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John Littlewood
Robert J. Howlett
Lakhmi C. Jain *Editors*

# Sustainability in Energy and Buildings 2020

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# Sustainability in Energy and Buildings 2020

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# Preface

The 12th International Conference on Sustainability and Energy in Buildings 2020 (SEB-20) is a major international conference organised by a partnership made up of KES International and the Sustainable and Resilient Built Environment group, Cardiff Metropolitan University.

SEB-20 invited contributions on a range of topics related to sustainable buildings and renewable energy and explored innovative themes regarding building adaptation responding to climate change.

The aim of the conference was to bring together university researchers, government and scientific experts and industry professionals to discuss the minimisation of energy use and associated carbon emissions in buildings, neighbourhoods and cities; from a theoretical, practical, implementation and simulation perspective. The conference formed an exciting chance to present, interact and learn about the latest research and practical developments on the subject. For the first time, SEB-20 was organised through KES International's Virtual Conference platform in response to the COVID-19 pandemic which rose to prominence in 2020.

The conference featured two general tracks chaired by experts in the fields:

- Sustainable and smart buildings
- Sustainable energy technologies

In addition, there were seven invited sessions proposed and organised by prominent researchers.

It is important that a conference provides high-quality talks from leading-edge presenters. SEB-20 featured two keynote speakers: Prof. Steve Goodhew, University of Plymouth, Plymouth, UK; and Associate Prof. Umberto Berardi, Ryerson University, Toronto, Canada.

The conference attracted submissions from around the world. Submissions for the full-paper track were subjected to a two-stage blind peer review process. With the objective of producing a high-quality conference, only the best of these were selected for presentation at the conference and publication in the Springer as book chapters. Submissions for the Short Paper Track were subjected to a 'lighter-touch' review and published in an online medium, but not in the Springer book.

Thanks are due to the very many people who have given their time and goodwill freely to make SEB-20 a success. We would like to thank the members of the International Programme Committee who were essential in providing their reviews of the conference papers, ensuring appropriate quality. We thank the high-profile keynote speakers for providing interesting talks to inform delegates and provoke discussion. Important contributors to the conference were made by the authors, presenters and delegates without whom the conference could not have taken place, so we offer them our thanks. Finally, we would like to thank the administrative staff of KES International.

It is hoped that you find the conference an interesting, informative and useful experience; and remain connected through the KES International Virtual Conference Experience.

Cardiff, UK — Dr. John Littlewood
Arad, Romania/Poole, UK/Sussex, UK — Prof. Robert J. Howlett
Liverpool, UK/Sydney, Australia/Sussex, UK — Prof. Lakhmi C. Jain
SEB-20 Conference Chairs

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# About the Editors

**Dr. John Littlewood** graduated in Building Surveying holds a Ph.D. in Building Performance Assessment and is a Chartered Building Engineer. He is Head of the Sustainable and Resilient Built Environment group in Cardiff School of Art & Design at Cardiff Metropolitan University (UK). He coordinates three Professional Doctorates in Art & Design, Engineering and Sustainable Built Environment, plus contributing to teaching in Architectural Design & Technology. John's research is industry focused, identifying and improving fire and thermal performance in existing and new dwellings, using innovative materials and construction and also improving occupant quality of life and thermal comfort. He has authored and co-authored 150 peer-reviewed publications and was also Co-Editor for the 'Smart Energy Control Systems for Sustainable Buildings' book published in June 2017.

**Dr. Robert J. Howlett** is the Executive Chair of KES International, a non-profit organisation that facilitates knowledge transfer and the dissemination of research results in areas including intelligent systems, sustainability and knowledge transfer. He is a Visiting Professor at 'Aurel Vlaicu' University of Arad, Romania, and Bournemouth University in the UK. His technical expertise is in the use of intelligent systems to solve industrial problems. He has been successful in applying artificial intelligence, machine learning and related technologies to sustainability and renewable energy systems; condition monitoring, diagnostic tools and systems; and automotive electronics and engine management systems. His current research work is focused on the use of smart microgrids to achieve reduced energy costs and lower carbon emissions in areas such as housing and protected horticulture.

**Dr. Lakhmi C. Jain**, Ph.D., M.E., B.E. (Hons), Fellow (Engineers Australia), is with the University of Technology Sydney, Australia, and Liverpool Hope University, UK. Professor Jain founded the KES International for providing a professional community the opportunities for publications, knowledge exchange, cooperation and teaming. Involving around 5,000 researchers drawn from universities and companies worldwide, KES facilitates international cooperation and generates synergy in teaching and research. KES regularly provides networking opportunities for professional community through one of the largest conferences of its kind in the area of KES.

