## Introduction

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| 【up2024 1107 16:31】   1. The urban heat island effect refers to the phenomenon where urban temperatures are significantly higher than those in surrounding rural areas (Oke, 1995), resulting in greater heat exposure for city residents during hot seasons. 2. With the continued warming of the global climate, the frequency and intensity of urban heat waves are expected to increase. It is projected that by 2050, urban summer temperatures could rise by as much as 3°C (Huang et al., 2019). 3. Increasingly frequent and intense urban heat waves have numerous negative impacts on urban ecosystems. Specifically, they can inhibit vegetation growth and raise the risk of forest fires (Ganeshan et al., 2013). In addition, heat waves adversely affect various aspects of urban socio-economic activities, including increasing energy consumption, reducing residents' comfort levels, and even elevating mortality risk (Santamouris, 2020; Huang et al., 2024; Gao et al., 2023). 4. As awareness of the harms caused by the urban heat island effect grows, finding effective ways to mitigate this effect and regulate urban microclimates has become one of the most pressing environmental issues facing cities today. | 【up2024 1107 16:31】  总结   * UHI概述 * 未来UHI趋势 * UHI危害 * 缓解UHI很有必要  1. 城市热岛效应指的是城市气温显著高于周边农村地区的现象（Oke, 1995），使得城市居民在炎热季节面临比乡村更高的热暴露。 2. 随着全球变暖的持续，城市热浪的频率和强度预计将不断上升。据预测，到2050年，夏季城市气温可能升高多达3℃（Huang et al., 2019）。 3. 越来越频繁和强烈的城市热浪对城市生态系统产生了诸多负面影响。具体而言，热浪会抑制植被生长，增加森林火灾风险等（Ganeshan et al., 2013）。此外，热浪对城市的社会经济活动也有广泛的负面影响，包括增加能源消耗、降低居民生活舒适度，甚至提高死亡风险（Santamouris, 2020; Huang et al., 2024; Gao et al., 2023）。随着人们对城市热岛效应危害认识的加深，如何有效缓解城市热岛效应并调节城市小气候，已成为当前最紧迫的城市环境问题之一。 |
| 【up2024 1107 17:31】   1. The creation and strategic placement of green spaces have been shown to be particularly effective in mitigating the negative impacts of extreme heat waves. Urban vegetation reduces heat absorption through shading and evapotranspiration, thereby lowering local temperatures. Among the factors influencing the cooling effect of green spaces, green space area has received considerable attention. Most studies indicate that as green area increases, both the cooling intensity and the cooling range of the surrounding area expand (Cao et al., 2010; Peng et al., 2021; Gomez-Martinez et al., 2021). 2. However, there remains some uncertainty regarding the effects of green space configuration. For example, a study involving multiple Asian cities found a positive correlation between the landscape shape index (LSI) and the urban cool island effect caused by vegetation. Conversely, studies in some African and Chinese cities have shown a negative correlation between these two factors (Ekwe et al., 2021; Zhou et al., 2019; Fan et al., 2019). Overall, the relationship between green space configuration and cooling effect is influenced by multiple factors such as region and season, warranting further analysis. 3. In addition, surrounding urban characteristics, including land cover patterns and three-dimensional morphology, play an important role in determining the strength and extent of green space cooling effects (Qiu et al., 2020; Liao et al., 2023). Most current research focuses on two-dimensional factors, with relatively less attention given to three-dimensional factors. In fact, buildings not only alter the absorption and release of ground radiation but also channel airflows. Some studies suggest that three-dimensional geometric structures may have a more significant impact on urban thermal environments (Yin et al., 2018; Tian et al., 2019; Unger, 2009). Therefore, further research is needed to explore the influence of three-dimensional urban morphological features, especially building characteristics, on the cooling effects of green spaces. | 【up2024 1107 17:31】  总结   * UHI缓解方法 * 绿地降温 * 绿地降温的影响因素 * 绿地自身 * 绿地周边环境 * 2D * 3D  1. 合理的绿地创建与布局已被证明在缓解极端热浪的负面影响方面尤为有效。城市植被通过遮阴和蒸散作用减少热量吸收，从而有效降低局部温度。在影响绿地降温效果的因素中，绿地面积受到广泛关注。大多数研究表明，随着绿地面积的增加，其降温强度和对周边区域的降温范围均会扩大（Cao et al., 2010; Peng et al., 2021; Gomez-Martinez et al., 2021）。 2. 关于绿地配置的影响，目前研究结果尚存在一定不确定性。例如，一项针对多个亚洲城市的研究发现，景观形状指数（LSI）与植被引起的城市冷岛效应呈正相关关系，而在非洲和中国部分城市的研究中则显示了两者的负相关关系（Ekwe et al., 2021; Zhou et al., 2019; Fan et al., 2019）。总体而言，绿地配置与降温效果的关系受到研究区域、季节等多因素的影响，需进一步深入分析。 3. 此外，周围的城市特征（如土地覆盖格局和三维形态特征）对绿地的降温强度和影响范围也起着重要作用（Qiu et al., 2020; Liao et al., 2023）。当前研究主要关注二维因素，而对三维因素的关注相对较少。事实上，建筑不仅会改变地面辐射的吸收和释放，还能引导气流。一些研究表明，三维几何结构可能对城市热环境产生更显著的影响（Yin et al., 2018; Tian et al., 2019; Unger, 2009）。因此，有必要进一步研究三维城市形态特征，尤其是建筑特征，对绿地降温效果的影响。 |
| 【up2024 1107 20:03】   1. Current methods for studying the cooling effects of green spaces primarily include remote sensing analysis, model simulations, and field measurements. Model simulations inevitably simplify real-world conditions to some degree, while remote sensing analysis relies on surface temperatures, which differ from air temperatures at pedestrian height (Cao et al., 2021). This discrepancy arises because surface temperature is directly driven by solar radiation, causing greater variability and closely linking it to surface material properties. In contrast, air temperature is mainly influenced by surface radiation, resulting in relatively smaller fluctuations. Additionally, the temporal variation patterns of these two types of measurements differ (Sheng et al., 2017). Although field measurements require more time and labor, they offer a more accurate reflection of local microclimatic conditions (Lin et al., 2017; Qi et al., 2022). 2. Existing field-based studies on green space cooling effects typically focus on a limited number of monitoring points around green spaces, resulting in low monitoring density. This limitation makes it challenging to capture high-resolution, continuous variations in thermal environmental indicators, such as temperature, across surrounding urban areas. Consequently, these studies may not accurately reflect the fine-scale spatial patterns of the thermal environment around large green spaces, affecting the precision of estimates for cooling distance, cooling intensity, and their correlations with environmental factors. 3. Therefore, establishing a high-density meteorological monitoring network is necessary to facilitate on-site monitoring of the thermal environment around green spaces. This approach would enable the quantification of fine-scale spatial and temporal patterns of temperature, relative humidity, and thermal comfort surrounding green spaces, along with an assessment of the environmental factors influencing these patterns. | 【up2024 1107 20:03】  总结   * 介绍绿地降温研究方法，指出只有实测才准确 * 介绍实测相关研究，指出实测相关研究的不足——密度低 * 指出有必要开展高密度监测  1. 当前研究绿地降温效果的主要方法包括遥感分析、模型模拟和现场实测。模型模拟不可避免地会对实际情况进行一定程度的简化，而遥感分析基于地表温度，与人行高度的气温存在差异（Cao 等, 2021）。这种差异是由于两者的驱动机制不同：地表温度直接受太阳辐射的驱动，导致较大的温度变化幅度，并与地表材料特性密切相关；相比之下，气温主要受地表辐射影响，变化幅度相对较小。此外，两者的时间变化特征也存在差异（Sheng 等, 2017）。尽管现场实测相对而言需要更大的时间和人力投入，但其分析能更准确地反映当地的微气候状况（Lin 等, 2017；Qi 等, 2022）。 2. 当前关于绿地降温效果的实测研究主要集中在绿地周边的个别监测点，监测密度较低。这种不足使得难以获取城区周边气温等热环境指标的高精度连续变化，从而可能无法准确反映大型绿地周边热环境的精细尺度空间格局。这也影响了对绿地降温距离、降温强度等指标及其与环境因素相关性估算的准确度。 3. 因此，有必要建立高密度的气象监测网络，以便对绿地周边的热环境进行现场监测，从而进一步量化绿地周边气温、相对湿度和热舒适度的精细尺度时空格局及其受到的环境因素影响。 |
