

Assessment of Outdoor Thermal Comfort in Different Courtyard Types: A Case Study of Konya, Turkey

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Abstract – Courtyards hold significant functional value in both traditional and contemporary architecture. They serve as open-air spaces that facilitate social interaction for users within urban environments. In order for these spaces to be utilized more efficiently by users, the provision of outdoor thermal comfort is of considerable importance. Outdoor thermal comfort refers to a state in which individuals experience a balanced perception of temperature, both physically and psychologically, without feeling any thermal discomfort in open or semi-open environments. In this context, ensuring appropriate thermal comfort conditions in courtyards enables users to actively utilize these spaces across different seasons and times of day, thereby supporting spatial continuity.

In this study, outdoor thermal comfort conditions were analyzed across different courtyard types during both summer and winter seasons in the city of Konya, which is characterized by a continental climate. In order to assess thermal comfort levels, Physiologically Equivalent Temperature (PET) values were calculated at representative points selected within each courtyard type. The PET values were obtained using ENVI-met, a microclimate simulation software. As a result of the study, the most suitable courtyard type for users during the summer and winter seasons in central Konya was identified, and various recommendations were provided.

Keywords – Courtyards, Outdoor Thermal Comfort, PET, Microclimate, Open Space

I. INTRODUCTION

Climate change is recognized as one of the greatest environmental threats of the 21st century and has profound impacts on both natural ecosystems and human settlements. Climate-related risks such as rising global average temperatures, increases in the frequency and severity of extreme weather events, sea level rise and drought necessitate new approaches in many areas from site selection to building design in the urbanization process [1]. Especially in urbanized areas, local climatic problems such as the urban heat island effect make thermal comfort conditions in open spaces even more adverse, which has direct impacts on human health, well-being and space use [2].

Urban users are increasingly exposed to climate change and experience adverse conditions. Factors such as increasing temperatures, decreasing wind circulation and insufficient shading negatively affect human thermal comfort in open spaces, especially in summer. In some cities, these effects are felt more prominently, and open spaces such as streets, squares and courtyards begin to lose their functionality for users. In this context, the development of sustainable and user-oriented urban design strategies that are resilient to the effects of climate change has become one of the priority research topics of planning and architecture disciplines.

Throughout history, courtyards in the urban fabric have gone beyond being just an architectural element and have been at the center of the environmental and social interactions that

users establish with daily life. Especially in the dense city center, courtyards are of great importance as open public spaces where citizens can meet and spend time in open space [3], [4]. With this aspect, courtyards appear as the refreshment point of cities, the urban space. At the same time, courtyards increase the duration of outdoor use thanks to the microclimatic advantages they offer and improve thermal comfort conditions through shading, air flow and evaporation [5]-[9].

Outdoor thermal comfort is the totality of environmental conditions that enable individuals to feel physically and psychologically comfortable in outdoor spaces and is one of the main factors that directly affect the usability of urban open spaces [10]. Courtyard arrangements in the city also offer qualified urban spaces to the user in terms of thermal comfort in the outdoor environment. By creating shaded areas thanks to the buildings surrounding it, it causes surface temperatures to decrease and provides a cool microclimate [5], [11]. The thermal performance of courtyards is not limited to shading, but is supported by mechanisms such as directing natural air circulation, promoting evaporative cooling and activating night cooling [12], [13]. Therefore, careful planning of passive strategies used in courtyard design is of great importance in terms of both increasing individual user comfort and providing more sustainable urban microclimate conditions.

Studies based on numerical simulations and field measurements show that compact courtyard designs can

reduce outdoor temperatures by 2-4 °C, especially in summer [14], [15]. Various field measurements and computer simulations have shown that vegetated courtyards reduce surface temperatures by 5-10 °C [15]. Díaz and Álvarez, in a study conducted in a Mediterranean climate, analyzed a shading element placed in a courtyard in comparison with ENVI-met and Ladybug Tools simulations and observed a maximum temperature reduction of up to 6°C [9]. Similarly, Berkovic, Yezioro, and Bitan, in a study based on field measurements in hot and dry climates, found that shading in courtyard areas significantly improved outdoor thermal comfort [16].

