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The Thermal Comfort of Local Climate Zone: in the Case of Hot-Humid Adana City

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ABSTRACT
In recent years, urban heat island studies have come to the fore with urbanization and the need to provide thermal comfort has emerged to create livable cities. In this context, the necessity of determining Local Climate Zone (LCZ), climate-based classification techniques in cities, has been revealed. The study includes the climate-based classification of Adana's urban settlement texture located in the hot, humid climate zone and the statistical comparison of these classes' thermal comfort conditions. The Physiological Equivalent Temperature (PET) index was used to determine the thermal comfort and the analyzes were carried out with the ENVI-met microclimate software. This study was carried out in 4 stages including, i) mapping of the LCZ classes of the study area, ii) determination of the thermal comfort situation of the study area using ENVI-met microclimate simulation; iii) determining the statistical relationship between LCZ and PET with ANOVA-Tukey HSD test, iv) developing suggestions for improving the thermal comfort of the city. The study determined that dense settlements (LCZ 1, 2, 3) are cooler than open space settlements (LCZ 4, 5, 6). The main reason for this cooler appearance is the high rate of shadowing in these areas. Besides, the land cover classes with a low shade ratio and high sun exposure (LCZ D, E, G) had higher temperatures than the classes with dense vegetation and shade ratio (LCZ A and B). While shade and wind speed affect thermal comfort positively in the study, direct exposure to the sun and low wind speed affect thermal comfort negatively.

***Keywords* –** Local Climate Zone, Physiological Equivalent Temperature (PET), Hot-humid city, ENVI-met

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I. INTRODUCTION

Rapid population growth has led to accelerating urbanization worldwide, transforming rural areas into urban areas by degrading the land use/cover, reducing the understanding of environmentally integrated urban plans and design, forming unplanned urban geometry, and caused a change in the urban climate [1]–[5].

In the 1980s, the concept of thermal comfort has been included in climate-balanced design studies. In ISO 7730 [6] standards (ISO: International Organization for Standardization), thermal comfort is defined as "the state of mind expressing satisfaction from the thermal environment". Although thermal comfort is easily understood as a quality, it is difficult to quantify as it varies from person to person [7]. Therefore, it is possible to define thermal comfort as "the comfort condition of the majority of individuals in terms of climatic conditions (temperature, humidity, wind, etc.) while carrying out their indoor or outdoor activities" [8]–[12].

Thermal comfort becomes essential for three main reasons. The first is creating a comfortable climate space for the users. The second is the minimization of consumption due to intense energy use and establishing standards for providing thermal comfort [13]. In this context, thermal indices have been produced in the classification of thermal comfort. In recent years, more than 100 human thermal indexes have been developed in thermal comfort studies, which include human-related elements (age, gender, metabolic rate, clothing, etc.) in addition to climatic characteristics. However, the indexes (such as Predicted Mean Vote (PMV), PET, Universal Thermal Comfort Index (UTCI), Standard Effective Temperature (SET), Effective Temperature (ET)) specially developed for the evaluation of outdoor thermal comfort are limited [14], [15]. One of the most common of these indexes in international studies is the physiological equivalent temperature (PET). PET helps to determine outdoor thermal comfort by evaluating climatic factors and human characteristics in different climatic regions together. While the thermal comfort index was initially based on mathematical calculation, it is more effectively calculated by ENVI-met and Rayman software to develop models in recent years.

Urban heat island studies show differences in cities according to the city's location, urban morphology, and local climate zones [16]. However, the most important features of urban areas that affect the urban climate are; urban structure and characteristics (factors such as morphology, macro form, green system, urban texture, building composition, etc.), urban surface albedo, dense and high-rise buildings, green areas and plant availability [17]. Therefore, the necessity of classifying the basic urban features that can affect the climate has emerged. In this context, the study aimed to classify the urban texture with LCZ developed by Stewart and Oke [18]. In this way, LCZ-based thermal comfort of the hot-humid city of Adana was evaluated, and improvement suggestions were developed for these areas.

