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Characteristics of the urban heat island in a tropical city of Phnom Penh, Cambodia

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Abstract
The rapid urbanization drives Phnom Penh, Cambodia experiences the increased urban heat island (UHI) effects. However, no studies on the UHI effect in Phnom Penh have been conducted to date. Air temperature and ventilation data during 2021-2023 were used to investigate daily, seasonal, yearly variations of the UHI intensity and evaluate the impact of ventilation on the UHI intensity in Phnom Penh. Findings indicated the UHI intensity is stronger during the daytime (0.55 °C) than at night (0.25 °C) in dry season, primarily due to the increase in impervious surfaces that trap more thermal energy throughout the day. Furthermore, the UHI intensity is greater in the dry season with 0.40 °C than in the wet season with 0.15 °C, mainly due to the less moisture and the cold island effects occurred during the cooler and drier months. The study emphasizes the importance of implementing approaches to mitigate the UHI intensity in Phnom Penh.

Keywords: Air temperature, Phnom Penh, tropical city, urban heat island, ventilation

Introduction
Urbanized areas experience higher temperatures than suburban or rural areas, a phenomenon known as the urban heat island (UHI) (Oke, 1982; Yuan and Bauer, 2007; Li *et al.*, 2011) [35, 56, 21]. This temperature difference derives from urbanization development that create more impervious surfaces due to the decrease in natural landscape, increasing their capacity to absorb more thermal energy, thus exacerbating the UHI effect (Imran *et al.*, 2021; Vujovic *et al.*, 2021; Aboulnaga *et al.*, 2024) [17, 48, 1]. Furthermore, human activities also produce heat to contribute to this phenomenon (Grajeda-Rosado *et al.*, 2022; Kabisch *et al.*, 2023; Liu *et al.*, 2024) [15, 18, 22]. Urbanization has substantially altered albedo and urban structures (Son *et al.*, 2017; Smith *et al.*, 2022; Kabisch *et al.*, 2023; *Schlaerth et al.*, 2023) [43, 42, 18], 39] contributing solar radiation absorption which influences temperature disparities between urban and rural environments (Vujovic *et al.*, 2021; Wu *et al.*, 2021) [48, 53].
Urbanization due to the increase of urban population (Ünal *et al.*, 2020; Delazeri *et al.*, 2021; Kim and Brown, 2021; Marcotullio and Sorensen, 2023; Kang *et al.*, 2024) [46, 8, 20, 25,19], economic growth (Di Clemente *et al.*, 2021; Shaban *et al.*, 2024; Anwar *et al.*, 2025) [9, 41, 4], and the increase of physical infrastructure (Halder *et al.*, 2021) [16], is a main factor in the UHI effect. Currently, there is a remarkable trend showing the increased movement of more people to cities for employment and housing. In 1950, 30% of the global population resided in urban areas, increased to 55% by 2018 (UNDESA, 2019) [47] and is expected to increase 68% by 2050 (UNDESA, 2019) [47]. This urban migration is expected to increase human activities and further expansion of urban areas (Milovanovic *et al.*, 2020; Angel, 2023; Lu *et al.*, 2023) [27, 3, 24].
The urban area of Phnom Penh has expanded rapidly in recent decades, from 40 km^2 in 1990 (Mialhe *et al.*, 2019) [26] to 678.47 km^2 in 2017 (NCSD *et al.*, 2019) [29]. This growth has transformed agricultural and natural land into impervious artificial surfaces. In 2003, approximately two-thirds of the city was agricultural land, while by 2023, artificial surfaces covered more than two-thirds of Phnom Penh (Figure 1a & b).
Temperature variations in Phnom Penh are likely affected by rapid urbanization, population increase, and the increase in economic activities. The fast increase in tall buildings creates a complex urban structure that captures more heat and changes air flow patterns, increasing thermal energy absorption and increasing urban temperatures.

Converting natural landscape in Phnom Penh to impervious artificial surfaces, potentially reduces air circulation and worsen the UHI effect. High density in the urbanized areas of Phnom Penh may impact ventilation from surrounding areas, significantly contributing to the UHI effect.

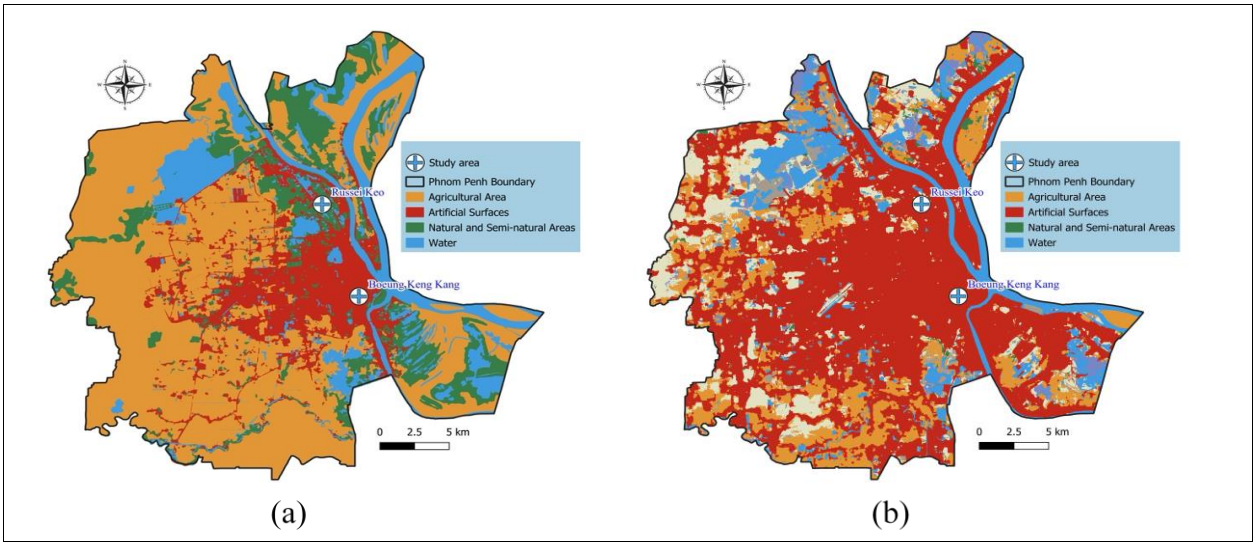

Fig 1: Land use/land cover change of Phnom Penh in (a) 2003 (WBG, 2023) [51] and (b) 2023 (Esri, 2024) [13]

