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Climate change, extreme heat, and outdoor thermal comfort in urban areas: Case of İzmir, Turkey

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Abstract

Recently, environmental problems, urban population growth, the expansion of urban areas, and climate-insensitive planning practices have significantly increased the effects of the climate crisis in urban areas. As cities' population increases, cities' vulnerability to disasters also increases. The negative effects of the climate crisis and global warming on both socio-economic and socio-ecological ecosystems vary at different scales. On the other hand, urbanization practices and the current spatial structure of Turkish cities reduce the resilience capacity of cities against the climate crisis and increase their vulnerability. When the environmental and social pressures of the climate crisis rise, hazards such as floods, extreme heat, and urban heat island (UHI) effects turn into disasters in cities. To prevent this, the effects of the climate crisis and the resilience capacity of existing urban structures should be well understood. This study focuses on extreme heat and the UHI effect, which is a critical socio-spatial problem. It is seen that the recent literature on climate change and extreme heat mostly focuses on UHI as an urban vulnerability and an effect of urban morphology, but previous studies partially cover morphological indicators. This study differs from many studies by relating local climate zone mapping with site-based study design and a comprehensive morphological dataset. The case study focuses on İzmir, Turkey; the relationship between outdoor temperature recordings and urban typo-morphological features is examined by using multivariate regression analysis. The findings correspond to the detection of the effective size of greening and the importance of ventilation for cooling in relatively high temperature climatic zones.

Keywords: climate change, urban heat islands, local climate zone, thermal comfort, İzmir, Turkey

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Introduction

In the recent era of climate crisis and environmental problems, urban population growth, urban sprawl, and conventional urban planning practices have exacerbated the effects of the climate crisis on urban areas. The negative effects of the climate crisis on socio-economic and socio-ecological ecosystems have emerged at different spatial scales. Heavy rainfall, droughts, extreme heat, and sea level rise occur in different urban areas of the world. Especially in dense urban areas, cities are more vulnerable to climate change-induced disasters such as floods and urban heat islands (UHIs) (Tapia, C. *et al.* 2017). The distribution of these impacts and their exposure levels are not equal among the urban population. Disadvantaged social groups, such as the elderly and disabled, are relatively more vulnerable to the impacts of the climate crisis in urban areas. Since 50.7 percent of the world's population resides in cities and 68.4 percent of them are expected to live in cities by 2050, the impacts of climate crisis on urban areas may be worse due to the rise of (especially disadvantaged) population that will be affected by climate crises in the upcoming years (He, H. *et al.* 2021).

Conventional urbanization practices, planetary urbanization, and the population rise

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of cities around the world make them more vulnerable to the effects of the climate crisis (Öztürk, S.P. and Tikik, M. 2022). Through the impacts of the climate crisis on socio-ecological systems in cities, hazards such as heavy rain, rise of sea level, and extreme heat turn into disasters. To prevent urban disasters, the impacts of the climate crisis in cities and their adaptive capacity should be well understood (Xu, L. *et al.* 2019). Relying on this understanding, climate crisis mitigation and adaptation policies should be developed and integrated into urban systems for more resilient and liveable cities.

In recent studies of climate crisis mitigation and adaptation, the concept of vulnerability provides a fundamental theoretical framework to understand the state of urban systems. The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as the degree to which a system is exposed to and copes with the adverse impacts of climate change. Since the concept of vulnerability is not a directly measurable concept, it is operationalised through a specific set of indicators. Recent literature defines vulnerability as the degree of three basic indicators: Exposure, sensitivity, and adaptive capacity (Weis, S.W.M. *et al.* 2016). When we examine the vulnerability of cities, sensitivity and adaptive capacity are the abilities of the urban systems to cope with climate-related hazards. Many measurable indicators may shape the sensitivity and adaptive capacity of urban systems. These indicators are the structural characteristics of the urban systems, such as macroform layout, green infrastructure, transportation network and traffic volumes, population distribution, etc. For instance, a more compact urban macroform and self-sufficient neighbourhood will help mitigate the urban heat island effect and thus reduce energy consumption demand. Sub-indicators such as building height, street width, sky view factor, and building density, amount of green space, land use diversity, and transportation system also affect the formation of urban heat islands and energy consumption demand (Urquizo, J. *et al*. 2017; Sakar, B. and Çalişkan, O. 2019; Öztürk, S.P. and Tikik, M. 2022; Zhou, L. *et al.* 2022; Xu, D. *et al.* 2023).

