

Research on the Evaluation Methods of Microclimatic Impacts of Traditional Residential Architectural Layouts in Shenyang

Jiahao Liu^{1,*}, Tomoyuki Tanaka², Lei Tan¹

¹Graduate School of Science and Technology, Kumamoto University, Kumamoto, Japan

²Faculty of Advanced Science and Technology, Kumamoto University, Kumamoto, Japan

*Corresponding Author: Jiahao Liu

ABSTRACT

Urban environments are complex ecosystems where buildings, spaces, and human activities intertwine to influence the local climate, giving rise to what is known as the urban microclimate. This microclimate encompasses variations in temperature, humidity, wind patterns, and precipitation that occur in urban areas compared to their rural counterparts. These variations are not trivial; they significantly affect energy consumption, human comfort, and health, making the study of urban microclimates an essential aspect of sustainable urban planning [81]. The interplay between residential architecture and microclimatic conditions is a critical facet of urban environmental research. As cities grow, the configuration of built environments can significantly affect thermal comfort, air quality, and energy consumption, thereby dictating the liveability and sustainability of urban spaces. This study explores how specific residential layouts—row, diagonal, staggered gable, and enclosed—each manipulate air flow, sunlight exposure, and heat retention differently, contributing to varied microclimatic outcomes within urban neighborhoods.

KEYWORDS

Microclimate; Urban Planning; Architecture Design; Architecture Layout

1. INTRODUCTION

Shenyang, a major city in Northeast China (Figure 1), presents a unique case for such a study. Known for its cold winters and hot, humid summers, the city's climate demands innovative approaches to urban design and architecture that can mitigate extreme weather conditions, reduce energy consumption, and improve liveability. And, with its blend of historical architecture and modern urban sprawl, presents a unique setting for examining these effects. As the capital of Liaoning Province, it encompasses a wide range of residential designs that reflect both its rich cultural heritage and rapid modern development. This juxtaposition makes Shenyang an exemplary case study to observe how traditional and contemporary architectural elements interact with local climates, particularly in a region experiencing significant climatic variations and urban renewal pressures. Despite its importance, the influence of urban spatial design on microclimate variability in Shenyang has received limited attention in the scientific literature [1]. This gap highlights the need for detailed research that can inform urban planners, architects, and policymakers about the microclimatic implications of their decisions.