# Chapter 1
# Analysis of the Spatial Morphology Facing Wind Environment in Harbin Central Area

**Di Song, Ming Lu, and Jun Xing**

**Abstract** In this paper, the wind, which affects the urban microclimate environment, is selected as the research perspective, taking the central area of Harbin as an example, on the premise of extracting the basic parameters of space. The development of urban space form includes the selection and construction of analysis parameters in four aspects: building height, plane space, shape space, roof space, and so on. Then, it relies on the analysis of different land use types in order to clarify the basic characteristics of the canopy and underlying surface of urban space. The method formed in this paper will act on the parameterized interpretation of spatial morphology on the urban scale, which is convenient to provide the basic database and analogy basis for the subsequent numerical simulation and spatial design.

**Keywords** Urban spatial form · Analytical method · Land type · Central area · Harbin (China)

## 1.1 Introduction

In the urban construction, the buildings with high and low changes form a sharp contrast with the surrounding natural environment [1]. The artificial environment of dense buildings, streets, and bridges constitutes a special climate type [2]. From the perspective of urban meteorology, the urban canopy is an important influence area of urban wind field changes, which in turn affects the diffusion of atmospheric pollutants and energy conversion efficiency [3]. Therefore, it is necessary to accurately describe the spatial distribution of the urban canopy and the environmental characteristics of the underlying surface for urban planning, environmental management, and spatial model construction. At the same time, the huge amount of data generated by urban space also improves the convenience of analysis tools.

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## 1.2 Literature Review

From the perspective of aerodynamics, the obstruction of the urban canopy formed by high-density construction on wind is very obvious [4]. Therefore, there is a close relationship between the wind environment and the spatial form of the city. Theoretically, the assessment of wind attenuation trends is initially explained by the rough length (z0) and the zero-plane displacement (zd) [5]. Later, the windward area and wind speed ratio were introduced to evaluate the urban ventilation path [6], and then, the city's ventilation performance was evaluated by the windward area density at different heights [7, 8]. Relying on building typology can reveal the problem of pollutant diffusion caused by high-density construction [9, 10] and improve the environmental improvement of buildings and street spaces by improving the windward area [11] and porosity [12] between buildings.

For a city as a complex mega system, the spatial morphological characteristics can directly reflect the dense arrangement of urban buildings and the complexity of individual buildings. This can be achieved by the height, density, and surface size of the spatial structure [13]. In the city, T.R.Oke divides the spatial form into four types and corresponds to the urban density distribution [14]; at the same time, it is found that there is a correlation between wind flow patterns and building spacing in different cities [15]. Mohamed F. Yassin used different roof heights to illustrate the impact on canyon air quality in urban streets [16]. Francisco Toja-Silva et al. The ventilation sensitivity of the roof width and the ventilation effect of the roof distribution at different heights were studied [17]. Steven J. Burian and Michael J Brown developed three-dimensional spatial analysis of major US cities based on ten morphological parameters and correlated with the wind and heat environment. This result summarizes the differences in the morphological characteristics corresponding to different land types, which can be used as a reference for the analysis of spatial morphology at the mesoscale [18].

From the above studies, in the research discipline, the current explanation of urban space wind speed attenuation is mainly based on aerodynamic related parameters. From the perspective of research, a single parameter study can no longer explain the complex urban space, which needs to be comprehensively considered in terms of canopy height, distribution density, and physical differences caused by different use buildings. Based on the existing foundation, this study uses statistical and spatial analysis techniques to analyze the relevant parameters, providing an explanation of the urban spatial morphological characteristics and providing building distribution rules and morphological references for subsequent numerical simulations.

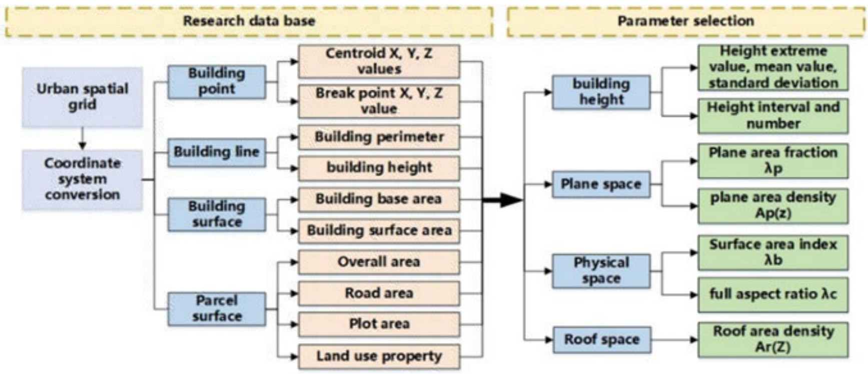


**Fig. 1.1** Analysis framework of urban spatial form

## 1.3 Methodology

### *1.3.1 Research Data Base*

In recent years, electronic map suppliers, including Baidu and Amap, have provided the possibility of information acquisition for buildings through the construction of three-dimensional panoramic maps.