The UHI effect is one of the most fundamental urban hazards, depending on extreme heat and urban structure in cities that directly affects the liveability and outdoor thermal comfort (Urquizo, J. *et al*. 2017; Mansuroğlu, S. *et al*. 2021; Zhou, L. *et al.* 2022) and the quality of water, air, soil, and food (Tapia, C. *et al.* 2017; Todeschi, V. and Pappalardo, S.E. 2022). Typological and morphological sub-indicators of urban structure, such as land-use, building density, building height, street network, floor area ratio, and sky view factor, directly affect the degree of urban heat island formation (Tapia, C. *et al.* 2017; Urquizo, J. *et al*. 2017; Sakar, B. and Çalişkan, O. 2019; Öztürk, S.P. and Tikik, M. 2022; Zhou, L. *et al.* 2022).

There have been ongoing investigations to mitigate UHIs' effects, such as the use of afforestation, grassing, and permeable surfaces (Amani-Beni, M. *et al.* 2018), as well as higher sky view factors and wider air corridors (Sakar, B. and Çalişkan, O. 2019). Although green areas and wet surfaces are preferred urban elements for reducing air temperature of the urban areas, their spatial organization in continuity and sizes higher than 30–40 hectares is much more successful (Çubukçu, K.M. and Şentürk, Y. 2022). Creating green areas connected to water bodies such as seas and streams, protecting large water bodies, rainwater recycling, roof gardens, and medium-sized green areas are vital urban design elements to mitigate UHIs (Liu, H.-Y. *et al.* 2023).

To make an accurate decision-making in urban design strategies, it is necessary to comprehend the state of vulnerability and adaptive capacity of cities. Urban vulnerability relies on the context of the city, that is, the demographic, socio-economic, physical, environmental, and institutional characteristics that affect the adaptation capacity against the climate crisis (Kaya, Y. 2018). City-specific vulnerabilities and adaptive capacity make it necessary to design policies to combat and adapt to climate crisis impacts in a city-specific manner. Therefore, the first step in making cities more resilient to climate change is to identify city-specific socioeconomic and socio-ecological vulnerability levels (Xu, L. *et al.* 2019). There are recent approaches to assess the vulnerability level of cities considering the state of urban typo-morphology that may exacerbate the impacts of climate change. Extreme diurnal heat in cities is one of them under consideration (Maiullari, D. *et al*. 2021; Ling, T.-Y. 2022; Ahmed, I. *et al.* 2023; Lemonsu, A. *et al.* 2024). The urban heat island effect is also an important impact of the urban typo-morphology that increases climate change pressure on socio-ecological systems. Studies assessing the relationship between urban typo-morphology and the urban heat islands use various approaches consisting 'multivariate statistical causality models' (Urquizo, J. *et al*. 2017; Xu, L. *et al.* 2019; Wang, Q. *et al.* 2022; Zhou, L. *et al.* 2022), "vulnerability index" calculation (Marquez-Ballesteros, M.J. *et al.* 2019; Akbaba, S. 2020; Bibri, S.E. and Krogstie, J. 2021), urban fragility mapping' and 'simulation modelling' using such as ENVI-Met, EnergyPlus simulation, CEEM-U (Economy and Energy for Urban Microgrids), CityBes, ArcGIS, Insight220, Urban Block Generator Grasshopper /rhinoceros, City Energy Analyst programs (Kardinal Jusuf, S. *et al.* 2007; Asfour, O. 2022; Kolokotsa, D. *et al.* 2022) and 'remote sensing techniques' upon city-wide scale (Galdies, C. and Lau, H.S. 2020; Jain, S. *et al.* 2020; Buo, I. *et al.* 2021; Gadekar, K. *et al.* 2023).