Zamani and Heidari, who studied traditional courtyard dwellings in desert climate regions of Iran, stated that these buildings create an average difference of 1.2°C between indoor and outdoor temperatures in summer, which indicates the heat regulation capacity of the courtyard [17]. Nasrollahi et al., in an ENVI-met based simulation study conducted in hot and dry climatic conditions, found that courtyard orientation and height have positive effects on thermal comfort by increasing the shading time [18].

Morphological factors such as the shape, size, orientation and environmental elements of the courtyard significantly affect the thermal comfort levels in these spaces [19]-[22]. The city of Konya, located in the Central Anatolia Region, constitutes a suitable example for such an evaluation as a residential area where continental climate characteristics are clearly felt and extreme temperatures are observed in summer months. This study aims to evaluate the outdoor thermal comfort conditions in different courtyard types in Konya for summer and winter seasons and accordingly, it determines which courtyard types are more comfortable for Konya city.

II. MATERIALS AND METHOD

There are many different methods for determining thermal comfort in the outdoor environment. The most commonly used of these methods today is the Physiological Equivalent Temperature (PET) value, which is one of the thermal comfort indices. PET is an important parameter used in the assessment of environmental thermal comfort and measures the human response to environmental conditions. PET expresses the effect of air temperature, humidity, wind speed and other environmental factors around a person with a temperature value by simulating the person's body temperature and physiological responses such as sweating [23], [24]. This value helps to understand a person's thermal comfort, cooling and warming mechanisms, and hence physiological responses in a given environmental situation.

Finding the PET value is usually realized through microclimate software. Especially ENVI-met software gives very reliable results in terms of analyzing environmental parameters such as temperature, humidity, air flows in urban environments. In this study, summer and winter meteorological data of different courtyard types were used and analyzed using ENVI-met software.

This software models the urban climate based on short and long wave radiation fluxes reflected from buildings and vegetation. It is capable of simulating the physical properties of plants in detail. Another prominent feature of the model is its ability to simulate complex urban structures and vegetation in detail. It also takes into account anthropogenic energy impacts from vehicles. ENVI-met software stands out with its uncomplicated and user-friendly structure and is therefore

frequently preferred in urban climate research [25], [26], [27]. Low computational costs also support this preference [28], [29], [30]. The software also takes into account dynamic interactions between the atmosphere and vegetation and soil moisture. It can also work with a cellular spatial resolution of 2 meters to support neighborhood-level analyses.

Konya city, which has a typical continental climate type (BSc) in the Köppen Geiger climate classification [31], was selected as the sample area in the study. This city has cold and harsh winters and hot and dry summers. Urban users may be exposed to unfavorable thermal comfort conditions especially in open public spaces. For this reason, the correct design of spaces such as squares, courtyards, parks, etc. in the city of Konya is very important for the city dwellers to spend a comfortable time.

Among the most important factors affecting the microclimatic conditions of a city are the morphology of the city, vegetation density, surface coverage (albedo), water surface area, anthropogenic impacts, topography, wind speed and direction. Especially in a dense urban fabric, urban morphology, i.e. the height and orientation of buildings, etc., is even more influential in shaping the microclimate. For this reason, the shape, direction and size of the spaces within the city (park areas, courtyards, squares) are also important.

The "Atrium Classification", introduced by Hasting [32], is a study that analyzes the different functional and design characteristics of atriums. This classification evaluates the design of atriums by considering factors such as thermal comfort, airflow, natural light and other environmental effects. In this study, these atrium types classified by Hasting were used (Figure 1). Accordingly, both winter and summer season analyses were performed for attached, core, linear, envelope and integrated atrium types.