As shown in Fig. 1.1, the research obtained by the supplier to obtain the building and road grids for coordinate system conversion and packaged as GIS element files provides convenience for spatial morphology analysis. It should be noted that due to different map construction years and purposes, there are some errors in the data obtained, so it is necessary to review the outline and height of some buildings in combination with remote sensing images and field surveys. In addition, the urban land use refers to the eight types of main land properties listed in the national standard "Urban Land Classification and Planning and Construction Land Standards" to improve the information on the land and its attached buildings [19]. Finally, all the data are sorted, and various data including spatial points, lines, and planes are further extracted to jointly form urban spatial feature classes.

### *1.3.2 Parameter Selection*

Same as Fig. 1.1, the description of urban space form is carried out based on the elements of urban space, which is divided into four aspects: building height, plane space, shape space, and roof space. The main results are as follows:

(1) Building height, which can directly explain the depth of the urban canopy that affects the atmosphere and in turn can explain the reason for the decrease in air

velocity due to the heterogeneous distribution of the building. Therefore, the influence range of the urban canopy, the concentration area, and the change of its discrete degree are expressed through the extreme height, mean, standard deviation, and number of buildings in different sections.

(2) Planar space, which can intuitively express the surface roughness on different urban cross sections. The surface roughness under the increase of building density also increases, and finally, a roughness threshold can be formed to produce effective resistance to air velocity. Therefore, the planar area fraction $\lambda_p$ and the planar area density $A_p(z)$ are introduced to express the change of urban surface roughness.

(3) Shape space, which can intuitively reflect the surface area change brought by buildings with different functions and take this into consideration to express the wind speed resistance effect brought by different building shapes. Similarly, the vegetation, terrain, etc., in the site can also produce similar effects. Therefore, the surface area index $\lambda_b$ and the complete aspect ratio $\lambda_c$ are introduced as a summary of the changes in the rough area of the building and the rough area of the canopy.

(4) Roof space. The significance of the roof area of urban buildings as a separate consideration is that the roof of the building not only represents the size of the rough element of the canopy formed at different heights, but also is an important part of urban heat exchange and affects the change of local wind. The combination changes of different forms of roofs will affect the ventilation effect of the building itself and the external space, so the roof area density $A_r(z)$ is introduced to express the changes in roof area at different heights.

### *1.3.3 Methods of Analysis*

As shown in Table 1.1, according to the different expression intentions of the spatial morphological parameters, corresponding calculation methods and graphical expressions are constructed, respectively [20]. The research utilizes the advantages of ARCGIS platform in database space visualization, VB data script operation, and Excel function processing under complex rules, etc., to expand the data processing and spatial description of urban spatial forms.

## 1.4 Urban Spatial Morphology Analysis

### *1.4.1 Regional Overview*

Harbin is the capital of Heilongjiang Province and the highest latitude mega-city in China [21]. It has long winters and short summers and short springs and autumns. The cold and warm air alternates frequently, and the climate is complex and changeable.

**Table 1.1** Analysis method of urban spatial shape parameters

| Parameters | Operational explanation | Expression method |
|---|---|---|
| Height extreme value, mean value, standard deviation | Arithmetic mean, maximum (small) value, standard deviation of regional building height | AVERAGE command, sequential command, STDEVP command |
| Height interval and number | Number distribution of buildings in different heights | STDEV command |
| Plane area fraction $\lambda_p$ | Ratio of the floor area of the building to the area of the site | ARCGIS-VB script operation |
| Plane area density $A_p(z)$ | Area density is defined as the ratio of the plane area of the building to the area of the site in height increments | SUMIF function command |
| Surface area index $\lambda_b$ | The ratio of the surface area of the building to the area of the site | Analysis tools ARCGIS-VB script operation |
| Full aspect ratio $\lambda_c$ | Ratio of all rough elements (building surface and other exposed features) to the site area | Analysis tools ARCGIS-VB script operation |
| Roof area density $A_r(z)$ | Ratio of roof area to site area in height increment | SUMIF function command |

The dominant wind direction throughout the year is the southwest wind, with an average wind speed of 2.5 m/s. Seasonal dominant wind directions are different in winter and summer. Low winter temperatures and high wind speeds aggravate the cold perception of the human body. In summer, the temperature and humidity are high, the wind speed is small, and the heat island effect is obvious, which is not conducive to human comfort [22]. Therefore, it has an overall impact on urban wind, and the rational use of research is of great value.

The central area referred to by the institute is shown in Fig. 1.2 [23]. This area is the main political, economic, and cultural area of Harbin. Feature data was imported through ArcMap, and basic feature maps and statistical tables were formed. After approval by statistics and field surveys, the area contains 21,312 buildings with an area of 58.209 km$^2$. The building function is complex and large in quantity, including most types of useful land classifications. The land use statistics are shown in Table 1.2.

