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Supply and Demand for Planning and Construction of Nighttime Urban Lighting: A Comparative Case Study of Binjiang District, Hangzhou

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Abstract: Demand planning-oriented research on nighttime urban lighting provides a foundation for formulating strategies to eliminate dark areas and reduce light pollution. In this paper, Binjiang District of Hangzhou was investigated. Four factors, namely land-use type, road grade, parcel volume, and nighttime crowds, were evaluated. Based on the spatiotemporal geographic data and the urban lighting planning of Hangzhou, a calculation method for the supply and demand of urban lighting at night in Hangzhou was constructed. In this process, the current state of lighting brightness in different areas of the district were calculated and compared with the results of the total lighting demand to analyze reasonableness. The research results show that according to the actual lighting demand classification, the first to fifth levels of lighting control zones accounted for 1.84%, 19.69%, 49.61%, 21.74%, and 7.12% of the total statistical land area of the district, respectively. Focus should thus be placed on the second, third, and fourth levels of lighting control zones when covering lighting demand. Importantly, areas with unreasonable supply and demand for lighting construction accounted for 20.8% of the total statistical land area, indicating that the nighttime lighting demand and carbon emissions in the Riverside District should be adjusted and optimized. This paper proposes a research method to compare supply and demand for the planning and construction of nighttime urban lighting, which can improve the science on lighting demand measurement.

Keywords: lighting demand; luminance; carbon emission; Binjiang district; Hangzhou

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1. Introduction

Good planning and construction of urban lighting (specifically during the night) can not only improve urban functions and enhance economic vitality [1,2], but can also improve people's quality of life at night [3–5]. These are key factors in effectively meeting "human needs" [6–8] and achieving "urban sustainable development" [9–11]. In contrast, unreasonable lighting planning and construction often have counterproductive effects, especially in public spaces [12], adversely affecting people and the environment in areas of concern [13–15]. For example, lighting construction is excessive in many cities [16], resulting in nuisance caused by light pollution [17], or energy waste [18]. On 1 August 2022, the new Shanghai Environmental Protection Regulation came into force. It introduced the prevention of nighttime light pollution and became the first local environmental protection law in China to include light pollution control. Studies have shown that urban interventions in lighting can produce positive results [19–23]. Considering the many remediation projects that aim to address dark areas in streets that have been carried out in major cities in recent years, urban lighting construction has attracted increasing social attention.

The First United Nations Conference on the Human Environment, initiated by the United Nations, was held in Stockholm, Sweden, from 5 to 16 June 1972. The conference, which produced the famous Declaration of the United Nations Conference on the Human Environment, was the first conference in human history to study the protection of the human environment on a global scale. In 2007, the United Nations Environment Programme introduced the concepts of a "low-carbon economy" and "low-carbon living" for the first time, with the aim of preserving Earth through environmental protection, energy conservation [24,25], and the use of renewable resources [26]. At present, low-carbon living has become a new way of life [27–29] and has gained increasing recognition and support [30].

In China, especially in the current era of ecological civilization, green ecological low-carbon construction has been incorporated into the basic national policy implemented by the government. The concept of dual carbon development, which has been deeply rooted in people's hearts, has become a guideline for urban construction [31,32]. Urban lighting planning should actively practice the concept of dual carbon development, and existing studies have shown a correlation between urban lighting and carbon emissions. This correlation can be obtained by comparing the nighttime lighting image data of urban clusters, represented by DMSP/OLS or NPP-VIIRS data, with the CO_2 emissions of the corresponding areas. It appears that the brightness level [33], range, and (mainly electrical) energy consumption of nighttime lighting are positively correlated with carbon emissions [34–36]. Urban light pollution is mainly determined by the brightness and range of lighting [37]; if the brightness and range of lighting at night are significantly beyond reasonability in an area of a city, it increases the city's carbon emissions. In July 2022, the Chinese Ministry of Housing and Urban-Rural Development and the Chinese Development and Reform Commission therefore issued a document to launch a comprehensive urban and rural low-carbon construction initiative (hereinafter "the initiative"), which clearly proposed that integrated research on future urban lighting planning and construction and carbon emissions should focus on how to control light pollution and excessive brightness through planning. Urban lighting planning should meet the needs of urban people and functions and put into practice a low-carbon approach to maintaining a balance between supply and demand without excessive construction. This paper presents a comparative study of supply and demand for nighttime urban lighting planning and construction, and a scientific assessment of urban lighting demand is a precondition for the study of the supply-and-demand balance. Quantitative accounting of urban lighting not only effectively assesses the reasonability of the current lighting plan, but also provides basic guidelines for scientific decision-making in future planning.

The significance of artificial light to people is self-evident [38–40], and artificial lighting has been integrated into people's daily lives since humans began to use fire [41,42]. artificial lighting has been gradually developed over time. However, in recent decades, the relationship between lighting, people, and cities has received more widespread attention. Existing studies have emphasized the impact of urban light pollution [43,44], while few researchers have used quantitative methods to study urban lighting demand. There are also relatively few studies on low-carbon urban lighting planning and construction. We examined the literature related to quantitative research on urban lighting demand, and then, summarized four representative research types according to our research methods and objectives. Typical case articles were selected for each type (Ye et al. [45], Beccali et al. [46], Hammad et al. [47], and Gao et al. [48]), from which the main ideas and the advantages and limitations of the various types of research are summarized in Table 1.

Table 1. Strengths and limitations of the four types of study.

No.	Category	Author	Summary of Research Results	Methodology and Merits of the Study	Limitations
1	Questionnaires and interviews	Ye et al.	Through questionnaires and interviews, the authors quantitatively analyzed and studied the needs of multifunctional intelligent lighting devices in different urban areas in terms of functional bearing, scene application, aesthetic demand, intelligent application, and energy-saving control.	Directly inquired about people's feelings about the application of intelligent lighting equipment.	The findings were highly subjective, and although the percentages of each factor were calculated based on the questionnaire results, the conclusions and opinions were more likely to be influenced by the sample selection.
2	Comprehensive judgment by measuring the parameters of each relevant influencing factor	Beccali et al.	Based on data such as the volume of road traffic, the environmental parameters affected by street lighting, and the amount of energy consumed, the authors examined the parameters of the lighting fixtures, and economic investment estimates were made for street lighting to provide a program that meets the technical requirements of street lighting design and economic feasibility.	Suitable for the needs of lighting renovation work on city streets of different sizes, and improved lighting systems.	The research scale was too small to be applied to research on the overall lighting of cities.
3	Deriving the results by constructing a mathematical model	Ahmed et al.	The problem of positioning urban lighting poles was solved through the construction of a mathematical model that seeks to achieve adequate street lighting coverage with minimal installation costs. The social demand for a certain degree of urban lighting was met while seeking to optimize the layout of light poles in urban areas.	Calculated how to balance cost and lighting coverage by constructing a mathematical model.	The research was based on the demand hypothesis, only considering social and environmental measures through a single objective function and ignoring the impact of multiple factors on the results.
4	Results from big data calculations.	Gao et al.	Based on the assumptions, the luminance values of small cities in less developed areas of China were calculated using various auxiliary data through light remote-sensing techniques to improve lighting needs.	The research method of big data was used, and the derivation process was objective.	The research was macro in nature, and although there were seemingly correct research processes and results, the conclusions could only be seen to argue for a phenomenon that does exist, with low subsequent actionability.

From the above table, we can see that the four types of research had their own advantages and limitations. Overall, the research had the following characteristics: (1) none of the lighting demand research was directly aimed at urban areas, but it reflected a certain degree of lighting demand; (2) the research scale was either macroscopic or microscopic, but there was a lack of research aimed at the urban mesoscale; and (3) none of the research observed lighting demand from the perspective of urban planning. Nevertheless, a set of mature research ideas can still be summarized; that is, by focusing on the roles of parameters and data, as well as adopting the method of conducting a superimposed analysis by selecting multiple factors and constructing a mathematical model, we can improve the research on urban lighting demand. Moreover, questionnaires and interviews can be used as auxiliary methods of research.

It is difficult to study the mesoscale lighting demands of urban areas, which requires an operating platform that can enable data collection, calculation, and feasibility control. Fortunately, several members of our research team once participated, as key personnel, in the compilation of the Hangzhou Urban Lighting Overall Plan (2019–2025), led by the government. In the process of compilation and research, a research method similar to that used in this paper was adopted to conduct experiments on small urban areas. According to the changes in the development of lighting in Hangzhou in recent years, this method has been judged to have good operability.

