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Assessing the impact of urban form on outdoor thermal comfort: Case Study of Tabriz City

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A B S T R A C T

Over the past decade, the development of theories surrounding sustainable cities, ecological cities, ecosystems, smart cities, and green cities has seen a growing emphasis from urban designers and planners on fostering harmony between urban design and nature. Increasingly, these professionals have prioritized environmental sustainability, addressing pressing climate challenges, and integrating ecological principles into urban planning practices. This focus reflects a broader commitment to creating resilient urban environments that not only adapt to but also mitigate the adverse impacts of climate change while promoting sustainable living. This study examines the urban microclimate characteristics that influence typical urban residential neighborhoods through urban planning and design. Different urban block forms provide different microclimates with varied comfort levels for citizens. In this study, outdoor thermal comfort is compared during the winter season (December 20) for three common residential blocks (courtyard, linear and single) in Tabriz city. For this purpose, ENVI-met software is used to simulate air temperature, predicted mean vote (PMV), wind speed, and relative humidity to determine which of these common blocks are suitable for Tabriz's cold climate. The main objective of the study is to clarify the impact of block form on the outdoor thermal comfort of dwellings in Tabriz. In this study, a constant building density is used to investigate the effects of different urban shapes on thermal comfort. The results demonstrate that in winter, the courtyard and singular models have a more substantial impact on people's outdoor thermal comfort. The simulation of the linear model shows that it is unsuitable for this region and cannot provide thermal comfort for dwellings in the cold seasons.

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Introduction

In recent years, numerous investigations have focused on cost-effective energy consumption in the building industry, as well as solutions to meet interior thermal comfort, e.g., lighting, heat, and appropriate water saving with an emphasis on their design. However, less consideration is devoted to designing on the scale of the neighbourhood unit and the urban block, as well as energy consumption drop on the urban scale [1, 2, 3]. Thermal comfort is one of the most crucial elements determining the quality of outdoor surroundings for pedestrians. Greater thermal comfort encourages more individuals to congregate in public areas. Town squares, parks, and other urban open spaces provide a variety of positive environmental, social, and economic effects [4, 5, 6, 8]. Urban outdoor thermal conditions for city residents received much attention in the early 2000s as a new area of study to generate tactics for sustainable urban areas. Until the start of the 21st century, the issue of warm consolation within the urban open-air environment had gotten little consideration. Most of the warm records were created primarily under steady-state conditions and identical temperatures, transferred from indoor to open air with the harmony of the thermoregulation framework and don't continuously speak about the expensive assortment of urban microclimates to which individuals are uncovered in ordinary life. [7, 8].

As a result, it is critical to investigate the influence of physical characteristics of urban form on energy consumption at a scale greater than a single structure and to create thermal comfort at the scale of urban textures [9]. Thermal comfort in open areas is influenced by numerous factors, such as urban design and geometry, urban density, vegetation, water levels, and surface characteristics [10]. Indeed, not only the building must be designed to have the least amount of energy loss while providing maximum thermal comfort for the residents, but also it should be done on a scale beyond the building (spaces and urban texture) by combining urban thoroughfares and open spaces with buildings to optimize energy consumption to enhance the maximum comfort of urban structures by making efficient modifications to the body and spatial arrangement. In the 1960s architects and urban planners addressed the idea of using the environmental building shape for the first time [9]. In the 1980s, pedestrians in urban canyons, plazas, and squares got attention; therefore, the number of research on thermal comfort in the outdoor environment has grown [11]. Urban Thermal comfort brings urban and landscape designers together, with biometeorology (which focuses on pedestrians) and climatology (which focuses on the climate). Thermal comfort developed with the help of both bio meteorologists and climatologists.

To assess the outdoor thermal comfort, various factors have been utilized. Comfort indices are used to characterize and rate outdoor thermal comfort in research. The two types of thermal comfort indices that are now employed to assess the outdoor thermal environment are rational and empirical indices. The former is based on an understanding of the mechanics of heat transmission (i.e., based on the heat balance equation of the human body), including the physiologically equivalent temperature (PET), predicted mean vote (PMV), standard effective temperature (SET*), and universal thermal climate index (UTCI) [12]. The SET*, PET, and UTCI indices were primarily created for outdoor applications, whereas the PMV and SET* indices have a strong foundation for indoor use [13]. While in comparative model, PMV can also be used to compare outdoor thermal comfort.