| 【up2024 1107 20:37】   * It is important to note that urban green spaces affect not only the temperature of the microclimate but also significantly influence the spatial and temporal patterns of humidity. Observations by Zhang et al. (2013) showed that, while green spaces in subtropical cities can lower air temperatures by up to 5°C, they can also increase relative humidity by approximately 8%. In Hong Kong's high-density urban environment, both humidifying and dehumidifying effects of small parks have been observed (Cheung et al., 2021). * While green spaces can decrease nearby temperatures, the rise in relative humidity may contribute to a greater feeling of mugginess, partially offsetting the relief in thermal comfort that cooler temperatures would otherwise provide. Therefore, under the combined effects of temperature and humidity, the spatial and temporal patterns of green spaces' influence on thermal comfort—as well as the driving factors behind them—remain unclear, especially during periods of extreme summer heat. * Unlike air temperature, which reflects the objective thermal conditions, thermal comfort relates more closely to the human body’s heat load and is a more accurate measure of people’s satisfaction with the thermal environment (Wang, 2019). Thus, when assessing the impact of the thermal environment on individuals or groups, thermal comfort serves as a more meaningful metric than conventional meteorological indicators like temperature alone. * Establishing a high-density monitoring network around green spaces is essential to capture multiple meteorological indicators. This approach will allow for a more comprehensive understanding of how large urban green spaces impact the surrounding thermal environment. | 【up2024 1107 20:37】  总结   * 绿地对湿度有影响 * 绿地对热舒适度有影响 * 但相关研究不足 * 需要深入  1. 需要注意的是，绿地不仅影响城市微气候的温度，还对湿度的时空格局有显著影响。根据张等人（2013）的观测结果，尽管绿地在亚热带城市中能够降低气温达5°C，但同时也使相对湿度增加了约8%。在香港的高密度城市环境中，小型公园的增湿和减湿效应均有观测到（Cheung et al., 2021）。 2. 尽管绿地周边的温度有所下降，但相对湿度的增加会导致居民产生更强的闷热感，在一定程度上抵消了温度下降带来的热舒适缓解。因此，在气温和相对湿度的综合作用下，绿地对热舒适度影响的时空格局及其影响因素仍不完全明了，尤其是在夏季高温的背景下。 3. 与仅反映客观热环境状况的气温不同，热舒适度更能体现人体承受的热负荷，因而能够更准确地反映人们对热环境的满意度（Wang, 2019）。因此，在评估热环境对个人或群体的影响时，热舒适度比单纯使用温度等气象指标具有更确切的意义。 4. 为了更全面地理解大型城市绿地对周边热环境的影响，有必要基于高密度监测网络，利用多个气象指标进行监测。 |
| 【up2024 1107 20:44】   * To this end, this study focuses on Chongqing Central Park, employing mobile measurement methods to conduct fine-scale, high-density measurements of meteorological variables around the park. The aim is to gain an in-depth understanding of the thermal environment characteristics surrounding the green space in terms of temperature, humidity, and the combined effect of both on comfort. * The specific objectives of this study are: (1) to analyze the microclimatic characteristics of the environment surrounding the green space; (2) to explore how environmental factors affect meteorological variables at varying distances from the park; and (3) to quantify the intensity and spatial extent of the green space's effect on the surrounding thermal environment and to analyze the role of associated driving factors. * The findings from this study will help deepen our understanding of the thermal environment surrounding green spaces and its interaction with surrounding environmental characteristics. | 【up2024 1107 20:44】   1. 为此，本研究选择重庆中央公园，利用移动测量方法对公园周边的气象变量进行了精细尺度和高密度测量。研究旨在从温度、湿度及其综合作用下的舒适度角度，深入理解绿地周边的热环境特征。 2. 具体研究目标包括：（1）分析绿地周边的微气候特征；（2）探讨不同距离条件下环境因素对气象变量的影响；（3）量化绿地对周边热环境的影响强度和范围，并分析相关驱动因素的作用。 3. 本研究的结果将有助于更深入地理解绿地周边的热环境特征及其与周围环境特征之间的相互作用。 |

## Data and Methods

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| 【up2024 1108 08:50】   * In this study, we first identified the measurement routes and collected meteorological data on appropriate dates. After completing the field measurements, we calculated the thermal comfort index, analyzed the spatial and temporal distribution characteristics of temperature, relative humidity, and thermal comfort, and explored the effects of driving factors on these variables. Considering significant fluctuations in weather conditions across different days, we used the average of all measurement days for correlation analysis. * Additionally, we calculated the impact intensity and penetration distance of the park on meteorological variables in the surrounding areas and quantified their correlation with driving factors. All data analyses were conducted in R 4.3. | 【up2024 1108 08:50】   1. 在本研究中，我们首先确定了测量路线，并在适当的日期采集气象数据。完成实地测量后，我们计算了热舒适度指数，分析了气温、相对湿度和热舒适度的时空分布特征，探讨了驱动因素对这些变量的影响。考虑到天气状况在不同日期间存在显著波动，我们采用所有测量日的均值进行相关性分析。 2. 此外，我们还计算了公园对周边区域气象变量的影响强度和渗透距离，并量化了其与驱动因素的相关性。所有数据分析均在 R 4.3 中完成。 |
| 2.1 Study area |  |