In addition, we found that relatively little research has been conducted on low-carbon urban lighting planning and construction, with papers mainly published in the areas of low-carbon architectural lighting, green space lighting, road lighting, and the low-carbon design and manufacturing of lamps. For example, Li et al. [49] analyze the energy consumption of architectural lighting to explore energy saving potential; they find that personnel behavior, control mode, and luminaire type all affect energy consumption. Łopuszyńska and Bartyna-Zielińska [50] discuss urban green space lighting its and associated factors to explore how to achieve a balanced relationship between nighttime lighting and darkness. Casavola et al. [51] design an adaptive urban smart lighting framework that can automatically adjust the brightness of street lights according to the needs of moving vehicles, with the sole purpose of reducing urban energy consumption on streets or specific road sections. Thurairajah et al. [52] study a pre-qualification mechanism to review energy-efficient light-emitting diode (LED) luminaires that can be used for outdoor lighting, with the aim of reducing or avoiding urban light pollution. Although the above research has a certain degree of operability, from the perspective of this study, it has varying degrees of limitations owing to its excessive focus on a small-scale single field and the lack of research on urban lighting needs.

In sum, in the field of urban planning, there have been few studies that systematically analyze the overall lighting supply and demand in urban outdoor spaces from a low-carbon perspective and use this as an entry point to support spatial and temporal planning. In this paper, first, four main factors are selected to provide a quantitative accounting method for urban lighting demand; next, Binjiang District in Hangzhou is taken as the study area for empirical research, and the results from the calculation of lighting demand are measured by combining temporal and spatial geographical data; finally, the lighting images of urban lighting in Binjiang District are introduced as the lighting supply, and a spatial distribution pattern matching supply and demand is obtained to assess the reasonableness of the current state of lighting and make suggestions for optimization.

2. Study Area and Data

2.1. Study Area

Binjiang District in Hangzhou (Figure 1) was selected for empirical research because Hangzhou, as one of the central cities in China's Yangtze River Delta urban agglomeration, has entered a period of a high level of urbanization. It is the political, economic, and cultural center of Zhejiang Province, ranking 80th on the Kearney list of global cities in 2021. Binjiang District (located on the south bank of Qiantang River, 30°08′20.4″–30°14′20.4″ N, 120°07′4.8″–120°13′55.2″ E), with an area of 72.2 square kilometers and a population of 530,000 (2022), is a relatively well-developed urban area for scientific and smart innovations and the modern service industry in Hangzhou. Several rounds of large-scale lighting construction and renovation have been implemented in Binjiang District in recent years to prepare for the 2022 Asian Games. The district will still be in a golden period of rapid development of lighting construction for the foreseeable future, although it is trying to reduce urban energy consumption and achieve carbon emission reduction through industrial pattern adjustment and structural upgrading. Binjiang District is thus clearly a suitable representation and can be used as a case study area.

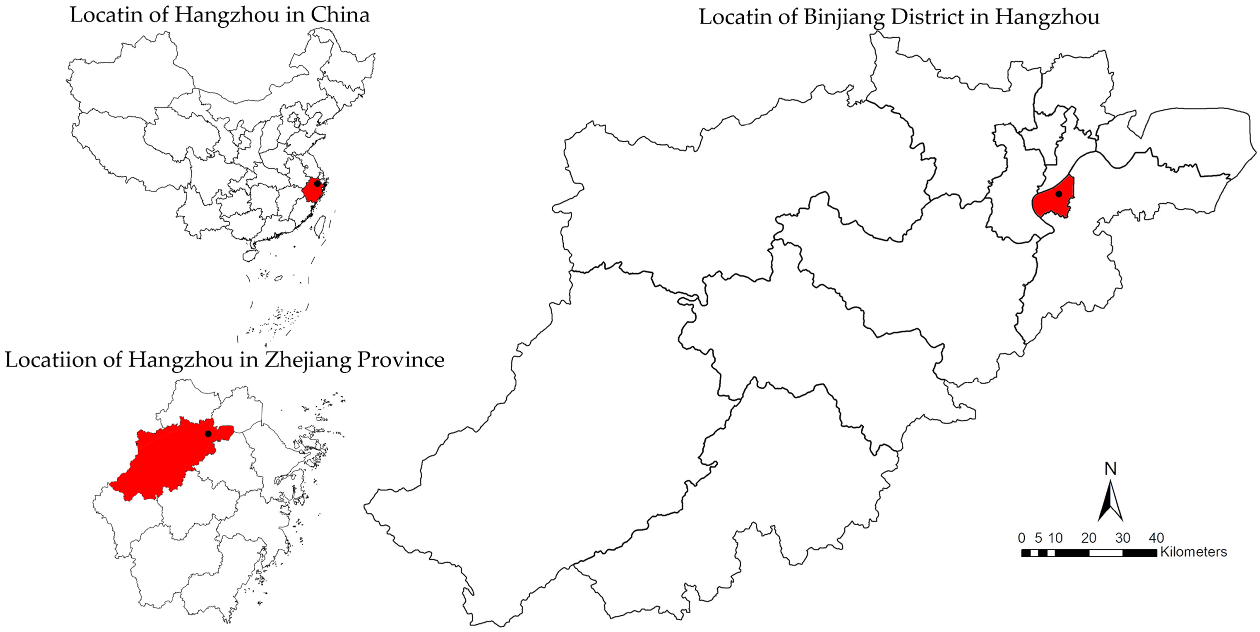


Figure 1. Location map: Binjiang District, Hangzhou.

2.2. Data

The data collection for this study is primarily dependent on geoinformation technology methods. First, the spatial information data are obtained by crawling the Baidu Map, which has rich panoramic data that contains information related to land-use type, roads, buildings, communities, merchants, real-time crowd flow, POIs, and various kinds of individual facility. The Baidu Map has more than one billion users every day. From the open-source data decoded by the Baidu Map from multiple sources, four types of data are collected: Binjiang District land, streets, building elevation models within parcels, and heat maps of crowd activities. The data are then classified and organized. The land-use type data are classified into five categories: land for public administration and services, residential land, commercial land, industrial land, and transportation land, as well as ten subcategories according to China's Urban Land Planning Standards [53]: land for education and scientific research, land for sports and culture, residential land, commercial office land, commercial service land, industrial land, medical and health land, park and green space land, and road land. The road data are sorted into five categories based on type: expressways, main roads, secondary roads, branch roads, and other minor roads. The building elevation model data contain the main building area, the quantity and height, and the distribution of green spaces in each parcel. The heat map data of nighttime crowd activities are derived from the average value of crowd activities from 18:00 to 24:00 at night for one week in spring and autumn 2022. The accuracy resolution of the data is 500 m. The data reflect the crowds gathering in different areas of the district—that is, the changes in crowd gathering density are measured using the established distance decay function. Except for the crowd heat map data, the remaining three types of data, which were formed in 2018, were calibrated and corrected in 2020 and 2022, respectively.

The nighttime lighting brightness image data from Binjiang District are then obtained through open network channels. The image data are primarily obtained from the 2022 Chinese remote sensing image data from DMSP/OLS on NASA's DMSP-OLS Nighttime Lights Time Series website, with data accuracy of 500 m.

3. Methodology

In this paper, we study the relationship between supply and demand in urban lighting planning through model construction. The relevant literature indicates that urban spatial form can have a root effect on urban carbon emissions [54–56]. This effect is derived from the general concepts considered when measuring spatial form, such as centrality, density, aggregation, accessibility, continuity, and mixed use [57,58]. The spatial and temporal factors involved influence nighttime urban human activities and parcels. The demand for urban lighting, in fact, represents the human demand for lighting in urban parcels. Lighting, from spatial and temporal standpoints, affects people's perceptions of a city [59], as well as their activities and spatial distribution [60]. This, in turn, exerts an influence on the final formation of nighttime urban spatial forms to varying degrees. Thus, considering the above, as well as the interrelationship between energy consumption and carbon emissions, and with reference to the links between people and lighting planning in the urban lighting master plan of Hangzhou, we determine the factors that can directly or indirectly affect nighttime lighting demand, people, and energy consumption in district parcels.