II. MATERIALS AND METHODS

II.1. Study area

Adana City is a highly developed and fifth crowded area in Turkey (Fig. 1). Adana has a typical Mediterranean 'Csa' climate, according to the Köppen-Geiger climate classification, with cool, wet winters and hot, dry summers. The average daily maximum air temperature is about 31 °C in August as the hottest period, and about 15-16 °C in January and February as the coldest period. August is a period when the weather is hot and humid, and there is no rainfall. The dominating wind direction is north- northeast in winter and south-southwest in summer.

II.2. Methods

The study method consists of four steps: i) modeling the thermal comfort map using ENVI-met microclimate model; ii) classification of local climate zones; iii) statistical analysis of relationship LCZ types and PET; iv) development of suggestions for improving thermal comfort.

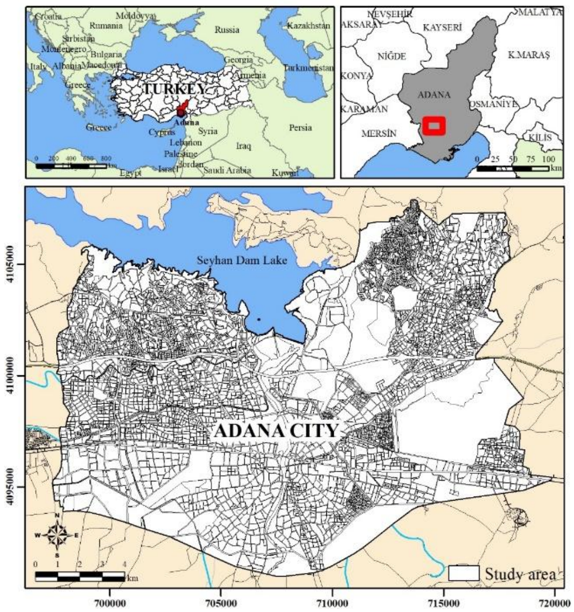

Fig 1. The study area

II.2.1. Local Climate Zones

Local climate zones (LCZ) define the region with similar surface-air temperature distributions at 100 m and 10,000 m on a horizontal [19]. LCZ types have been determined according to the characteristics of similar areas in terms of geometry and land cover under climatic conditions with calm and open skies. Factors considered in determining LCZ classes are vegetation, building/tree height and spacing, soil moisture, and anthropogenic heat flow. The differences in these features constitute the 17 LCZ classes as settlement types (1-10) and land cover types (A-G) (Fig. 2) [18] .

The mapping of LCZs is based on three methods, including manual sampling, remote sensing, and vectors in the GIS environment considering the data sources and analytical techniques. Most previous studies have used raster-based open-source data and software such as the World Urban Database and Access Portal Tools (WUDAPT) to map LCZ [4], [20]–[24]. However, in this study, LCZ types were classified in the Geographic Information Systems environment using Zheng's et al. calculations [1]. While the classes were determined, the building block's boundaries were taken into consideration, and a more detailed and accurate classification was produced.