| 【up2024 1108 08:55】   * Chongqing, located in the upper reaches of the Yangtze River in southwestern China, is a major metropolis. Over the past two decades, Chongqing's urban population has grown rapidly, from 6 million in 2000 to 10 million in 2020. * Chongqing has a subtropical monsoon climate, with a cold and damp winter from December to January and a hot summer from May to September. Days with temperatures exceeding 35°C can reach up to 40 annually, with peak temperatures reaching 43°C. * Chongqing Central Park, situated in the northern part of the city, spans approximately 1.6 square kilometers in a rectangular shape, stretching about 2 kilometers north to south and 0.8 kilometers east to west, making it the largest urban park in Chongqing (Figure 1). The park is surrounded by newly developed residential and commercial areas, featuring high-rise tower buildings, low-rise slab buildings, and villas. * Since this area is a newly developed district, it experiences relatively low levels of pedestrian and vehicular traffic, so human activities have a negligible impact on the thermal environment. * This study will conduct field measurements to assess the impact of Chongqing Central Park and its surrounding areas on the thermal environment, focusing on temperature, relative humidity, and thermal comfort. | 【up2024 1108 08:55】   1. 重庆位于中国西南地区长江上游，是一座特大城市。过去二十多年间，重庆的城市人口迅速增长，从2000年的600万增加到2020年的1000万。 2. 重庆属于亚热带季风气候。冬季主要集中在12月至1月，天气阴冷潮湿；夏季则从5月至9月，频繁出现高温天气。每年气温超过35°C的高温日数可达40天，最高气温可达43°C。 3. 重庆中央公园位于市区北部，占地约1.6平方公里，呈规则的长方形布局，南北长约2公里，东西宽约0.8公里，是重庆市最大的城市公园（见图1）。公园周边为新建的住宅区和商业区，包括高层塔式建筑、低层板式建筑及别墅等。 4. 由于该区域为新开发城区，人流和车流量较少，因此人类活动对该区域热环境的影响可以忽略不计。 5. 本研究将基于气温、相对湿度和热舒适度，对重庆中央公园及其周边地区的热环境影响进行实地测量和研究。 |
| 2.2. Field measurement |  |
| 【up2024 1107 09:17】   * Chongqing’s summer typically lasts from May to September, with July and August being the hottest months. This study chose August 2023 for meteorological data collection. To minimize the influence of rainy weather on the regional thermal environment and ensure representative data, we specifically selected six days that were mostly clear and sunny. * On each of these six days, measurements were conducted at two times: starting at 14:00 for daytime data and at 21:00 for nighttime data. The daytime measurements were taken during the hottest part of the day, when strong sunlight significantly impacts the spatial distribution of meteorological variables. The nighttime measurements, although taken when solar radiation had weakened, captured a period when the urban heat island effect was more pronounced due to heat release from buildings and other impervious surfaces. According to data from a nearby standard meteorological station, the 14:00 temperatures on these six days ranged from 28.5°C to 36.8°C, with relative humidity between 44% and 56%, representing typical midsummer weather in Chongqing. The basic meteorological conditions for the six measurement days are shown in Table 1. | 【up2024 1107 09:17】   1. 重庆的夏季通常从5月持续至9月，其中7月和8月最为炎热。本研究选择在2023年8月进行气象数据测量。为尽量减少阴雨天气对区域热环境的影响，并确保数据的代表性，我们特意选取了6个少云且晴朗的日子。 2. 在这6天中，我们每天在两个时间段进行测量，分别从14:00和21:00开始，分别对应白天和夜间。白天测量选择在一天中最热的时段，此时日照强烈，对气象变量的空间分布有显著影响。夜间测量则在日照减弱后进行，但由于建筑物和其他不透水表面释放的热量，城市热岛效应在夜间相对更为显著。根据附近标准气象站的监测数据，6天中14:00的气温范围为28.5°C至36.8°C，相对湿度介于44%至56%，代表了重庆盛夏的典型天气条件。6个测量日的基本气象状况如表1所示。 |
| 【up2024 1107 10:15】   * This study focuses on fine-scale meteorological measurements, with high-density measurement points. Therefore, a mobile measurement method was used to collect data. * For field measurements, we selected six parallel routes, all oriented east-west and perpendicular to Chongqing Central Park. Each route started from the park’s edge and extended 500 meters into the residential area. * Six volunteers collected data simultaneously along their designated routes, moving forward at a pace of 10 meters per minute and pausing for at least 40 seconds at each measurement point to record data for later analysis. Each route included 50 measurement points, with a total of 300 points across the study area. To minimize the impact of obstacles such as vegetation, all points were placed away from street trees and other shaded areas. Each route took approximately 50 minutes to sample. * To account for time differences between measurement points, we established two fixed reference points approximately 500 meters from the park to ensure that the meteorological data collected at these reference points were unaffected by the park. The location of the fixed reference points is shown in Figure 1. During analysis, we used the start time of each measurement period as the reference point. By calculating the difference in meteorological data at the fixed reference points between each measurement time and the reference time, we adjusted the mobile measurement data, enabling comparative analysis based on the same reference time across all datasets. | 【up2024 1107 10:15】   * 本研究重点关注精细尺度的气象测量，因而设置了较高密度的测量点，并采用了移动测量方法来收集数据。 * 在现场测量中，我们选择了六条平行路线，均为东西向并垂直穿过重庆中央公园。每条路线从公园边缘开始，延伸500米进入周边住宅区。 * 六名志愿者沿各自指定路线同时进行测量，按每分钟前进10米的速度移动，并在每个测量点停留40秒以上以记录数据，供后续分析。每条路线包含50个测量点，整个研究区域共计300个点。为尽量减少植被等障碍物的影响，所有测量点均避开街道树木和其他遮阴区域。每条路线的测量时间约为50分钟。 * 为了校正各测量点之间的时间差异，我们在路线附近设置了两个固定参考点，距离公园约500米，以确保其气象数据基本不受中央公园的影响。固定参考点的位置如图1所示。在分析中，我们以每个时段的起始时间作为参考，通过计算固定参考点在各测量时间与参考时间点之间的气象数据差异，来调整移动测量数据，从而实现基于统一参考时间的对比分析。 |
| 【up2024 1107 10:25】   * We used the TESTO 175H1 data logger to collect meteorological data, including temperature and relative humidity. This device has high measurement accuracy, with a temperature error of ±0.1°C and a relative humidity error of ±0.1%, and offers quick responsiveness. In this study, the data logger recorded measurements every 60 seconds. * Additionally, we used a GPS logger to obtain geographical information, such as the latitude and longitude of each measurement point. * Prior to measurements, the temperature and humidity logger was mounted at approximately 1.5 meters in height and shielded with a Stevenson screen to minimize interference from external factors like radiation. All equipment was attached to a mobile vertical pole fixed to a pushcart, and each volunteer slowly moved the cart forward to complete the measurements. | 【up2024 1107 10:25】   * 我们使用 TESTO 175H1 数据记录仪采集气象数据，包括气温和相对湿度。该设备具备较高的测量精度，气温误差为 ±0.1°C，相对湿度误差为 ±0.1%，且响应迅速。在本研究中，记录仪每 60 秒记录一次数据。 * 此外，我们使用 GPS 记录仪获取每个测量点的经纬度等地理位置信息。 * 测量前，将温湿度记录仪固定在约 1.5 米的高度，并用百叶箱遮挡，以减少辐射等外界因素的干扰。所有设备均安装在一个可移动的竖杆上，该竖杆固定在手推车上，由志愿者推着手推车缓慢移动，完成测量任务。 |
| 2.3. Data |  |
| 【up2024 1108 10:32】   * High-resolution GF-2 satellite imagery was used in this study for land cover classification analysis. * This imagery, with a spatial resolution of 1 meter, was captured on May 24, 2023, and obtained via the China Remote Sensing Satellite Data Sharing Service Platform. * We applied a supervised classification method to categorize the study area into three main land cover types: vegetation, impervious surfaces (e.g., roads and plazas), and other types (e.g., water bodies or bare land). * All building information (including location, footprint, and number of floors) was collected from Gaode Map. Based on typical residential building characteristics in Chongqing, we estimated actual building heights by multiplying the floor count by 3, which was then used to calculate building-related environmental indicators. | 【up2024 1108 10:32】   * 本研究采用 GF-2 高分辨率遥感影像进行土地覆盖分类分析。 * 该影像的空间分辨率为 1 米，拍摄时间为 2023 年 5 月 24 日，并通过中国遥感卫星数据共享服务平台获取。 * 我们使用监督分类方法，将研究区域划分为三类主要土地覆盖类型：植被、不透水地表（如道路和广场）以及其他类型（如水体或裸地）。 * 所有建筑信息（包括位置、足迹和楼层数）均采集自高德地图。根据重庆市住宅楼的实际情况，我们将建筑层数乘以 3，以估算实际建筑高度，用于计算与建筑相关的环境指标。 |