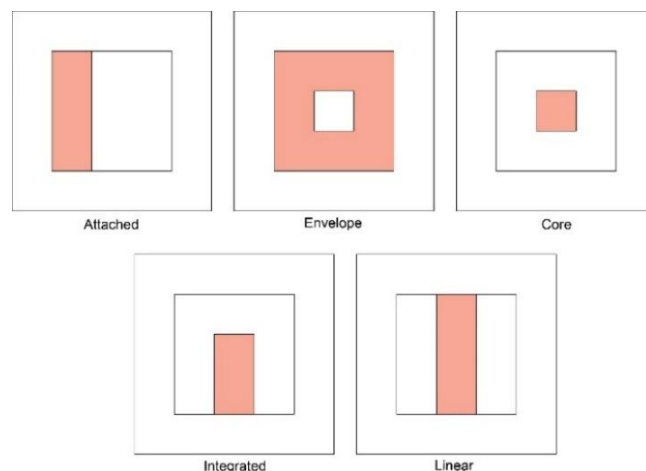


Fig. 1 Courtyard types [32]

The courtyard types determined for the study were assumed to be of the same size, including empty and occupied areas. The study areas were modelled as 20 m x 20 m and the courtyard and building areas as 12 m x 12 m. The building heights around the courtyard areas were taken as 6 m (approximately two storeys) for all models. It is also assumed that there is a 4m wide asphalt paved driveway around all courtyard types. All models were created prior to ENVI-met simulation (Figure 2). In the modelling, general assumptions were taken for all courtyard types, such as the perimeter being completely

covered with a driveway (asphalt) and the absence of any green areas or trees.

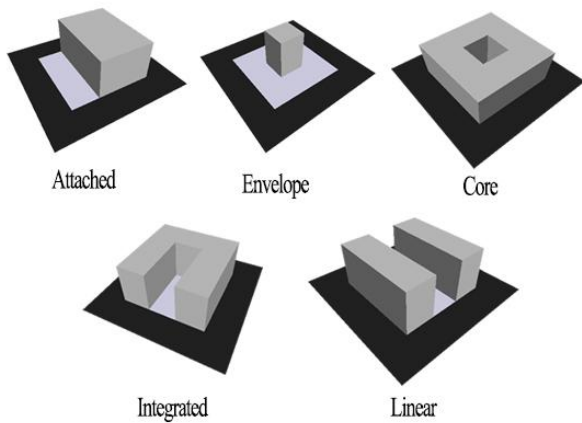


Fig. 2 Different courtyard types modelled in ENVI-met software

In the analyses, July 10 for the summer season and January 10 for the winter season were accepted as typical days. Hourly air temperature, relative humidity and wind speed values for these dates were obtained from Konya Meteorological Regional Directorate for the years 2013-2023. The averages of the 10-year data were used in ENVI-met software (Table 1). The weather data used in the simulation are presented in tables below for summer and winter seasons.

Table 1. 10-year average meteorological data for summer and winter

Time	Date 10.01.2024 (Winter)			Date 10.07.2024 (Summer)		
	Air Temp. (°C)	Rel.Hum. (%)	Wind speed (m/sn)	Air Temp. (°C)	Rel.Hum. (%)	Wind speed (m/sn)
00:00:00	-2.48	75	1.13	21.12	44	1.3
01:00:00	-2.69	77.3	1.03	20.7	45.8	0.7
02:00:00	-3.04	77.5	1.1	20.23	48.6	0.8
03:00:00	-3.07	78.8	0.94	19.75	50.5	0.9
04:00:00	-3.04	79.4	0.99	20.07	49.5	1.4
05:00:00	-3.17	81.2	0.85	22.5	42	2.5
06:00:00	-3.17	80.5	0.83	24.84	37.6	2.2
07:00:00	-2.17	76.7	0.87	25.87	35.2	2.6
08:00:00	-1.18	74.2	1.03	27.09	31.5	2.7
09:00:00	0.72	68.1	1	28.05	29.6	2.4
10:00:00	1.68	64.3	1.09	28.95	27.3	2.1
11:00:00	2.62	64.9	1.11	30.05	24.8	2
12:00:00	2.53	66.2	1.35	30.48	24	2.4
13:00:00	2.55	69	1.11	31.14	22.4	2.2
14:00:00	2.23	73	1.18	31.26	22.2	2
15:00:00	1.66	75.6	1.12	31.02	21.8	2
16:00:00	1.26	77.8	0.97	30.04	23.2	1.5
17:00:00	1.13	79.9	0.98	28.43	24.9	1
18:00:00	0.94	82.6	0.96	27.09	28.2	0.7
19:00:00	0.83	82.7	1.02	26.01	32	0.5
20:00:00	0.63	84	0.89	24.92	34.5	0.6
21:00:00	0.43	85.5	0.98	24.27	36.9	0.9
22:00:00	0.36	86.1	0.92	23.42	39	1.8
23:00:00	0.2	85.7	0.93	22.96	41.7	1.7