The UHI presents significant challenges for energy consumption and human health in urban planning. The urban climate analysis is crucial for developing the UHI-related mitigation and adaptation strategies to deal with these challenges. Therefore, understanding the UHI intensity in Phnom Penh is essential for developing effective urban climate design and planning approaches to mitigate its impact. However, no studies on the UHI effect in Phnom Penh, Cambodia, have been conducted to date. A case study was conducted in Phnom Penh to examine the UHI characteristics. This study aims to analyze the UHI effect in Phnom Penh, Cambodia by investigating the variations in daily, seasonal, and annual UHI intensities; and evaluating the impact of ventilation on the UHI intensity in Phnom Penh.

Materials and Methods

Study Area

Phnom Penh, with its coordinates 11.562108, 104.888535, is positioned where the Tonle Sap, Tonle Bassac, Upper Mekong, and Lower Mekong rivers meet (Olson and Morton, 2018) [36]. The city, along with rest of Cambodia experiences a tropical monsoonal climate with yearly average rainfall of 1557.07 mm and temperature of 29.61 °C (WBG, 2024) [52]. Its population density reaches 13.6% (NIS, 2025) [33], and it functions as the main economic center, being the largest and most rapidly expanding urban area in Cambodia (WBG, 2017) [50]. As a result, the land cover of Phnom Penh has changed from permeable to impermeable surfaces (Babel *et al.*, 2021) [6], which may capture and store more heat during daytime.

This research was conducted in BKK and RSK (Figure 1a & b). BKK is an urbanized district with 66,658 residents in a 4.1 km^2 area (NIS, 2019) [32], creating a high population density of 16,258 people per km^2. Its crowded population and limited area have resulted in numerous tall buildings that receive direct sunlight and absorb additional heat, intensifying the UHI effect behind these structures (Figure 2a). Conversely, RSK is a suburb area with a larger population of 274,861 in 23.3 km^2 (NIS, 2019) [32], resulting a lower density of 11,797 people per km^2. This district features low-rise buildings and more open spaces, allowing better air circulation. This reduces the UHI effect in RSK compared to BKK (Figure 2b).

Fig 2: Professional wideband code division multiple access/global system for mobile communication weather station in (a) BKK and (b) RSK

Data Sources: For this study, two automatic weather stations (AWSs) were installed in BKK at coordinates 104.925365, 11.548953, and RSK at coordinates 104.901, 11.614014 (Figure 1a & b). These stations were installed on

building rooftops to continuously record data of air temperature, wind velocity, and wind direction at 5-minute intervals from January 1, 2021 to December 31, 2023. The 5-minute data was then aggregated into 15-minute intervals to analyze daily, seasonal, and yearly variations of UHI intensity along with wind patterns.

Methods

The analysis of air temperature between urban BKK and suburban RSK illustrates the UHI intensity. This intensity differs across areas due to varying urban development stages and climate conditions. Therefore, it is crucial to examine the UHI intensity variations during day and night, as well as across different days, seasons, and years in both urban and suburban settings. Every 15 minutes of air temperature were calculated. To determine the UHI intensity, the suburban air temperature ($T_{suburban}$) was subtracted from the urban air temperature (T_{Urban}), following the methodology of Oke (1973) [35], as shown in below equation:

$$UHI = T_{Urban} - T_{Suburban} \quad (1)$$

Thus,

$$UHI = T_{BKK} - T_{RSK} \quad (2)$$

Daily, seasonal, and annual UHI intensity variations were calculated and examined for both daytime and nighttime during the dry season (November-April) and wet season (May-October). Daily variation of the UHI (DVUHI) was examined based on the daily UHI range. Seasonal variation of the UHI intensity during day ($SVUHI_{day}$) and night ($SVUHI_{night}$) was defined by the wet and dry UHI range, following the methodology of Sun *et al.* (2019) [44], as shown in the following equations:

$$DVUHI = UHII_{day} - UHII_{night} \quad (3)$$

$$SVUHI_{day} = UHII_{day}^{dry} - UHII_{day}^{wet} \quad (4)$$

$$SVUHI_{night} = UHII_{night}^{dry} - UHII_{night}^{wet} \quad (5)$$

The study also investigated the role of ventilation in reducing the UHI intensity. A 15-minute wind velocity and direction data were collected to analyze the ventilation characteristics. Seasonal wind rose plots were created to identify prevailing wind directions over the study period. Regression analysis was also performed to evaluate the relationships between temperature difference and wind velocity. This analysis helped determine the strength of these relationships and assess the impact of ventilation on UHI intensity at the city scale.

Results and Discussion

Air temperature variation

Air temperature data from the AWSs during 2021-2023 were utilized to study the temperature variation. Result shows that average air temperatures in BKK is higher than that in RSK. This temperature difference is likely due to tall buildings, dense neighborhoods, and narrow street canyons in BKK, which restrict wind flow and reduce cooling effects in the city center. Average temperatures in BKK are 28.98 °C, 28.91 °C, and 29.13 °C from 2021 to 2023, while those in RSK are slightly lower at 28.72 °C, 28.43 °C, and 29.06 °C, respectively (Figure 3). These findings demonstrate that BKK consistently experienced higher temperatures than RSK throughout the study period. This aligns with research from other global cities, Mughal *et al.* (2020) [28] and Ng (2015) [30] reported higher temperatures in the urban areas of Singapore compared to the suburban regions. Nichol *et al.* (2014) [31] observed similar patterns in Hong Kong. Zhang and Ren (2005) [58] observed that the UHI intensity increased the annual mean temperature in the urban areas of Shandong province in China. Ayanlade *et al.* (2021) [5] also found that built-up areas have higher air temperatures than vegetated areas. Dian *et al.* (2020) [10] confirmed the UHI effects in the built environment of Budapest. Milovanovic *et al.* (2020) [27] showed that built-up areas of Belgrade stay higher year-round temperatures than surrounding areas. Locally, Se *et al.* (2024) [40] reported that the urbanized area of Phnom Penh experiences higher temperatures than the suburban areas. This study confirms that average temperature in BKK is consistently hotter than RSK in Phnom Penh throughout the study period.