| 2.4. Indexes |  |
| 【up2024 1108 11:01】   * It is generally accepted that meteorological variables around green spaces exhibit a gradual change pattern. As the distance from green spaces increases, temperature gradually rises until it reaches a certain distance where it stops increasing and stabilizes. Similarly, for variables that tend to decrease with distance (such as relative humidity), this downward trend ceases at a particular distance. We define this point of trend termination as the “turning point” of the variable. Figure 2 illustrates the variation in temperature with increasing distance. * Previous studies indicate that changes in meteorological variables with distance from green spaces tend to follow a cubic function pattern (Jaganmohan et al., 2016). In this study, we define the turning point as the first inflection point of the fitted cubic polynomial. The distance between the starting point and the turning point is termed the "penetration distance," while the difference in meteorological variables at these two points is defined as the “impact intensity.” * For temperature, relative humidity, and the discomfort index (DI), the penetration distances are referred to as “Park Cooling Distance” (PCD), “Park Moistening Distance” (PWD), and “Park Cooling Distance for Thermal Comfort” (PCDTC), respectively. The corresponding impact intensities are defined as “Park Cooling Intensity” (PCI), “Park Moistening Intensity” (PWI), and “Park Cooling Intensity for Thermal Comfort” (PCIDC). * For temperature, which gradually increases with distance from green spaces, the definition of the penetration distance is shown in Equation 1. * For relative humidity, which decreases gradually with increasing distance from green spaces, the penetration distance is calculated using Equation 2. * Accordingly, the impact intensity is defined as the difference in meteorological variables between the starting point and the turning point, as shown below.   PD | 【up2024 1108 11:01】   1. 通常认为，绿地周围的气象变量会呈现渐进变化的趋势。随着与绿地距离的增加，气温逐渐上升，直到某一距离后停止上升，进入相对稳定状态。同样，对于一些随着距离增加而逐渐下降的气象变量（如相对湿度），这种下降趋势也会在某一距离停止。我们将这一趋势终止点称为该变量的“转折点”。图 2 展示了气温随距离变化的趋势。 2. 现有研究表明，气象变量随与绿地距离的增加通常表现为三次函数的变化模式 (Jaganmohan et al., 2016)。在本研究中，我们将转折点定义为拟合三次多项式的第一个拐点。起始点与转折点之间的距离称为“渗透距离”，而这两个点对应气象变量的差值则定义为“影响强度”。 3. 对于气温、相对湿度和不舒适指数（DI），渗透距离分别称为“公园降温距离”（PCD）、“公园变湿距离”（PWD）和“公园热舒适降温距离”（PCDTC）；相应的影响强度则定义为“公园降温强度”（PCI）、“公园变湿强度”（PWI）和“公园热舒适降温强度”（PCITC）。 4. 以气温随与绿地距离增加而逐渐上升的趋势为例，渗透距离的定义如公式 1 所示： 5. 而对于相对湿度这种随与绿地距离增加而逐渐下降的变量，其渗透距离由公式 2 计算： 6. 相应地，影响强度定义为起始点与转折点之间的气象变量差值，具体如下所示：   Impact IntensityPD |
| 2.5. Discomfort Index |  |
| 【up2024 1108 11:40】   * To evaluate the combined effect of air temperature and humidity on human thermal comfort, we used the Discomfort Index (DI). This index was initially proposed by Thom and later revised by Giles. It has since been widely applied in assessments related to urban thermal comfort (Giles et al., 1990). The calculation formula is as follows: * In which Ta is the air dry-bulb temperature (°C) and RH represents the relative humidity (%). | 【up2024 1108 11:40】   * 为了评估空气温度和湿度对人体热舒适度的综合影响，本研究采用了不适指数（Discomfort Index，DI）。该指数最早由 Thom 提出，后经 Giles 修订，目前已广泛应用于城市热舒适度的相关评估（Giles et al., 1990）。其计算公式如下： * 其中，Ta为环境干球温度（℃），RH为相对湿度（%）。 |
| 2.6. Driving factors |  |
| 【up2024 1108 11:19】   * Urban climate characteristics result from the combined influence of multiple factors. In this study, we selected environmental variables from dimensions such as land cover characteristics, urban morphology, and relative location to examine how urban green spaces affect the surrounding thermal environment. * For land cover characteristics, we selected building area ratio and green space area ratio. For urban morphology, we included average building height, sky view factor (SVF), and street width. * Average building height refers to the mean height of buildings within the site, weighted by building area. The sky view factor represents the ratio of visible sky area to the total sky area at a given location, which may influence the extent of sunlight obstruction at that location. Street width is defined as the minimum distance between buildings on both sides of each street. For the six streets in this study, the width ranges from 29 to 54 meters and remains constant for each street. * It is worth noting that since the study area primarily consists of residential zones, with buildings aligned along east-west roads, building orientations are generally consistent. Thus, this study does not consider building orientation as a variable. * Additionally, the distance between green space and measurement points was considered an important factor, as the thermal environment is more significantly impacted closer to the park. * To calculate these environmental variables and analyze their relationship with meteorological variables, we established a 100-meter radius buffer zone. The buffer size was determined by comparing the correlations between environmental factors and meteorological variables across different buffer sizes, selecting the size with the highest correlation. | 【up2024 1108 11:19】   1. 城市气候特征是由多种因素共同作用的结果。本研究从土地覆盖特征、城市形态特征及相对位置等多个维度选取环境变量，以探讨城市绿地对周边热环境的影响。 2. 在土地覆盖特征方面，我们选取了建筑面积比和绿地面积比；在城市形态方面，选择了平均建筑高度、天空视角因子（SVF）和街道宽度。 3. 平均建筑高度指场地范围内各建筑按建筑面积加权的高度均值。天空视角因子表示某位置的可视天空面积与总天空面积的比值，这一指标可能影响该位置的日照遮挡程度。街道宽度是指对应街道两侧建筑物之间的最近距离，在本研究的6条街道中宽度范围为29至54米，且每条街道的宽度保持不变。 4. 需要注意的是，由于研究区域主要为住宅区，不同类型的建筑沿东西走向的道路排列，建筑朝向趋于一致，因此本研究不考虑建筑朝向的影响。 5. 此外，绿地与测量点之间的距离作为重要因素之一，因为距离公园越近，热环境受其影响越显著。 6. 为了计算这些环境变量并分析其与气象变量的关系，我们设置了半径为100米的缓冲扇区。缓冲区大小是通过比较不同尺寸下环境因素与气象变量的相关性来确定的，最终选择了相关性最大的尺寸。 |

## Results

* 表1

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Daytime | | | Night | | |
|  | TP (℃) | RH (%) | DI (℃) | TP (℃) | RH (%) | DI (℃) |
| Average | 34.3 | 49.8 | 28.7 | 31.3 | 56.9 | 27.2 |
| Standard Deviation | 0.38 | 1.00 | 0.17 | 0.58 | 1.33 | 0.32 |

