorgan, open morphology, green structure and terrain form the dominant combination. The result is not a universal spatial template but a consistent analytical procedure whose outcome remains city-specific. This finding is central to the method: comparability is provided by common criteria, while climatic specificity is preserved through local interpretation.

From Zoning Information to Bioclimatic Design Priorities. Microclimatic zoning is intended to diagnose design priorities before a fixed building form is selected. Wind-exposed territories require consideration of protection and orientation; restricted-aeration areas require permeability and ventilation; high solar exposure requires seasonal control of gains and shading; green structures should be treated as climatic resources; and terrain-related conditions require siting to respond to relief. Thus, zoning does not prescribe a single architectural solution but identifies the environmental question that the concept must address. Its position within the early-stage design process is summarized schematically (Fig. 2).

Table 2

Analytical Criteria for Microclimatic Zone Identification

Criterion	What is evaluated	Microclimatic implication
Urban morphology	Density, openness, enclosure	Heat accumulation, shading, permeability
Ventilation potential	Exposure and continuity of airflow	Ventilation, excessive exposure or stagnation
Solar exposure	Exposure related to spatial structure	Passive gains or overheating risk
Green-blue infrastructure	Vegetation and water-related landscape	Shading, moderation, airflow modification
Topographic context	Slope, valley/foothill condition	Air movement, exposure, solar differentiation

Source: authors' material.

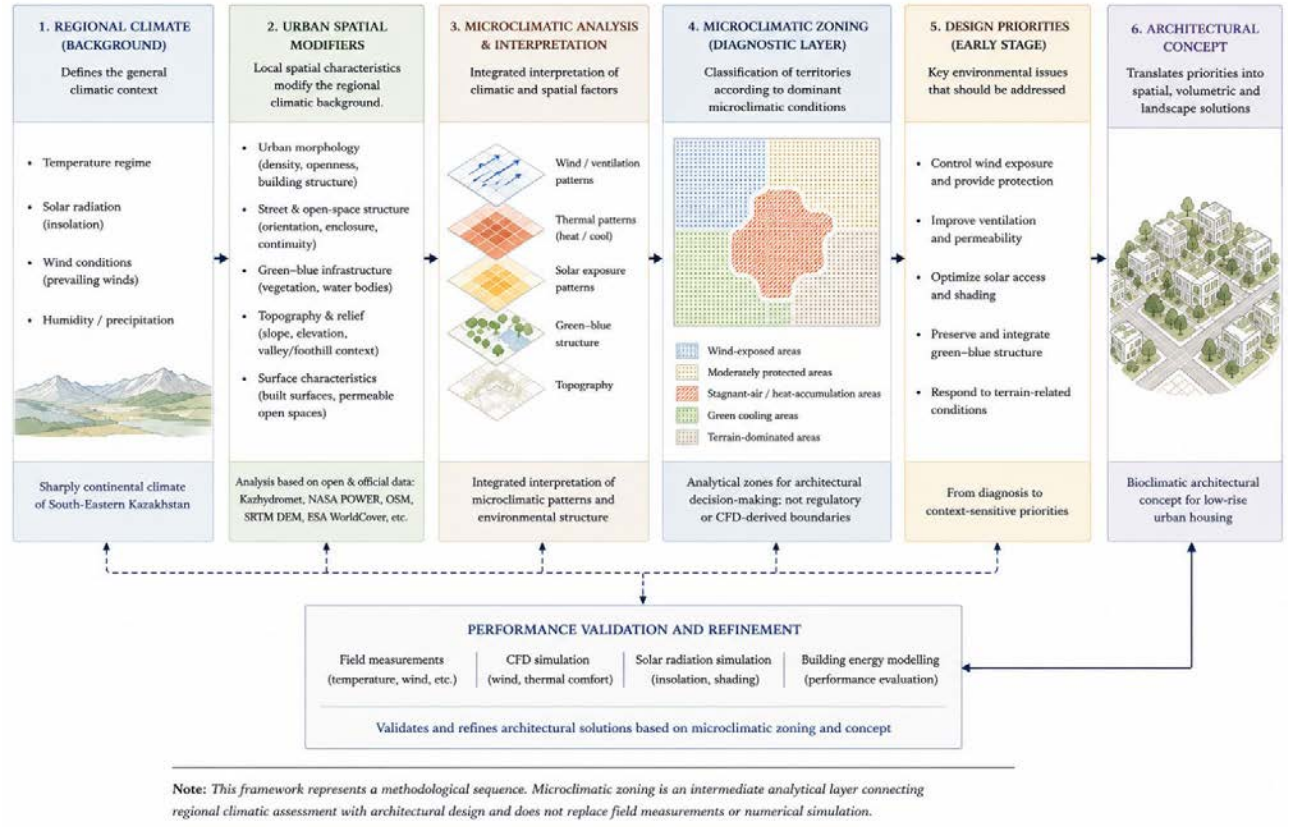


Fig. 2. Microclimatic Zoning as an Intermediate Design-Support Layer. [Authors' material]