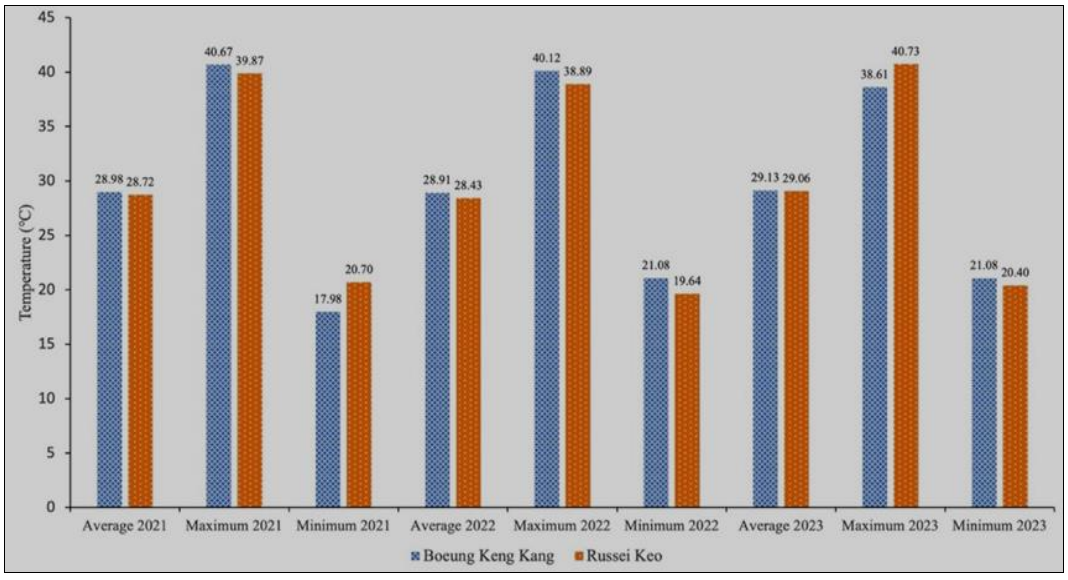

Fig 3: Air temperature of the study area

Daily urban heat island intensity

The hourly variation of the UHI intensity was analyzed using recorded data from the ground-based AWSs during 2021-2023. Two representative days, March 16th (dry season) and September 28th (wet season) were selected for detailed observation and comprehensive comparison of hourly UHI intensity over the study period. Figure 4 shows that average daytime UHI intensity was 0.23 °C (dry season) and 0.95 °C (wet season) in 2021, 0.48 °C (dry season) and 0.32 °C (wet season) in 2022, and -0.44 °C (dry season) and -0.94 °C (wet season) in 2023. Average nighttime UHI intensity was 0.10 °C (dry season) and 0.24 °C (wet season) in 2021, 0.25 °C (dry season) and 0.08 °C (wet season) in 2022, and -0.02 °C (dry season) and 0.20 °C (wet season) in 2023. Thus, the hourly UHI intensity was stronger during daytime than during nighttime in 2021 and 2022. However, this pattern reversed in 2023 due to the alteration of thermal dynamics during the study period. Cold island effects occurred in some occasions during daytime in the both dry and wet seasons. This is consistent with findings of Gaffin *et al.* (2008) [14] in New York City, where the daytime UHI and cold island effects were observed in some locations. Tabassum *et al.* (2024) [45] also found that the daily maximum UHI intensity was stronger during the daytime than at night within the monsoon and pre-monsoon periods. Also, Sun *et al.* (2019) [44] reported that the diurnal intensity was greater in the urban area than in the suburban areas. Additionally, Yang *et al.* (2019) [54] also found that hourly UHI intensity was higher in the urban area of Changchun city than in the rural areas, particularly in the afternoon during 14:00. A similar pattern was observed in Phnom Penh by Se *et al.* (2024) [40], the hourly UHI intensity occurred around 14:00. These results indicate that the hourly UHI intensity in Phnom Penh generally occurs during daytime, with the presence of occasional cold island effects. Built structures, urban structures and urban geometry influence to higher daytime temperatures in the urban area of BKK compared to the suburban area of RSK, primarily due to the increased heat storage in underlying surfaces and buildings. This results in a typical daytime UHI phenomenon, particularly in the afternoon hours.