|  |  |
| --- | --- |
| 3.1. The spatiotemporal patterns of meteorological variables |  |
| 【up2024 1108 14:28】  IMG_256   * Fig. 3 Box plots of air temperature, relative humidity, and DI at daytime and night. | 【up2024 1108 14:28】   * 图3 气温、相对湿度和DI的箱线图在白天和夜间 |
| 【up2024 1108 14:28】   * Table 1 Basic statistics of temperature, relative humidity, and DI. | 【up2024 1108 14:28】   * 表1 气温、相对湿度和DI的基本统计值 |
| 【up2024 1108 14:28】   * Figure 1 presents box plots showing the distribution of daily average temperature, relative humidity, and discomfort index (DI) across all measurement points during daytime and nighttime. The figure clearly illustrates a significant drop in temperature and an increase in relative humidity at night compared to daytime. This combined shift in temperature and humidity contributes to a noticeable reduction in DI at night. Specifically, as shown in Table 1, the average temperature decreases from 34.3°C during the day to 31.3°C at night, while the average relative humidity rises from 49.8% to 56.9%. Correspondingly, the DI drops from 28.7°C to 27.2°C. These changes indicate that, despite the increase in humidity at night, the cooling effect provided by green spaces still reduces thermal discomfort, enhancing comfort in the surrounding environment. However, the reduction in DI is slightly smaller than the decrease in temperature. * Additionally, Figure 1 reveals greater spatial variability in these three meteorological indicators at night than during the day across the study area. This observation is further supported by the standard deviation data in Table 1: the standard deviations of temperature, relative humidity, and DI increase from 0.38°C, 1.00%, and 0.17°C during the day to 0.58°C, 1.33%, and 0.32°C at night, respectively. This suggests that nighttime microclimatic conditions in the study area are more heterogeneous, likely influenced by factors such as surrounding buildings, green spaces, and urban morphology. | 【up2024 1108 14:28】   1. 图3展示了所有测量点白天和夜间的日均气温、相对湿度和不适指数的箱线图。由图可以清晰地看出，夜间气温较白天显著降低，而相对湿度则有所上升。这种气温和相对湿度的变化对不适指数产生了综合影响，使不适指数在夜间也显著下降。具体而言，从表1的均值数据来看，夜间气温均值从白天的34.3℃下降至31.3℃，相对湿度均值则从白天的49.8%上升至56.9%。相应地，不适指数从28.7℃降至27.2℃。这说明，尽管夜间相对湿度有所上升，绿地的降温效果仍能有效降低热不适感，为周边区域提供更舒适的环境。然而，不适指数的下降幅度略低于气温的下降幅度。 2. 此外，图3还揭示出夜间三个气象指标在研究区域内的空间异质性大于白天。表1中的标准差数据进一步说明了这一点：夜间气温、相对湿度和不适指数的标准差分别从白天的0.38℃、1.00%和0.17℃增至夜间的0.58℃、1.33%和0.32℃。这表明夜间研究区域内的微气候特征更加多样化，可能受到周边建筑、绿地和城市形态等多种因素的影响。 |
| 【up2024 1108 17:46】  FIG2_DAY_TPFIG2_DAY_RHFIG2_DAY_DI  FIG2_NIGHT_TPIMG_256FIG2_NIGHT_DI   * Spatial patterns of daily mean temperature (a, b), relative humidity (c, d), and DI (e, f) during daytime (a-c) and nighttime (d-f). | 【up2024 1108 17:46】   * 图4 气温(a,b)、相对湿度(c,d)和DI(e,f)日均值在白天(a-c)和夜间(d-f)的空间格局 |
| 【up2024 1108 17:46】   * Figure 4 illustrates the spatial distribution patterns of the daily mean values of three meteorological variables. Within a certain distance from the park, these variables exhibit noticeable fluctuations, indicating the park's thermal effects. These effects result in an increase in temperature and discomfort index, and a decrease in relative humidity, with the strength of the influence weakening as the distance from the park increases. Beyond this distance, temperature, relative humidity, and discomfort index tend to stabilize. * It is worth noting that the park's thermal influence varies significantly between day and night. Both the penetration distance and the strength of the effect are greater at night than during the day. Specifically, the penetration distance of temperature, relative humidity, and DI extends to approximately 200 meters at night, whereas during the day it reduces to around 100 meters. In terms of influence intensity, the temperature drop at night is about 2°C, while during the day it decreases to around 1°C. Similarly, the rise in relative humidity is approximately 4% at night and falls to 2% during the day, and the decrease in discomfort index is 2°C at night, compared to 1°C during the day. * These differences help explain why the range of daily mean temperatures at night in Figure 3 is significantly broader than during the day. | 【up2024 1108 17:46】   * 图4展示了三个气象变量日均值的空间分布格局。可以看到，在距公园一定距离以内，气象变量呈现出波动变化的趋势。这表明公园的热环境效应在发挥作用，使得气温和不适指数上升、相对湿度下降，且影响强度随着距离的增加逐渐减弱。而在这一范围之外，气温、相对湿度和不适指数趋于相对稳定的格局。 * 值得注意的是，公园的热环境效应在昼夜间表现出较大差异。无论是渗透距离还是影响强度，夜间的影响均大于白天。具体而言，夜间气温、相对湿度和DI的渗透距离约为200米，而白天则减小到约100米。从影响强度来看，夜间气温的降幅约为2℃，白天减少至约1℃；相对湿度的升幅夜间为4%，白天则降至2%；不适指数的降幅在夜间为2℃，白天则降至1℃。 * 这些差异可以解释为什么在图3中夜间的日均温度分布范围显著大于白天。 |
| 3.2. The Influence of Driving Factors on Meteorological Variables |  |
| ppa_2302_fig_3_scatter_TP  ppa_2302_fig_3_scatter_RH ppa_2302_fig_3_scatter_DI   * Fig. 5. Scatter plots of distance to the park versus air temperature across various distance intervals * Fig. 6. Scatter plots of distance to the park versus relative humidity across various distance intervals * Fig. 7. Scatter plots of distance to the park versus DI across various distance intervals |  |
| * As the distance from the green space increases, the influence of the green space gradually weakens, while the impact of other environmental factors shifts accordingly. Therefore, this study divides the research area into five distance intervals from the green space: 0-100 meters, 100-200 meters, 200-300 meters, 300-400 meters, and 400-500 meters. A quantitative analysis is conducted for each interval to examine the relationship between environmental factors and meteorological variables. | * 随着距离绿地的增加，绿地的影响逐渐减弱，而其他环境因素的作用则随之变化。因此，本研究将研究区域按与绿地的距离划分为5个区段：0-100米、100-200米、200-300米、300-400米和400-500米。针对每个区段，进行了量化分析，以评估环境因素与气象变量之间的关系。 |