Table 3

Translation of Microclimatic Diagnosis into Early-Stage Design Priorities

Diagnosed condition	Primary issue	Early-stage priority
Wind exposure	Excessive air movement	Protection, enclosure and orientation
Restricted ventilation / heat accumulation	Stagnation and thermal stress	Permeability and airflow
High solar exposure	Useful gains / summer overheating	Seasonal solar control and shading
Green-cooling influence	Existing thermal moderation	Preserve and integrate vegetation
Terrain influence	Relief-dependent airflow/exposure	Coordinate siting with terrain

Source: authors' material.

Methodological Scope and Synthesis. The proposed maps and zones are based on graphic-analytical integration of climatic, morphological, landscape and topographic information. They identify dominant spatial relationships for design interpretation and are not quantitative predictions of temperature, wind velocity or thermal comfort at individual points. Field measurements and CFD remain necessary for detailed verification [11, p. 1; 12, p. 1; 13, p. 1]. The proposed method addresses an earlier stage, when detailed geometry may not yet exist. Its sequence can be summarized as: regional climate → spatial

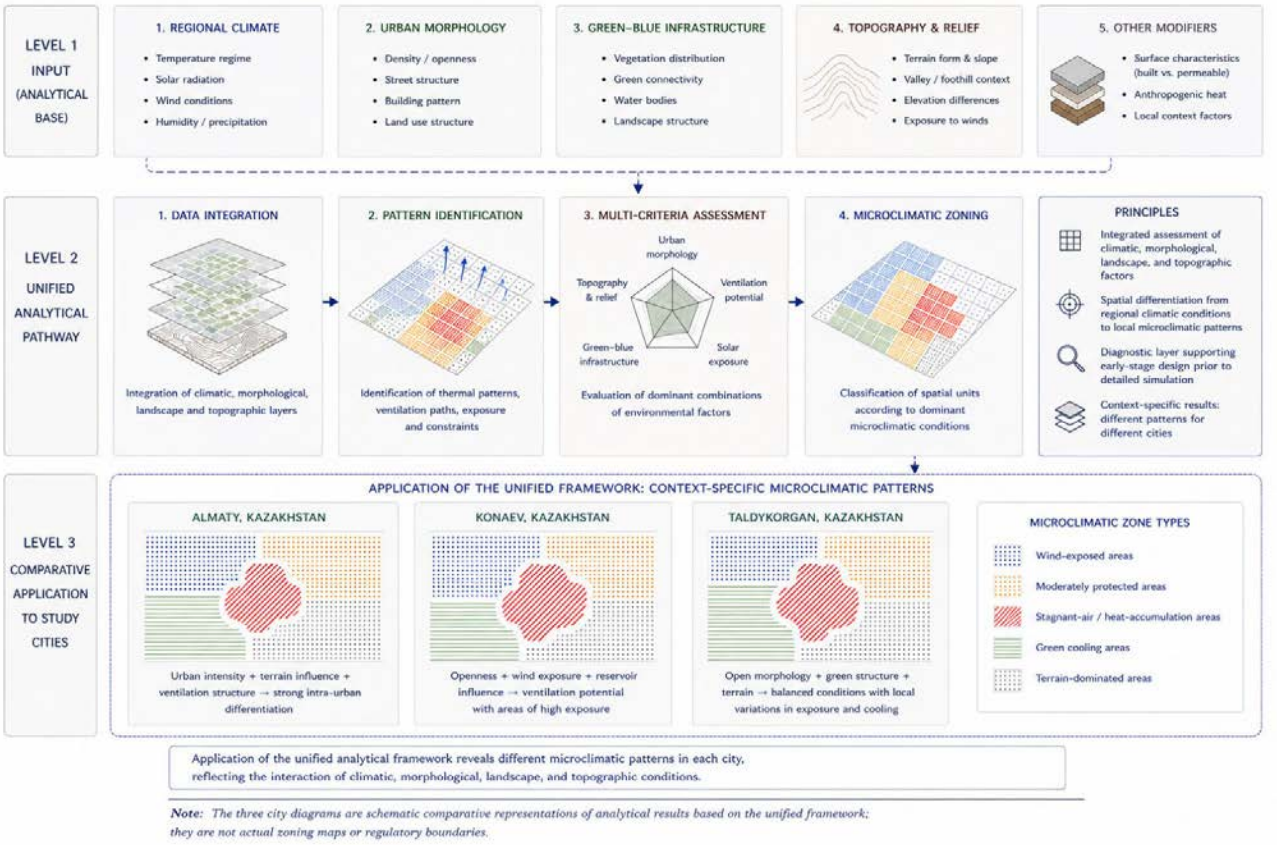


Fig. 3. Integrated Microclimatic Zoning Framework. [Authors' material]

modifiers → microclimatic diagnosis → zoning → design priorities → architectural concept → detailed performance testing. The complete methodological sequence is summarized schematically (Fig. 3).