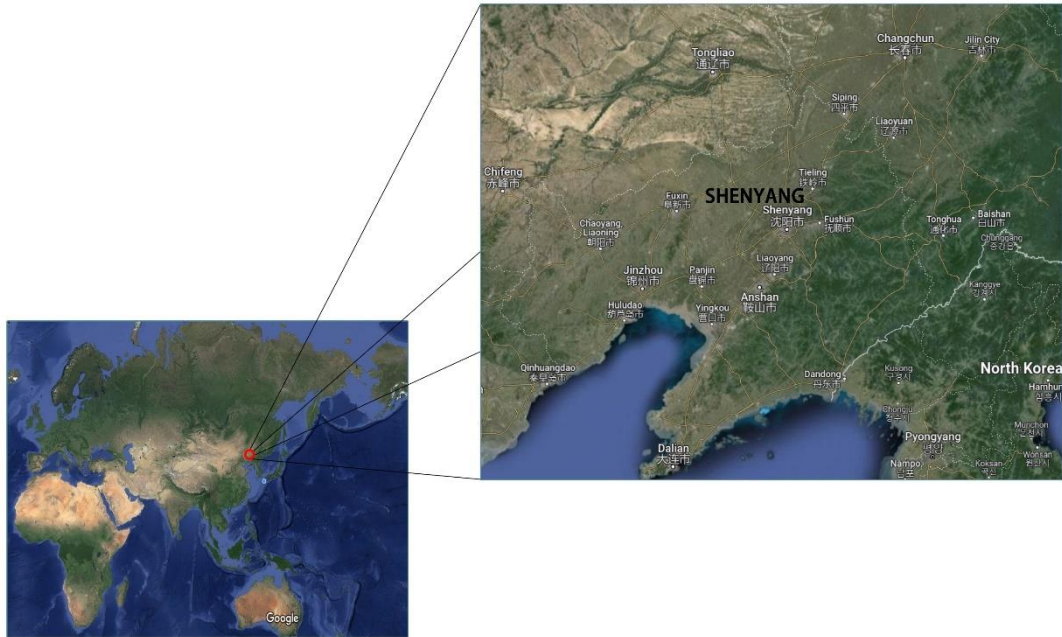


Figure 1 Geographic location map of Shenyang

The primary question this research seeks to answer is the feasibility of different evaluation methods in accurately predicting and analyzing the microclimatic effects caused by traditional Chinese residential layouts. By identifying the most effective assessment techniques, this study hopes to contribute to the development of guidelines that could influence future urban planning and residential design, ensuring they are both culturally respectful and environmentally sustainable. A key component of our methodology involves the use of ENVI-met, a sophisticated simulation software designed to model microclimates within complex urban areas. By integrating this tool, we aim to identify the most effective assessment techniques, contributing to the development of guidelines that could influence future urban planning and residential design, ensuring they are both culturally respectful and environmentally sustainable [2]. Through this analysis, the research contributes to the broader field of urban microclimates, offering practical insights and strategies for sustainable urban development in Shenyang and regions with similar climatic challenges.

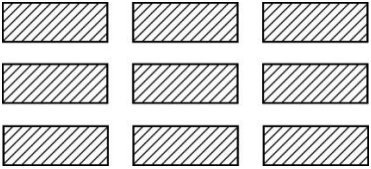

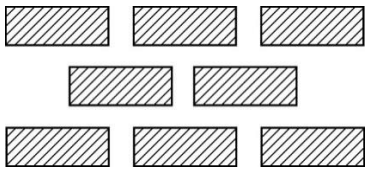

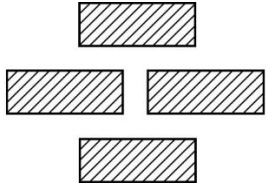

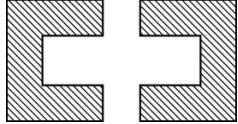

2. METHOD

This investigation delineates its focus to the exploration of open space layout modes within centralized high-rise residential districts in Shenyang. Specifically, the study is confined to examining enclaves consisting of no fewer than five high-rise buildings, predominantly characterized by such structures. This delineation arises from the consideration that aggregations of fewer than five high-rise buildings seldom constitute a comprehensive open space, thereby limiting the feasibility of their inclusion for a focused study on open space layouts. In addressing the diversity of layout modes present within these residential communities, this research prioritizes the predominant layout mode of the district as the focal point of analysis. Such an approach is necessitated by the practical challenges and complexities associated with multifarious layout configurations within a single residential area [3].

Utilizing Google Earth satellite imagery, an exhaustive survey of Shenyang's urban landscape was conducted. This meticulous examination facilitated the identification of 120 residential districts that align with the predefined criteria of this study (Table 1). Following the comprehensive survey, the open space layout modes identified within these high-rise residential districts were methodically

categorized into four principal types. These are delineated as follows: (1) Row Layout, characterized by linear arrangements of buildings; (2) Diagonal Layout, where buildings are positioned in diagonal lines, creating dynamic open spaces; (3) Staggered Gable Layout, featuring a non-linear configuration that allows for varied building orientations and open spaces; and (4) Enclosed Layout, which encompasses buildings arranged in a manner that encloses open spaces, thus creating distinct interior courtyards or communal areas.

Table 1 Residential Layout Types and Examples

Layout pattern	Illustration	Cases	Quantity	Proportion
Row Layout			27	22.5%
Diagonal Layout			45	37.5%
Staggered Gable Layout			30	25%
Enclosed Layout			18	15%

The wind in residential architectural layouts is variable and can affect the convective heat exchange between the human skin surface and the surrounding air, facilitating the expulsion of body moisture. After conducting field measurements, surveys, and extensive experiments, a relationship between human comfort and wind speed was established, as shown in Table 2

Table 2 Human comfort and wind speed

Wind Speed (V)	Perception
$V < 5 \text{ m/s}$	Comfort Gentle Breeze
$5 \text{ m/s} < V < 10 \text{ m/s}$	Uncomfortable, movement affected
$5 \text{ m/s} < V < 10 \text{ m/s}$	Very uncomfortable, severely affected by movement
$15 \text{ m/s} < V < 20 \text{ m/s}$	Unable to tolerate
$20 \text{ m/s} < V$	Danger

The quality of the climatic environment in residential areas can be determined by human comfort. Human comfort refers to the degree of a person's sensation of the air being cold or warm, divided into seven levels: sweltering, hot, warm, mild, cool, chilly, and cold.