Climate variables influence human comfort in the outdoor environment and ongoing human activities. Considering the increased concern for pedestrian activities in urban areas, the number of studies on outdoor thermal comfort has increased significantly [14, 15]. Irmak and colleagues (2013) determine the favourable characteristics of tree species growing in the city for the comfortable conditions of the human bioclimate. In this study, the temperature, humidity and wind were measured under different tree canopies in the Atatürk University's Atat Botanical Garden in July and August 2008. Research showed that the crown of pine trees could provide the most comfortable environment by improving human thermal conditions [16]. Taleghani et al. (2015) investigated the effect of urban forms on thermal comfort in the Netherlands. The results revealed that the most critical factors for thermal comfort were the average radiant temperature and the duration of direct sunlight, both of which were influenced by the typology of the city. In addition, the courtyard model has the most pleasant microclimate in the Netherlands in June [17].

Gaspari and Fabbri (2017) improve the regeneration phase by evaluating neighbourhood microclimate modelling in a demo case - a building plot with internal courtyards - and investigating technical and design options to enhance outdoor comfort [18]. Toudert and collaborators (2017) discuss the contribution of street design to creating a pleasant street-level microclimate for pedestrians. The study is carried out with the three-dimensional numerical model ENVI-met. A comparison of all the case studies shows the time and period of extreme heat stress and the spatial distribution of PETs at the street level, strongly depend on aspect ratio and street orientation [19]. Yilmaz et al. (2021) investigated the thermal comfort of Erzurum Cumhuriyeti Street during the winter and summer seasons of 2018 using ENVI-met V.4.4.2. A different green scenario was presented and the best thermal comfort scenario for both seasons was determined. They revealed that it is possible to increase thermal comfort by improving the width of the street and plant preferences more suitable for residential urbanization [20]. Ma t al. (2020) used microclimate monitoring and numerical simulation in a commercial pedestrian street area of Tai Zhou, China, to investigate the thermal comfort of people in the extreme summer heat. The results of the study indicated that the most effective strategy for improving thermal comfort in open space is to increase the coverage ratio of trees [21]. Galal et al. (2020) use the ENVI-met simulation to simulate microclimates in one neighbourhood of New Aswan and four areas of the GCR to improve outdoor thermal conditions for the future growth of New Aswan [22]. Yilmaz et al (2021) investigated winter thermal comfort conditions in Erzurum streets by using the ENVI-met V.4.4.2 model to determine the outdoor thermal comfort level. The results revealed that the semi-open canopy design provided high thermal comfort in roads that people could walk and cycle during winter [23]. Table 1 provides a summary of the background.

Table 1. Research background

Author(s), Year	Discussion	Case study	Method	Variables	Results
Irmak et al, (2013)	Evaluating different thermal conditions based on different tree species	Ata botanic garden in eastern Turkey	Climatic measurements	Temperature, humidity, and wind	The canopy of Scotch pine trees provides the most outdoor thermal comfortable
Taleghani et al, 2015	Comparing thermal comfort between five different urban forms	Netherland	ENVI-met simulation, RayMan	Outdoor air temperature, mean radiant temperature, wind speed, relative humidity ant PET	The most crucial factors in thermal comfort are the length of direct sunlight and mean radiant temperature, which are influenced by urban form. In the Netherlands, the courtyard form provides the most comfortable microclimate.
Gaspari & Fabbri (2017)	Using outdoor microclimate map for address design solutions	Bologna	ENVI-met simulation	Temperature, solar radiation, wind distribution, wind speed and relative humidity	Improves the regeneration phase by evaluating neighborhood microclimate modelling in a demo case
Toudert et al, (2017)	contribution of street design to creating a pleasant street-level microclimate for pedestrians.	Ghardaia, Algeria	ENVI-met simulation	Air temperature, wind, relative humidity and PET	A comparison of all the case studies shows the time and period of extreme heat stress and the spatial distribution of PETs at the street level, strongly depend on aspect ratio and street orientation.