Main Conclusions and Prospects for the Use of the Research Results. The study confirms that generalized regional climatic characteristics are necessary but insufficient for site-specific bioclimatic design. In Almaty, Konaev and Taldykorgan, a broadly comparable continental climate is locally modified by different combinations of morphology, ventilation, topography, vegetation, water and spatial exposure. Common analytical criteria therefore produce different city-specific outcomes.

Microclimatic zoning is proposed as an intermediate architectural-climatic layer between regional assessment and site-specific design. Its contribution lies in a repeatable sequence that integrates climatic background, local spatial modifiers and multi-criteria interpretation into a diagnostic zoning structure. The five recurrent conditions are not regulatory classes and do not prescribe fixed building forms; they identify environmental priorities that should be addressed during orientation, massing, openness, landscape and outdoor-space decisions.

The methodological sequence may be adapted to other continental-climate cities, but the resulting zoning cannot be transferred directly because it depends on local morphology and environmental structure. Further research should validate zone characteristics and boundaries through seasonal field measurements, GIS and remote-sensing analysis and numerical microclimate modelling. Validation against measured data is particularly important for reliable CFD-based assessment [12, p. 1; 13, p. 1]. The principal conclusion is that microclimatic zoning can bridge the gap between generalized climate information and early architectural decision-making while retaining detailed simulation as a subsequent verification stage.

Information on the use of artificial intelligence. *Artificial intelligence tools were used as auxiliary support during manuscript preparation, including language editing, text organization, and development of preliminary diagram layouts. All scientific content, source data, analytical interpretations, results, conclusions, and final materials were reviewed and verified by the authors.*

Bibliography

1. Scherer D., Fehrenbach U., Beha H.-D., Parlow E. Improved concepts and methods in analysis and evaluation of the urban climate for optimizing urban planning processes. *Atmospheric Environment*. 1999. Vol. 33. P. 4185–4193.
2. Fehrenbach U., Scherer D., Parlow E. Automated classification of planning objectives for the consideration of climate and air quality in urban and regional planning for the example of the region of Basel/Switzerland. *Atmospheric Environment*. 2001. Vol. 35. P. 5605–5615.
3. Ren C., Ng E. Y. Y., Katzschner L. Urban climatic map studies: a review. *International Journal of Climatology*. 2011. Vol. 31, No. 15. P. 2213–2233. DOI: 10.1002/joc.2237.
4. Stewart I. D., Oke T. R. Local Climate Zones for urban temperature studies. *Bulletin of the American Meteorological Society*. 2012. Vol. 93, No. 12. P. 1879–1900. DOI: 10.1175/BAMS-D-11-00019.1.
5. Ren C., Lau K. K.-L., Yiu K.-P., Ng E. The application of urban climatic mapping to the urban planning of high-density cities: The case of Kaohsiung, Taiwan. *Cities*. 2013. Vol. 31. P. 1–16. DOI: 10.1016/j.cities.2012.12.005.
6. Demuzere M. et al. A global map of Local Climate Zones to support earth system modelling and urban-scale environmental science. *Earth System Science Data.* 2022. Vol. 14. P. 3835–3873. DOI: 10.5194/essd-14-3835-2022.
7. Huang F. et al. Mapping Local Climate Zones for cities: A large review. *Remote Sensing of Environment*. 2023. Vol. 292. Art. 113573. DOI: 10.1016/j.rse.2023.113573.
8. Banerjee S. et al. Analysing impacts of urban morphological variables and density on outdoor microclimate for tropical cities: A review and a framework proposal for future research directions. *Building and Environment*. 2022. Vol. 225. Art. 109646. DOI: 10.1016/j.buildenv.2022.109646.
9. Abd Elraouf R., Elmokadem A., Megahed N. A., Abo Eleinen O., Eltarabily S. The impact of urban geometry on outdoor thermal comfort in a hot-humid climate. *Building and Environment.* 2022. Vol. 225. Art. 109632. DOI: 10.1016/j.buildenv.2022.109632.
10. Gál T., Unger J. Detection of ventilation paths using high-resolution roughness parameter mapping in a large urban area. *Building and Environment*. 2009. Vol. 44. P. 198–206. DOI: 10.1016/j.buildenv.2008.02.008.
11. Yang S., Wang L., Stathopoulos T., Marey A. Urban microclimate and its impact on built environment – A review. *Building and Environment*. 2023. Vol. 238. Art. 110334. DOI: 10.1016/j.buildenv.2023.110334.
12. Antoniou N., Montazeri H., Neophytou M., Blocken B. CFD simulation of urban microclimate: Validation using high-resolution field measurements. *Science of the Total Environment.* 2019. Vol. 695. Art. 133743. DOI: 10.1016/j.scitotenv.2019.133743.
13. Kim G., Lee G. Validation of CFD models of urban microclimates under high temperature and humidity conditions during daytime heatwaves in dense low-rise areas. *Building and Environment.* 2024. Vol. 266. Art. 112087. DOI: 10.1016/j.buildenv.2024.112087.