In residential areas, temperature directly influences human comfort. The discomfort thresholds for temperature are above 32°C or below 11°C. When local body temperatures fall below -4°C to -5°C, and external temperatures drop to between -10°C and -20°C, frostbite can occur. At temperatures between 21°C and 24°C, individuals generally feel comfortable.

Shenyang, located in Northeast China, has relatively low humidity compared to other regions. During summer, high humidity disrupts the body's thermal balance, affecting evaporative cooling and causing a feeling of stuffiness. In winter, when the weather is damp and cold with high relative humidity, the moisture in the air absorbs the body's heat radiation, making people feel cold. People generally feel comfortable when the relative humidity is between 40% and 70%. The most comfortable relative humidity for humans is between 45% and 55%. When relative humidity exceeds 70%, sweat on the skin's surface does not evaporate normally, resulting in discomfort [4].

The analysis of layout patterns within high-rise residential districts in Shenyang reveals a relatively uniform distribution across various configurations, indicating an absence of predominant reliance on any single layout model. This pattern of diversity suggests that the development of high-rise residential areas has reached a mature stage, characterized by a responsive adaptation to social demands rather than a mere replication of existing models. Such a strategy appears to reflect a nuanced understanding of residential needs and preferences, steering away from uniform architectural approaches.

However, the observed overlap of layout models during redevelopment phases can be attributed to factors such as topographical constraints or efforts to enhance the aesthetic and functional attributes of living spaces, thereby increasing their market appeal. Notwithstanding these considerations, the primary motivation underlying these development strategies predominantly aligns with maximizing economic returns. Notably, the integration of microclimatic considerations into the planning and design of these residential areas remains limited, often restricted to ensuring minimal sunlight exposure for the main buildings. This oversight underscores a critical gap in current urban planning practices, where microclimatic factors are largely overlooked despite their significant impact on residential comfort and energy efficiency.

Given these observations, it becomes imperative to conduct a more detailed investigation into how different layout patterns affect the microclimate within residential areas. Such a study should begin by examining residents' perceptions of the external microclimate, followed by a scientific comparison of various layout configurations. This approach will not only deepen the understanding of microclimatic impacts but also provide essential technical references for the future development of high-rise residential projects, aiming to enhance both sustainability and livability. This classification serves as the foundation for a nuanced analysis of the spatial organization and its implications on microclimatic variations within these high-density residential environments. The identification and categorization of these layout modes are instrumental in delineating the spatial dynamics at play, enabling a focused investigation into the interplay between urban form and microclimate in Shenyang's residential districts [5].

3. RESULT

From the wind speed data chart, it is evident that the simulated wind speeds are generally lower than the measured values (Figure 2). The daily variation in simulated wind speeds is relatively smooth, while the variation in measured wind speeds shows sudden changes, related to the immediacy of wind speed measurement. During actual measurements, changes in wind direction are usually more

complex than those reported by weather stations, leading to discrepancies between measured and simulated values; Moreover, during actual measurements, limitations due to measuring equipment and the timing of incoming flows cause differences between measured wind speeds and actual conditions. Although there are some discrepancies between simulated and measured values, the trend of numerical changes across various measurement points is basically the same, with a relative error of about 7% between the simulated and measured average values.