Galal et al, 2020	Impact of urban form on outdoor thermal comfort	Cairo region, New Aswan	ENVI-met simulation	Air temperature, relative humidity and PET	At the level of individual streets, the average temperature PET changed by up to 9 °C, with shading being the most important parameter. At the block level, the extent of enclosure and area ratio were most important, while at the street level, aspect ratio and orientation had the greatest impact.
Ma et al, (2020)	Improving outdoor thermal comfort in a pedestrianized zone by utilizing different urban design parameters	Zhou, China	On-site measurement and numerical simulation with ENVI-met	Air temperature, relative humidity and SVF	Increasing the coverage ratio of trees is the most effective strategy for improving outdoor thermal comfort in open spaces
Yilmaz et al, (2021)	Investigating outdoor thermal comfort for Cumhuriyeti street during the winter and summer seasons	Erzurum, Turkey	ENVI-met simulation and RayMan model	sky view factor (SVF)	Study results that by improving the width of the street and plant preferences thermal comfort increases and become more suitable citizens

Methodology

This paper uses a quantitative methodology. This study investigates the thermal comfort of dwellers in three urban layouts exposed in urban blocks and outdoor spaces in Tabriz, Iran. This research aims to investigate the concepts of building form and thermal comfort in urban open spaces in the city of Tabriz. For this purpose, first, the thermal comfort periods are evaluated for the city of Tabriz; then, the level of thermal comfort provided by three popular forms in Tabriz city is examined; and then, ENVI-met software is used to simulate air temperature, mean radiant temperature, predicted mean vote (PMV), wind speed and humidity.

Case study

Tabriz is the capital of the province of East Azerbaijan in northwest Iran (Fig. 1). This city has a continental climate with regular seasons bordering a cold arid climate. It is a city with annual precipitation of around 320 millimeters, and an average annual temperature of 12.6 °C.

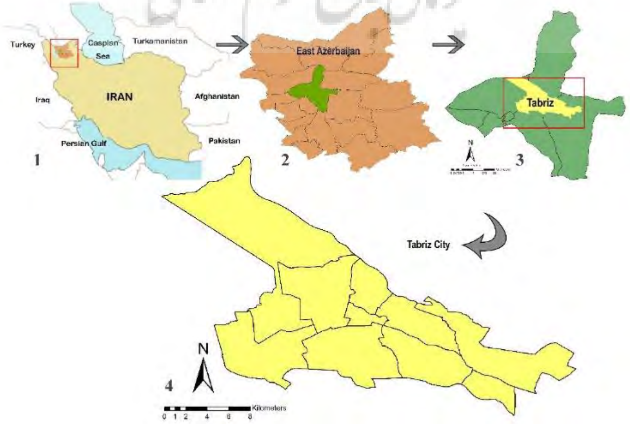


Fig.1. (1) Iran country, (2) Location of East Azerbaijan in Iran, (3) location of Tabriz in East Azerbaijan, (4) map of Tabriz city.

In Tabriz, South-West (SW) to North-East (NE) wind is blowing strongly. The airflow rises from Siberia and Scandinavia and blows east and northeast of Tabriz, which is the strongest annual wind in Tabriz [24]. As shown in Figure 2, winds from the west and then the northeast have the highest values in the last ten years, therefore Tabriz is a relatively windy city.

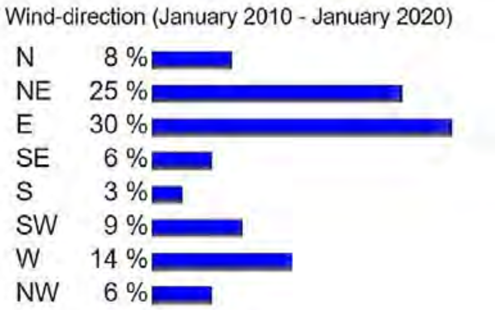


Fig.2. The wind direction of Tabriz city (January 2010 – January 2020)

Since the weather in Tabriz is cold (table 2), and as the table below demonstrates, men need to change in climate to achieve thermal comfort in cold seasons, simulations in winter were conducted as part of the research.

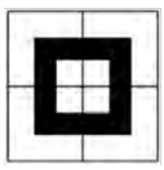
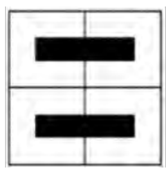
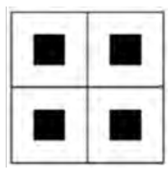
Table 2. Climatic needs to ensure human comfort in the climate of Tabriz