### *1.4.2 Building Height Analysis*

Overall, the study based on the national standard "General Rules for the Design of Civil Buildings" for the high classification of residential and other civil buildings is divided into six categories of height intervals and statistics [24]. As shown in the statistics in Fig. 1.3, the maximum value of the building in the central area is 3–173 m,

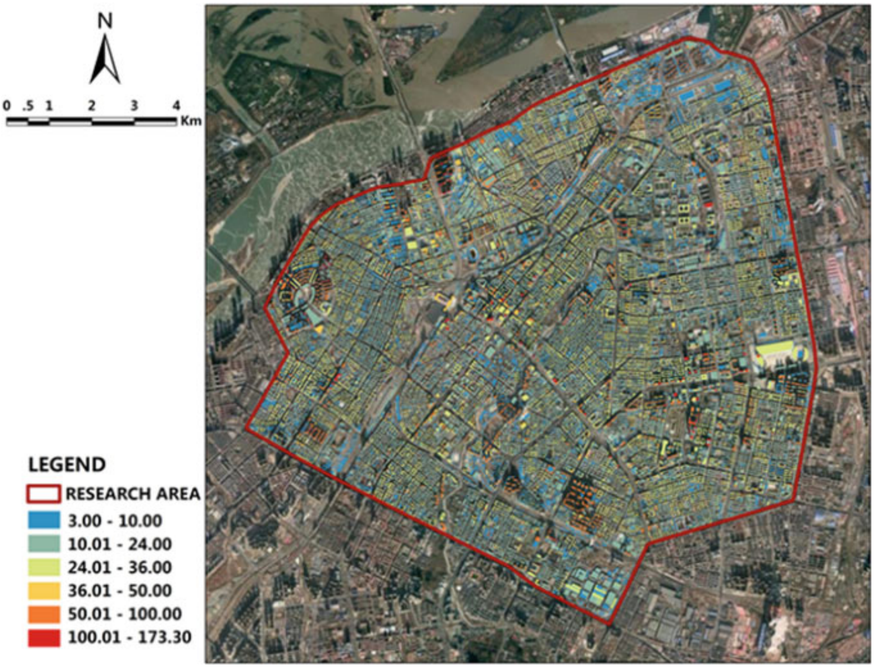


**Fig. 1.2** Urban spatial morphology parameters

the average height is 20.29 m, and the regional standard deviation is 18.85. From the perspective of proportional distribution, it is mainly that the height of buildings is in the range of 10–24 m. Buildings (low-rise and multi-storey) within this height range account for 70% of the total buildings, constitute the most impact was rough urban wind attenuation. In addition, due to the large number of high-rise residential buildings and commercial office buildings in recent years, more than 1,500 high-rise and super-tall buildings with more than 50 m in the central area will have a negative impact on the air flow in the higher range.

Table 1.2 lists the building height statistics of various sites, the administrative office, culture, education, medical care, commercial business, and residential buildings are mostly distributed in multiple layers (less than 36 m), and the construction volume of high-rise buildings larger than 50 m in recent years has increased. Larger. Facilities such as sports, transportation stations, entertainment, industry, and logistics have a large base area, and the height is mostly below 24 m (multi-storey buildings). A very small number of buildings with large heights are used for office or entertainment purposes.

**Table 1.2** Analysis method of urban spatial shape parameters

| Land use nature | Code | Land area ($km^2$) | Amount | Average (m) | Height rang (m) | $\lambda_p$ | $\lambda_b$ | $\lambda_c$ |
|---|---|---|---|---|---|---|---|---|
| Administration | A1 | 1.05 | 517 | 25.67 | 3–125 | 0.34 | 2.29 | 2.92 |
| Culture | A2 | 0.51 | 94 | 16.52 | 3–171 | 0.25 | 1.11 | 1.67 |
| Education and research | A3 | 5.96 | 2027 | 15.90 | 3–121 | 0.24 | 1.27 | 1.90 |
| Physical culture | A4 | 0.61 | 124 | 12.91 | 3–33 | 0.23 | 0.87 | 1.31 |
| Medical hygiene | A5 | 0.82 | 424 | 17.94 | 3–103 | 0.31 | 1.68 | 2.22 |
| Ancient artifacts | A7 | 0.16 | 115 | 8.09 | 3–30 | 0.30 | 1.25 | 1.96 |
| Religious facilities | A9 | | | | | 0.34 | 1.66 | 2.31 |
| Business | B1 | 3.70 | 1970 | 20.64 | 3–120 | 0.40 | 2.35 | 2.88 |
| Commercial affairs | B2 | 1.70 | 881 | 28.77 | 3–173 | 0.33 | 2.58 | 3.15 |
| Entertainment | B3 | 0.38 | 238 | 10.68 | 3–90 | 0.42 | 2.39 | 2.96 |
| Public facilities | B4 | | | | | 0.24 | 0.99 | 1.51 |
| Other services | B9 | | | | | 0.36 | 1.71 | 2.35 |
| Public park | G1 | 2.99 | 384 | 6.51 | 3–32 | 0.03 | 0.11 | 0.37 |
| Protective green | G2 | | | | | 0.00 | 0.01 | 0.03 |
| Square | G3 | | | | | 0.04 | 0.17 | 0.51 |
| Regional traffic | H2 | 1.09 | 130 | 7.92 | 3–39 | 0.03 | 0.10 | 0.43 |
| Military facility | H4 | 0.54 | 275 | 11.72 | 3–69 | 0.23 | 1.37 | 2.07 |
| To be built | H9 | 2.22 | 809 | 9.16 | 3–86 | 0.35 | 1.50 | 1.98 |
| Shanty Town | R3 | | | | | 0.40 | 1.31 | 1.84 |
| Industry | M | 1.17 | 394 | 13.98 | 3–104 | 0.36 | 1.47 | 2.00 |
| City traffic | S | 0.74 | 173 | 10.18 | 3–56 | 0.12 | 0.47 | 0.80 |
| Residential | R2 | 26.56 | 12,571 | 22.51 | 3–166 | 0.33 | 2.19 | 2.79 |
| Municipal facilities | U | 0.32 | 186 | 12.54 | 3–67 | 0.32 | 1.63 | 2.31 |
| Logistics facilities | W | | | | | 0.34 | 1.34 | 2.00 |