We first determined the relationships between the target parcel attributes and lighting demand. At present, dividing urban lighting control zoning according to different target parcel functional attributes is still the prevailing global mainstream method for determining urban lighting demand [61,62]. Different lighting planning control levels determine parameters such as the selection of lighting brightness, illuminance, and color temperature within that level of zoning, which also affect energy consumption and reflect carbon emissions. The road grade attributes around the target parcel also affect lighting demand in the target parcel [63]. The buildings and structures on both sides of the road present different lighting demands because of the different road grades around them. Parcel volume may also reflect the construction intensity of a parcel [64], which can be seen as another way to distinguish the differences between parcels from a lighting perspective. Finally, a nighttime crowd's travel activity directly reflects the crowd's demand for lighting in a target parcel [65]. Our comparison of functional spaces of the same nature shows that the larger the crowd that gathers, the greater the demand for lighting in a given parcel space [66].

To calculate the lighting supply comparison, we introduce a light image of urban lighting in the current year, use the luminance data of the current light image as the lighting supply, convert it into the current nighttime urban parcel lighting demand value, and then, compare it with the newly calculated lighting demand to determine whether the supply matches the demand. This study is divided into the following two steps: in step 1, a quantitative model of nighttime urban lighting demand in Binjiang District is constructed, and in step 2, the relationships between the supply and demand for lighting construction in the district are calculated and compared. This study also provides ideas for how to optimize the lighting pattern and balance carbon emissions (see Figure 2 for a flow chart of the study).

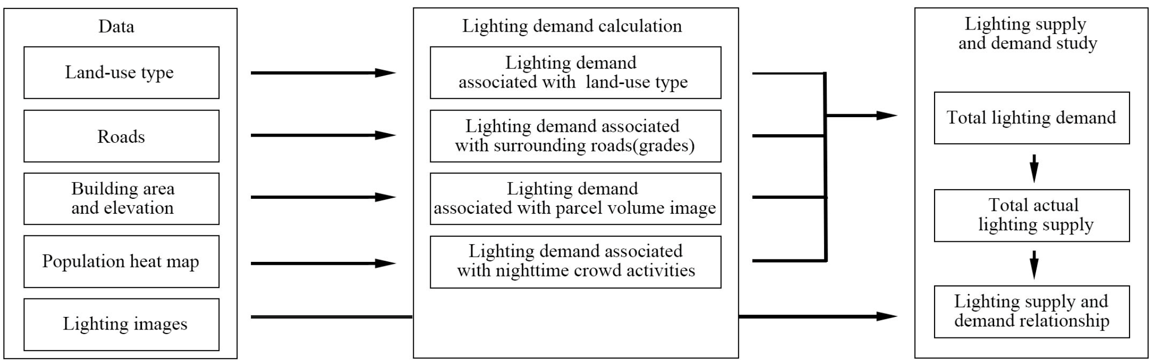


Figure 2. Flow chart of the study.

3.1. Method for Calculating Lighting Demand

3.1.1. Derivation of the Lighting Demand Calculation Model

The factors associated with the lighting demand and energy consumption of a parcel (i.e., the energy consumption required for lighting) are quantified separately to obtain the lighting demand created by each factor. The total lighting demand of a parcel is the sum of the lighting demand of all of the factors. The total lighting demand is set as E, which is calculated using Equation (1):

$$E = \sum_{i=1}^{n} E_i, \tag{1}$$

where n is the total number of factors, and i is the i-th factor.

As mentioned above, there are four main factors influencing the lighting demand of an urban target parcel; thus, $n = 4$, and the factors are target parcel attributes (P_1), roads (grades) around the parcel (P_2), parcel volume (P_3), and nighttime crowd activity characteristics (P_4). The lighting demand formed by each factor can be set as E_1, E_2, E_3, and E_4. The total demand is the sum of the demand of each factor, as shown in Equation (2):

$$E = E_1 + E_2 + E_3 + E_4, \tag{2}$$

where E is the total lighting demand, E_1 is the lighting demand associated with the parcel's land-use type, E_2 is the lighting demand associated with the surrounding roads (grades), E_3 is the lighting demand associated with the volume of the parcel, and E_4 is the lighting demand associated with the characteristics of the nighttime crowd travel activities. The lighting demand for each factor can be viewed as the product of the factor and the corresponding coefficient and weight, which leads to Equation (3):

$$E_n = W_n \beta_n P_n, \tag{3}$$

where E_n is the lighting demand corresponding to each factor, $n = 1, 2, 3, 4$; W_n is the weight; β_n is the coefficient corresponding to each of the four factors; and P_n denotes the factor.

3.1.2. Description of Model Factors and Parameter Assignment

In the measurement model, Table 1 shows lighting demand associated with land-use type (E_1) and lighting demand associated with surrounding roads (grades) (E_2). When assigning values to the product of the above two factors and the corresponding coefficients ($P_1 \times \beta_1$, $P_2 \times \beta_2$), reference is made to the overall urban planning of Hangzhou and the Hangzhou city lighting master plan. In terms of the lighting demand associated with parcel volume (E_3) and lighting demand associated with nighttime crowd activities on a given land-use type (E_4), value assignment to $P_3 \times \beta_3$ and $P_4 \times \beta_4$ was performed according to the actual needs in the research practice of urban lighting planning engineering. In Table 1, the coefficient values (1, 2, 3, 4, 5) of the four factors were only used to distinguish the differences in the degree of influence, not the absolute value of the scale of demand.

The values of $P_1 \times \beta_1$ represent the five levels of the luminance control zones. The luminance control zoning groups spaces with similar brightness together. In lighting planning, different luminance control zones reflect the different needs of people or plots for lighting. In the current mainstream research methods of urban lighting planning, urban areas or plots with the same function are usually regarded as being in the same luminance control zone. Establishing different control zones is conducive to the formulation of different lighting luminance control indicators and strategies [67].

The weights of the factors were implemented using the expert scoring method. Specific descriptions are provided in Table 2.

Table 2. Urban lighting demand measurement classification, weight, coefficient value assignment, and description for lighting demand associated with land-use type.

No.	Lighting Demand Associated with Land-Use Type E_1			Level of Luminance Control Zone	Weight	$P_1 \times \beta_1$	Description
	Category		Subcategory				
1	1	Commercial land	Commercial service land	Level 1	0.45	5	The Level 1 luminance control zone has the highest demand for nighttime outdoor urban lighting. The demand decreases from Level 2 to Level 3 and Level 4, and the Level 5 luminance control zone (dark sky protection zone) has the lowest demand.
	2		Commercial office land	Level 2		4	
	3	Public admin-istration and service land	Sports and cultural land	Level 2		4	
	4		Land for education and scientific research	Level 3		3	
	5		Administrative office land				
	6		Medical and health care land	Level 3		3	
	7		Park and green space land	Level 4		2	
	8	Residential land	Residential land	Level 3		3	
	9	Industrial land	Industrial land	Level 4		2	
	10	Dark sky protection zone		Level 5		1	

$P_2 \times \beta_2$ represents the different lighting requirements of buildings and structures on both sides of different levels of roads [68,69]. Due to a major initiative issued by the State Council to activate nighttime businesses and markets and develop a nighttime economy—coupled with the 2022 Asian Games renovation activities—the city of Hangzhou has been prompted to carry out a new round of planning and updating of a larger range of neighborhood landscape lighting, led by the government and businesses. The most important renovation strategy has been to enhance lighting for buildings and structures along the streets according to demand. Determination of the extent to which lighting should be enhanced is based on the road grade, traffic flow, pedestrian flow, and size of the buildings in the parcel on both sides of the road. Specific descriptions are provided in Table 3.

Table 3. Urban lighting demand measurement classification, weight, coefficient value assignment, and description for lighting demand associated with surrounding roads.