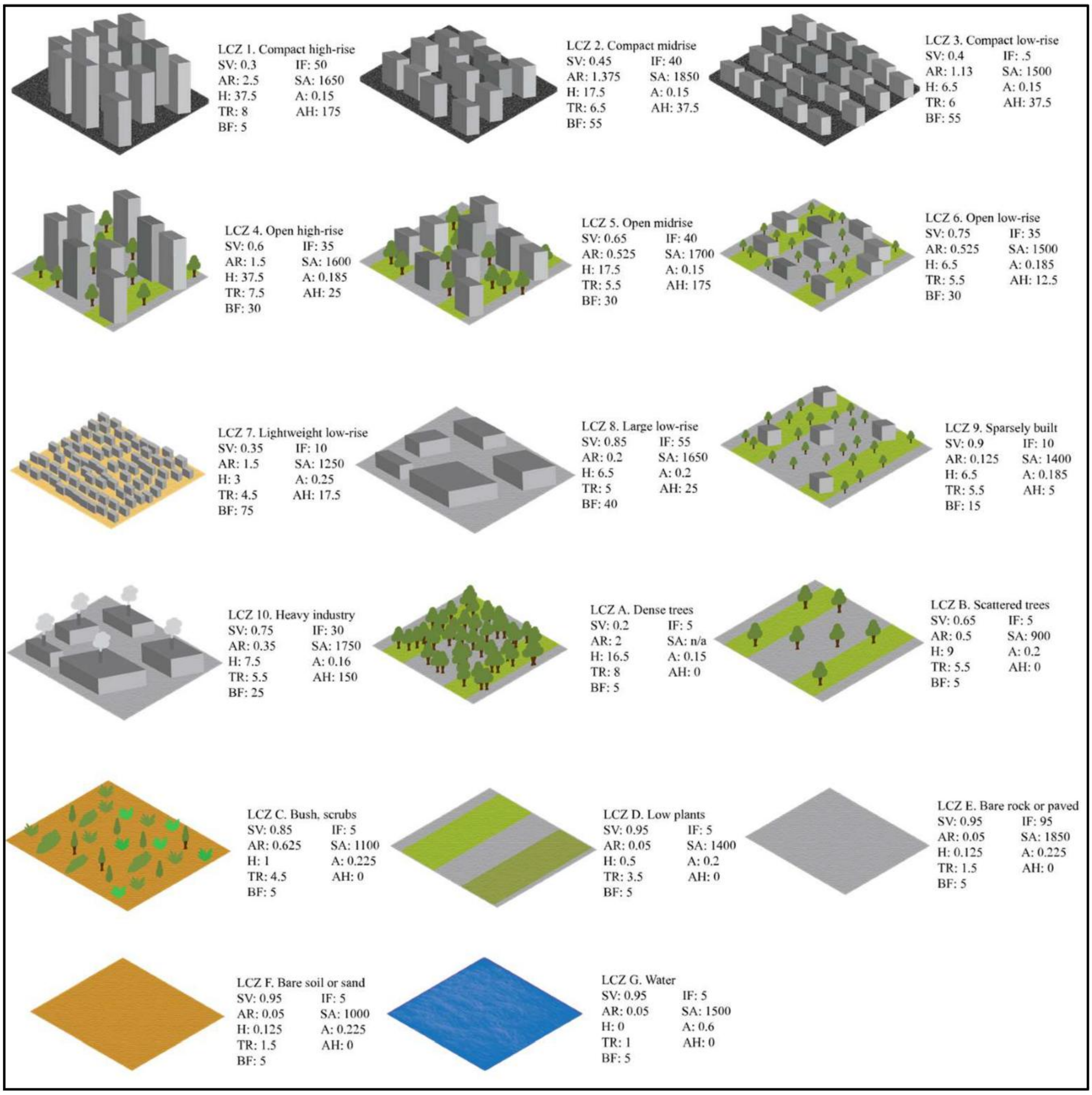

Fig 2. The classification of each LCZ type; and average values of parameters (sky view factor (SV); aspect ratio (AR); mean building/tree height (H); terrain roughness class (TR); building surface fraction (BF); impervious surface fraction (IF); surface admittance (SA), surface albedo (A); and anthropogenic heat flux (AH) [25] [18]

II.2.2. ANALYSIS OF THERMAL COMFORT

ENVI-met is a non-hydrostatic four-dimensional (three spatial dimensions plus one-time dimension) microclimate model, with horizontal resolution ranging from 0.5 m-10 m, developed to calculate and simulate climate variables in urban areas. ENVI-met is a model that aims to reproduce the main processes in the atmosphere that affect the microclimate on a well-established physical basis.

The model simulates the microclimate dynamics within a 24 or 48-hour cycle, taking into account the relationships of all variables, including temperature, humidity, wind speed, radiation fluxes, turbulence, and mean radiant temperature [26], [27]. The ENVI-met model can simulate anywhere from the microclimate to the local climate scale, combining the influence of buildings, vegetation, surface properties, soils, and climatic conditions [28]. ENVI-met is a widely validated and respected model for urban microclimate assessment and is the only model with the necessary features and capabilities for microclimatic studies [29].