| * Figure 3 presents scatter plots of daytime and nighttime air temperature versus distance from the park across various distance intervals. It shows that, at night, the relationship between temperature and distance is particularly significant within 300 meters of the green space. Specifically, in the 0-100 meter range, the correlation coefficient is 0.71; in the 100-200 meter and 200-300 meter ranges, the coefficients decrease to 0.57 and 0.41, respectively. Beyond 300 meters, in the 300-500 meter intervals, the correlation between temperature and distance falls below 0.3. * During the day, the correlation between temperature and distance weakens considerably, with a correlation coefficient of 0.44 in the 0-100 meter range, and significantly lower correlations (below 0.2) in the 100-500 meter intervals. This indicates that, during the day, the green space has a weaker influence beyond 100 meters. * A similar trend appears in the analysis of the correlation between relative humidity (RH) and distance. At night, the correlation coefficients are 0.76 and 0.66 in the 0-100 meter and 100-200 meter intervals, respectively, while during the day, only the 0-100 meter interval has a correlation coefficient of 0.42, with the rest falling below 0.3. For the Discomfort Index (DI) and distance, the nighttime correlation coefficients decline from 0.67 in the 0-100 meter range to 0.17 in the 400-500 meter range, while during the day, only the 0-100 meter interval has a correlation coefficient above 0.3. * In summary, as the distance from the green space increases, its influence diminishes significantly, nearly disappearing beyond a certain distance. The extent of this influence also varies by time of day: at night, the green space impacts surrounding meteorological variables within 200-300 meters, whereas during the day, its influence is generally limited to around 100 meters. | * 图3展示了不同距离区段内白天和夜间气温与距公园距离的散点图。可以看出，夜间气温与距离之间的关系在距绿地300米以内尤为显著。具体而言，在0-100米范围内，两者的相关系数为0.71；在100-200米和200-300米范围内，相关系数分别降至0.57和0.41。而在300-500米的区段内，气温与距离的相关性均低于0.3。 * 白天时，气温与距离的相关性明显减弱。在0-100米范围内，相关系数为0.44，而在100-500米的区段中，相关性均显著低于0.2，表明白天绿地对100米以外区域的影响较弱。 * 相似的模式也出现在相对湿度（RH）与距离的相关性分析中。夜间，在0-100米和100-200米区间内，相关系数分别为0.76和0.66，而白天仅在0-100米区间内相关系数达到0.42，其他区段均小于0.3。不适指数（DI）与距离的相关性在夜间的五个区段内相关系数从0.67（0-100米）逐渐降低至0.17（400-500米）；而在白天，仅0-100米区间的相关系数大于0.3。 * 总体来看，随着距绿地距离的增加，绿地的影响程度显著减弱，直至某一特定距离后几乎消失。影响范围在一天的不同时间段内也存在显著差异：夜间绿地对周围气象变量的影响可达200-300米，而白天的影响范围则通常仅限于100米左右。 |
| * The previous figure illustrates that as the distance from the park increases, the influence of proximity to the park diminishes significantly, nearly disappearing beyond a certain distance. However, for other variables, the degree of influence also changes notably. Figure 8 displays the impact of selected environmental factors on meteorological variables across different distance intervals from the park. | * 上图已表明，随着与公园距离的增加，绿地的影响强度显著减弱，直至在某一特定距离后几乎消失。然而，对于其他变量，影响的强度也呈现出显著变化。图8展示了在不同距离区间内，各环境因素对气象变量的影响程度。 |
| ppa_2302_fig_4   * Correlation coefficients between driving factors and meteorological variables across different intervals of distance to the park | * 图8 驱动因素与气象变量在不同公园距离区间的相关系数 |
| * At night, a noticeable difference in the correlation patterns between air temperature and environmental factors can be observed in the 0-200 m and 200-500 m distance intervals. In the 200-500 m range, SVF, building height (BH), vegetation cover (VEG), and building coverage ratio (BCR) all significantly impact air temperature. Among these factors, average building height is positively correlated with air temperature, while building area and vegetation area are negatively correlated. The negative correlation between vegetation area and air temperature is understandable, as increased vegetation enhances evapotranspiration, promoting a cooling effect. The positive correlation between building height and air temperature can be attributed to the fact that taller buildings increase the area’s heat storage. The negative correlation between building area and air temperature may be due to the larger building areas near Central Park generally having lower overall building heights, resulting in slightly lower temperatures. | * 【夜间，影响的正负性】在夜间，可以观察到气温与环境因素的相关性在0-200米与200-500米两个区间内呈现显著差异。在200-500米的区间中，SVF、平均建筑高度（BH）、植被覆盖率（VEG）和建筑覆盖率（BCR）对气温均有显著影响。其中，平均建筑高度与气温呈正相关，而建筑面积和植被面积则与气温呈负相关。植被面积与气温的负相关较容易理解，这是由于随着周围植被面积的增加，蒸散作用增强，从而促进了气温的下降。而建筑高度与气温的正相关可以解释为增加的建筑高度提升了区域的储热能力。至于建筑面积与气温的负相关，可能是由于在中央公园附近，建筑面积较大的区域通常建筑高度较低，从而使得气温略微偏低。 |
| * The figure shows that within the 200-500 m range, building height exhibits the strongest correlation with air temperature, with correlation coefficients of 0.52, 0.52, and 0.48 across the three intervals. In contrast, the relative effects of vegetation area, building area, and SVF are weaker. This suggests that the heat storage effect of building height plays a significant role in areas where the cooling impact of green space is weaker at night. Notably, within the 200-300 m range, the influence of vegetation on air temperature is weaker, likely due to the combined effects of buildings, surrounding vegetation, and park cooling, which creates a more complex temperature pattern. * In contrast to areas beyond 200 m, within 200 m of Central Park, the effect of distance to the green space becomes more pronounced, with an increase in the impact of vegetation area. This can be explained by the higher proportion of vegetation as proximity to the park increases. Due to the park's cooling effect, other building morphology indicators have a negligible influence on air temperature. Therefore, for nighttime air temperatures, building morphology plays a crucial role in areas where the park's cooling effect is less pronounced. | * 由上图可见，在200-500米范围内，建筑高度的相关性最强，在三个区间中的相关系数分别为0.52、0.52和0.48。相比之下，植被面积、建筑面积和SVF的相对影响较弱。这表明，建筑高度所带来的储热效应对夜间绿地影响减弱区域的气温具有显著作用。需要注意的是，在200-300米区间内，植被对气温的影响较小，这可能是因为该区域不仅受建筑和周边植被的影响，还受到来自公园的降温效应的影响，导致气温格局更加复杂。 * 与200米以外的区域不同，在距中央公园200米以内的区域，距绿地的距离对气温的影响显著增加，同时植被面积的作用也增强。这可以用以下事实解释：距公园越近，植被比例越高。由于公园的降温效应，与建筑形态相关的其他指标对气温的影响变得可以忽略不计。因此，对于夜间气温而言，在公园降温效应影响较弱的区域，建筑形态起到关键作用。 |
| * The impact of environmental factors on relative humidity contrasts with their effect on air temperature. In the 200-500 m range, building height has a significant negative effect on relative humidity, while vegetation proportion, building proportion, and sky view factor (SVF) exhibit a significant but weaker positive effect. Within the 0-200 m range, the influence of distance to the park and vegetation cover is stronger, with correlation coefficients of 0.77 and 0.6 for distance and 0.77 and 0.32 for vegetation cover. * Additionally, under the combined effects of air temperature and relative humidity, environmental factors’ impact on the discomfort index (DI) mirrors the pattern and strength observed for air temperature. Building height shows the strongest influence, with correlation coefficients of 0.52, 0.53, and 0.51 across the three intervals within 300-500 m, while SVF, building coverage ratio (BCR), and vegetation coverage (VEG) have relatively weaker correlations. Thus, compared to relative humidity, air temperature exerts a more significant influence on the spatial-temporal pattern of DI and its relationship with environmental factors. | * 环境因素对相对湿度的影响与对气温的影响正好相反。在200-500米区间内，建筑高度对相对湿度产生显著的负效应，而植被比例、建筑比例和天空视域因子 (SVF) 则对相对湿度有较弱但显著的正效应。在0-200米区间，与公园距离和植被覆盖比例的影响更为显著。其中，与公园距离的相关系数分别为0.77和0.6，而与植被覆盖的相关系数为0.77和0.32。 * 此外，在气温和相对湿度的共同作用下，环境因素对不适指数 (DI) 的影响呈现出与气温类似的模式和强度。建筑高度的影响最为显著，在300-500米的三个区间中，其相关系数分别为0.52、0.53和0.51，而SVF、建筑覆盖率 (BCR) 和植被覆盖率 (VEG) 的相关系数则相对较小。因此，与相对湿度相比，气温对DI的时空格局及其与环境因素的关系影响更为显著。 |