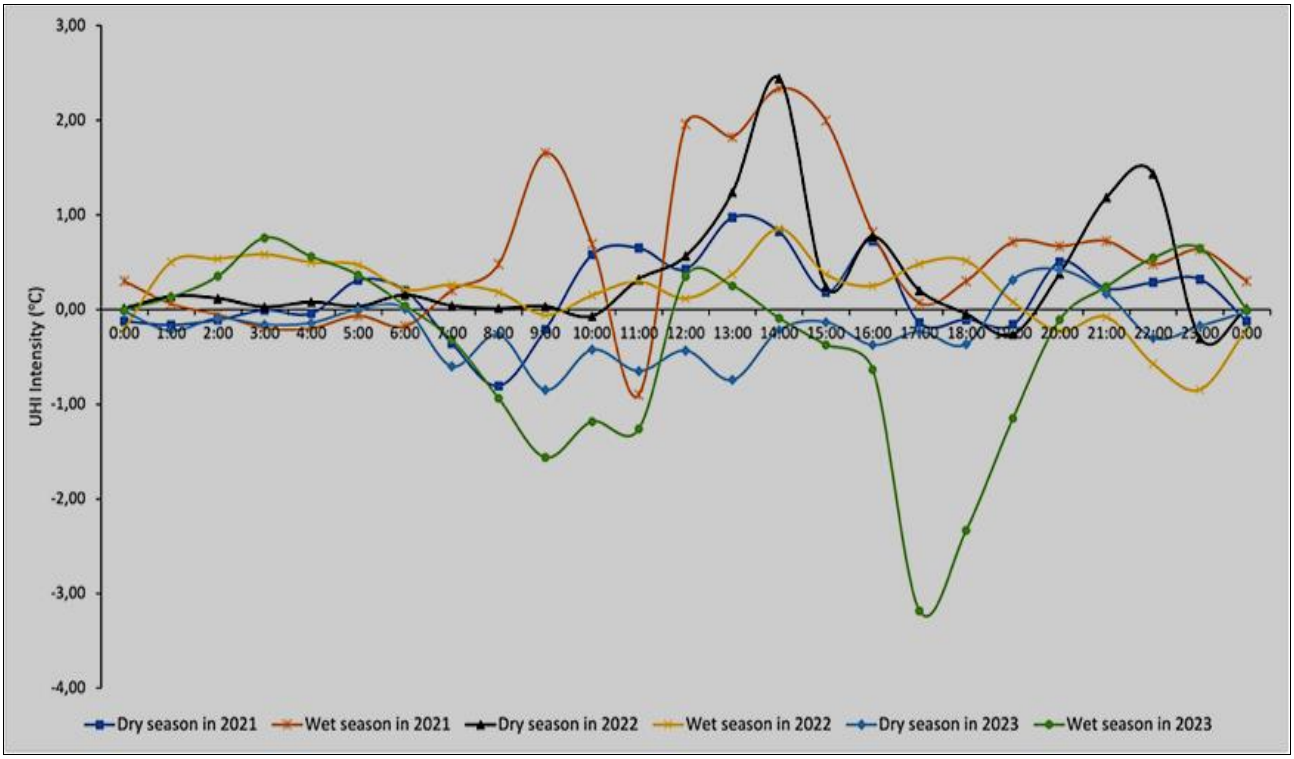

Fig 4: Hourly variation of the UHI intensity of selected days in dry and wet seasons

Seasonal urban heat island intensity: Daytime and nighttime seasonal variations of the UHI (SVUHI) intensity in the both dry and wet seasons were analyzed using ground-based AWS data during 2021-2023. The result shows that the average daytime SVUHI intensity was 0.55 °C in the dry season and 0.01 °C in the wet season while average nighttime SVUHI intensity was 0.25 °C in the dry season and 0.30 °C in the wet season throughout the study period (Figure 5). Remarkably, this result also indicated that the daytime cold island effects occurred in some occasions leading to a decrease in the UHI intensity in the wet season. Supporting this study, Sun *et al.* (2019) [44] reported that an average SVUHI intensity is 1.38 °C during daytime compared to 0.74 °C during nighttime within the Yangtze Delta, China. This aligns with the study by Du *et al.* (2016) [11], who confirmed that higher daytime UHI intensity is 0.98 °C compared to 0.50 °C during nighttime. More locally, Se *et al.* (2024) [40] also reported that the SVUHI intensity is stronger during daytime than during nighttime, especially in the dry season. Furthermore, Tabassum *et al.* (2024) [45] also found that the UHI intensity is stronger in the winter season (0.95 °C) than in the monsoon season (0.23 °C). Overall, this study indicates that the SVUHI intensity was generally stronger during the daytime than at nighttime. Therefore, the daytime SVUHI intensity tended to be higher in the dry season than in the wet season, likely due to lower humidity in mitigating the UHI intensity within the city and the increased heat accumulation on the urban impervious surfaces, which cannot be effectively dissipated due to lower wind velocities.

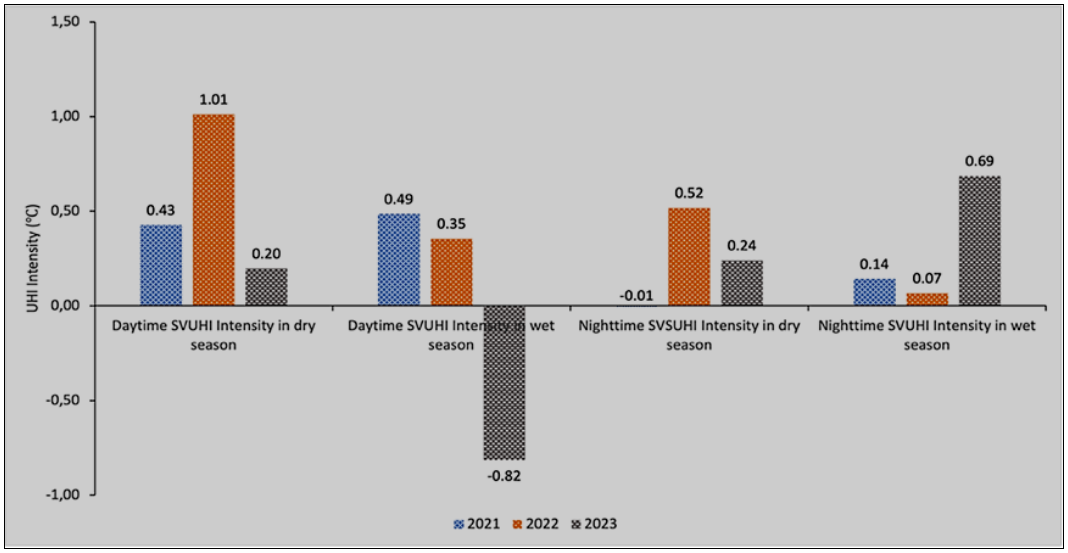

Fig 5: The daytime and nighttime seasonal variation of the UHI intensity in dry and wet seasons