No.	Lighting Demand Associated with Surrounding Roads (Grades) E_2		Weight	$P_2 \times \beta_2$	Description
2	1	Impact of urban expressway on surrounding parcels	0.15	5	The land near urban expressways was influenced by nighttime lighting the most. The influence of other roads decreased proportion-ally, with minor roads and alleys being influenced the least.
	2	Impact of urban main roads on surrounding parcels		4	
	3	Impact of urban secondary roads on surrounding parcels		3	
	4	Impact of urban branch roads on surrounding land		2	
	5	Impact of other minor roads and alleys on surrounding parcels		1	

The elevation data of buildings and structures within the parcel are incorporated into the lighting demand assessment by parcel volume (E_3); that is, the parcel volume is a product of the parcel construction area and the average height of the buildings within the parcel ($P_3 \times \beta_3$). Compared with a flat, two-dimensional concept of land-use type, the parcel volume calculation makes the target parcel more three-dimensional [70]. The calculation results for the volume data result in characteristics similar to the Zipf distribution; that is, the frequency of the parcel volume distribution is inversely proportional to the size. The threshold value of parcel volume is thus suitable for the quantile division method. From the median value, the values are divided into five levels upward and downward. This allows for better differentiation of different volumes of the parcels in Binjiang District, so that the calculation of total lighting demand can be more scientific. Specific descriptions are provided in Table 4.

Table 4. Urban lighting demand measurement classification, weight, coefficient value assignment, and description for lighting demand associated with parcel volume.

No.	Lighting Demand Associated with Parcel Volume E_3		Weight	$P_3 \times \beta_3$	Description
3	1	Greater than the third quartile	0.11	5	The median size of the parcel volume was used to divide the five levels. A greater median level means higher lighting demand for the parcel volume.
	2	Greater than the median of the second and third quartiles and less than or equal to the third quartile		4	
	3	Greater than the median of the first and second quartiles and less than or equal to the median of the second and third quartiles		3	
	4	Greater than the first quartile and less than or equal to the median of the first and second quartiles		2	
	5	Less than or equal to the first quartile		1	

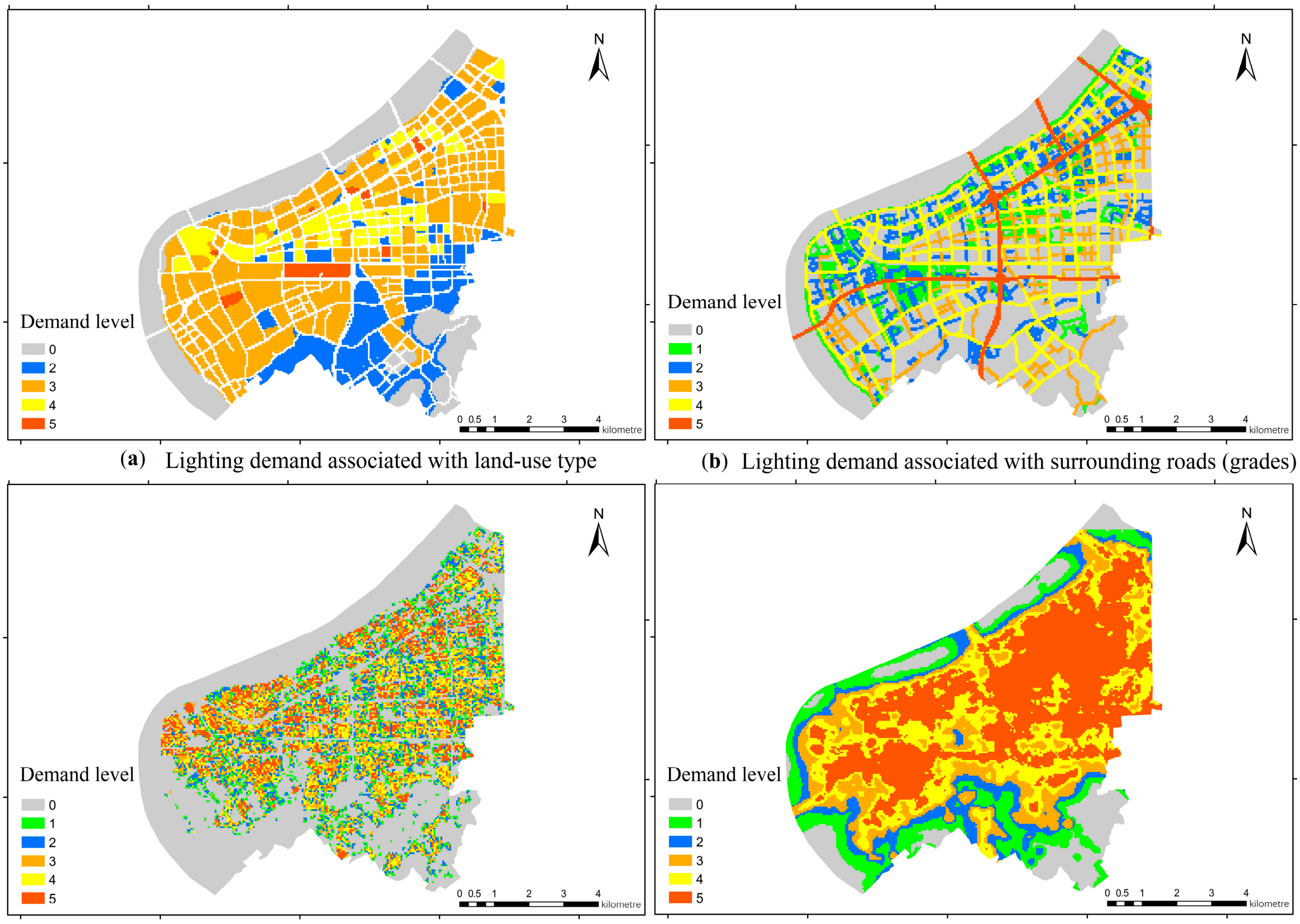
The inclusion of lighting demand associated with nighttime human activities (E_4) in the calculation is attributed to the importance of the human-centered concept of lighting planning and construction [71]. This importance can be briefly described as attention to social elements that reflect people's quality of life [72]. In recent years in China, new evaluation systems in urban development have emerged, such as the Harmonious Society Index System and the Scientific Evaluation Criteria for Livable Cities, and their focus has shifted from the early measurement of material inputs to the evaluation of quality of life [73]. The results of resident satisfaction surveys in China have increasingly been incorporated into the evaluation of urban planning and construction [74] as an important part of the measurement criteria. According to the density distribution characteristics of the population heat map data, threshold division was carried out after the relative rounding of the natural breaks method division results. In the process of the weighted addition of factors to form the total lighting demand, the population heat map data were analyzed separately according to land-use type by multiplying the population heat map results with the land-use type attribute coefficients ($P_4 \times \beta_4$). In general, for a given land-use type, a higher population aggregation indicates higher parcel lighting demand. Specific descriptions are provided in Table 5.

Table 5. Urban lighting demand measurement classification, weight, coefficient value assignment, and description for lighting demand associated with nighttime crowd activities on a given land-use type.

No.	Lighting Demand Associated with Nighttime Crowd Activities on a Given Land-Use Type (Degree of Crowd Gathering, Unit: People/Hectare) E_4 (Land-Use Type)		Weight	$P_4 \times \beta_4$	Description
4	1	>60	0.29	5	In general, for a given land-use type, a higher con-centration of people is asso-ciated with higher lighting demand for the parcel.
	2	40–60		4	
	3	20–39		3	
	4	>10–19		2	
	5	≤10		1	

3.1.3. Result of Calculation

After the value assignment of parameters and factors for the calculation model, the parcels within the whole Binjiang District were divided into a grid map of 50 m × 50 m grid cells with the help of ArcGIS10.5, and this grid was used as the base map for the subsequent study. In this paper, the size of the grid cell was 50 m × 50 m for the following reasons. Lighting planning tends to be conducted at the macro level, and the planning unit of luminance control zones is usually the community, a city's functional plate range with the public consensus, or other large-scale ranges. A luminance control zone is generally composed of one or more grid cells. Micro-level designs, such as for a building, a street, or a shop, should be completed by planning and management departments below the district level or planning or construction companies responsible for project implementation. According to the derivation formula, E_1, E_2, E_3, and E_4 were calculated first using the parameters in Tables 1–4, and Figure 3a–d are generated in turn. The results were substituted into Equation (3) to obtain the total lighting demand (see Figure 4). The lighting demand levels were then reclassified according to the total lighting demand.



(a) Lighting demand associated with land-use type **(b)** Lighting demand associated with surrounding roads (grades)

(c) Lighting demand associated with parcel volume **(d)** Lighting demand associated with nighttime crowd activities

Figure 3. Lighting demand levels calculated from each factor.