Within the scope of UHIs and extreme heat in cities, there is a limited number of studies focusing on data collection by field study in cities (Urquizo, J. *et al*. 2017; Privitera, R. *et al.* 2018; Kuang, W. 2020; Zhou, L. *et al.* 2022). In addition, there is a lack of comprehensive studies that address local typological-morphological characteristics together with other urban factors and socio-ecological elements (wind speed generation of the urban fabric, density of traffic, green space types, etc.). The explanatory capacity of these studies is also limited due to low indicator datasets and lack of field study (Čeh, M. *et al.* 2018; Yu, Z. *et al.* 2020; Wang, Q. *et al.* 2022). In this context, detailed research is needed to decide which of these features is the most important indicator and to understand the effect of different indicator compositions (Sakar, B. and Çalışkan, O. 2019; Yu, Z. *et al.* 2020; Öztürk, S.P. and Tikik, M. 2022; Wang, Q. *et al.* 2022; Zhou, L. *et al.* 2022). This study differs in its field study based on multiple regression analysis. It focuses on the relationship between urban built environments and extreme heat that may cause urban heat islands (Lemonsu, A. *et al.* 2021; Ling, T.-Y. 2022).

The main argument of this study is that the relationship between urban typo-morphology and extreme outdoor heat must be in focus to design UHI mitigation strategies in cities, and there is a need for micro-spatial scale investigations to understand driving factors (Maiullari, D. *et al*. 2021; Ahmed, I. *et al*. 2023; Lemonsu, A. *et al.* 2024). This study investigates the effect of different features of the built environment on extreme outdoor heat and the impact on the potential configuration of UHIs in İzmir city. The effects on the configuration of extreme outdoor heat as a trigger of UHIs are examined through statistical analysis at close surrounding environments (500 m) of different building types. The unique value of this study is that it has a hierarchical spatial approach from meso- to micro-scale to have a deeper understanding of micro-scale spatial and environmental dynamics. It simulates the 'local climate zones' and continually focuses on 'high climatic zones' to discover prominent features that exacerbate extreme heat. Furthermore, this study aims to provide insights to examine the latent effects of the built environment on the configuration of extreme outdoor heat and UHIs.

Literature review

In recent studies on mitigating and preventing the impacts of the climate crisis, which is a socio-ecological phenomenon, it is seen that the concept of vulnerability provides a theoretical framework. The concept of vulnerability is the degree of three basic indicators: exposure, sensitivity, and adaptive capacity. Exposure is the degree to which a system is exposed to climate crisis-based events. Sensitivity is the degree of positive or negative impacts of the climate crisis on a system. Adaptive capacity is determined by local resources and conditions that limit or support a system's ability to adapt to the climate crisis (IPCC, 2021). When we examine the situation of cities against the climate crisis within the framework of vulnerability, urban disasters such as flooding, inundation, urban heat island, and extreme heat events are the substantial impacts that challenge the vulnerability of an urban system (Weis, S.W.M. *et al.* 2016; Tapia, C. *et al*. 2017; Xu, L. *et al.* 2019; Öztürk, S.P. and Tikik, M. 2022; Todeschi, V. and Pappalardo, S.E. 2022).

UHI is a phenomenon that makes cities vulnerable to climate crisis-based extreme heat, and it is where the cooling process of an urban area is much lower and slower than its nearby rural area, especially at night (Rajagopal, P. *et al.* 2023). Prevailing studies on urban heat islands and extreme heat mitigation are focused on urban environmental quality degradation, urban form, energy demand, urban environment materials, and urban planning policies (Gonzalez-Trevizo, M.E. *et al.* 2021; Karimi, A. *et al.* 2023). Previous studies of UHI have utilized multiple linear regression models and regression-based spatial mappings using Ordinary Least Square, Pearson R, Root Mean Square Error, Mean Bias Error, etc. Besides, the urban canopy model is used to model the relationship between the urban environment and atmospheric parameters (e.g., temperature, wind speed, and solar radiation) (Gonzalez-Trevizo, M.E. *et al.* 2021; Ren, C. *et al.* 2021; Karimi, A. *et al.* 2023). The heat retaining capacity of an urban area is related to the atmospheric parameters (e.g., diurnal temperature, wind speed, and solar radiation) and morphological characteristics of the area. Therefore, diurnal extreme heat events may increase the urban heat island effect caused by urban morphology. Since the temperature differences unfold not only between urban-rural but also within urban areas, it is important to analyse the local climate zones and their atmospheric and typo-morphological characteristics (Martilli, A. *et al.* 2020).