Annual urban heat island intensity

The data retrieved from both AWSs during 2021-2023 were used to examine the annual variations of the UHI intensity. Figure 6 shows that the annual variation of the UHI intensity is stronger during the daytime in 2021 and 2022 while that occurred stronger during the nighttime in 2023. The cold island effect observed in 2023 because the high relative humidity occurred during daytime that may mitigate the UHI intensity. The daytime cold island effect in 2023 is the result of the recent growth of high-rise buildings and urban morphology (Wang *et al.*, 2016) [29] that provide canyon shading in urban areas (Oke, 1982) [35]. This aligns with study by Yang *et al.* (2019) [54] who reported that the UHI intensity is stronger during nighttime than during daytime. Peng *et al.* (2012) [37] reported that an average annual UHI intensity of 1.5 ±1.2 °C during the daytime is higher than that of 1.1 ±0.5 °C during the nighttime. Similarly, Sun *et al.* (2019) [44] also confirmed that the UHI intensity is higher during the daytime than at nighttime. Furthermore, Ünal *et al.* (2020) [46] also reported that the daytime UHI intensity in Istanbul peaks significantly during the summer season, and Yue *et al.* (2019) [57] also confirmed the increased UHI intensity in the built-up areas compared to surrounding areas across the South, East, and Northeast parts of China during summer days. Overall, this study indicated that daytime UHI intensity occurs more often than nighttime UHI intensity in Phnom Penh.

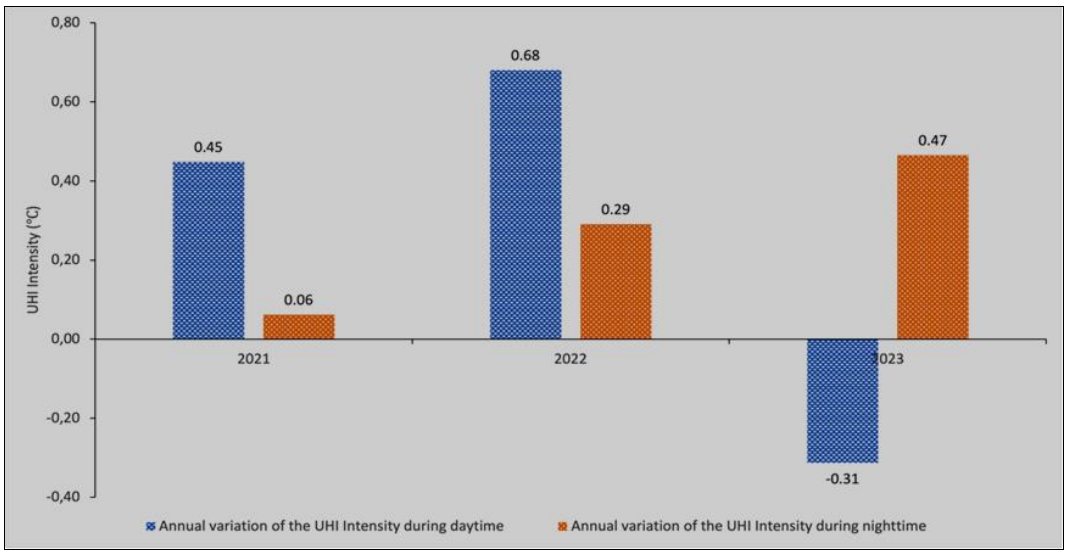

Fig 6: Annual variation of the UHI intensity during daytime and nighttime

The relationship between ventilation and urban heat island

Wind velocity and direction data from both AWSs during 2021-2023 were analyzed for both the dry and wet seasons. Wind velocity is measured in meters per second ($m.s^{-1}$). In BKK, maximum and minimum wind velocities ranged from 3.30 to 4.70 $m.s^{-1}$ and consistently 0 $m.s^{-1}$ while those in RSK ranged from 5.20 to 7.20 $m.s^{-1}$ and 0 $m.s^{-1}$. Thus, the average wind velocity in BKK ranged from 0.44 to 0.73 $m.s^{-1}$ while that in RSK ranged from 1.44 to 1.67 $m.s^{-1}$.

The UHI intensity is influenced by ventilation characteristics. The growth of tall, dense buildings in BKK is likely to reduce inflowing winds contributing to higher UHI intensity in the area. In the dry season, the predominant wind flow in BKK originated from the South and Southeast, with velocities typically ranging from 0.0 and 3.8 $m.s^{-1}$ (Figure 7a). In the wet season, winds also came from the South and Southeast, with velocities generally between 0.0

and 3.6 m.s^{-1} (Figure 7b). In RSK, the lower building density is expected to increase inflowing winds leading to the weak UHI intensity. Wind flow during the dry season primarily originated from the South and Southeast, with velocities ranging from 0.0 to 5.4 m.s^{-1} (Figure 7c), while in the wet season, winds came predominantly from the South and Southwest, with velocities ranging from 0.0 to 5.8 m.s^{-1} (Figure 7d).

Urban structure and geometry have significantly impacted air temperature and wind patterns in both BKK and RSK. The rapid growth of high-rise buildings in the urbanized area of BKK restricts sky view factors and reduces ventilation resulting in lower wind velocities and a reduced capacity to dissipate heat. In contrast, wider open spaces and low-rise buildings in the suburban area of RSK allow the greater ventilation transporting heat out and reducing the UHI intensity in the area.

Higher wind velocities in the suburban area of RSK contribute further to lowering the UHI intensity, and this finding aligns with studies conducted by Rajagopalan *et al.* (2014) [38] and Se *et al.* (2024) [40] demonstrated that higher wind velocities are correlated with the reduced UHI intensity. This is consistent with existing research indicating the role of wind in transporting the heat load from the city center (Du *et al.*, 2016; Chen *et al.*, 2020; Liu *et al.*, 2020) [11, 7, 23]. Thus, this study supports the conclusion that the UHI intensity is greater in the urbanized area of BKK compared to the suburban area of RSK due to the reduced wind velocities in the more urbanized areas.