Table 1. PET thermal comfort classes and thermal perception [31]

PET (°C)	Thermal perception	Grade of physiological stress
<4	Very cold	Extreme cold stress
4.1 – 8.0	Cold	Strong cold stress
8.1 – 13.0	Cool	Moderate cold stress
13.1 – 18.0	Slightly cool	Slight cold stress
18.1 – 23.0	**Comfortable**	**No thermal stress**
23.1 – 29.0	Slightly warm	Slight heat stress
29.1 – 35.0	Warm	Moderate heat stress
35.1 – 41.0	Hot	Strong heat stress
>41.0	Very hot	Extreme heat stress

Thermal Index: Physiological Equivalent Temperature (PET) was used to examine the relationship between human outdoor thermal comfort and thermal environment (Table 1). PET is defined as the reflection of human body temperature at a typical indoor air temperature to real and complex outdoor conditions. PET enables users to compare their outdoor thermal experiences with indoor experiences and considers the physiological capacities of the human body to adapt to stressful microclimates [9], [30]. The unit of temperature is calculated as degrees Celsius (°C) and makes it easier to understand the effect of the human body's thermal environment.

II.2.3. Statistical Analysis

One of the statistical methods used in determining the difference between groups with different characteristics is an analysis of variance (ANOVA-Analysis of Variance). However, homogeneity and normality tests should be applied in order to perform variance analysis. ANOVA, which examines the significance of the difference between the groups, tries to determine whether there is a difference in general but does not investigate which group or groups are caused by. If the difference between groups is significant, post-hoc analyses are applied to determine the difference's origin [32]. One of the important factors in the selection of statistical types belonging to post-hocs is whether the intergroup variance is equal or not.

In this study, the relationships between each LCZ type and the PET values obtained from the ENVI-met results were statistically analyzed. First, Welch's one-way ANOVA test was used to determine the differences in PET values between LCZ types. Then, Tukey HSD post-hoc test was used to compare the mean PET values for each LCZ type as group variances were equal. As a result of these post-hoc statistics tests, it was determined that there is a statistically significant difference between the groups with p-value less than 0.05 ($p < 0.05$).

III. RESULTS

The study methodology includes three main steps and the findings were listed according to these steps. The first step is the classification of the Local Climate Zone. Local climate zones of Adana were mapped in line with the numerical values determined by Stewart and Oke [18] (Fig.3).

While 46.8% of the study area consists of LCZ 1-10 classes, which are build types, 53.2% of the study areas are LCZ A-G classes, land cover types. Although all LCZ classes existed in the study area except LCZ F (bare soil and sand), some classes are dominant. The dominant classes are LCZ 3 (compact low rise) (9.1 %), LCZ 4 (open high-rise) (7.8 %), LCZ 5 (open midrise) (4.5%) and LCZ 6 (open low rise) (19.5%). LCZ 1 (compact high-rise), LCZ 2 (compact mid-rise), and LCZ 7 (lightweight low-rise) are very few in the city, with a total of 0.5%. Additionally, LCZ 8 (large low-rise) and LCZ 9 (sparsely built) are covered 3.4% of the total study area. LCZ 10 (heavy industry) is covered in only 2.0% of the study area.

The percentage of LCZ A (dense trees) is 7.0% of the study area, and LCZ B (scattered tree) covers 2.3% of the study area. LCZ C, which forms natural scrub areas, is included in only 0.6%. The highest rate of land cover types are LCZ D (low plants), which represents agricultural areas and pastures, with 28.7%, and LCZ E (bare rock and paved), which represents street networks, with 13.8%. LCZ F (bare soil and sand) is not existed in the study area. The LCZ G (water) class, which includes irrigation channels and river water surfaces in the city, covers 0.7% of the study area.