The local climate zone (LCZ) is a theoretical and practical framework to determine urban and rural areas with distinct land use-built types and land cover non-built types that may influence the UHI effect (Geletič, J. *et al.* 2016). These two characteristics consist of building density, building height, surface reflectance, surface roughness length, sky view factor, green spaces, soil and bare lands, water bodies, etc. To classify LCZ, the main methods are supervised manual classification, k-means clustering, remote sensing image classification, and GIS-based urban spatial clustering analysis (Milošević, D.D. *et al.* 2016; Xu, D. *et al.* 2023).

UHI controlling and mitigation studies mainly concentrate on the effects of urban green infrastructure. Urban vegetation, as a greening arrangement, is recommended as a vital strategy to decrease the effects of UHI as well as to control extreme air temperatures at both day and night. Vegetation for UHI mitigation is formed as parks, parklets, street trees, green refuges, green roofs, lawns, green building facades, etc. It is observed that urban green space is usually colder than the surrounding building environment, and its effect is called a 'park cold island' (PCI). Its cooling effect is mainly based on the effects of evapotranspiration and blocking shortwave radiation and providing shadow (Cui, F. *et al.* 2021; Rakoto, P.Y. *et al.* 2021; Wang, Y. *et al.* 2021; Han, D. *et al*. 2023). A case study evident that increasing green cover such as parks, parklets, and street trees up to 10 percent is the most appropriate strategy for UHI mitigation (Wang, Y. *et al.* 2021). It is claimed that the larger green spaces have a much more cooling effect than smaller ones (smaller than 40 ha) (Çubukçu, K.M. and Şentürk, Y. 2022). To succeed 1 °C decrease in outdoor temperature requires an increase in green cover up to 16 percent (Marando, F. *et al.* 2022). Besides, it is recommended that the increasing height-to-width (sky view factor > 0.2) greatly enhance the cooling effect of vegetation (Karimi, A. *et al.* 2023).

Relying on previous studies on UHI and extreme heat events in urban areas, it is vital to evaluate the contributors to the urban heat island effect. It is recommended that further studies focus on identifying 'local climate zones' and microclimates of urban areas, urban design features, and their impacts on UHI, extreme heat, and outdoor thermal comfort (Shi, Y. *et al.* 2019). Outdoor thermal comfort is an important indicator of the quality of urban life and liveability that must be considered in urban planning and design processes.

Study site and methodology

The study area is the city of İzmir, located in the Aegean region and the third largest city in Turkey. İzmir city has a population of 4,500,000 and a surface area of 12,012 km². İzmir's population density is 375 persons per km², and its building density is 15 buildings per km² in the central urban area. The metropolitan urban area has 30 districts, and the central urban area has 11 districts *(Figure 1).* İzmir city has a Mediterranean climate with hot and dry summers and mild and rainy winters. The average annual temperature is 17.3 °C. The annual maximum temperature is 40.5 °C, and the annual minimum temperature is -4.0 °C. The hot summer season is five months long from May to the end of September. Due to its population size and temperatures of up to 40 °C in hot summers, İzmir is an important case of climate crisis-sensitive urbanization.

The study has mainly two parts, one is local climate zones mapping to determine sub-urban areas with distinct land cover and typo-morphological characteristics. The second

Fig. 1. Central districts of İzmir with site measured points. *Source*: Authors' compilation.

part assesses the relationship between built environment features and diurnal outdoor heat records. The methodological approach of the first part is based on overlay mapping of these parameters in ArcGIS 10.8 using the spatial analysis overlay tool to create local climate zones. The second part relies on multi-variable regression analysis to measure the relationship between built environment features and diurnal outdoor heat within relatively 'high climatic zones' in SPSS using the regression tool. The site study focuses on different typo-morphological features in the 'high local climate zones' of İzmir. The study operationalizes the effects of the built environment on outdoor heat by using measurable indicators.