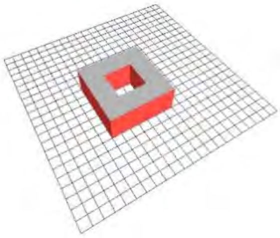
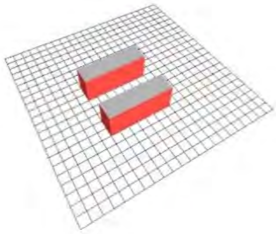
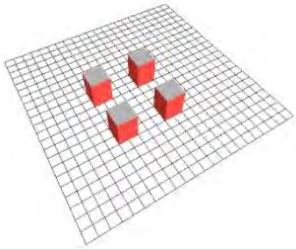
season	weather	Day	Night
Cold seasons	Glacial	3 up to 4.5 day	-
	Avoiding cold winds	2 up to 3 months	5 up to 7 months
	Heating equipment	7 up to 10 months	7 up to 10 months
	Sun	6 up to 7 months	-
Warm seasons	Shade and use the open air at night	6 months	-
	Air blizzard	4 months	-
	Evaporation	4 months	-
	Cooling equipment	-	-

Results

Three common urban forms were chosen for this research to be examined in terms of thermal comfort in Tabriz's cold arid climate [25]. The urban forms are simplified and taken from existing common examples in the urban contexts (table 3). The research aims to investigate thermal comfort for a pedestrian in the center of the urban forms. In this regard, simulations were performed in the winter season with the ENVI-met model.

Table 3. Graphical displays of Common urban block forms from Tabriz city context

	Courtyard model	Linear model	Singular model
Common urban block forms			

Model			

Firstly, the area's plan is defined in ENVI-met software, and each of the residential blocks with a height of 12 meter is simulated in the region (the typical number of floors of residential structures in Tabriz are 3 to 4 stories) .The materials of the walls and the roof have also been selected for the samples according to the native materials used in Tabriz, which are bricks. In the next step, climatic and geographical information such as geographical location, wind speed and direction, etc. are entered. Then thermal comfort is prepared for a specific group in the cold season and finally, the results are summarized in a table.

Thermal Comfort

According to ASHRAE Standard 55 [7], Thermal comfort is a subjective measure of a person's satisfaction with the surrounding thermal conditions. It is also influenced by the climate zone, which changes by region. Outdoor thermal comfort is a critical factor for determining the perceived level of urban microclimate quality and design considerations, which may help people better comprehend sustainable development [26]. Predicted Mean Vote (PMV) is a standardized thermal comfort index (ISO 7730) that predicts the average vote of a large group of people on a 7-point thermal sensation scale, ranging from -3 (cold) to +3 (hot). Table 4 demonstrates the classification of thermal comfort sensation.

Table 4. Classification of thermal comfort sensation [26]

PMV	Thermal Sensation	Level of Heat Stress
- 3.5	Very cold	Extreme cold stress
- 2.5	Cold	Strong cold stress
- 1.5	Cool	Moderate cold stress
- 0.5	Slightly cool	Slight cold stress
0	Neutral	No thermal stress
+ 0.5	Slightly warm	Slight heat stress
+ 1.5	Warm	Moderate heat stress
+ 2.5	Hot	Strong heat stress
+ 3.5	Very hot	Extreme heat stress

Climatic urban design is characterized as a design approach that considers the fundamental aspects of the microclimate (wind, sun, and air temperature) [26]. There are two types of parameters (physical and nonphysical parameters) that are considered in designing responsive areas for microclimate change. Physical and non-physical parameters are considered while designing responsive zones for microclimate change [27]. Climate conditions in the area can be affected by urban geometry such as building average height, a gap within, building H/W ratio, and building configuration [28]. In order to discover a significant relationship between urban form and outdoor thermal comfort, the influence of urban block forms on wind blow, as well as the effect of wind and solar conditions on citizen's comfort, are investigated.

ENVI-met model

ENVI-met is a three-dimensional microclimate model designed to simulate the interaction between surfaces, plants, and air in an urban environment. In this research, ENVI-met 4.4.5 is used. The air temperature (°C), vapor pressure (hPa), specific humidity (g/kg), relative humidity (%), wind speed (m/s), and mean radiant temperature (°C) of the receptors in the center of models could all be determined using this software. Mean Radiant Temperature (MRT) represents the average temperature of all surfaces surrounding a person (e.g., buildings, ground, sky) that exchange radiant heat with the human body. Unlike air temperature, MRT accounts for solar radiation, reflected heat, and thermal emissions from surfaces.