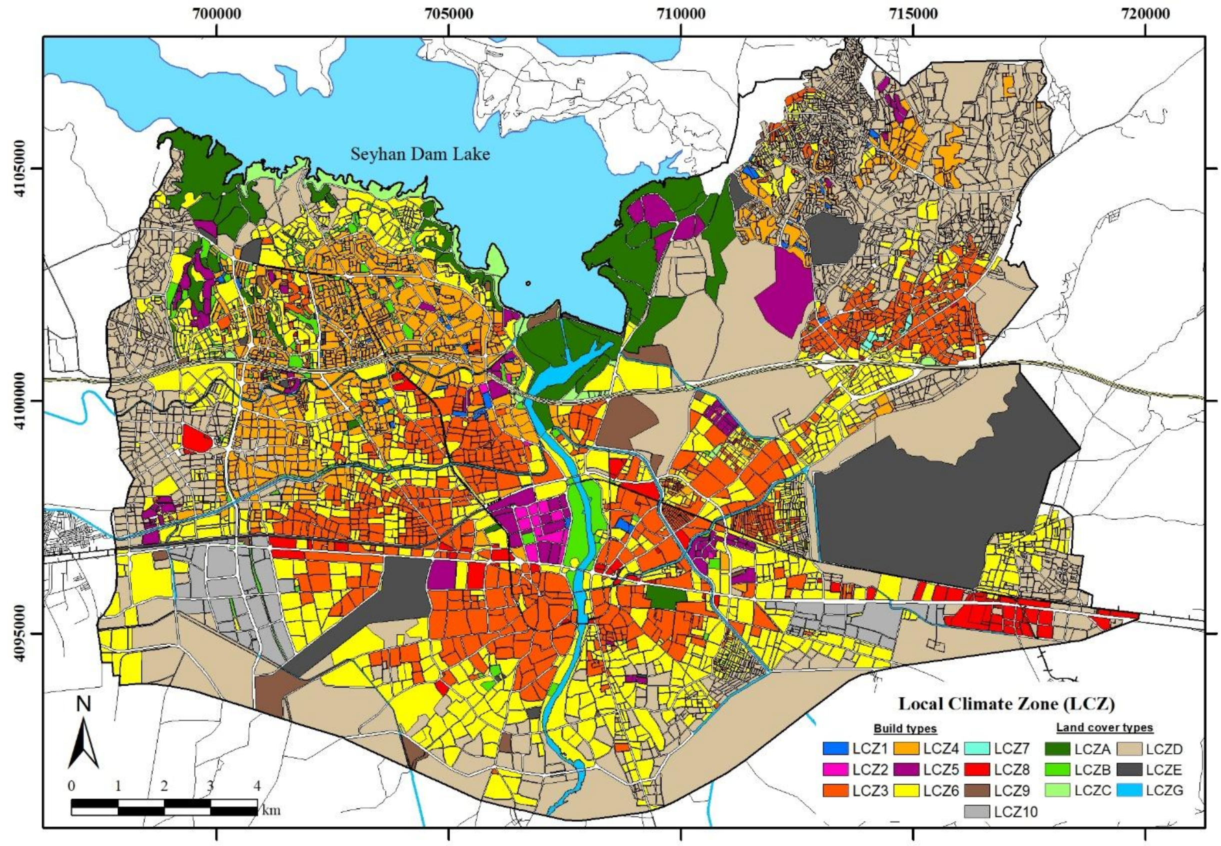

Fig. 3: Local Climate Zone maps for Adana City

The second step is to determine the outdoor thermal comfort situation of Adana City by ENVI-met model. Spatial data, climatic data, simulation data, and personal human parameters were determined to analyze the thermal comfort of Adana City (Table 2).

Table 2. Parameters used for ENVI-met simulations

Spatial data	with Spaces and Monde	Building height	Variety			
		Outdoor surface materials	Roads and parking lots		ST-Asphalt	
			Urban Green Spaces		%50 tree, %50 grass	
			Other surfaces		LO-Loamy soil	
			Water surface		WW-Water	
			Forest area		BS- 20 m tree density, mixed crown	
			Coast		SD- Sandy soil	
Simulation data	with ENVI-guide	Date	8 August		Hottest day	
		Start Finish	12.00.00-15.00.00			
		Simulation period	3 hours			
		Grid size (m)	x =20; y=20; z=3			
Climate data		Simulation day	8 August (1990-2019 climate data)			
		Simulation hours	12.00	13.00	14.00	15.00
		Air temperature (°C)	33,80 °C	34,45 °C	34,47 °C	33,92 °C
		Relative humidity (%)	47,50 %	44,22 %	44,00 %	49,10 %
		Wind speed (m/h)	2.4 (min)		2.9 (max)	
		Prevailing wind direction	45° (NE)		225° (SW)	
		Specific humidity (g/kg)	2.2 (min)		8.0 (max)	
Personal Human Parameters	with Biomet	Age	35			
		Size	1.75 m (ISO 7730)			
		Weight	75 kg			
		BMI	18.5-24.9 kg/m^2 (*healthy weight*)			
		Metabolic rate	1.4 (5 km/h walking speed)			
		Clothes	0.60 clo in the summer (trousers or skirts and shirts made of fine fabric)			