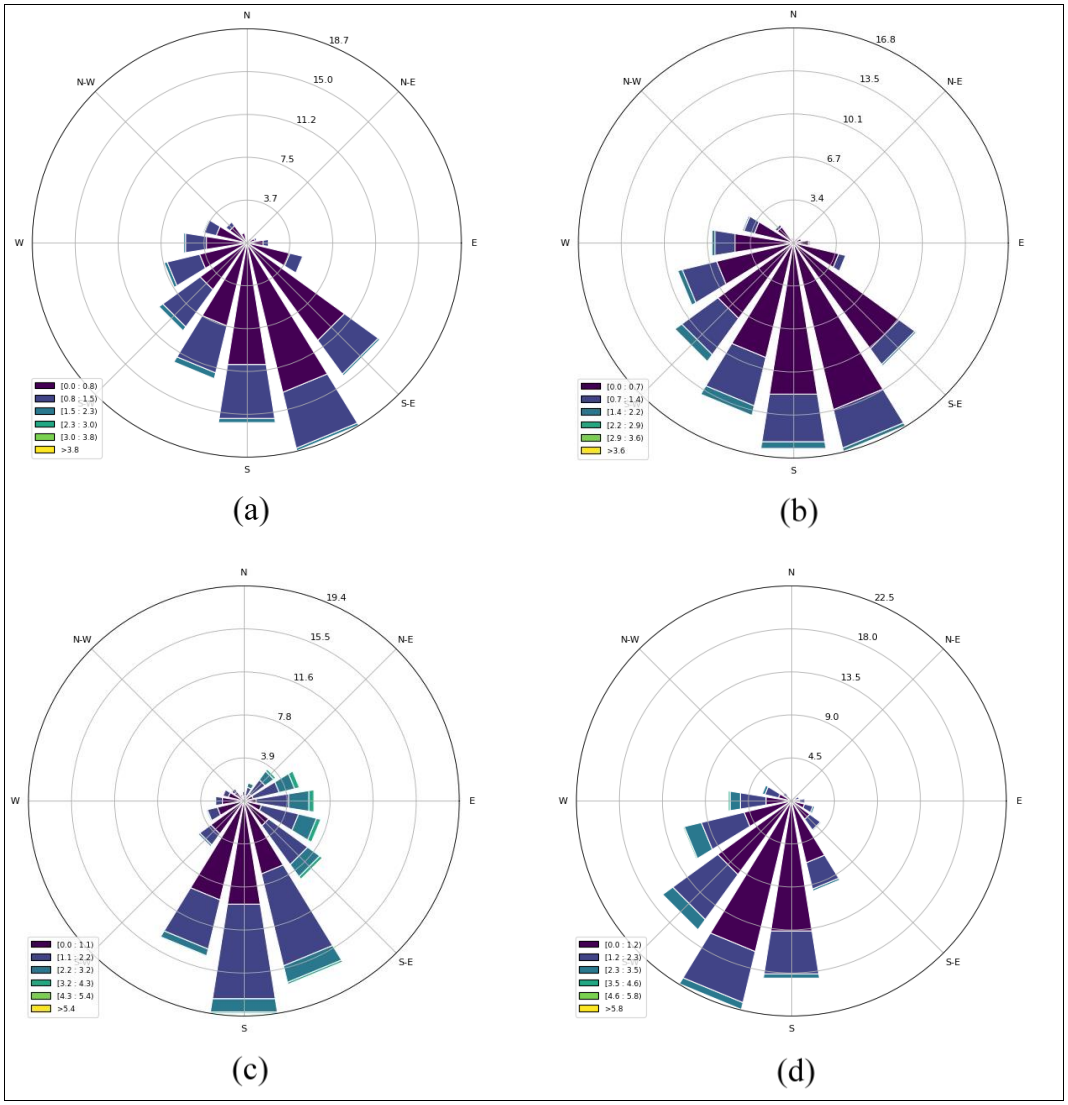

Fig 7: Wind rose diagrams indicating wind velocity in m.s^{-1} in BKK in (a) dry season and (b) wet season, and RSK in (c) dry season and (d) wet season over the studied period

Correlation between temperature difference and wind velocity: Daytime and nighttime temperature differences were determined by daytime average temperature minus nighttime average temperature. Temperature difference and average wind velocity were plotted to understand their relationships. Temperature difference and average wind velocity in BKK are negatively correlated during daytime and nighttime throughout the study period. Both daytime and nighttime temperature differences show significant correlations with average wind velocity in BKK (Figure 8). In particular, the daytime temperature difference in BKK showed a strong negative correlation with average wind velocity in both the dry season (R= -0.40, P<0.001) and the wet season (R = -0.40, P<0.001) (Figure 8a & b). The nighttime temperature difference also showed a negative correlation with average wind velocity, but the correlation is weaker. In the dry season, the correlation was negative, but it was not statistically significant (R= -0.12, P=0.111), while

in the wet season, it was significant (R= -0.21, P=0.005) (Figure 8c & d). Wind velocities were higher during the daytime than at nighttime. In the dry season, the average wind velocities reached 0.75 m.s^{-1} during the daytime and 0.40 m.s^{-1} during the nighttime. In the wet season, it reached 0.71 m.s^{-1} during the daytime and 0.27 m.s^{-1} during nighttime.

As shown in Figure 9, the correlations between temperature difference and average wind velocity in RSK are negative during the daytime and nighttime over the study period. The daytime and nighttime temperature differences are significantly correlated with the average wind velocity in RSK. During the daytime, the temperature difference in RSK showed a strong negative correlation with average wind velocity in the dry season (R = -0.55, *P*<0.001) and the wet season (R= -0.37, *P*<0.001) (Figure 9a & b). During nighttime, temperature difference also showed a negative correlation with average wind velocity in both the dry season (R = -0.27, *P*<0.001) and the wet season (R= -0.19, P=0.009) (Figure 9c & d). Wind velocities were generally higher during the daytime than at nighttime. In the dry season, average wind velocities reached 1.54 m.s^{-1} during the daytime and 0.96 m.s^{-1} during the nighttime. In the wet season, the average wind velocities were 1.44 m.s^{-1} during the daytime and 0.66 m.s^{-1} during the nighttime.

The correlations between temperature difference and average wind velocity in BKK and RSK are significantly negative during the daytime and the nighttime in both the dry and wet seasons throughout the study period. These correlations were stronger in the dry season than in the wet season. This indicates a more pronounced effect of wind velocity on temperature variations during drier and cooler months. Overall, the strongest correlation occurred in the dry season, followed by the wet season for the urbanized area of BKK and the suburban area of RSK.