The ENVI-met model is the most comprehensive in terms of human comfort calculations. The four key thermal comfort parameters are air temperature, mean radiant temperature (Tmrt), wind speed, and humidity, which are all included in the output. The SOLWEIG model developed by Göteborg University is another model that calculates outdoor conditions. The SOLWEIG model is a radiation model that is particularly good at predicting the mean radiant temperature but does not provide the output of the three other thermal comfort parameters [29]. For ENVI-met simulation, a random day during the winter season (December 20) was selected. Input data and data Configuration of ENVI-met Simulation in this study are shown in Table 5 and Processing and input information are shown in figure 3 below.

Table 5. Data Configuration of ENVI-met Simulation

Configuration Data	December 20th
Boundary model	88m * 88m
Grids	22 * 22
Total Simulation Time in Hours	12
Wind Direction	70°
Wind Speed	2 m\s
Min Temperature	-4
Max Temperature	+4
Humidity	70%

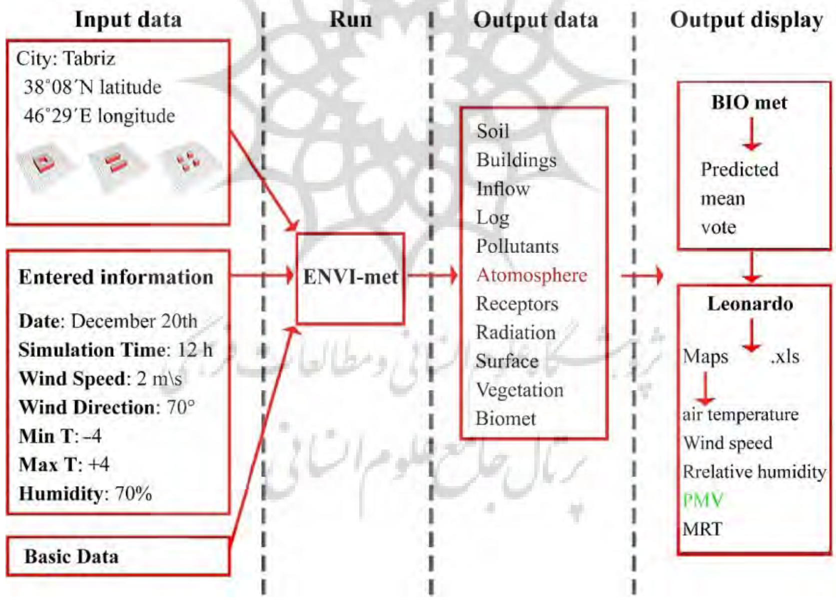


Fig. 3. Processing and input information

After modelling, ENVI-met software was used to simulate the outputs of the models for three time periods on December 20: morning (time 8:00), noon (time 12:00), and afternoon (time 17:00), and then graphical displays were extracted with the Leonardo. All outputs are measured at the height of 1/20m from the ground (k=1.2).

Predicted Mean Vote (PMV)

The computation of thermal comfort in addition to climatic factors and spatial location is influenced by the age, gender, coverage, and activity level of users. According to the ENVI met software's settings, the study population is 35-year-old males with slow walking activity and a metabolic rate (W / m2) of 164. Same as the table below for the clothing parameter has a Static Clothing Insulation 1.01clo (Table 6).

According to the table, all three models are in the range of thermal comfort (-3 to +3) during noon (12 o'clock). Although the results of all three blocks are quite near, based on the minimum and maximum PMV of the Singular model, it can be concluded that in Tabriz's climate, this model has shown better results (Table 7 and Table 8).

Table 6. Static Clothing Insulation (clo)

Clothing parameters	I_{cl} (clo)
Long-sleeved shirt, Trousers, T-shirt and Long sleeved sweater	1.01