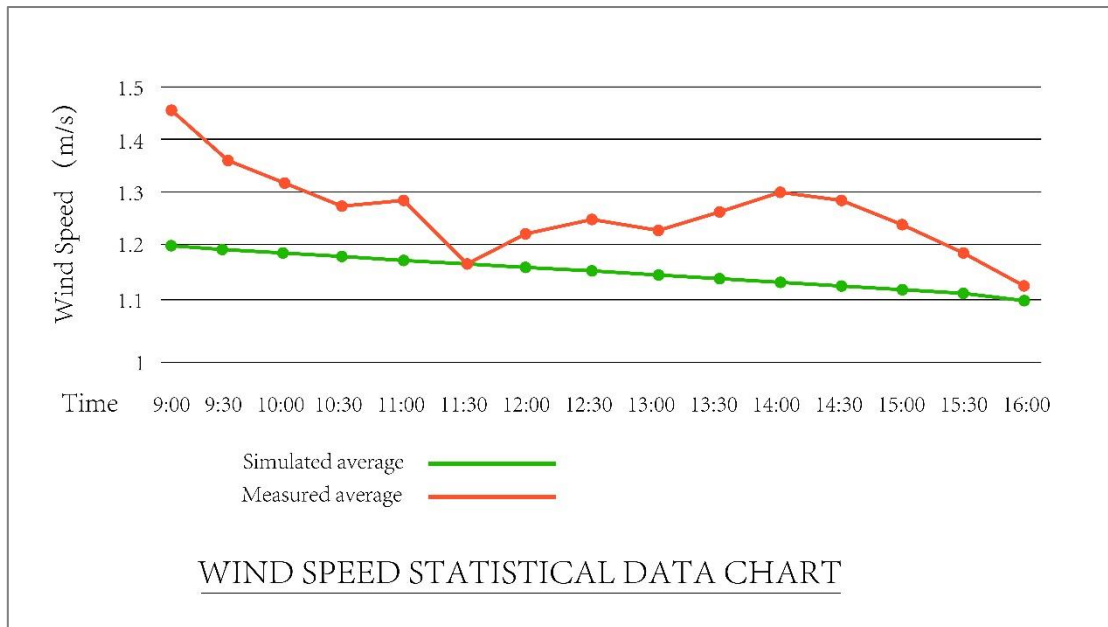


Figure 2 Wind speed data chart

The temperature data chart (Figure 3) shows that from 9 AM to 1 PM, the simulated values are consistently higher than the measured values, likely due to the omission of the cooling effects of greenery in the simulations; Furthermore, during simulations, settings for buildings, vegetation, and underlying surface materials are typically based on visual inspection or relevant experience, leading to inaccuracies in the simulated values. Although there are discrepancies between simulated and measured values, most measurement points have small errors, with some even approaching zero.

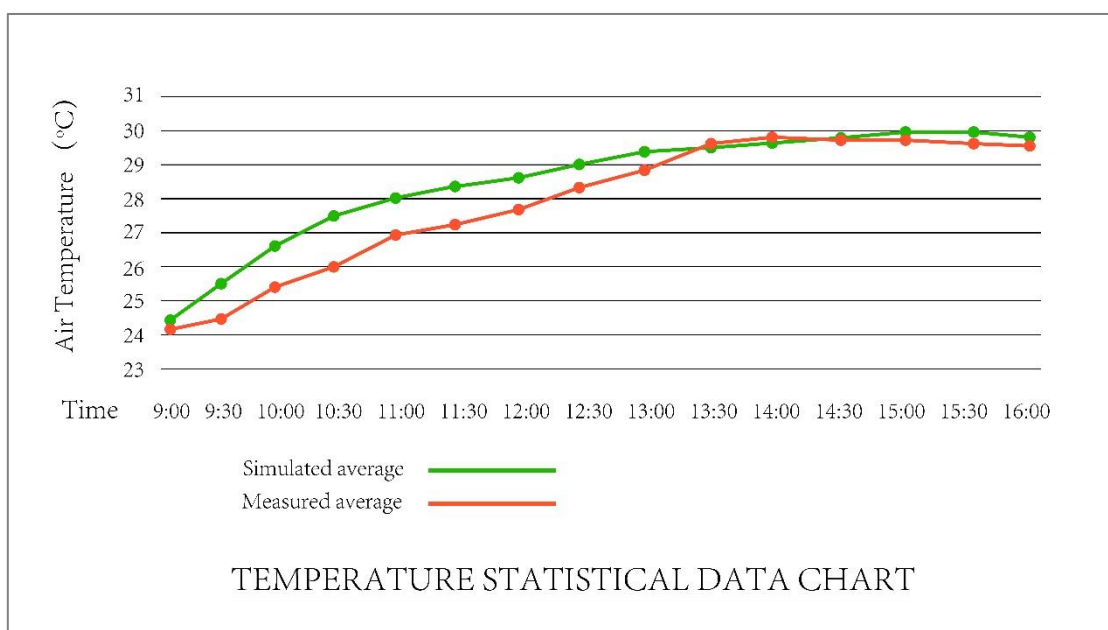


Figure 3 Temperature data chart

The humidity data charts show that the simulated humidity values are consistently higher than the measured values, and humidity is also affected by factors such as wind speed and temperature. Although the simulated humidity values are higher, the simulation data and actual data at various measurement points show similar trends, with a relative error of about 9%.

Overall, the ENVI-met software can relatively accurately simulate the microclimate environment of residential areas in Shenyang, and can be used to analyze the impact of architectural layouts on outdoor wind, temperature, and humidity environments and other microclimatic elements.