Analyses were generally performed for the hours between 12.00-18.00, when the city dwellers spend the most time outdoors. As a result of the analysis, PET, air temperature (Ta), relative humidity (RH), mean radian temperature (MRT) and wind speed (Ws) values were determined for each hour. These values were found for all points in the courtyard and then average values were determined (Table 2).

Table 2. ENVI-met software model specifications

All Courtyard Types (attached, envelope, core, integrated, linear)	
Location	Konya, Turkey (37.87;32.48)
Model size	10x10x20
Grid size	2x2x2
Rotation relative to north	0
Simulation date	10.07.2024 (Summer) 10.01.2024 (Winter)
Simulation start time	12:00
Simulation duration	6 hours

The data obtained were averaged over the courtyard area within the modelling. In this case, 12 points were averaged for attached, 32 for envelope, 4 for core, 8 for integrated and 12 for linear (Figure 3).

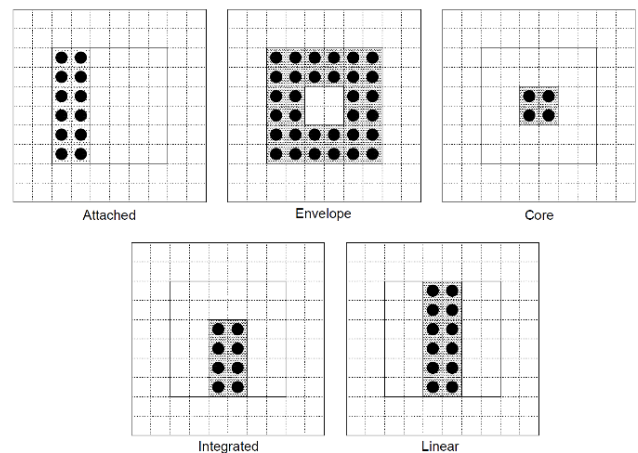


Fig. 3 Different courtyard types modelled in ENVI-met software

III. RESULTS

The simulation results cover the time intervals between 12.00-18.00 on 10.01.2024 and 10.07.2024, which are typical days for summer and winter seasons. These data are air temperature (°C), wind speed (m/sec), relative humidity (%), mean radiant temperature (°C) and physical equivalent temperature (PET).

As a result of the analyzes obtained, outdoor thermal comfort comparisons of different courtyard types in Konya city were made. The comparisons are based on PET values.

Two main sets of parameters are needed to calculate PET values. The first group consists of basic meteorological data such as air temperature (Ta), relative humidity (RH), wind speed (Ws) and mean radiation temperature (Tmrt). The second group includes individual characteristics such as age, gender, height, weight, physical activity level and clothing worn [33]. In this study, considering that many studies in the literature focus on male individuals, a 35-year-old male individual with a height of 175 cm and a weight of 75 kg was selected as a reference. The thermal resistance value of the clothes worn was assumed to be 0.9 clo and the metabolic energy production was determined as approximately 85 W/m², assuming that the individuals were walking.

Many studies refer to the PET thermal perception categories developed by Matzarakis and Mayer [34]. However, it should be kept in mind that these categories should be adapted to regional climate and sociocultural conditions in order to obtain reliable results [35]. Therefore, in this study, the site-specific

thermal perception categories developed by Canan et al. [33] were used for the city of Konya (Table 3).