Table 7. Graphical displays of PMV Simulation

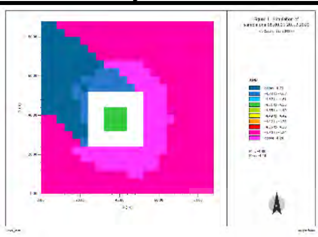
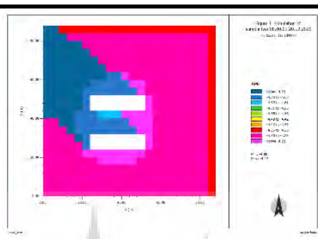
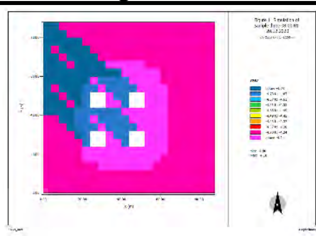
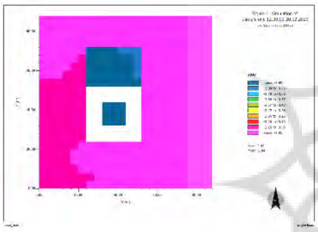
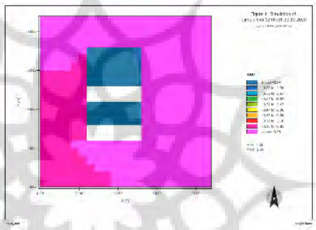
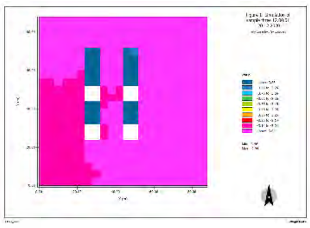
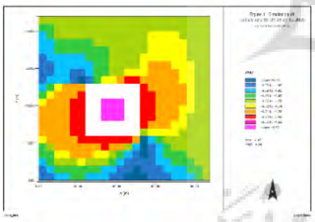
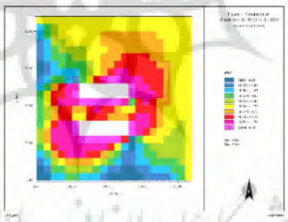
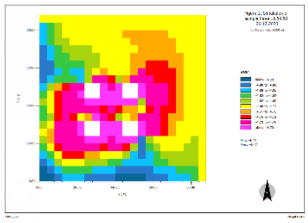
	Courtyard model	Linear model	Singular model
time 8:00			
time 12:00			
time 17:00			

Table 8. PMV Simulation

		Courtyard model	Linear model	Singular model
time 8:00	Min	-4.80	-4.80	-4.80
	Max	-4.18	-4.17	-4.18
time 12:00	Min	-3.99	-3.98	-3.96
	Max	-2.94	-2.95	-2.94
time 17:00	Min	-4.96	-4.93	-4.93
	Max	-4.58	-4.67	-4.67

Wind

Wind flow is another factor that influences the level of thermal comfort. The prevailing winds in Tabriz in winter come from the northeast and east. As can be seen, the wind speed in the inner area of the Courtyard model is less than 0.2ms. In general, while comparing all three models, it can be shown that the courtyard model has performed better than the other three models in terms of reducing wind speed (tables 9 and 10).

Table 9. Graphical displays of Wind Simulation

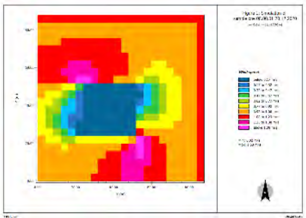
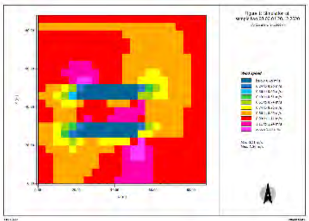
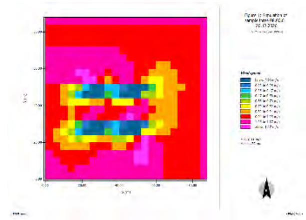
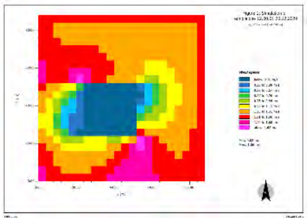
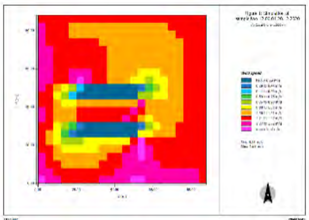
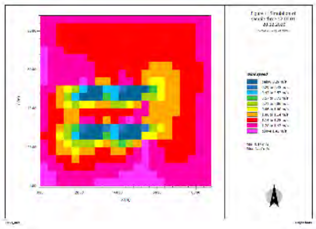
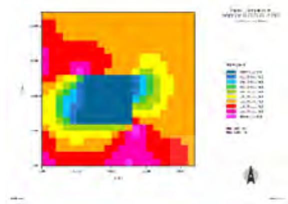
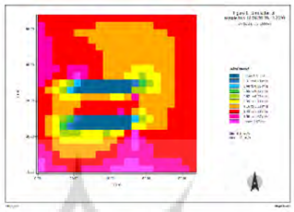
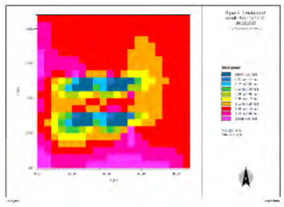
	Courtyard model	Linear model	Singular model
time 8:00			
time 12:00			
time 17:00			