Within the context of first part of the study, the local climate zones of İzmir are mapped using eight indicators: 1) building heights, 2) building density, 3) street density, 4) arterial road density, 5) green space density, 6) aspect of solar radiation, 7) aspect of sea breeze exposure, 8) water bodies are used in ArcGIS 10.8. Subsequently, three climatic zones were identified, and zones with relatively high building density and low green areas and water bodies, as 'high urbanized' (LCZ 2 and LCZ 3), are selected for outdoor diurnal temperature recording.

The LCZ map was developed using GIS software of ArcGIS 10.8-based on spatial clustering analysis using weighted sum under the overlay tool of ArcMap 10.8 by ex-

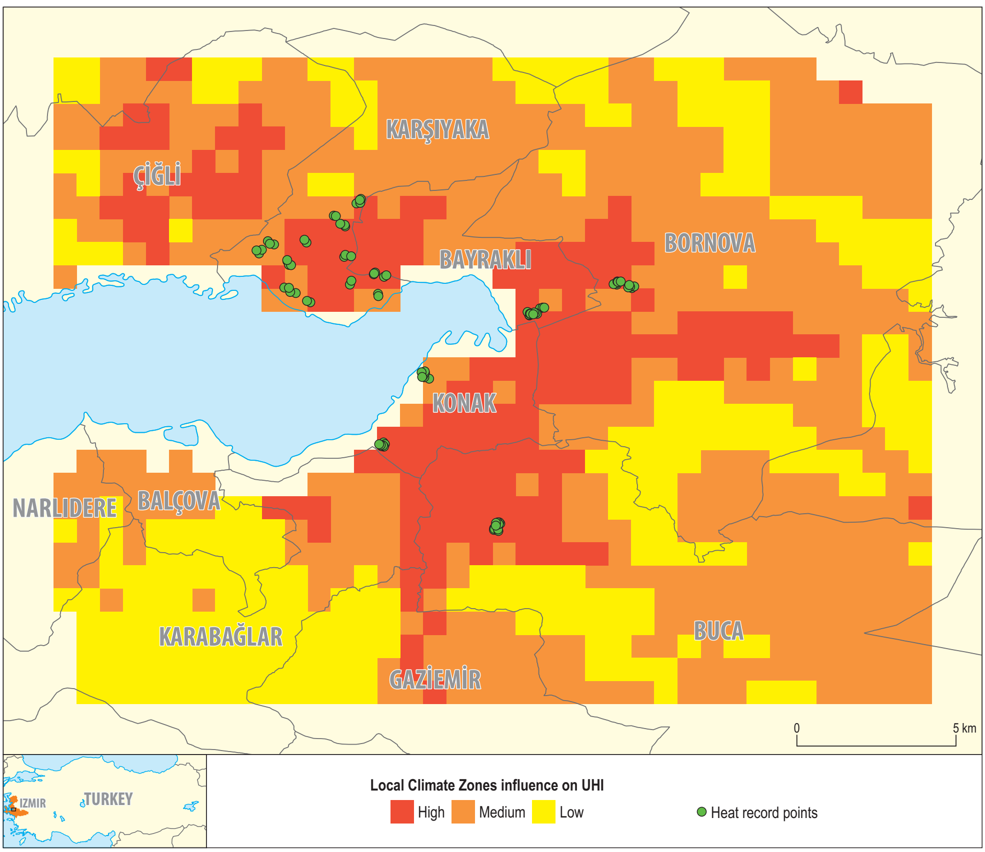

Fig. 2. Local climate zones and locations of temperature records. *Source*: Authors' compilation.

amining the eight indicators of İzmir city. These indicators are categorized into three categories as high, medium, and low using natural break classification. The indicators are combined by aggregating the indicators with equal weighting factors. The suburban areas that have the highest building density, lowest green space density, no water body, without direct sea breeze, and in the south-west direction with direct solar radiation are defined as high: LCZ 3. The suburban areas with medium building density, medium green space density, without direct sea breeze, without water body, and in the south-west direction are defined as medium: LCZ 2. Subsequently, the urban areas with the lowest building density, highest green space density, close to the water body, in the west direction with direct sea breeze, and without direct solar radiation are defined as low: LCZ 1 *(Figure 2).* The most populated urban areas correspond to LCZ 3, with the highest density and lowest green density. Within the scope of outdoor temperature recordings, the locations are indicated within 'high urbanized' zones, considering different morphological and atmospheric features as seen in *Figure 2*.