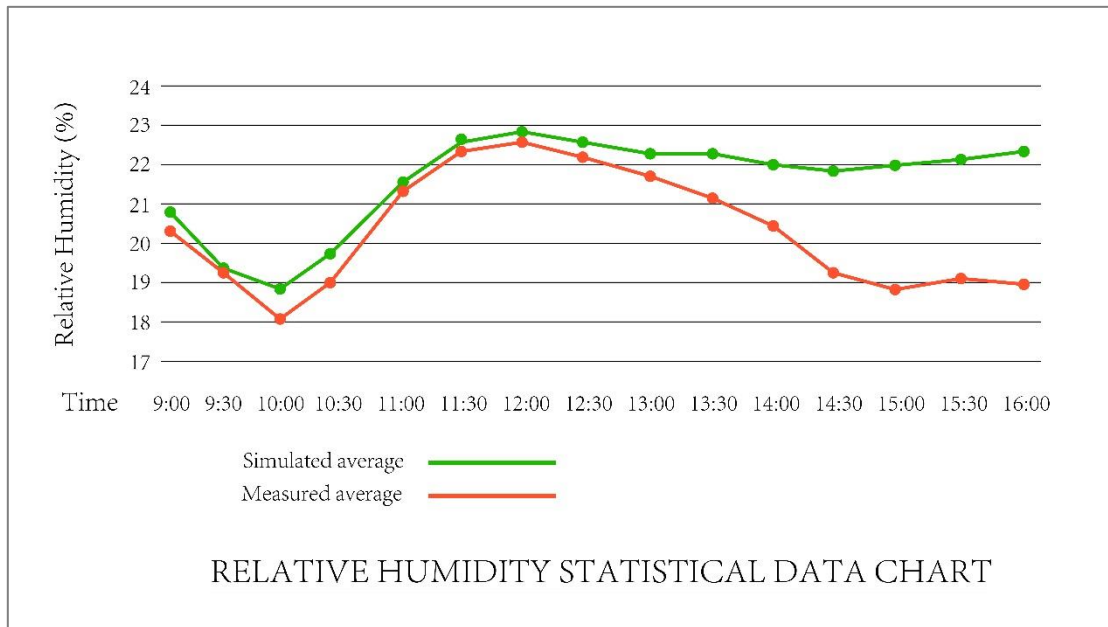


Figure 4 Humidity data charts

The analysis of the differences in correlation results among various layout patterns shows that the most significant effect on the wind environment in open spaces is the venturi effect. Downwash wind, corner flow wind, and counter flow wind effects also increase adverse effects when superimposed with other wind effects. Therefore, when selecting architectural layout patterns for residential open spaces, it is important to first reduce the occurrence of the venturi effect, and then to minimize the superposition of various wind effects. Thus, comprehensive data analysis and computational results indicate that the more suitable layout patterns for residential areas in Shenyang are the enclosed and staggered gable styles. Additionally, the row and diagonal row styles, due to the influence and superposition of various wind effects, sequentially weaken the microclimatic environment of open spaces. Meanwhile, the differences in the impact on the microclimate between the regular enclosed and diagonal row layout patterns are minimal.

4. DISCUSSION

Since Shenyang is located in a cold region, its architectural layout must consider climatic factors. Within the context of green building design, the construction of residential areas in Shenyang is typically approached from the perspective of microclimate regulation. Based on conclusions from previous studies on different architectural layout models, optimization strategies for the architectural layout of residential areas in Shenyang are proposed from both winter and summer perspectives [6]. Comparative analysis of onsite measurements and optimization simulations demonstrates the feasibility of the proposed optimization strategies. Additionally, when optimizing real-world cases, the impact of various practical factors must be considered, though in this study, the optimization of actual cases primarily serves to demonstrate the feasibility of the strategies.