The Physiological Equivalent Temperature (PET) of the study area was calculated using Biomet, one extension tool of the ENVI-met software. ENVI-met uses four climatic parameters to calculate the PET value. These are air temperature (℃), wind speed (m/s), specific humidity (g/kg), and Mean Radiant Temperature (MRT) (℃).

The focus of outdoor thermal comfort is human. Therefore, ENVI-met-based PET calculation considers the body mass index, age, height, weight, clothing and metabolic rates depending on the activity and spatial data and climatic data. The PET map of the study area is given in Fig. 4, and the distribution of PET values according to LCZ classes is given in Fig. 5.

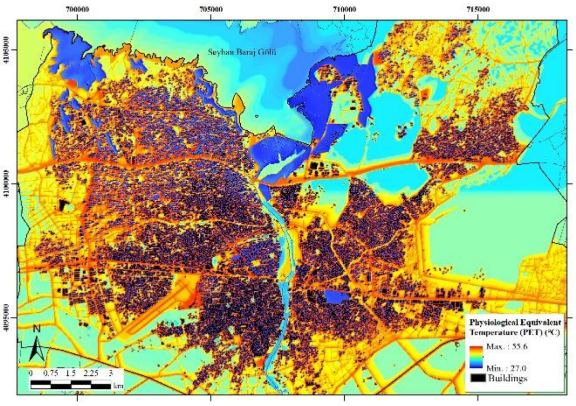

Fig. 4: Local Climate Zone maps for Adana City

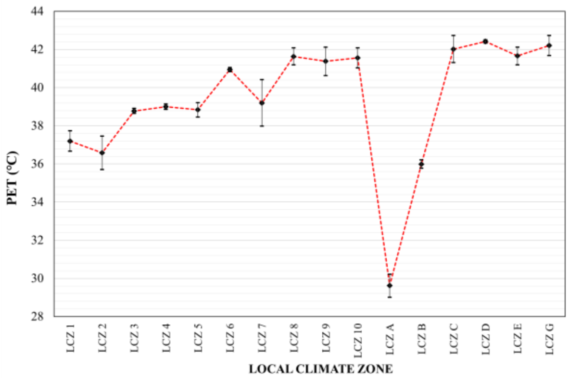

Fig. 5: Distribution of PET values according to LCZ classes

Fig. 4 and Fig. 5 show that land cover types are generally warmer than build types. LCZ D (low plants) has the highest mean PET value (42.3℃) among the land cover types, while LCZ A (dense trees) has the lowest mean PET value (29.1℃) in all LCZ classes due to having a high shadow ratio, low air temperature and low MRT. Therefore, LCZ A was categorized as slight heat stress. On the other hand, LCZ 1 (compact high-rise), LCZ 2 (compact midrise), LCZ 3 (compact low rise), and LCZ 4 (open high-rise) has the lowest PET values. One of the main reasons is that the shading area is high due to the low ratio of H/W in these LCZ classes. The average PET values of these classes varied between 36-40℃, which is the strong heat stress category. The PET values of LCZ classes, which directly exposed solar radiation, including LCZ 8 (large low rise), LCZ 9 (sparsely built), LCZ 10 (heavy industry), LCZ C (bush shrub), LCZ D (low plants), LCZ E (bare rock and paved), and LCZ G (water) were ranged from 41°C to 43°C, extreme heat stress category.