### *1.4.3 Planar Spatial Analysis*

(1) Plane area fraction $\lambda_p$: The total area of the building base in the central area is 153,100 $m^2$, and the overall density is 0.26. Generally, the urban wind is prone to wake disturbance flow, which affects the area where the city's downwind direction is located.

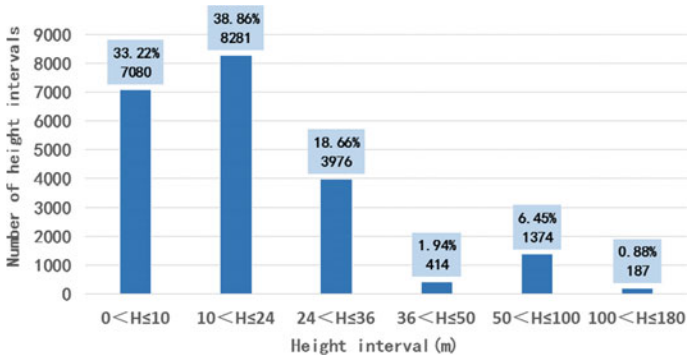


**Fig. 1.3** Statistical study overall height range

According to the statistics of the plane area scores of various types of land in Table 1.2, most of the $\lambda_p$ values are in the range of prone to wake interference flow, administrative office, monuments and religion, commercial business, entertainment and recreation, industry, residence, Logistics has a relatively high flat area fraction. Other types of land use include a large number of buildings and also have green space or square distribution space $\lambda_p$ value is slightly smaller. As shown in Fig. 1.4, most of the plots with isolated roughness flow are located in the city's main broad roads and major urban green spaces. This part is also