3.2. Comparison between Supply and Demand in Lighting Planning and Construction

3.2.1. Current Supply-and-Demand Comparison Measurement Method in Lighting Planning and Construction

The nighttime lighting images acquired for Binjiang District's (proportional to the actual carbon emissions) were compared to the total lighting demand calculation results to assess the match between lighting supply and demand in different urban areas from a low-carbon perspective. The analysis process and steps are as follows:

In step 1, the nighttime urban lighting image data and the total lighting demand calculation result data of Binjiang District were read by ArcGIS10.5. The WGS-84 geocentric coordinate system was used as the reference system to project all of the data in Mercator. Incidental noise such as clouds and fires were filtered out from the city light image data, and the grayscale range of the data was set to 1–63 to generate luminance images. To correspond to the accuracy of the grids divided by the lighting demand calculation results, the light image grids were subdivided and transformed from 500 m × 500 m grids to 50 m × 50 m grids.

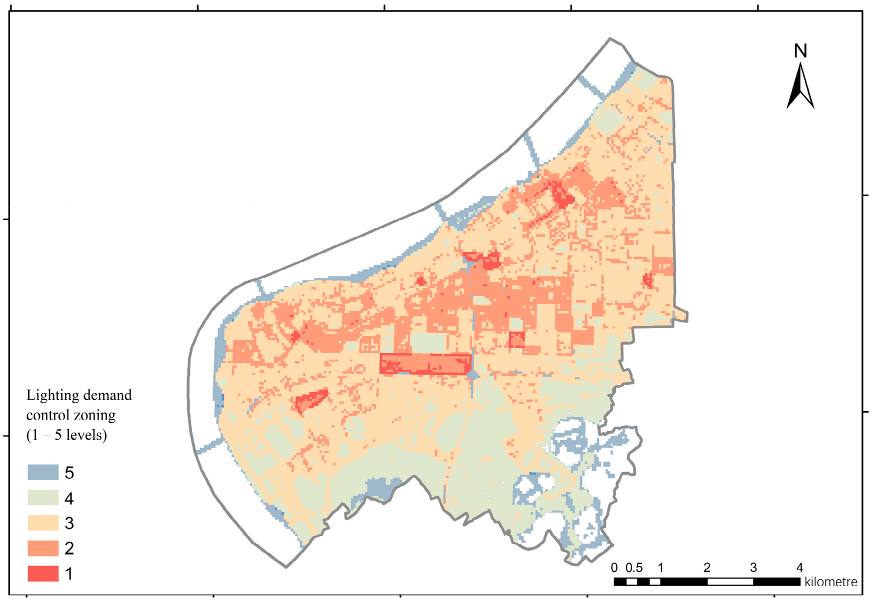


Figure 4. Total lighting calculation results.

In step 2, the quotient was calculated for the image brightness of each grid in the light image of the district and the corresponding lighting demand to define the ratio of the brightness supply for each grid (representing the actual carbon emissions) and the lighting demand (representing the carbon emission demand), as shown in Equation (4):

$$S_i = \frac{A_i}{E_i}, \tag{4}$$

where S_i is the quotient of the image brightness of the i-th grid and the corresponding lighting demand; A_i is the light image value of the i-th grid; and E_i is the calculated value of the corresponding lighting demand of the i-th grid. The results were classified according to the brightness level control zoning.

In step 3, expert scoring was used to identify realistic brightness in multiple places in each level-based lighting zone and areas with reasonable carbon emissions relative to the carbon emissions demand. Specifically, for each type of level-based lighting zone, multiple (about 10) sampling spaces were first selected to measure field illuminance and brightness as well as to record images. Second, five lighting experts in the industry were invited to participate in the review and score all sampling spaces. The total score was then used to calculate the average of the experts' scores. Third, the scoring content included personal feelings about whether the measured light environment in the gridded area is comfortable and meets the needs of the scene, whether the illuminance and brightness measurement values in the main scene in the gridded area are in line with the specification, and whether the lighting design in the gridded area is in line with the three requirements for Hangzhou's lighting planning. Fourth, the maximum score for each sub-item was set to five, and the total score was then calculated by adding up the scores obtained. A sampling space with a total score of 17.5 or more was considered a reasonable area. Fifth, considering the complexity of space, the scale of the district, and the actual sampling workload, five corresponding reasonable areas were selected for each type of lighting level-based lighting zone (see Figure 5).

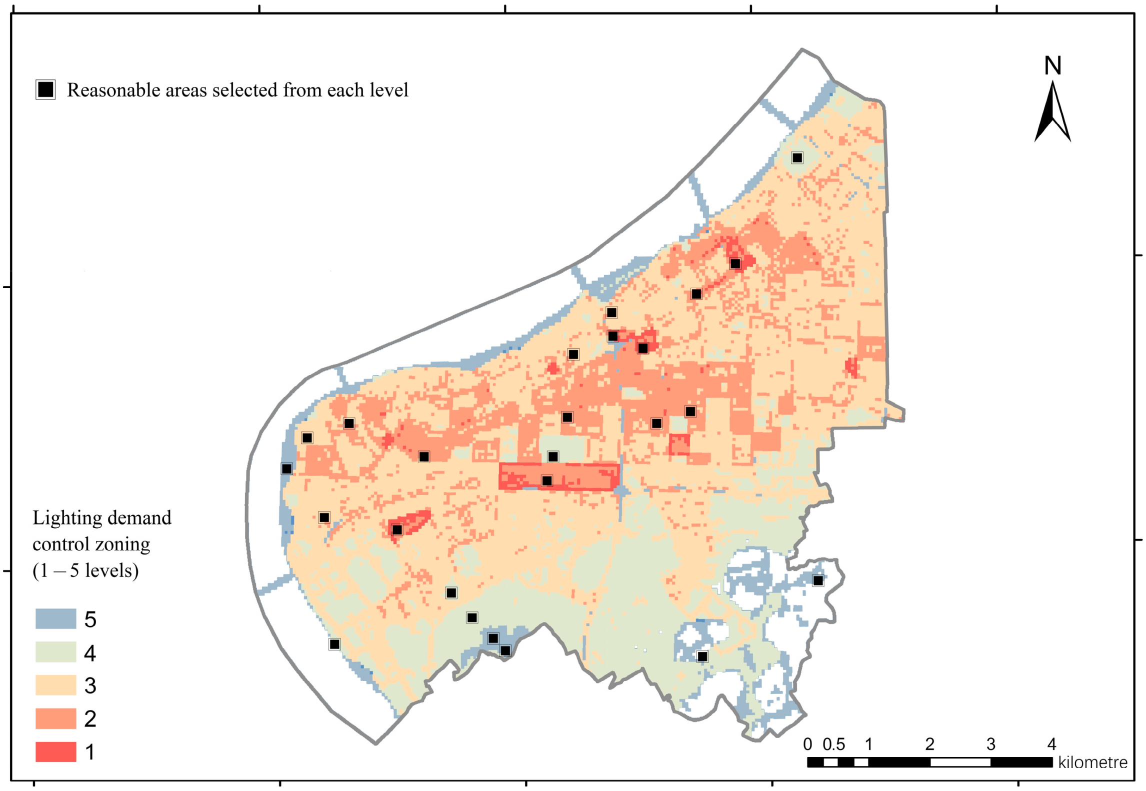


Figure 5. Selection of reasonable areas by experts.

In step 4, the average value of the ratio of light images to the total lighting demand in a reasonable area was calculated according to different lighting level control zones as the benchmark value for the supply-and-demand relationship. That is, in the calculation results of equation 4, with reference to a reasonable area, the ratios of reasonable areas of the same level of control zone were added up, and then, divided by the number of grids in the reasonable areas to derive the benchmark value for the supply-and-demand relationship for each level of lighting control zone, as shown in Equation (5):

$$V_n = \frac{\sum_{i=1}^{k} \frac{A_i}{E_i}}{k}, \tag{5}$$

where V_n is the benchmark value, n is the number of levels of lighting demand, and n = 1, 2, 3, 4, and 5 correspond to the five lighting control zone levels. A_i is the lighting image value of the i-th grid in a reasonable area, E_i is the calculated value of the lighting demand corresponding to the i-th grid in a reasonable area, and k is the number of grids in a reasonable area. For each lighting control zone, V_n (benchmark value) was calculated.