| * During the day, the influence of environmental factors on meteorological variables differs significantly from that at night, primarily due to variations in the driving mechanisms of meteorological indicators and the cooling effects of Central Park between day and night. Within the 100-500 m range, sky view factor (SVF) and vegetation coverage ratio have the strongest impact on air temperature, especially SVF. This is readily explained as a larger SVF allows for more direct sunlight, leading to higher temperatures. In daylight, under strong solar radiation, SVF exerts a dominant influence on temperature compared to other urban morphology variables. Furthermore, vegetation’s cooling effect on the surrounding environment remains significant due to evapotranspiration. * In terms of relative humidity, environmental factors have an opposite trend to their effect on temperature. Analysis also shows that the influence of vegetation coverage on relative humidity slightly increases during the day, while the impact of SVF decreases. This indicates that sunlight variations mainly affect temperature, while vegetation plays a more significant role in relative humidity. * Similar to nighttime, the discomfort index (DI) during the day is more influenced by air temperature than by relative humidity, with its correlations to environmental factors closely aligning with those observed between temperature and environmental variables. | * 在白天，环境因素对气象变量的影响与夜间有显著差异，这很大程度上是由白天和夜间之间气象指标的驱动机制以及来自中央公园的降温效应的差异所导致的。在100-500米的区间范围内，SVF和植被覆盖比例对气温的影响最强，尤其是SVF。这很容易解释，因为SVF越大，太阳直射的面积越大，因此气温就越高。而白天由于日照强烈，因此相对于其它建筑形态变量，SVF对气温的影响起主导作用。此外，受植被蒸散作用等效应的影响，植被对周边环境的降温仍起显著作用。 * 在白天，环境因素对相对湿度的影响与对气温的影响趋势相反。在对相对湿度的分析中，我们还发现，植被覆盖比例的影响程度略微上升，而SVF影响的程度相对下降。这表明日照差异主要影响气温，而植被对相对湿度的影响更为显著。 * 与夜间相同，相对于相对湿度，DI也更受到气温的影响，与环境因素的相关系数更接近于气温与环境因素的相关分析结果。 |

### 3.3 降温指标及其影响因素

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| ppa_2302_fig_5RCD | * 图XX 在白天和夜间，公园对气温、相对湿度和DI热环境效应渗透距离分布的箱线图 |
| ppa_2302_fig_6RCI | * 图XX 在白天和夜间，公园对气温、相对湿度和DI热环境效应影响强度分布的箱线图 |
| * Figures 9 and 10 display box plots of Central Park’s impact on surrounding temperature, relative humidity, and the Discomfort Index (DI) thermal environment. For temperature, the average nighttime penetration distance is 245 meters, with a maximum of 400 meters, whereas during the day, the average penetration distance is only 116 meters, with a maximum of 222 meters. The cooling intensity averages 1.8°C at night, decreasing to 0.5°C during the day. * For relative humidity and DI, the average nighttime penetration distances are 200 meters and 230 meters, respectively, reducing to 100 meters and 110 meters during the day. The nighttime influence intensity is 5% and 1°C, dropping to 2% and 0.5°C during the day. These findings indicate that both the penetration distance and influence intensity of the park’s thermal environment effect are significantly greater at night than during the day. | * 图9和图10分别展示了中央公园对周边气温、相对湿度和热不舒适指数 (DI) 的热环境影响的箱线图。对于气温，夜间的平均渗透距离为245米，最大值可达400米，而白天的平均渗透距离仅为116米，最大值为222米。在降温强度方面，夜间的平均值为1.8℃，白天则下降至0.5℃。 * 在相对湿度和DI方面，夜间的平均渗透距离分别为200米和230米，白天则分别缩减至100米和110米；其影响强度在夜间分别为5%和1℃，白天则降至2%和0.5℃。由此可见，从渗透距离和影响强度来看，公园的热环境效应在夜间显著大于白天。 |
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| 图11显示了白天和夜间公园热环境影响的指标与环境因素的相关性。结果表明，对于RCI，环境因素与其相关性较弱。除在夜间建筑高度与其有较为显著的正相关外，其它环境因素的相关性低于0.3.而对于RCD而言，环境变量与其呈显著相关。但是，夜间的相关性强于白天。具体来说，街道宽度和建筑高度与RCD的相关系数在夜间分别为XX和XX，而在白天则分别为XX和XX。 |  |
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## Discussions

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| * Green spaces act as cooling sources in urban areas, with temperatures that are not only lower than the surrounding environment but also capable of significantly cooling nearby areas (Park et al., 2021; Qi et al., 2022). Currently, studies on the impacts of large urban green spaces on the surrounding thermal environment primarily focus on air temperature, while research on fine-scale spatial patterns of relative humidity and thermal comfort, closely related to human perception, remains limited (Dronova et al., 2018; Fan et al., 2019). This study, utilizing a high-density monitoring network and accounting for both 2D and 3D environmental factors, systematically analyzes the comprehensive effects of large urban parks on the temperature, humidity, and thermal comfort of surrounding areas. | * 【研究概述】绿地作为城市区域的冷源，不仅自身温度低于周边环境，还能显著降低周边区域的温度 (Park et al., 2021; Qi et al., 2022)。目前，关于城市大型绿地对周边热环境影响的实地研究主要集中在气温方面，而在相对湿度及与人体感知密切相关的热舒适度时空格局的研究，尤其在精细尺度上，仍然不足 (Dronova et al., 2018; Fan et al., 2019)。本研究基于高密度监测网络，综合考虑二维和三维环境因素，系统性地分析了大型城市公园对周边区域气温、相对湿度及热舒适度的时空特征。 |
| * This study found that the average nighttime cooling intensity of Central Park in Chongqing is 1.7°C, with a cooling influence range of 200-300 meters. Yin et al. (2022) found a similar cooling intensity for Purple Mountain in Nanjing, but with a cooling distance exceeding 500 meters, significantly greater than that observed in this study, likely due to Central Park’s smaller area compared to Purple Mountain. * Nevertheless, our results are consistent with findings from a park in Guangzhou and related studies in Japan (Qi et al., 2022; Hamada et al., 2010), suggesting that this study’s results may be representative of large urban parks. | * 【降温指标的比较】本研究发现，重庆中央公园夜间的平均降温强度为1.7℃，降温影响范围在200-300米之间。Yin等人（2022）在研究南京紫金山时发现其降温强度与本研究接近，但其降温影响距离超过500米，显著大于本研究的结果，这可能是由于中央公园面积相对紫金山较小。 * 尽管如此，本研究结果与广州某公园及日本的相关研究结果相似 (Qi等, 2022; Hamada等, 2010)，表明本文的研究结果在一定程度上具有对城市内部大型公园的代表性。 |