The second phase of the study seeks to identify built environment features associated with higher temperatures using multivariate regression analysis for site temperature recordings with sensors, and typo-morphological indicators. The study area is focused on LCZ 2 and LCZ 3 in the city centre, with red coloured, which are relatively the densest urbanized zones. Within these zones, diurnal outdoor temperature was recorded at 88 different locations with sensors, and 11 indicators of the built environment were collected (Zhou, W. *et al.* 2011; Yan, H. *et al.* 2018; Peker, E. 2021).

These indicators are classified such as urban form layout: (1) average building storey at the point of measurement; (2) building facade material; (3) street width (m); (4) nearest green area type (park, recreation area, residence garden, refuge, traffic island, cemetery, garden of mosques, garden of schools etc.); (5) direct wind exposure (used with 1 and 0 to indicate direct exposure to prevailing sea wind [west and north-west in İzmir]); (6) average building storey within 500 m radius; (7) amount of green space within 500 m radius; (8) building typology (attached, detached, block, twin-attached); (9) street morphology within 500 m (grid, organic, radial); (10) street paving material (stone paving, asphalt); (11) average number of street lanes (width) within 500 m radius (average lane information is used to represent vehicle traffic volume), as seen in descriptive statistics in *Table 1* (Sakar, B. and Çalışkan, O. 2019; Martilli, A. *et al.* 2020; Gonzalez-Trevizo, M.E. *et al.* 2021; Marando, F. *et al.* 2022; Karimi, A. *et al.* 2023).

*Table 1. Descriptive statistics**

Indicator	Mean	Standard deviation
temperature	30.350	1.7237
build_storey	8.22	7.866
facade_material	1.09	0.289
street_width	12.563	5.9436
type_greenspace	Residence garden, 3000 m^2	1.597
directwind	50% direct sea breeze exposure	0.502
ave_build_storey_around	5.94	2.351
ave_greenspace_around	10.3532 ha	13.30750
type_building_morphology	detached	0.730
street_morphology	grid iron	0.664
street_material	asphalt	0.468
ave_streeline_around	2.94	0.998

*N = 88.

Findings and results

In the study, outdoor temperature is recorded at highly urbanized zones as LCZ 2 and LCZ 3. In the city centre, the outdoor temperature of 88 locations is recorded, and the built environment indicators in 11 different sub-categories are collected, and descriptive statistics are seen in *Table 1*. According to the data of 88 locations, the most common green typology is semi-public green areas of residential units, the average building storey is 8, the average street width is 12.56 m, the most common building typology is detached housing, and the most common street morphology is a grid-iron layout. Besides, the average height-to-width (H/W) ratio (mass to street) is measured at 2.12, which may cause huge solar radiation exposure (especially in east-west orientation).

In the regression model *(Table 2)*, the correlation coefficient R and the coefficient of determination R^2 are measured. The R-value of 0.726 indicates that the model is highly correlated. The R^2 value shows that 52.8 percent of the temperature value can be explained in light of the collected data, and an R-squared between 0.50 to 0.99 is acceptable in social science research, especially when most of the explanatory variables are statistically significant (Ozili, P.K. 2022). In the ANOVA table, we see that the regression model predicts the dependent variable significantly well with a reliable (sig.) coefficient of 0.000. The F value is 7.715; a value greater than 1.000 indicates that the efficiency of the model is within acceptable ranges *(Table 3)*.