In step 5, the concept of the supply–demand ratio was introduced to calculate the ratio G_j, which is the ratio between the supply of luminance (representing actual carbon emissions) and the demand for lighting (representing the demand for carbon emissions) for each grid in each lighting control zone at various levels. This calculation leads to Equation (6):

$$G_j = \frac{S_j}{V_n}, \tag{6}$$

where G_j is the quotient value, S_j is the quotient value of the image brightness of the j-th grid and the corresponding lighting control level zone, and V_n. is the benchmark value for the corresponding control level.

3.2.2. The Logic of Comparative Analysis of Lighting in Planning and Construction for Different Zones

From the above calculations, it is possible to determine the reasonableness of the carbon emission scale relative to demand in the gridded area of each lighting control zone level based on G_j. A G_j value closer to 1 indicates greater reasonableness. Conversely, a G_j value farther away from 1 indicates lower reasonableness. When $G_j > 1$, the actual light image value of the area is too high, which suggests that the actual lighting brightness is greater than the demand, and carbon emissions are too high; the area's carbon emissions should thus be adjusted and optimized through lighting planning to become reasonable. When $G_j < 1$, it means the actual light image value of the region is too low, which suggests that the actual brightness is less than the demand, so the problem should be identified, and the gap should be filled according to the demand.

4. Results

4.1. Results of Lighting Demand Calculations

4.1.1. Lighting Demand Associated with Land-Use Type

The calculation results (see Figure 3a) show that the area formed when the assigned coefficient value is 3 is the largest, accounting for 61.53% of the total statistical area of land in Binjiang District (all percentages are rounded to two decimal places), followed by the area formed when the assigned coefficient value is 2, which accounts for 21.10% of the total land area. The area assigned a coefficient value of 4 ranks third, accounting for 14.25% of the total statistical land area in the district. Finally, the area formed when the assigned coefficient value is 5 accounts for 3.20%. Binjiang District is mainly composed of residential land, commercial office land, and industrial land. If the lighting control level zones are determined by land-use type alone, as is the case in conventional urban lighting planning and construction, the figure already shows the lighting demands for various parcels from strong to weak, in accordance with the coefficients of 5 to 1. The figure also shows the demand for lighting and illumination in the target area, as well as the resulting energy consumption and carbon emissions ranging from strong to weak. However, this paper is based on calculation via superposition of the four factors, so it is necessary to calculate the total lighting demand for the parcel in combination with the other three factors.

4.1.2. Lighting Demand Associated with Surrounding Roads (Grades)

The result of the E_2 calculation (see Figure 3b) shows that the distribution of roads in Binjiang District exhibits a pattern whereby they are dense in the north and sparse in the south. The distribution of the main roads, secondary roads, and branch roads affects nighttime lighting demand. The impacts of expressways, main roads, secondary roads, and branch roads in each parcel in Binjiang District account for 9.24%, 32.83%, 15.74%, and 21.33% of the total statistical impact in the entire area. In terms of proportion, studies of urban lighting demand should pay more attention to the parcels affected by the main roads. As the lighting demands of buildings and structures on both sides of urban expressways and main roads are higher, their corresponding energy consumption and carbon emissions are also higher than those on both sides of secondary roads, branch roads, and other minor roads. Our field research also finds that a large number of large buildings and structures are located on both sides of the district's expressways and main roads, such as Jiangnan Avenue. The nighttime lighting brightness for both sides of Jiangnan Avenue is beyond that for both sides of the secondary roads, branch roads, and other minor roads. In Figure 3b, in accordance with Table 3, coefficients of 5 to 1 are assigned to lighting demand and energy consumption to denote levels ranging from high to low, which are factors involved in the calculation of total lighting demand.

4.1.3. Lighting Demand Associated with Parcel Volume

When calculating E_3 (see Figure 3c), consideration is given to the actual data characteristics, such that the impact study of parcel volume is divided into break points based on median parcel volume. The result of the E_3 calculation shows that areas with coefficients of 5 to 1 account for 20.10%, 20.31%, 20.22%, 19.86%, and 19.51% of the total statistical land area in Binjiang District, respectively. The size of parcel volumes in the district is relatively average, but it is noticeable that the distribution of parcel volumes in the northern parcels is denser than in the southern parcels, and there are more large-volume parcels in the east than in the west. According to the land-use type data and a field visit to the district, areas with larger parcel volumes are more likely to be large commercial buildings, business buildings, large industrial parks, and continuous high-rise residential areas. Most of these areas are also concentrated on both sides of the expressways, main roads, and secondary roads. In planning China's future urban lighting enhancement, these large buildings and structures are the focus of enhanced lighting construction.

4.1.4. Lighting Demand Associated with Nighttime Crowd Activities

The result of calculating E_4 (see Figure 3d), together with the field investigation, indicates that there is a strong correlation between nighttime crowd gathering and where these crowds gather. Areas with higher degrees of gathering are mostly concentrated in areas with better accessibility and higher attraction value, such as commercial service areas, large residential buildings, business office buildings, and main traffic routes. Statistically, the areas with coefficients of 5 to 1 account for 39.70%, 23.15%, 14.08%, 9.30%, and 13.77% of the total statistical land area of the district, respectively. Areas with nighttime gatherings of more than 60 people per grid cell have the largest counts. Concentrated in these areas are the main commercial service areas, commercial office areas, residential areas, as well as other related supporting public service facilities for education, administration, and health care. The areas assigned coefficients of 5, 4, and 3 account for a total of 76.93%, which indicates that Hangzhou has a high degree of year-round crowd gathering. The areas with less crowd gathering have coefficients of 2 and 1 and are mainly located in the southern part of the district, where there are mainly residential areas, parks and green areas, urban landscape resorts, and industrial areas.

4.1.5. Analysis of Total Lighting Demand Calculation Results

The lighting demand calculation results for E_1, E_2, E_3, and E_4 were weighted and summed to determine the total demand (see Figure 4). According to the lighting demand for the different parcels, Binjiang District was divided into five lighting control zone levels. In addition to revealing the size of the lighting demand at each lighting level, dividing the control zones also provided a basis for the subsequent calculation and analysis of lighting supply and demand. The control zones were identified from red to blue according to levels one to five (i.e., 1, 2, 3, 4, and 5 in Figure 4).

The Level 1 lighting control zones account for 1.84% of the statistical land area in the entire district, Level 2 for 19.69%, Level 3 for 49.61%, Level 4 for 21.74%, and Level 5 for 7.12%. In Figure 4, lighting demand and the required energy consumption are arranged in descending order based on the lighting control zones from Level 1 to Level 5. Considering the actual situation of the district, Level 3 lighting control zones account for the largest proportion, distributed in the eastern, central, and western areas, but not in the southern area. This is, in part, related to the fact that the district boasts a large number of residential areas and office industrial parks where more people gather. It also has better education, administration, medical, and other related supporting public services. These areas are mostly near the city's main and secondary roads. The difference in proportion between the Level 2 and Level 4 lighting control zones is relatively small. Together, these zones account for a total of 34.15% of the statistical land area of the district, with Level 2 zones mainly distributed in the central part of the district, where there is a concentration of commercial offices, sports, and cultural areas, as well as some commercial service areas. These areas, being close to expressways, main roads, and secondary roads, have a high degree of crowd gathering. Level 4 lighting control zones exist in the southern part of the district, where industrial areas (including industrial parks), green spaces, and a non-clustered distribution of residential areas are concentrated. They occupy a small unit parcel volume, and most are far away from the city's main and secondary roads. Perhaps due to poor accessibility, the degree of crowd gathering in these areas is low. Level 5 lighting control zones are mainly distributed in the south and southeast of the district, as well as along the Qiantang River, and consist mainly of parks, green spaces, resort hotels, scenic areas, and scattered residential and other related supporting facilities. The main reason for the formation of Level 5 lighting control zones may be related to their being in the low-luminance control zone. They are far from the main roads of the city, their parcel volume is small, and their degree of crowd gathering is low. Level 1 lighting control zones account for the smallest proportion, where there are mainly commercial service complexes and related facilities with good accessibility and dense gatherings of people.

There is a significant difference between the results of the lighting demand calculation and the results of the lighting control zoning based on land-use type alone, and this is mainly due to the superposition of multiple factors.