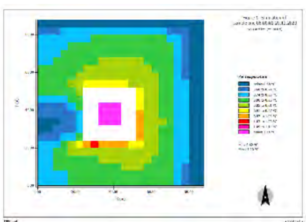
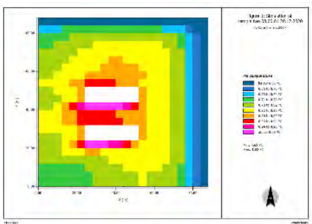
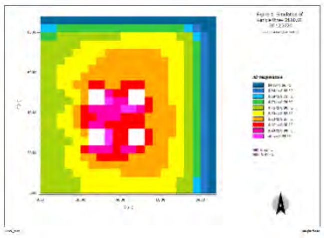
Table 10. Wind Simulation

		Courtyard model	Linear model	Singular model
time 8:00	Min Max	0.02 (m\s) 1.53 (m\s)	0.02 (m\s) 1.86 (m\s)	0.02 (m\s) 2.03 (m\s)
time 12:00	Min Max	0.11 (m\s) 1.36 (m\s)	0.13 (m\s) 1.68 (m\s)	0.14 (m\s) 1.84 (m\s)
time 17:00	Min Max	0.11 (m\s) 1.29 (m\s)	0.14 (m\s) 1.57 (m\s)	0.15 (m\s) 1.76 (m\s)

Air Temperature

ENVI-met output maps show that as the color spectrum approaches pink and red, the air temperature gets higher degree (warmer). As it approaches the blue color the air temperature gets lower degree. According to the outputs, the Courtyard model had the highest temperature at 12 o'clock, and during other hours, model one has a higher maximum temperature than other models. The temperatures in the three models reached their peak at 12:00 (Tables 11 and 12).

Table 11. Graphical displays of Air Temperature Simulation

	Courtyard model	Linear model	Singular model
time 8:00			

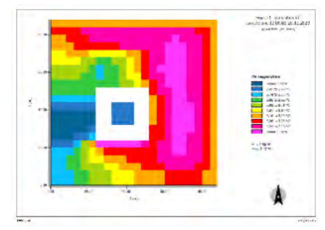
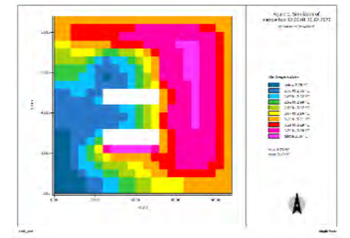
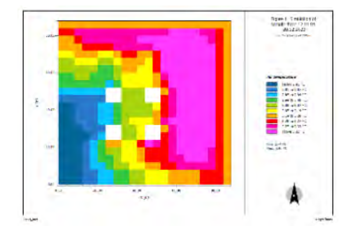
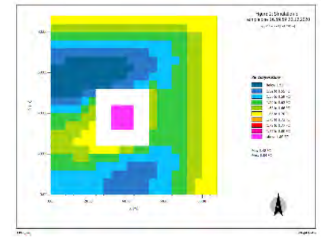
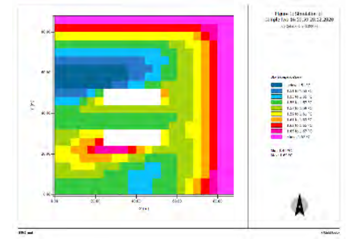
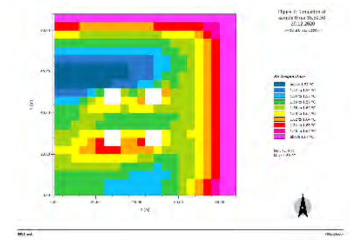
time 12:00			
time 17:00			

Table 12. Air temperature Simulation

		Courtyard model	Linear model	Singular model
time 8:00	Min Max	0.62 °C 1.20 °C	0.62 °C 1.02 °C	0.62 °C 0.97 °C
time 12:00	Min Max	2.56 °C 3.47 °C	2.70 °C 3.43 °C	2.74 °C 3.40 °C
time 17:00	Min Max	1.48 °C 1.84 °C	1.49 °C 1.69 °C	1.50 °C 1.69 °C