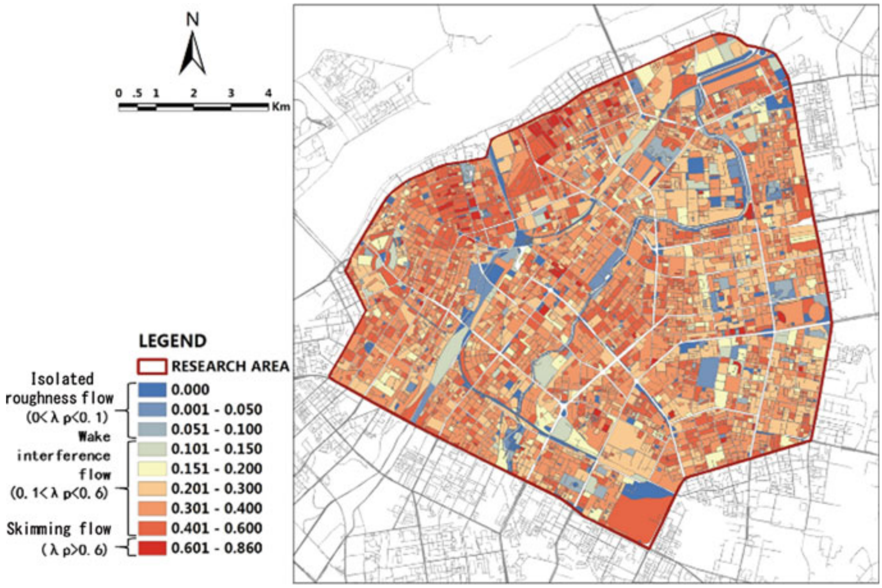


**Fig. 1.4** Central area fractional map

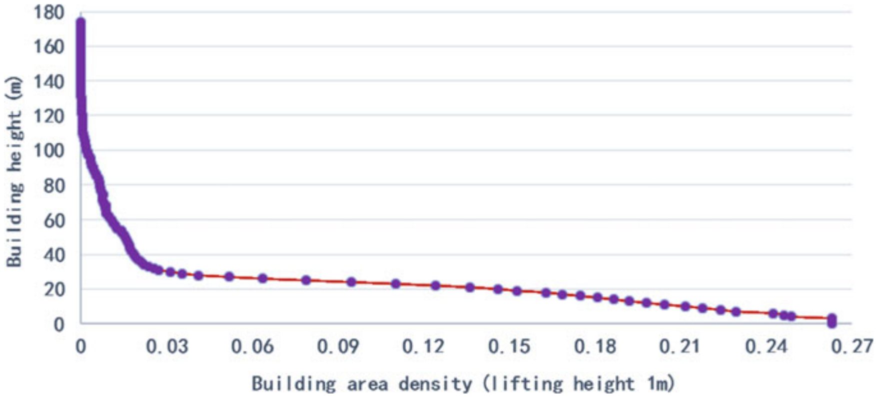


**Fig. 1.5** Urban area density map

often a better urban ventilation area. However, a very small number of skimming flow areas are mainly distributed in commercial buildings with dense layout and some un-demolition shanty towns. This part will make it difficult for the urban wind to enter the canyon formed by the building, resulting in poor local space ventilation, affect the comfort of the space.

(2) Plane area density $A_p(z)$: The statistical result is shown in Fig. 1.5. Before the building reaches the minimum building height of 3 m, its plane area is constant, which is equivalent to the constant crown roughness, starting from 4 to 30 m, building. The flat area decreases rapidly, the canopy roughness decreases, and the resistance to urban winds also drops significantly. From then on to the highest value of the building in the block, due to the decrease in the proportion of the plane area in the height of the area, the degree of decline in the resistance to the urban wind gradually slowed down and reached zero infinitely.

The comparison of the $A_p(z)$ values of various types of land is shown in Fig. 1.6. The administrative office, culture, education, medical care, commercial business, and residential buildings have a high span, a large initial density, and a rapid decline. Sports, monuments, and religious facilities are small in height, entertainment, health, public facilities and other facilities, transportation facilities, military facilities, municipal facilities, and logistics storage density are moderately low, with a slow decline. Green space, regional transportation facilities, low-density initial value is small, and the height changes gently and slowly declines.

### *1.4.4 Physical Space Analysis*

(1) Surface area index $\lambda_b$: According to Table 1.2 and Fig. 1.7, most of the building roughness elements are concentrated in the central area, which not only has resistance to urban winds, but also affects urban heat exchange. The areas with