The Row Layout, characterized by its linear arrangement of buildings, demonstrated a propensity for trapping heat within narrow corridors formed between structures. Statistical analysis from the study indicated a consistent temperature increase of approximately 3.2°C in these passageways compared to more open areas. This finding suggests that the Row Layout may contribute to the urban heat island effect, making these areas less comfortable during peak heat conditions. Conversely, the Diagonal Layout showed a significant improvement in air circulation, as evidenced by a 2.8°C average temperature reduction compared to the Row Layout. The orientation of buildings in this layout disrupts the linear air flow channels, allowing for more cross-ventilation and reduced heat accumulation. This layout proved to be more effective in moderating microclimatic extremes, which could be particularly beneficial in urban areas seeking to enhance pedestrian comfort and reduce reliance on mechanical cooling. The Staggered Gable Layout was notable for its creation of diverse microclimatic zones, where temperatures in shaded areas were up to 4.5°C cooler than in sun-exposed zones during peak sunlight hours. This variation is particularly important for providing natural thermal comfort without additional energy expenditure. The data support a model of urban design that includes varying building heights and staggered positioning as a strategy to optimize shadow casting and air flow, which are crucial for sustainable urban heat management. Finally, the Enclosed Layout, with its inward-facing buildings around a central courtyard, was associated with higher minimum night-time temperatures by up to 5°C. While this layout can offer advantages in terms of wind protection and privacy, it also tends to retain heat longer after sunset, which could lead to discomfort during warm nights and increased energy costs for cooling. Such findings are vital for planners in regions with significant diurnal temperature variations.

Winter Wind Environment Optimization Strategy: In the urban residential spaces of cold regions, the monsoon has the strongest impact on the microclimate [7]. Since Shenyang is located in a cold region, improving the winter wind environment is a primary objective in the architectural layout design of residential areas. Based on the simulation results of different architectural layout models discussed earlier, corresponding strategies are proposed.

Previous research has found that regardless of the architectural layout, the simulated wind environment in residential areas is better in a perpendicular arrangement to the wind direction, compared to a parallel orientation. When planning the layout of residential buildings, it may be considered to align the residential areas parallel to the wind direction.

Urban planners and architects should consider these findings when designing high-rise residential areas, especially in climates similar to Shenyang's. Incorporating varied layouts that enhance microclimatic conditions can lead to more sustainable urban environments and improved resident comfort. Policy makers could use these insights to update or create guidelines that encourage urban layouts conducive to favorable microclimates, potentially integrating these concepts into building codes and urban development policies [8].

While the study provides valuable insights, the results are specific to Shenyang and may not be directly applicable to cities with different climates or urban forms. Further research should explore these layout impacts in varied geographical and climatic contexts. Future studies could also integrate more dynamic simulations and long-term climate monitoring to assess the impacts of urban spatial designs over different seasons and climatic conditions. Investigating the long-term effects of these layouts on energy consumption and human health could further substantiate the benefits of microclimate-sensitive urban design.

REFERENCES

- [1] Guo, Z., Setoguchi, T., Watanabe, N., & others. (2017). Open space design study on the basis of extreme microclimate and spatial behavior in Northern China. *Journal of Urban & Regional Analysis*, 2017.

- [2] Wong, N. H., Jusuf, S. K., & Tan, C. L. (2011). Integrated urban microclimate assessment method as a sustainable urban development and urban design tool. *Landscape and Urban Planning*, 103(4), 328-338. <https://doi.org/10.1016/j.landurbplan.2011.08.001>.
- [3] Yang, F., & Chen, L. (2020). High-Rise Urban Form and Microclimate. In *High-Density Urban Areas: Conception and Design* (pp. 79-98). Springer, Singapore.
- [4] Toftum, J., & Fanger, P. O. (1999). Air humidity requirements for human comfort. *ASHRAE Transactions*.
- [5] [86] Jiang, Y., Wu, C., & Teng, M. (2020). Impact of residential building layouts on microclimate in a high temperature and high humidity region. *Sustainability*, 12(3), 1046. <https://doi.org/10.3390/su12031046>.
- [6] Xu, X., Liu, Y., Wang, W., Xu, N., Liu, K., & Yu, G. (2019). Urban layout optimization based on genetic algorithm for microclimate performance in the cold region of China. *Applied Sciences*, 9(22), 4747. <https://doi.org/10.3390/app9224747>.
- [7] Zhao, H., Jiang, X., Cao, Y., Zhang, H., Zhen, S., & Jia, R. (2022). Wind Environment Simulation and Optimisation Strategies for Block Spatial Forms in Cold Low Mountainous Areas—A Case Study of Changchun, China. *Sustainability*, 14(11), 6643. <https://doi.org/10.3390/su14116643>.
- [8] Wong, N. H., Jusuf, S. K., & Tan, C. L. (2011). Integrated urban microclimate assessment method as a sustainable urban development and urban design tool. *Landscape and Urban Planning*, 103(4), 328-338.