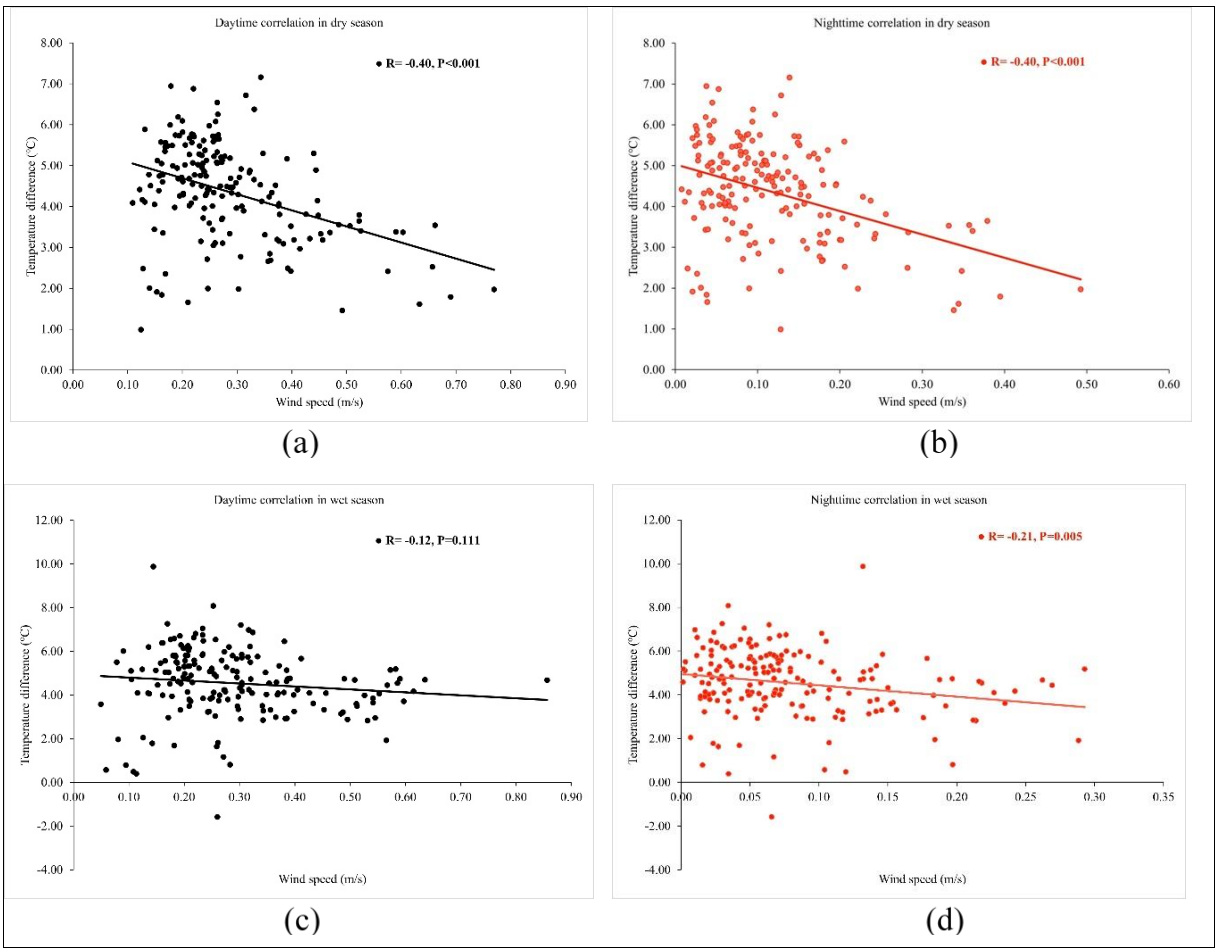

Fig 8: Correlations between temperature difference and average wind velocity in BKK during (a) daytime in the dry season, (b) nighttime in the dry season, (c) daytime in the wet season, and (d) nighttime in the wet season

In summary, the correlations between temperature difference and average wind velocity in both BKK and RSK were most significant in the dry season. Wind velocity played a significant role in mitigating temperature in the suburban area of RSK more effectively than in the more urbanized area of BKK. Liu *et al.* (2020) [23] also found that the correlations between air temperature and wind velocity are most significant during daytime and nighttime, and this aligns with this study. Additionally, Al-Obaidi *et al.* (2021) [2] reported that the UHI intensity and wind velocity are significantly correlated in large Australian cities, indicating a significant influence of wind velocity on the reduced UHI intensity. Furthermore, Tabassum *et al.* (2024) [45] also reported that the negative correlation between the UHI intensity and wind velocity during the daytime (-0.20) and the nighttime (-0.19) in the pre-monsoon season, and this indicates the potential role of wind velocity in reducing the UHI intensity in Dhaka, Bangladesh. The increased temperature leading to the UHI effect is a major urban climate challenge globally. Thus, understanding urban climate dynamics is crucial for developing effective strategies to mitigate its impacts on urban quality of life. In

urban planning, considering sky view factors and urban microclimate design is important to reduce the UHI effect. Many studies conducted by Yow (2007) [55], Du *et al.* (2016) [11], and Se *et al.* (2024) [40] found that higher wind velocities significantly mitigate the UHI intensity in various regions. Additionally, Erell *et al.* (2011) [12] reported that wind velocities ranging from 1 to 1.5 $m.s^{-1}$ in Singapore decreased temperature of 2 °C. Overall, wind velocity plays a significant and potential role in reducing the UHI intensity in the suburban area of RSK more effectively than in the urbanized area of BKK in Phnom Penh.