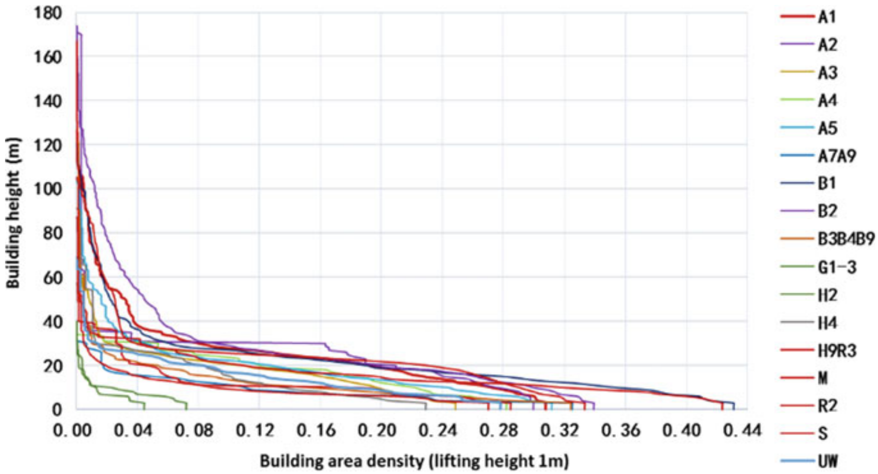


**Fig. 1.6** Plane area density map of all kinds of land

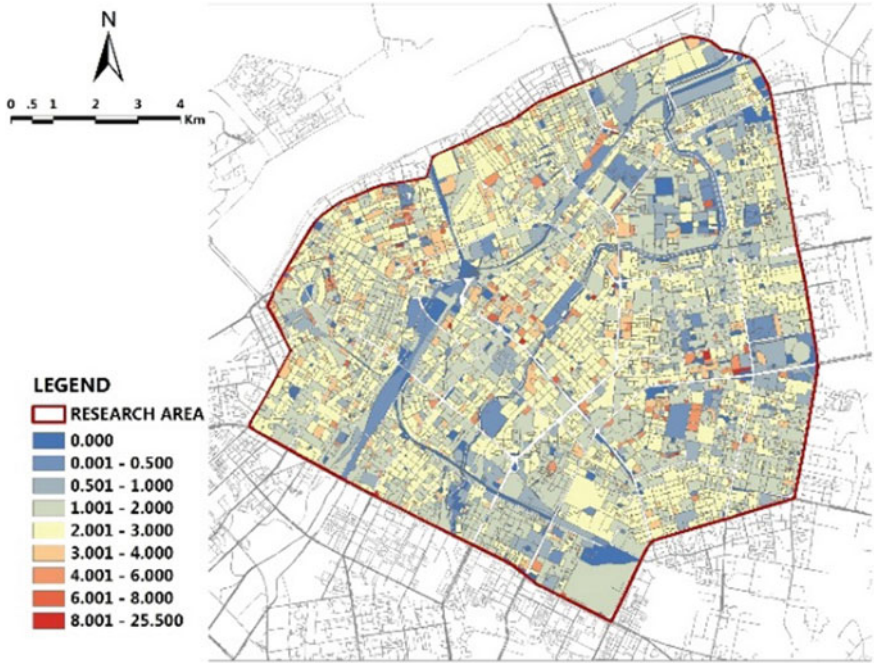


**Fig. 1.7** Surface area fraction diagram of central area

large $\lambda_b$ values mainly include the main commercial circles, high-rise residential areas and development areas in the city and also reflect the above areas with the greatest land value.

(2) Complete aspect ratio $\lambda_c$: The magnitude of the $\lambda_c$ value in the study range does not depend entirely on the surface area of the building in which the block is located. Covering trees or shrub sites is also an important part of its impact. Especially in residential areas, having green space near the house and central greening will also have some resistance to the wind environment [25]. At the same time, the appropriate green area can effectively alleviate the urban heat island effect. According to Table 1.2 and Fig. 1.8, most of the central region has a $\lambda_c$ value in the range of 2.5–4, while the larger $\lambda_c$ value is mainly located in the commercial center of the city and most of the high-rise residential areas. Administrative offices, commercial commerce, second-class residences, and medical buildings have relatively high $\lambda_c$ values (more high-rise buildings). In the case of considering the three-dimensional surface area of greening, the value of residential, educational, and green land and other buildings will be further enhanced.

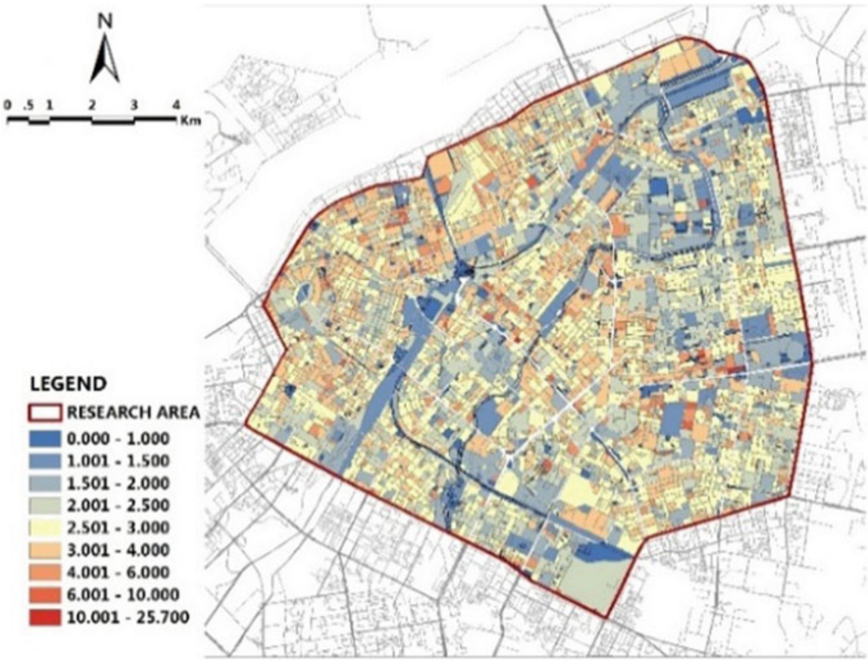


**Fig. 1.8** Complete horizontal and vertical ratio map of the central area

### 1.4.5 Roof Space Analysis

The statistical results are shown in Fig. 1.9. A large portion of the roof area density is located between 3 and 35 m above the ground (multilayer and small high-rise dominated). Its value is below 3 m, indicating that no building height is less than 3 m (slightly below one floor). In contrast, high-rise buildings have a more uniform roof density distribution and less impact on wind speed.

The variation of the roof area density of different nature land is shown in Fig. 1.10.