Table 3. Categories of thermal perception

Thermal stress level	Human sensation	West/Central Europe [34] PET (°C)	Konya/Türkiye [33] PET (°C)
Extreme cold stress	Very cold	< 4	< -5.6
Strong cold stress	Cold	4-8	-5.6-6.2
Moderate cold stress	Cool	8-13	6.2-17.9
Slight cold stress	Slightly cool	13-18	-
No thermal stress	Comfortable	18-23	17.9-29.7
Slight heat stress	Slightly warm	23-29	-
Moderate heat stress	Warm	29-35	29.7-41.5
Strong heat stress	Hot	35-41	41.5-53.3
Extreme heat stress	Very hot	> 41	> 53.3

A. Summer Season Analysis

According to the findings obtained as a result of the analyzes; the comparison table of the average air temperature values in the summer season for different courtyard types is as follows (Table 4).

Table 4 Summer air temperature (°C) values for different courtyard types

Time	Attached	Envelope	Core	Integrated	Linear
13.00.00	33.48	32.41	30.93	32.89	32.45
14.00.00	34.90	33.14	32.69	34.29	33.75
15.00.00	35.23	33.18	32.45	33.26	32.82
16.00.00	34.59	32.12	31.93	32.34	31.98
17.00.00	32.98	30.37	30.78	30.67	30.39
18.00.00	30.76	28.54	29.36	28.98	28.74
Ort.	33.65	31.63	31.36	32.07	31.69

According to this situation, the highest temperature values between 13.00-18.00 hours are observed in Attached courtyard type. The lowest temperatures between 13.00-16.00 are observed in Core type, while Linear at 17.00 and envelope at 18.00. When we look at the daily average values, the highest air temperature is Attached, followed by integrated, linear, envelope and core, respectively (Figure 4).

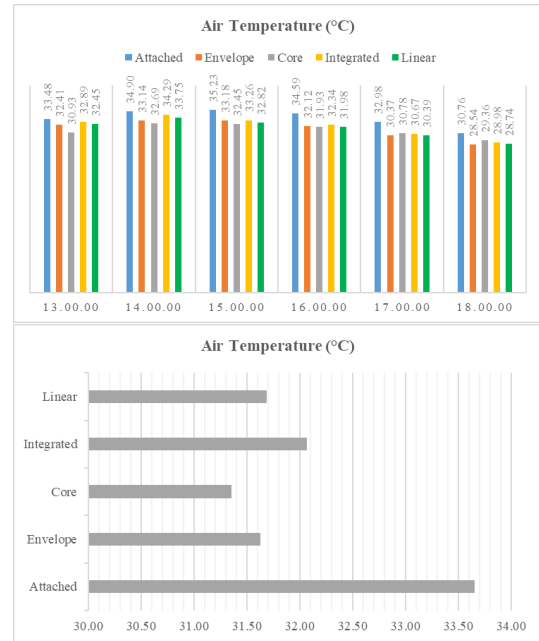


Fig. 4 Summer air temperature (°C) values for different courtyard types

According to the findings obtained for air temperature in summer, the Core type courtyard with the lowest air temperature seems to be the most comfortable.

The comparison table of the average PET values in the summer season for different courtyard types is as follows (Table 5).

Table 5. Summer PET values for different courtyard types

Time	Attached	Envelope	Core	Integrated	Linear
13.00.00	49.30	38.50	37.00	44.20	42.70
14.00.00	54.40	40.10	40.90	46.10	44.90
15.00.00	57.30	40.60	37.50	38.40	37.70
16.00.00	57.60	39.10	35.20	35.30	34.80
17.00.00	54.00	35.60	33.60	32.80	32.30
18.00.00	44.90	30.40	31.20	29.50	29.60
Ort.	52.92	37.38	35.90	37.72	37.00

According to the table, quite high PET values equivalent to air temperature values were detected in attached courtyard type. The highest values are observed in this courtyard type in all hour intervals. At the same time, the highest value of daily average PET values was determined in this courtyard type with 52.92. It can be said that the reason for this is that this courtyard type has a courtyard in only one direction, the incoming sun rays cast shadows on the other side of the building, and no shadow falls into the courtyard. In all other courtyard types, cooling can be provided with the shadow area as a result of the sun's rays creating a shadow with the building. The best example of this is the core courtyard type. Since the entire perimeter of the courtyard is covered by the building, shade can fall on the courtyard and cool areas are formed.