According to the regression analysis, the statistically significant variables that have a positive relation with outdoor temperature are *street width, type of nearest (closer than 500 m) green space, direct wind (sea breeze) exposure, street material, and average number of street lanes within 500 m radius (Table 4)*. Considering the Beta constant value, it is seen that *direct sea breeze (west and north-west) exposure, the number of street lanes (representing traffic volume), and street pavement material* are the most positive effective indicators of the outdoor temperature in İzmir city. Notably, it is observed that the urban areas without direct sea breeze and closer to the asphalt streets with 3 additional traffic lanes *(city highway in İzmir)* have the highest diurnal outdoor temperature, and they are in LCZ 3. Since they are in LCZ 3, with limited green space and the highest building density, they may have the highest potential to intensify urban heat island effects during night-time.

As mentioned above, important indicators are determined as 'direct exposure to wind *(sea breeze)*', 'the number of street lanes'

Table 2. Model summary

Model	R	R square	Adjusted R square	Standard error of the estimate
1	0.726[a]	0.528	0.459	1.2676

[a]Predictors: (Constant), ave_streeline_around, street_material, ave_greenspace_around, build_storey, ave_build_storey_around, type_greenspace, directwind, street_width, type_building_morphology, facade_material, street_morphology

Table 3. ANOVA[a] table

Model 1	Sum of squares	df	Mean square	F	Sig.
Regression	136.376	11	12.398	7.715	0.000[b]
Residual	122.124	76	1.607	–	–
Total	*258.500*	*87*	–	–	–

[a]Dependent variable: temperature. [b]Predictors: (Constant), ave_streeline_around, street_material, ave_greenspace_around, build_storey, ave_build_storey_around, type_greenspace, directwind, street_width, type_building_morphology, facade_material, street_morphology.

Table 4. Coefficients[a] table

Model 1	Unstandardized coefficients Beta	Standard error	Standardized coefficients Beta	t	Sig.	95% confidence interval for Beta	
						Lower bound	Upper bound
(Constant)	25.268	1.464	–	17.257	0.000	22.352	28.184
build_storey	-0.009	0.026	-0,039	-0.324	0.747	-0.061	0.044
façade_material	0.633	0.688	0.106	0.921	0.360	-0.736	2.002
street_width	0.084	0.028	0.291	3.004	0.004	0.028	0.140
type_greenspace*	-0.242	0.099	-0.224	-2.432	0.017	-0.440	-0.044
Directwind (sea breeze)**	-1.303	0.326	-0.379	-3.997	0.000	-1.952	-0.653
ave_build_storey_around	-0.058	0.067	-0.080	-0.866	0.389	-0.193	0.076
ave_greenspace_within 500 m radius, ha	0.024	0.016	0.182	1.485	0.142	-0.008	0.055
type_building_morphology	0.101	0.242	0.043	0.419	0.676	-0.380	0.583
street_morphology	0.329	0.311	0.127	1.059	0.293	-0.290	0.948
street_material***	1.780	0.352	0.484	5.057	0.000	1.079	2.481
ave_street_lane within 500 m radius	0.755	0.183	0.437	4.113	0.000	0.389	1.120

[a]Dependent variable: temperature. *Ordinal data as: 8 = Fair green area, 435,589 m^2; 7 = Recreation area, 15,584 m^2; 6 = Cemetery, 9730 m^2; 5 = Park, 6748 m^2; 4 = Residence garden, 3100 m^2; 3 = School garden, 2785 m^2; 2 = Mosque garden, 1300 m^2; 1 = Refuge, 900 m^2. **Ordinal data as: 1 = Direct sea breeze from west and northwest; 0 = No direct sea breeze. *** Nominal data as: 1 = Asphalt; 2 = Cobble-stone paving.

representing the traffic volume, and 'street pavement material'. When the sea breeze exposure (prevailing wind direction is west and northwest) increases by one unit, the temperature decreases by 1303 units in the İzmir case. Afterwards, a one-unit increase in the street lane roughly increases the temperature by 0.755 units in the İzmir case. It is claimed that a height-to-width (H/W) ratio lower than 1.00 and strong air flow through urban canyons (sky view factor > 2.0) have a cooling effect on ambient outdoor temperature. In the study area, the H/W ratio is calculated at 2.12, and the common street layout is grid-iron, which causes a low sky view factor and high solar radiation exposure of urban canyons (streets), especially in east-to-west orientation in İzmir.