| * Through day-night comparisons, this study also found a stronger cooling effect of green spaces at night, attributed to the heat release from surrounding buildings, which raises temperatures in built-up areas and increases the temperature differential between the buildings and the park. * Unlike previous studies, this research also examined the impact of green spaces on surrounding humidity levels. Results indicate that the influence of green spaces on humidity is opposite to that on temperature, which aligns with expectations, as rising temperatures increase the saturation vapor pressure, thereby reducing relative humidity when moisture content remains constant. Additionally, areas with significant temperature drops often experience cooler, humid airflows from green spaces, resulting in higher moisture content in those areas. * Considering both temperature and humidity effects, we found that although green spaces increase relative humidity in nearby areas, thermal comfort still decreases. This indicates that the humidity increase is insufficient to offset the cooling effect of green spaces, thereby improving thermal comfort conditions during the summer. | * 【昼夜差异】通过昼夜对比，本研究也发现了夜间更强的绿地降温效应，这是因为夜间周边建筑的储热释放导致建筑覆盖区域的温度较高，从而导致建筑与公园之间的气温差异较大。 * 【湿度】与以往研究不同的是，本研究还探讨了绿地对周围环境湿度的影响。研究发现绿地对湿度的影响与温度相反，这与预期一致，因为温度的上升会导致饱和蒸气压的增加，在相同水分含量的情况下，相对湿度会出现下降。此外，温度下降显著的区域往往是由于受到来自绿地的较冷湿的气流影响，因此相应区域受气流影响的水分含量会增加。 * 【热舒适度】综合温湿度的影响，我们发现虽然绿地导致周边地区的相对湿度增加，但热舒适度仍然下降，这表明湿度的增加不足以抵消绿地导致的温度下降，因此绿地仍能够改善夏季热舒适状态。 |
| * For areas not influenced by green spaces, this study found that, compared to 2D indicators, 3D indicators have a considerable impact on temperature and humidity, with different influencing factors during the day and night. At night, average building height shows the strongest correlation with air temperature, while during the day, the sky view factor (SVF) plays a more significant role. This can be explained by the differing mechanisms of urban climate formation between day and night. At night, the spatial temperature pattern is mainly driven by heat release from buildings, making average building height—closely associated with building heat storage—a significant factor in temperature. In the daytime, solar radiation strongly influences the temperature pattern, with the extent of solar exposure in each area heavily impacting the spatial temperature distribution. * Additionally, relative humidity correlates more closely with vegetation area than with 3D morphological indicators, suggesting that vegetation area has a stronger effect on relative humidity than on air temperature. This is understandable, as relative humidity is influenced not only by temperature but also by the influx of humid air from large green spaces. | * 【2D与3D因素的比较】对于未受绿地影响的区域，本研究发现，与二维指标相比，三维指标对温湿度有显著影响，且白天与夜间的影响因素有所不同。其中，夜间平均建筑高度与气温的相关性最强；而白天，天空视域因子 (SVF) 的作用更为显著。这一现象可通过昼夜城市气候形成机制的差异来解释。夜间，气温的空间格局主要受建筑物储热释放驱动，而平均建筑高度与建筑储热密切相关，因此可以解释建筑高度与气温的相关性。而在白天，太阳辐射对气温格局的作用更为显著，区域接受太阳照射的程度对气温空间分布产生了重要影响。 * 此外，相对湿度与植被面积的相关性强于与三维形态指标的相关性，说明植被面积对相对湿度的影响大于其对气温的影响。这一结果符合预期，因为相对湿度不仅受气温变化影响，还会受到来自大型绿地的湿润空气流的影响。 |
| * For the cooling penetration distance of park thermal environments, we found that 3D indicators play a more significant role than land cover characteristics. Specifically, as building height increases, the cooling distance is noticeably reduced. This is understandable, as taller buildings create a stronger barrier to park cooling effects, causing the cooler airflow from green spaces to dissipate more quickly. Additionally, street width has a negative impact; wider streets reduce surrounding building density, which in turn decreases the ability of cool air from the green space to accumulate effectively. | * 【公园降温指标的相关因素分析】对于公园热环境的渗透距离，本研究发现三维指标的作用更为显著，而土地覆盖特征的影响较为有限。其中，建筑高度越高，降温距离显著缩短。这可以理解为建筑高度增加对公园降温效果的阻挡作用更加显著，使得来自绿地的较凉气流更快地被削弱。此外，街道宽度也有负面影响，增加的街道宽度会减少周边建筑面积，从而降低了绿地冷空气的聚集效果。 |
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| * As urbanization continues in China, with many new areas under development and older districts undergoing urban renewal, the findings of this study provide valuable insights for planning and designing areas surrounding large urban green spaces in the future. Our study highlights that, in the urban planning of green space surroundings, urban morphological indicators such as building height and street width should take precedence over land cover analysis. * To enhance the thermal environment during summer, future development around parks should consider lowering building heights to reduce heat release from buildings, thereby improving thermal comfort, particularly in residential areas where residents are active in the early morning and evening. Additionally, increasing building density and designing narrower streets in areas near parks may further support the cooling effect of green spaces, allowing it to penetrate more effectively into the surrounding areas. | * 随着中国城市化进程的推进，众多新区正在开发建设，同时老城区也在进行改造工作，基于本研究的结果，为未来大型城市绿地周边的规划设计提供了重要的参考意义。 * 通过本研究，我们发现，在进行绿地周边的城市规划时，与土地覆盖相比，应更加关注建筑高度、街道宽度等城市形态指标。为改善夏季的热环境，未来在公园周边的建设中应适当降低建筑高度，以减少建筑热的释放，从而进一步提升热舒适度，这对居民活动主要集中在早晚时段的住宅区尤为重要。此外，在公园周边区域，适当增加建筑密度并设置较窄的街道，可能更有利于绿地的冷却效应向周边区域渗透。 |
| * This study has some limitations, and future research could expand in the following directions. First, this study is based on a single large park, so the influence of the park’s specific characteristics on its surrounding thermal environment remains unclear. Future studies could include a greater number of parks to further validate these findings and explore the role of park characteristics. Second, this study only analyzed data from the summer season, and the characteristics and influencing factors of the thermal environment around parks in other seasons remain to be thoroughly examined. Furthermore, this study focused primarily on residential areas, so additional attention should be given to other types of areas, such as commercial and industrial zones, to obtain more comprehensive results. | * 【不足与未来展望】本研究仍存在一些不足，未来相关研究可以在以下方向进行拓展。首先，本研究仅基于一个大型公园，因此公园自身特征对其周边热环境的影响尚不明确。未来研究可以增加研究公园的数量，以进一步验证本研究结果并探讨公园特征的具体影响。其次，本研究仅分析了夏季数据，其他季节的公园周边热环境特征及其影响因素仍需深入研究。此外，本研究区域主要为住宅区，后续还应关注其他类型的区域，如商业区、工业区等，以获得更全面的结果。 |

对于降温指标，我们选择了街道宽度和建筑高度作为影响因素。结果表明，街道宽度和建筑高度对于降温距离影响显著，然而对降温强度的影响不明显。对于气温的降温距离，SW和BH的影响率为0.18和0.13。而对于RH，两者的影响程度相对下降，为xx和xx。对于DI，这两个指标则分别为xx和xx。

在白天，上述两个因素的影响强度显著低于夜间。对于气温、相对湿度和DI，两者的影响指标分别为XX,XX XX, XX, XX, XX.

总体而言，建筑高度和街道宽度均与降温距离呈负相关。相对于建筑高度、街道宽度对降温效应的影响显著更强。这表明相对较窄的道路更有利于公园降温效应的向内陆渗透。

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