References

1. Scherer, D., Fehrenbach, U., Beha, H.-D., & Parlow, E. (1999). Improved concepts and methods in analysis and evaluation of the urban climate for optimizing urban planning processes. *Atmospheric Environment*, 33, 4185–4193 [in English].
2. Fehrenbach, U., Scherer, D., & Parlow, E. (2001). Automated classification of planning objectives for the consideration of climate and air quality in urban and regional planning for the example of the region of Basel/Switzerland. *Atmospheric Environment*, 35, 5605–5615 [in English].
3. Ren, C., Ng, E. Y. Y., & Katzschner, L. (2011). Urban climatic map studies: A review. *International Journal of Climatology*, 31(15), 2213–2233. https://doi.org/10.1002/joc.2237 [in English].
4. Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for urban temperature studies. *Bulletin of the American Meteorological Society*, 93(12), 1879–1900. https://doi.org/10.1175/BAMS-D-11-00019.1 [in English].
5. Ren, C., Lau, K. K.-L., Yiu, K.-P., & Ng, E. (2013). The application of urban climatic mapping to the urban planning of high-density cities: The case of Kaohsiung, Taiwan. *Cities*, 31, 1–16. https://doi.org/10.1016/j.cities.2012.12.005 [in English].
6. Demuzere, M., et al. (2022). A global map of Local Climate Zones to support earth system modelling and urban-scale environmental science. *Earth System Science Data*, 14, 3835–3873. https://doi.org/10.5194/essd-14-3835-2022 [in English].
7. Huang, F., Jiang, S., Zhan, W., Bechtel, B., Liu, Z., Demuzere, M., et al. (2023). Mapping Local Climate Zones for cities: A large review. *Remote Sensing of Environment*, 292, 113573. https://doi.org/10.1016/j.rse.2023.113573 [in English].
8. Banerjee, S., Ching, N. Y., Yik, S. K., Dzyuban, Y., Crank, P. J., Pek, X. Y., & Chow, W. T. L. (2022). Analysing impacts of urban morphological variables and density on outdoor microclimate for tropical cities: A review and a framework proposal for future research directions. *Building and Environment*, 225, 109646. https://doi.org/10.1016/j.buildenv.2022.109646 [in English].
9. Abd Elraouf, R., Elmokadem, A., Megahed, N. A., Abo Eleinen, O., & Eltarabily, S. (2022). The impact of urban geometry on outdoor thermal comfort in a hot-humid climate. *Building and Environment*, 225, 109632. https://doi.org/10.1016/j.buildenv.2022.109632 [in English].
10. Gál, T., & Unger, J. (2009). Detection of ventilation paths using high-resolution roughness parameter mapping in a large urban area. *Building and Environment*, 44, 198–206. https://doi.org/10.1016/j.buildenv.2008.02.008 [in English].
11. Yang, S., Wang, L., Stathopoulos, T., & Marey, A. (2023). Urban microclimate and its impact on built environment – A review. *Building and Environment*, 238, 110334. https://doi.org/10.1016/j.buildenv.2023.110334 [in English].
12. Antoniou, N., Montazeri, H., Neophytou, M., & Blocken, B. (2019). CFD simulation of urban microclimate: Validation using high-resolution field measurements. *Science of the Total Environment*, 695, 133743. https://doi.org/10.1016/j.scitotenv.2019.133743 [in English].
13. Kim, G., & Lee, G. (2024). Validation of CFD models of urban microclimates under high temperature and humidity conditions during daytime heatwaves in dense low-rise areas. *Building and Environment*, 266, 112087. https://doi.org/10.1016/j.buildenv.2024.112087 [in English].

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