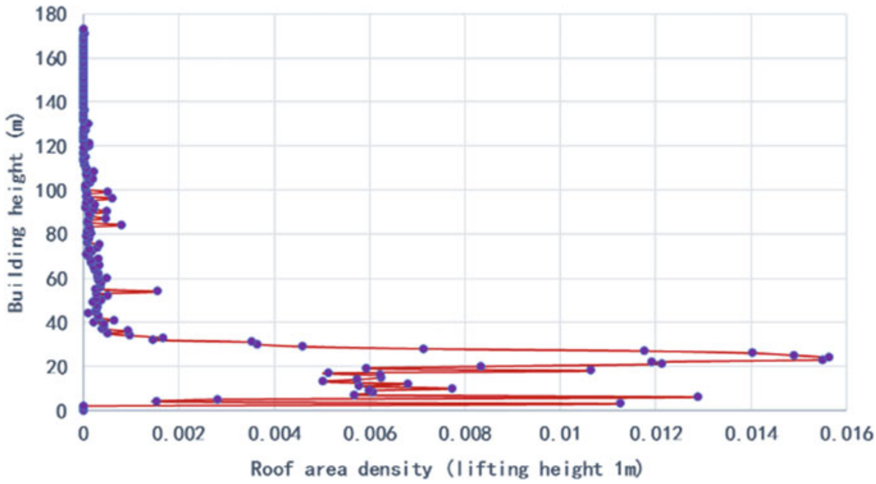


**Fig. 1.9** Roof area density map

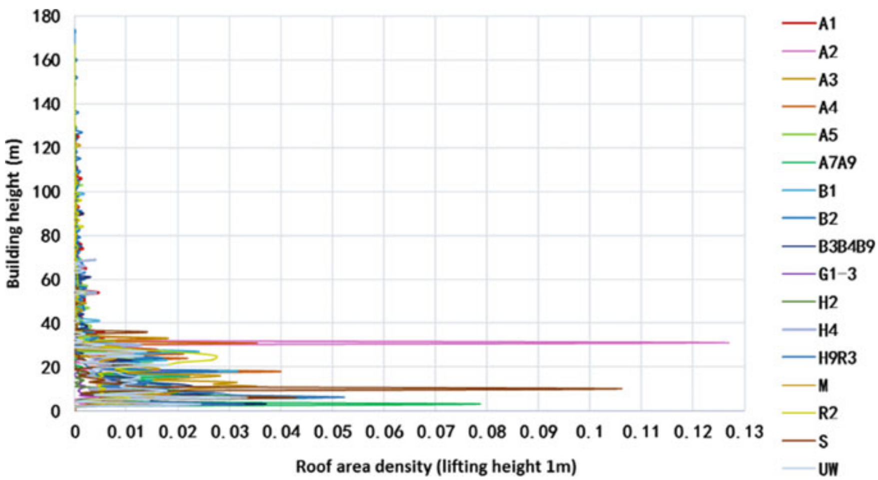


**Fig. 1.10** Roof area density map of all kinds of land

In comparison, the administrative office, education, medical, commercial business, residential buildings have a high span, and the roof density varies moderately. Cultural and transportation facilities have a large variation in density due to the presence of exhibition centers and train stations (extreme points). Sports, recreation and recreation, utilities and other facilities, military facilities, municipal facilities, logistics storage height changes and density changes are small. Green spaces, regional transportation facilities, and height and density are the smallest.

## 1.5 Discussion

In this study, multi-parameter considerations are used to explain the spatial morphological changes, which can provide a statistical basis for subsequent models used in numerical simulation. Subsequent research will focus on the coupling relationship between parameters and urban wind to provide suitable spatial development suggestions.

The limitation at this stage is that the current situation of the distribution of Chinese urban buildings is usually completed by the relevant surveying and mapping departments, and it is difficult to obtain the right of use due to the land transfer. Therefore, if follow-up research is carried out through cooperation with government departments, the accuracy of the research can be effectively improved.

For the future of urban development, the construction of high-rise buildings will become the main method. The urban canopy will be higher, the building surface area will be larger, and the requirements for building form and spatial layout will be more precise. Therefore, the reasonable building form and the layout of the building group will have a more important impact on the effective air circulation in the city.

## 1.6 Conclusions

This study builds statistical methods based on urban spatial morphological parameters to describe the characteristics of the current spatial morphology in Harbin and its impact on wind. Study the following conclusions:

The research uses the GIS platform to build models and excel functions suitable for city-scale analysis, which can carry out effective statistical analysis.

Harbin Center area as an example, the total urban canopy height 174 m. The height of the building is mainly concentrated within about 30 m above the underlying surface; the distribution of high-rise buildings in the central area of concentration, body building itself also creates urban wind Influence, surface area and the presence of ground objects increase the degree of obstruction.

It is difficult to form a comfortable space on some property blocks due to the high density of the building. Most spatial patterns will have an impact on the downwind