When the daily average values are analyzed, attached is the highest followed by integrated, envelope, linear and core courtyard types respectively (Figure 5).

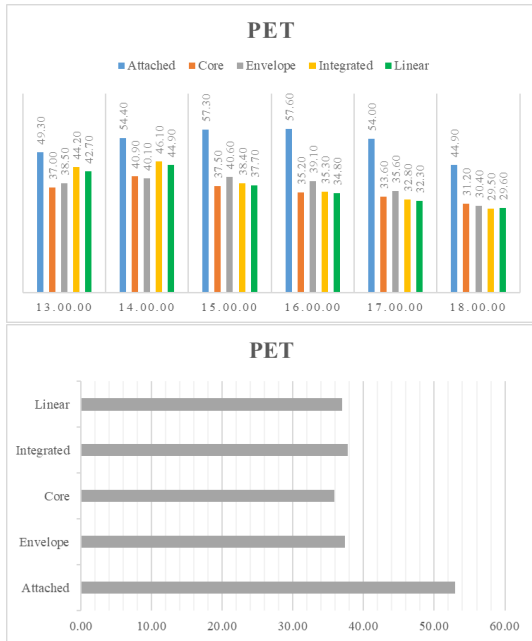


Fig. 5 Summer PET values for different courtyard types

When the thermal perception categories for the summer season are analyzed, it is observed that the attached courtyard type is very hot, envelope and core types are all warm, integrated type is very hot, hot, warm and comfortable, and linear type is hot, warm and comfortable. In this case, only integrated and linear courtyard types have PET values that are ideal for 18.00. As mentioned above, the attached courtyard type has the highest thermal stress compared to the others (Figure 6).

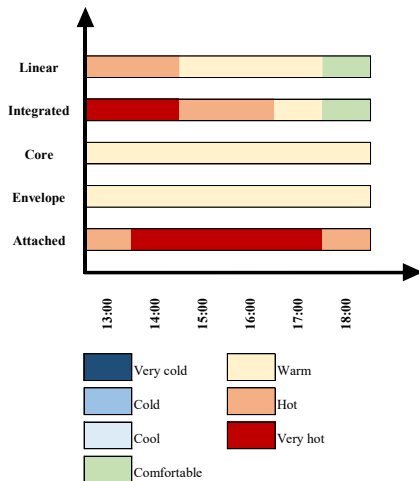


Fig. 6 Categories of hourly thermal perception for the summer season in different courtyard types

B. Winter Season Analysis

The comparison table of the average air temperature values in winter for different courtyard types is as follows (Table 6).

Table 6. Winter air temperature (°C) values for different courtyard types

Time	Attached	Envelope	Core	Integrated	Linear
13.00.00	6.77	5.01	7.99	8.22	6.97
14.00.00	6.50	4.45	7.30	7.66	6.16
15.00.00	5.78	3.64	6.45	6.62	5.34
16.00.00	4.61	2.72	5.52	5.30	4.24
17.00.00	3.16	1.98	4.65	4.09	3.25
18.00.00	2.45	1.60	4.20	3.36	2.67
Ort.	4.88	3.23	6.02	5.87	4.77

Accordingly, the highest temperature values between 13.00-18.00 hours are observed in Core and the lowest temperature values are observed in envelope courtyard type. Considering the daily average values, Core has the highest air temperature, followed by integrated, attached, linear and envelope, respectively (Figure 7).