4.2. Comparison of Lighting Supply and Demand

4.2.1. Calculation Results of Supply-and-Demand Reasonableness

This paper evaluates the reasonableness of the actual brightness and carbon emissions of Binjiang District based on lighting demand (see Figure 6). According to supply and demand ratio data distribution characteristics, as well as the actual lighting in different areas, the location entropy values of the grids were set to 0.356445–3.257936, representing five levels: "unreasonable: too dark", "reasonable: somewhat dark", "reasonable,", "reasonable: somewhat bright", and "unreasonable: too bright" (see Table 6). All unreasonable and reasonable levels were classified using the lighting levels based on the overall demand calculation results in Section 4.1.5. The areas classified as "unreasonable: too dark", "reasonable: somewhat dark", "reasonable", "reasonable: somewhat bright", and "unreasonable: too bright" account for 4.51%, 12.72%, 44.28%, 22.2%, and 16.29% of the total statistical land area in the district, respectively (see Table 7). In the "unreasonable: too dark" areas, the actual lighting brightness and coverage should be increased to eliminate dark areas. For the "unreasonable: too bright" areas, unnecessary lighting should be reduced to mitigate light pollution and reduce carbon emissions.

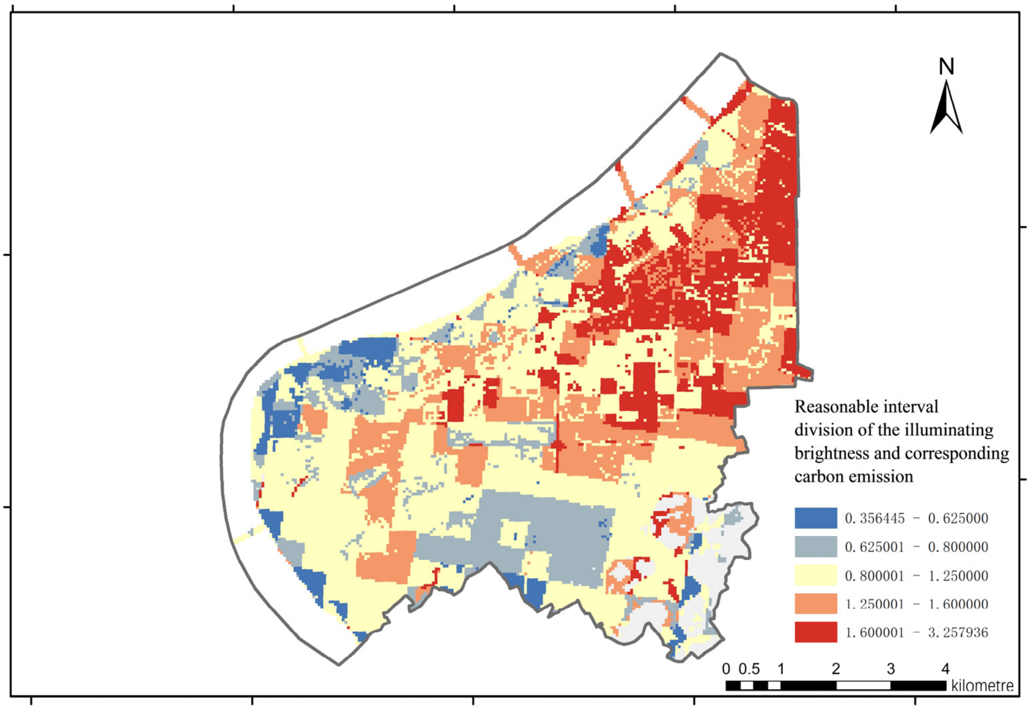


Figure 6. Lighting comparison based on the relationship between supply and demand.

Table 6. Reasonableness value ranges for the brightness of Binjiang District nighttime urban lighting and corresponding carbon emissions.

No.	Value Range	Value Range Corresponding to Reasonable Brightness/Carbon Emissions in a Zone	No.	Value Range	Value Range Corresponding to Reasonable Brightness/Carbon Emissions in a Zone
1	0.356445–0.625000	Unreasonable: too dark/low	4	1.250001–1.600000	Reasonable: somewhat bright/somewhat high
2	0.625001–0.800000	Reasonable: somewhat dark/low	5	1.600001–3.257936	Unreasonable: too bright/too high
3	0.800001–1.250000	Reasonable			

Table 7. Binjiang District nighttime lighting control zone brightness and corresponding carbon emissions reasonableness (%).

No.	Lighting Level Control Zone	Unreasonable: Too Dark (%)	Reasonable: Somewhat Dark (%)	Reasonable (%)	Reasonable: Somewhat Bright (%)	Unreasonable: Too Bright (%)	Percent of the Statistical Land Area of the Entire Area
1	Level 1 lighting control zone	0.13	0.79	0.92	—	—	1.84
2	Level 2 lighting control zone	1.56	2.22	13.44	2.47	—	19.69
3	Level 3 lighting control zone	1.47	3.27	16.60	14.96	13.31	49.61
4	Level 4 lighting control zone	1.31	5.86	10.35	2.84	1.38	21.74
5	Level 5 lighting control zone	0.04	0.58	2.97	1.93	1.60	7.12
6	Total (percentage of the statistical land area of the entire area)	4.51	12.72	44.28	22.2	16.29	100

Note: Percentage statistics are limited to 2 decimal places and rounded.

4.2.2. Comparison of Supply and Demand for Lighting in Different Areas

As shown in Table 3, according to all the levels of lighting control zones as a percentage of their total statistical land area, there are not many "unreasonable: too dark" areas in the district, which may be due to Hangzhou's large-scale projects in recent years that aim to improve lighting in dark areas. Areas that are too dark are mainly concentrated in the southwest and northwest of the district, and in the north along the Qiantang River, as well as in the southern part near the edge of the city. Field visits to the area reveal that there are large park spaces and walking trails distributed in the area, and that there are many residents walking, running, loitering, and sightseeing at around 20:00 at night. From a human perspective, full attention should be paid to the area's pedestrian safety at night and the surrounding lighting quality. Lighting enhancement should not be limited to brightness. In improving functional lighting, more consideration should be given to the feelings of pedestrians in terms of interactive, smart lighting. A major reason for the formation of dark areas in the south is that there is vacant land and there are several construction sites in the area waiting to be developed. There is also a lack of surrounding infrastructure, and the level of crowd gathering at night is low. These elements typically contribute to the formation of urban dark areas. Even so, the low lighting coverage still makes the area extremely unsafe. The construction of lighting to obtain more policy guidance may be a more effective way to accelerate the development of the area.

The areas that are "unreasonable: too bright" are mainly located in the central, southeastern, and eastern portions of the district, with the east being the worst. This may be attributed to two factors. One is that the planners and builders do not understand residents' actual demand for lighting, which results in a contradiction between demand and supply, with actual carbon emissions exceeding those calculated by supply and demand. The other is the forward-looking lighting policy formulated by the government, which has resulted in the current supply of lighting in the parcel exceeding actual demand.

From the calculation and statistical results, most zones in Binjiang District fall within reasonable levels, but 16.29% of the areas could possibly have excessive carbon emissions. In terms of reasonable supply and demand, balanced energy consumption, and carbon emissions, an urgent problem for city lighting managers and planning workers is solving how to reduce unnecessary lighting on a micro level.

5. Discussion

5.1. Innovation of Research

Compared with the existing relevant quantitative research (the four types of research listed in Table 1), the uniqueness and innovations of this research can be summarized as follows: (1) Different research position and scale. From the standpoint of urban lighting planning, this research looked at the lighting demand of Binjiang District at night from a mesoscopic perspective, while existing relevant studies have often been based on the measurement of various parameters of microscopic scenes such as lamps, to optimize lighting design schemes. (2) Different research methods and processes. This research built a calculation model based on the actual situation of urban lighting development in China, as well as Hangzhou Binjiang District, so it had a theoretical and practical basis, while existing relevant research has been conducted in a manner closer to quantitative simulation methods, with different factors chosen for the research. (3) Different purpose and significance. The purpose of this research was to calculate the supply–demand relationship between urban lighting planning and construction by building a model. Additionally, at the planning level, the model's important practical significance is that it can provide a research basis for the relationship between supply and demand to assist in the formulation of urban lighting planning. Although existing research has solved the problem of insufficient lighting in some existing scenes to varying degrees, as well as partly improving the demand for urban lighting, it has not taken the supply–demand relationship as its main theme or focus, so its significance is naturally different from that of this research. The above three innovation points represent the main contributions of this paper; that is, a calculation model based on different factors was created, which makes up for the deficiency in the research field pertaining to the supply-and-demand relationship in urban lighting planning and construction.