The third step is to determine statistically significant relationships between PET and LCZ classes with the ANOVA-Tukey HSD test. Results were summarized in Fig.6. Fig. 6 shows that LCZ 1 to LCZ 5 from built types and LCZ A and LCZ B from land cover types are statistically differentiated from LCZ 7- LCZ 10 and LCZ C-LCZ G ($p>0,05$). LCZ 1 (compact high-rise) and LCZ 2 (compact midrise) are -3℃ to -5℃ cooler than other LCZ classes due to their high shade ratio, while LCZ 4 (open high-rise) and LCZ 5 (open midrise) classes have -2℃ to -3℃ temperature difference. For land cover classes, LCZ A (dense trees) are -7℃ to -12℃ cooler and LCZ B (scattered trees) -2℃ to -6℃ cooler than other classes.

LCZ 1	LCZ 2	LCZ 3	LCZ 4	LCZ 5	LCZ 6	LCZ 7	LCZ 8	LCZ 9	LCZ 10	LCZ A	LCZ B	LCZ C	LCZ D	LCZ E	LCZ G	
	0,63	-1,58	-1,80	-1,64	-3,74	-2,00	-4,43	-4,17	-4,36	7,59	1,21	-4,82	-5,22	-4,45	-5,01	**LCZ 1**
		-2,20	-2,43	-2,26	-4,37	-2,62	-5,06	-4,80	-4,98	6,96	0,58	-5,44	-5,84	-5,08	-5,63	**LCZ 2**
			-0,23	-0,06	-2,17	-0,42	-2,86	-2,60	-2,78	9,17	2,79	-3,24	-3,64	-2,88	-3,43	**LCZ 3**
				0,17	-1,94	-0,20	-2,63	-2,37	-2,55	9,39	3,01	-3,01	-3,41	-2,65	-3,20	**LCZ 4**
					-2,11	-0,36	-2,80	-2,54	-2,72	9,23	2,85	-3,18	-3,58	-2,82	-3,37	**LCZ 5**
						1,74	-0,69	-0,43	-0,61	11,33	4,95	-1,08	-1,47	-0,71	-1,27	**LCZ 6**
							-2,43	-2,17	-2,36	9,59	3,21	-2,82	-3,22	-2,45	-3,01	**LCZ 7**
								0,26	0,08	12,02	5,64	-0,39	-0,78	-0,02	-0,58	**LCZ 8**
									-0,18	11,76	5,38	-0,65	-1,04	-0,28	-0,84	**LCZ 9**
										11,94	5,57	-0,46	-0,86	-0,10	-0,65	**LCZ 10**
											-6,38	-12,41	-12,80	-12,04	-12,60	**LCZ A**
												-6,03	-6,43	-5,66	-6,22	**LCZ B**
													-0,40	0,36	-0,19	**LCZ C**
														0,76	0,21	**LCZ D**
															-0,55	**LCZ E**
																LCZ G

Fig. 6: Tukey-HSD comparison matrix for all scenarios, where the blue and red grids show the significantly different ($p < 0.05$) mean PETs.

IV. CONCLUSION

With the development of urbanization, outdoor activities have gained importance, and the need to provide thermal comfort in these places has emerged. For this purpose, this study aims to examine outdoor thermal comfort by classifying the urban texture on a climatic basis and statistically determining the PET difference between LCZ types. The general results of the study can be listed as follows.

- This study was carried out in August, which is the hottest period of Adana city, located in a hot-humid climate zone.
- To better interpret the temperature difference in the urban texture, vegetation in settlement types was not considered due to the positive effect of vegetation on thermal comfort.
- It has been revealed that the most important feature in providing thermal comfort is creating shadows. Therefore, LCZ types with high shade ratio (LCZ 1, 2, 3, 4, 5, A, B) have lower PET values than LCZ grades with low shade ratio (LCZ 6, 7, 8, 9, 10, C, D, E, G).
- In LCZ types having high PET, it should be brought to optimum conditions by developing improvement scenarios (vegetation, shading elements, albedo) in line with the design principles to improve thermal comfort. In addition, by adding the thermal comfort conditions of these scenarios in different seasonal conditions, holistic planning and design decisions for the city should be taken.

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