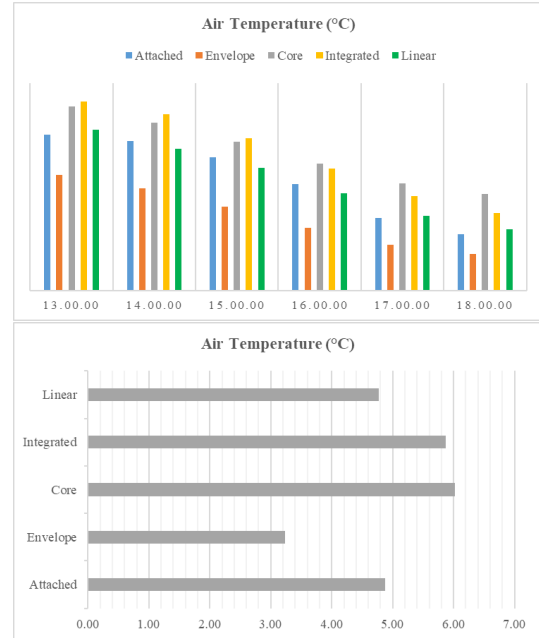


Fig. 7 Winter air temperature (°C) values for different courtyard types

The comparison table of the average PET values in winter for different courtyard types is as follows (Table 7).

Table 7. Winter PET values for different courtyard types

Time	Attached	Envelope	Core	Integrated	Linear
13.00.00	23.70	9.00	13.20	26.80	21.00
14.00.00	23.70	7.50	12.10	20.40	14.40
15.00.00	21.00	5.20	10.30	15.00	10.80
16.00.00	12.00	-0.20	8.20	8.20	5.00
17.00.00	0.60	-4.70	6.50	4.20	2.10
18.00.00	-0.60	-5.20	5.90	3.00	1.20
Ort.	13.40	1.93	9.37	12.93	9.08

When the PET values for the winter season are analyzed, the lowest values are observed for the envelope courtyard type at all time intervals. In fact, these values decrease to values below zero for the 17.00-18.00-hour intervals. This may be due to the fact that the entire perimeter of this courtyard type is open to external factors and especially the effect of winter winds is felt intensely. While air temperature values were high in the Core courtyard type, this situation changed in PET values. The highest PET values are observed in integrated at 13.00, attached between 14.00-16.00, and core at 17.00 and 18.00. This variability can be attributed to the effect of falling air temperatures in the evening hours. The courtyard types, which show different approaches with the effect of the sun during the day, exhibit different behaviors in the evening due to the decrease in the effect of the sun and thus the decrease in the shading effect.

When daily average PET values are analyzed, the highest values are observed in attached, followed by integrated, core, linear and envelope courtyard types (Figure 8). Envelope courtyard type has very low values compared to the others.

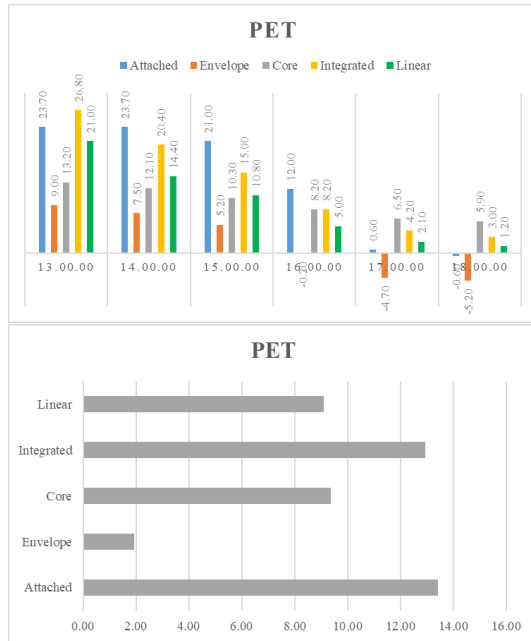


Fig. 8 Winter PET values for different courtyard types

When the thermal perception categories for the winter season were analyzed, comfortable, cool and cold perception categories were observed in attached, integrated and linear courtyard types, cool and cold perception categories were observed in envelope courtyard type, and cool perception categories were observed in all core courtyard types. According to this graph, envelope was the courtyard type with the highest thermal stress, while attached was the courtyard type with the highest number of comfortable hours (Figure 9).