5.2. Suggestions for the Optimization of the Urban Lighting Planning Pattern

The process, methods, and conclusions of this research can provide support for urban lighting planning formulation and management. Understanding the current demand for night lighting in the city and clarifying the relationship between lighting supply and demand is conducive to coordinating the balance between supply and demand, guiding the adjustment of lighting planning structure, and continuously improving the quality of the lighting supply system. Through this research, we found that the main problem in Binjiang District at night is that light pollution in the middle and eastern areas is prominent, and that there are some overly dark areas near the administrative boundary of Binjiang District in the west, northwest, and southwest. In this regard, our optimization suggestions are as follows: (1) Investigate areas where the lighting construction is unreasonable within the jurisdiction. The relevant department of the sub-district office of Binjiang District Government should be responsible for further investigation of the streets and buildings in the areas with unreasonable lighting construction within their jurisdiction. This investigation can be conducted by measuring the installed lamps and lanterns and the installation layout on the spot using light measurement instruments, and the measurement results should be compared with the lighting specifications and standards. Testing personnel should accurately record the location of unreasonable lighting, the size of lighting parameters exceeding the standard, and the causes; the government should also invite relevant experts to formulate a transformation scheme. (2) On weekdays, it is recommended to turn off unnecessary lighting equipment or devices and strictly control the "weekday lighting mode" and the "festival lighting mode". That is, only the most basic functional lighting should be used on weekdays, and all the lighting can be used on weekends or festivals so that the lighting on weekdays is darker than that on weekends and during festivals. (3) For those buildings, structures, and landscapes that are unessential but need to implement high-brightness lighting for some reason (e.g., nighttime city image projects), planning records and explanations should be provided, and the time of lighting should be strictly controlled.

From the perspective of macro-policy adjustment, our optimization suggestions are as follows. One idea is to optimize lighting control zoning reasonably. According to the lighting demand of Binjiang District calculated in this paper, the lighting control zones can be re-classified into five levels. Control indicators and requirements, such as a the reasonable clarification of lighting brightness and range supplied to each zone, can be established for zones with different levels of demand. Zoning adjustments may also affect the original landscape lighting pattern. In the framework of the original landscape pattern, it is therefore necessary to make fine adjustments according to the brightness requirements of the control zone. Another idea is to carry out lighting optimization and transformation projects from a humanistic perspective to match lighting demands in each area. Efforts should be made not only to keep an eye on the light pollution of the central and eastern areas of Binjiang District (to reduce the brightness to a reasonable level), but also to focus on the transformation of the city's dark areas. In areas that are too dark, it is necessary to appropriately increase the brightness to enhance the safety and beauty of the nighttime environment. Furthermore, urban development can be achieved using a combination of questionnaires, visits, and other ways to understand local people's views and needs regarding nighttime city lighting construction; strengthening the "public participation" system; and engaging the public. The third idea is to conduct lighting pattern optimization using a closed-loop mechanism. The analysis of the supply-and-demand relationship for nighttime lighting can be seen as a kind of evaluation study for lighting planning. This relationship can be regularly evaluated to guide adjustments to lighting zoning and provide a reference for the subsequent revision of urban lighting planning.

5.3. Possible Directions for Improvement

This paper involved an empirical study conducted in Binjiang District, Hangzhou, to provide a reference methodology for comparative studies of urban lighting supply and demand. However, there is room for improvement. First, the data were collected from heat maps of crowd activities in Binjiang District for one week in the spring and one week in the autumn to calculate the average. This may add randomness to the derivation of the study results. Because the basis of classification by crowd size/grid area is influenced by the data, more than 60 people were automatically grouped into one category when generating the results. However, Hangzhou is a relatively large city, so most areas of the district show a high demand for lighting. This is due to the low accuracy of data acquisition. Future studies could expand the channels of data acquisition to obtain data that are more precise or editable according to actual demand to improve the accuracy of the research results. Second, the parameters of the empirical research part of this paper primarily refer to Hangzhou's urban plan and expert scoring opinions. Because conditions vary from city to city, it may be necessary to make different adjustments to the method, such as adding other factors, when calculating nighttime lighting supply and demand for other cities. More cities should be selected for study in subsequent work to further summarize the mathematical and physical patterns of urban lighting supply-and-demand calculations. Third, due to its space limitations and research directions, this study does not include field investigation and research on the causes of the supply–demand relationship for specific parcels in Binjiang District from a microscopic perspective. It also does not include questionnaires, which would make the research results richer and could be discussed in depth in subsequent research. Fourth, again, due to its space limitations and research directions, this study does include an in-depth analysis of the carbon emissions generated by lighting at night, based on the relationship between supply and demand. Follow-up research should establish a balanced relationship between lighting demand, energy consumption, and carbon emissions in Binjiang District as soon as possible, and research on low-carbon methods of satisfying lighting demand should be incorporated into the field of urban lighting planning. Fifth, the study scale was mesoscopic, and the model still had errors when viewed from a microscopic scale. Thus, the size of the study plot grid can also be subdivided according to the needs of the study, such as from the original 50 m $\times$ 50 m to 10 m $\times$ 10 m or even smaller. The basis of the plot grid size selection was explained in the paper. Finally, the paper investigated the temporal and spatial aspects of people's activities and included them as important factors associated with urban lighting demand. Future studies should pay more attention to nighttime crowd activities, considering the importance of the "human-centered concept" in urban lighting planning and construction.

6. Conclusions

This study conducts an empirical study of Binjiang District in Hangzhou to provide a reference methodology for the comparative study of urban lighting supply and demand. The process consists of two parts. In the first part, four factors that can affect urban lighting demand are selected. The total lighting demand for a parcel is calculated and categorized into lighting level control zones according to demand by establishing mathematical models. In the second part, image maps of Hangzhou Binjiang District are introduced to calculate and compare the lighting brightness and range in different areas, as well as the reasonableness of the supply and demand for carbon emissions. A comparative analysis is then conducted on the calculation results.

This study can draw four main conclusions. First, the areas with unreasonable lighting brightness account for 20.8% of the total statistical area of the study district, of which dark areas account for 4.51%, occurring mainly in the southwest and northwest, the northern area along the Qiantang River, and the southern area near the edge of the district. Areas prone to light pollution account for 16.29% of the total area, and are mainly concentrated in the central, southeastern, and eastern areas. Second, according to lighting demand, areas in the Level 1 lighting control zone account for 1.84% of total land, which is the smallest proportion of the total area for the five lighting level control zones. Most parcels belong to the Level 3 lighting control zone, which accounts for 49.61%, and is mainly distributed in large areas of the central, southern, and eastern part of the district. Third, the planning and construction of urban lighting is closely related to carbon emissions. Rationalizing nighttime lighting demand in Binjiang District will greatly help to adjust and optimize regional carbon emissions, which can be balanced by reducing unnecessary lighting or increasing lighting construction. A lighting demand–carbon emission balancing mechanism should be established for nighttime lighting in Binjiang District as soon as possible. Fourth, this study constructs a research method to calculate the comparative relationship between lighting supply and demand, which provides a reference for future research on the planning and construction of urban lighting.

The process, methods, and conclusions of this study provide support for the preparation and management of urban lighting planning. An accurate grasp of current urban nighttime lighting demand and clarification of the relationship between lighting supply and demand will help to coordinate this balance, guide the structural adjustment of lighting planning, and continuously improve the quality of the lighting supply system.

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Abbreviations

DMSP #OLS	Global day and night images obtained through Operational Linescan System sensors based on operations of the United States Defense Meteorological Satellite Program. DMSP#OLS night light images can reflect comprehensive night information such as cities, road traffic, and habitation distribution.
NPP-VIIRS	Global day and night images obtained through Visible Infrared Imaging Radiometer sensors on board based on the Suomi National Polar-orbiting Partnership (Suomi NPP) satellite. NPP-VIIRS night light images also reflect comprehensive night information on cities, traffic, and habitation distribution.
POI	Points of interest, which are any meaningful locations on a map that are geographically significant

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