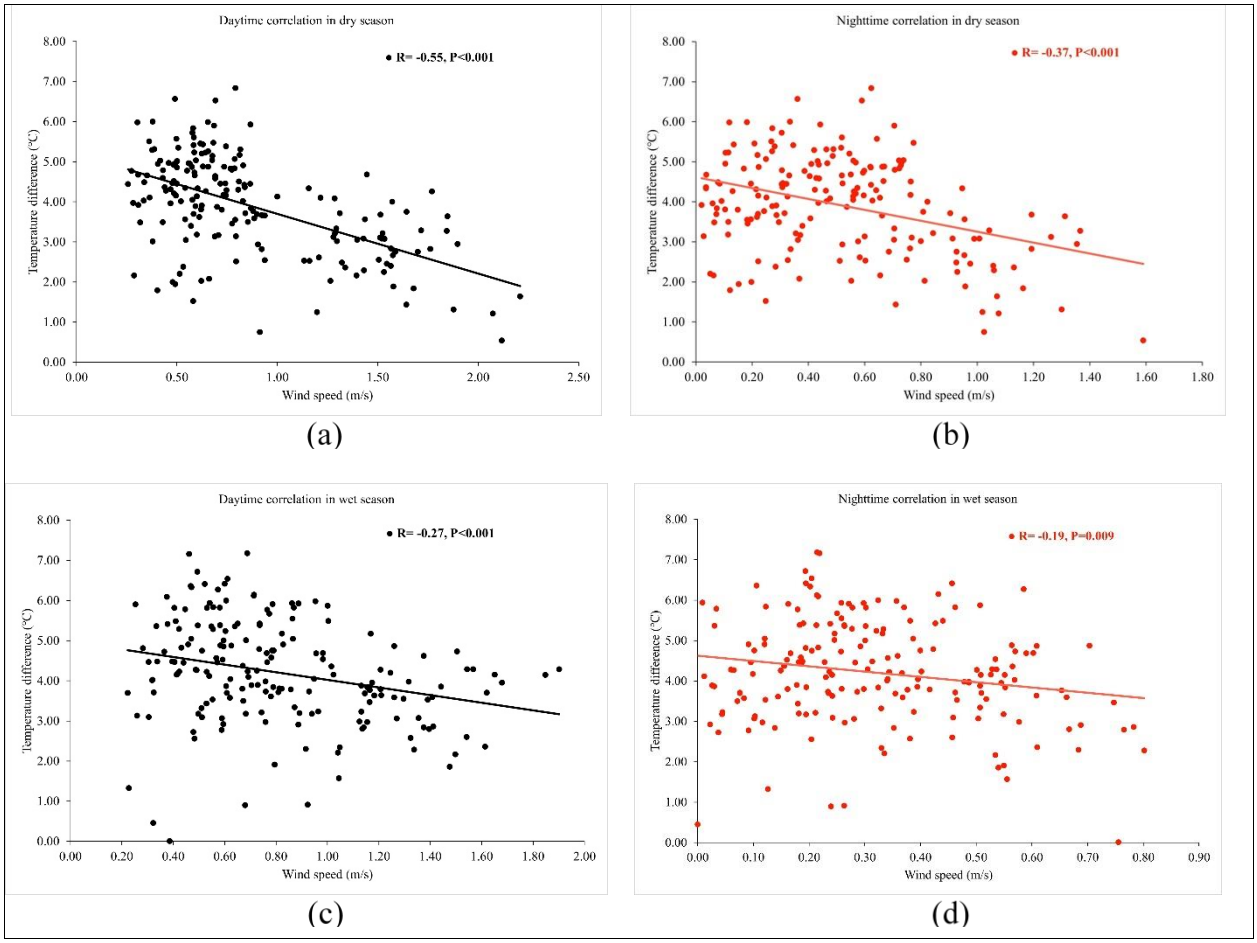

Fig 9: Correlations between temperature difference and average wind velocity in RSK during (a) daytime in the dry season, (b) nighttime in the dry season, (c) daytime in the wet season, and (d) nighttime in the wet season

Conclusion

This study investigated the daily, seasonal and yearly variations of the UHI intensity, ventilation characteristics, and correlations between temperature and wind velocity in Phnom Penh, Cambodia. The study found that the average air temperature in the urbanized area of BKK was higher than in the suburban area of RSK. The hourly UHI intensity was stronger during the daytime than at nighttime and was more pronounced in the dry season compared to the wet season. However, cold island effects were observed at nighttime for the hourly UHI intensity. Similarly, the seasonal variation of the UHI (SVUHI) intensity was observed to be stronger during the daytime than at nighttime and was also more intense in the dry season than in the wet season, though occasional cold island effects were observed during the daytime in the wet season. The annual UHI intensity also followed a similar pattern, with higher intensity during the daytime compared to nighttime.

Ventilation plays a significant role in mitigating the UHI intensity in all scale of the urban setting, with its impact on the UHI intensity depending on how strong the wind velocity is and where wind direction come from. The study found that wind velocities were generally stronger in the suburban area of RSK than in the urbanized area of BKK and also stronger during daytime than at nighttime. Southwesterly winds in the wet season also contributed in mitigating the UHI effect, while slower wind velocities at nighttime were less effective. The correlations between temperature difference and average wind velocity in BKK and RSK were most significant in the dry season, followed by the wet season. Therefore, the higher the wind velocity, the weaker the UHI intensity. This highlighted the significant role of wind velocity in mitigating the UHI effect in Phnom Penh.

In summary, this study confirmed that higher UHI intensity occurs in the urban area of BKK compared to the suburban area of RSK. This is likely due to BKK being dominated by tall buildings, dense neighborhoods, and narrow street canyons, which can obstruct wind flow and contribute to higher UHI intensity. The study also demonstrated that the UHI intensity is generally higher during the daytime than at nighttime across daily, seasonal, and annual scales. This study is the first to analyze the characteristics of the UHI effect in Phnom Penh using ground-based meteorological data, providing a preliminary understanding of urban heat dynamics in the urban setting. The results offer valuable

insights for policymakers and urban planners, emphasizing the importance of designing sustainable and livable cities by implementing UHI mitigation and adaptation strategies. Recommendations include expanding green spaces, utilizing lighter-colored construction materials, preserving and creating water bodies to enhance localized ventilation, and encouraging sustainable transportation methods. Further future research on the relationships between urbanization development, climate change, and the UHI effects are required. Future studies should investigate long-term urban development trends and their impact on the urban climate to support more effective strategies for improving the quality of life for urban residents.

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