It is seen that wind exposure, street pavement material, and the number of street lanes are much more effective on urban outdoor air temperature than green spaces in İzmir. These indicators are more strongly correlated with lower temperatures rather than green space size in İzmir city. Moreover, there is no significant change in outdoor air temperature by the rise of green space size up to 50 hectares at most and an average of 10 hectares *(it is recorded 10.35 hectares in average and standard deviation is 13.30 at 88 different locations)* in LCZ 2 and LCZ 3 of İzmir city. The largest total amount of green space is recorded as 50 hectares, and it is rarely seen in LCZ 2 and LCZ 3, and the smallest total green space was measured at 0.98 hectares. There are various types of green spaces, such as parks with tree canopy, refuges, gardens of residential units, cemeteries, gardens of mosques, school gardens, and recreation areas in İzmir. The findings indicate that the average size of green space up to 10 hectares has no relation with the cooling effect on outdoor temperature in İzmir city.

Relying on the results of regression analysis with temperature records, the main related indicators with higher outdoor temperature are detected as traffic volume (*the arterial roads bigger than two-lane streets*) and the high levels of solar radiation exposure of urban canyons (*asphalt streets along the east-west direction).* It is assessed that it is important to lower solar radiation by narrower urban canyons (streets) in the east-west direction and designing elongated streets along the north-south axis instead of a grid iron layout. Moreover, direct exposure to sea breezes is one of the main sources of the cooling effect on higher outdoor temperatures across the study area.

Conclusions

In the era of climate change, urban areas are facing great challenges stemming from climate change-related hazards, high density, and rising population. The urban areas host huge populations and have varied economic facilities, social groups, and ecological systems. To manage climate change effects in urban areas, it is important to comprehend the mechanisms that exacerbate its impacts on socio-ecological and socio-economic systems. One of the major challenges that urban areas face is extreme heat and UHIs. The UHIs' impacts cause atmospheric and environmental problems, uncomfortable thermal conditions, individual health problems, and rising energy demand.

It is vital to discover the features of urban built environments that may cause UHIs configuration and decrease thermal comfort. This study uses LCZs mapping to discover 'highly urbanized' areas with limited green space and water bodies, and further performs a multivariate regression analysis to understand the relationship between urban typo-morphology and outdoor air temperature by taking advantage of site recordings in İzmir city. The main argument of this study is that urban morphology and typology must be in focus to design appropriate UHI mitigation strategies in cities. LCZs mapping helps to reveal distinct urban areas susceptible to urban heat island formation, and the regression model helps to discover prominent indicators that significantly contribute to elevated outdoor air temperature.

Within the scope of this study, it is found that urban typo-morphological and atmospheric features have a substantial impact in outdoor temperature. The direct sea breeze exposure is highly associated with higher temperatures rather than green space in İzmir. Moreover, the traffic volume based on street width is highly associated with higher temperatures. Due to the lower wind exposure and high traffic volume, highly urbanized zones (LCZ 2 and LCZ 3) have higher outdoor temperatures relatively. It is also assessed that it is important to lower solar radiation by narrower urban canyons (streets) in an east-west direction and increasing linear streets along the north-south direction. Besides, there is no significant relationship between daytime outdoor temperature and green space size, for a noticeable decrease in temperature, the average size of the green spaces must be increased within the context of İzmir city.

In conclusion, the findings show that direct wind (sea breeze in İzmir) exposure is much more associated with lower temperatures than small parks and green areas. Besides, relatively wider streets with solar radiation exposure and higher traffic volume are much more associated with higher outdoor temperature in İzmir. The study's scope is constrained by the complexity and heterogeneity of urban environments. The heat records of the sites and the number of sites (88 in this study) should be increased to reduce potential bias. Moreover, the results of the study are highly associated with the climatic conditions of İzmir, and there is a need for comparative studies of cities with different climatic conditions to draw broader generalizations. For further studies, the cooling performances of each indicator and each mitigation strategy should be compared by context-specific simulations. For convenient UHI mitigation and thermal comfort, rising capacity, a proper ventilation design, adequately sized vegetation and cool materials in urban canyons (streets) should be systematically integrated into urban design and planning decisions.

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