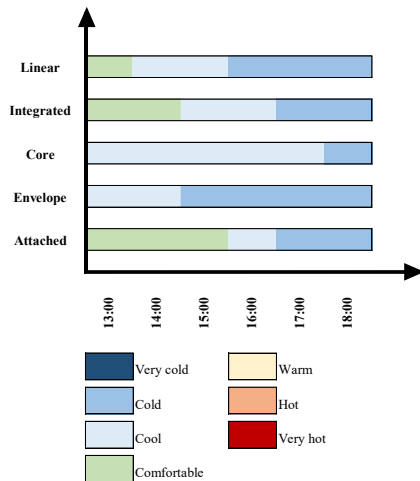


Fig. 9 Categories of hourly thermal perception for the winter season in different courtyard types

IV. DISCUSSION

In the light of the findings obtained; in terms of thermal comfort in the outdoor environment for Konya city, Core courtyard type in summer season and attached courtyard type in winter season are the most comfortable places. While attached is the type with the most intense thermal stress in summer season, envelope type is the most uncomfortable place in winter season. Integrated courtyard type can be recommended for comfortable courtyard type for both seasons (Table 8).

Table 8. The most comfortable and uncomfortable courtyard types according to the seasons

Seasons	Most Comfortable	Most Uncomfortable
Summer	Core	Attached
Winter	Attached	Envelope

Especially for the summer season, the use of courtyards in the city of Konya, even the use of green areas and trees in the courtyard, provides thermal comfortable spaces in the outdoor environment by reducing PET values. There was a difference of 2.29 °C in air temperature and 17.02 °C in PET between different courtyard types. This is the most important indicator that the types of courtyards used in the city affect the thermal comfort in the outdoor environment.

When the results obtained from the winter season are examined, it is determined that the courtyard designs in Konya city, especially considering the prevailing wind direction, positively affect the thermal comfort in the outdoor environment. There is a difference of 2.79 °C in air temperature for different courtyard types and 11.47 °C for PET.

The use of broad-leaved shrubs that shed their leaves in winter will provide favorable thermal comfort conditions for both summer and winter seasons. While broad-leaved trees used in the courtyard in the summer season provide an extra shading and cooling effect, the shading effect will not occur with the shedding of leaves in the winter season. At the same time, by taking into account the prevailing wind direction, favorable thermal comfort conditions will be created in the courtyard.

In addition to the many studies mentioned in the literature review, it has been proven that different types of courtyards create different thermal comfort conditions in a city with the same climatic conditions.

V. CONCLUSION

Based on the PET (Physiological Equivalent Temperature) index, this study aimed to evaluate the effects of different courtyard types on outdoor thermal comfort in Konya city. As a result of the analysis for both summer and winter seasons, it was proved that different types of courtyards with different shapes used in the city create differences in microclimate. According to the results obtained, the temperature differences between different courtyard types in the summer season are 2.29 °C, while this situation is 2.79 °C for the winter season.

Analyses of different courtyard types (enclosed, semi-open and open courtyards) have shown that microclimatic conditions have significant effects on the perception of thermal comfort. In particular, semi-open courtyards provide both air circulation and shaded areas, creating more balanced and acceptable thermal comfort conditions for users. In fully open spaces, on the other hand, serious heat stress was observed due to high PET values, especially in summer. Closed courtyards tend to create extremely hot conditions in summer and cold conditions in winter due to the lack of sufficient air movement.

In contrast, semi-open courtyards provide more balanced and user-friendly thermal environments by partially filtering solar radiation and directing air flow without restricting it. Semi-open designs provide shading by preventing overheating, especially in summer, and create a milder microclimate by reducing the wind effect in winter. Therefore, it has been determined that semi-open courtyard types offer significant advantages in terms of both energy efficiency and user comfort.

The results of the study reveal that courtyard forms and arrangements in urban design have a direct impact on thermal comfort. Careful planning of shading elements, planting and building formations plays a critical role in increasing user comfort, especially in continental climate regions such as Konya, which has climatically challenging conditions. In this context, it can be said that semi-open courtyard types contribute to sustainable open space designs by providing more balanced thermal environments in both summer and winter.

In future studies, it is recommended to diversify thermal comfort analyses with wider user profiles including different age and gender groups. In addition, examining the effects of different floor coverings, vegetation types and water surfaces will contribute to making open spaces more efficient in terms of thermal comfort.

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