Humidity

Specific Humidity refers to the weight (amount) of water vapour contained in a unit weight (amount) of air (expressed as grams of water vapour per kilogram of air). Humidity and temperature variations have a significant negative relationship [30]. Humans are more sensitive to temperature changes than to changes in relative humidity, even though humidity is an important element for thermal comfort [31]. When air temperatures are low, humidity has a small effect on outdoor thermal comfort; when air temperatures are moderate, humidity has a somewhat more noticeable effect; and when air temperatures are high, humidity has more significant effect. Specific humidity was chosen for its temperature-independent nature, providing a stable measure of absolute moisture content. It helps to see how urban designs affect moisture levels clearly. Table 13 shows the main differences between specific humidity and relative humidity.

Table 13. Key differences between specific humidity and relative humidity

Criteria	Specific Humidity	Relative Humidity
Type of Measurement	Absolute moisture content	Ratio of moisture to maximum air capacity
Temperature Dependency	None	Temperature-dependent
Unit	grams per kilogram (g/kg)	percentage (%)

The impact of humidity on thermal comfort in our model is also low because the study was done during the cold season and at low temperatures (Tables 14 and 15).

Table 14. Graphical displays of Specific Humidity Simulation

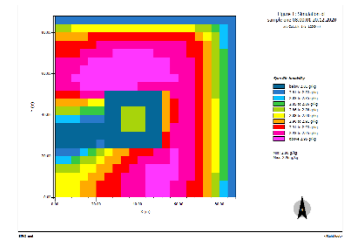
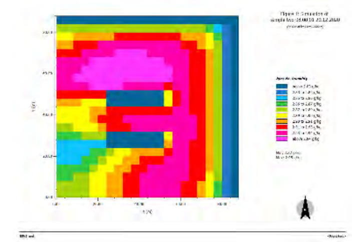
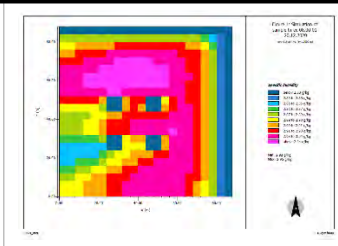
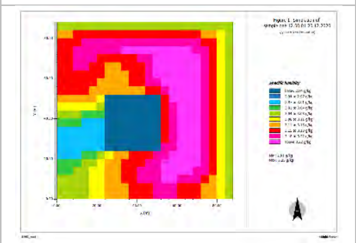
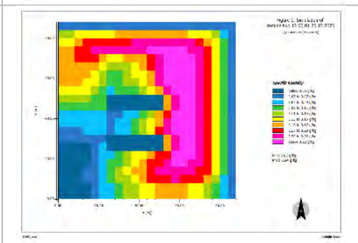
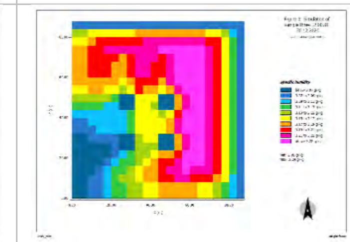
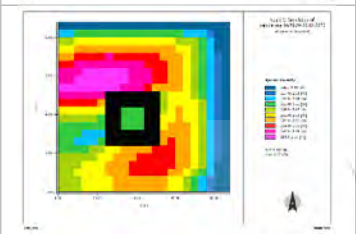
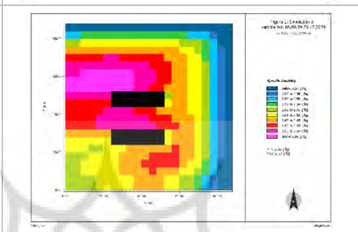
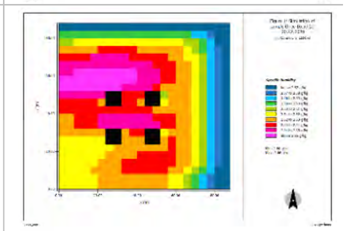
	Courtyard model	Linear model	Singular model
time 8:00			
time 12:00			
time 17:00			

Table 15. Specific humidity Simulation

		Courtyard model	Linear model	Singular model
time 8:00	Min Max	2.80 (g/kg) 2.96 (g/kg)	2.82 (g/kg) 2.95 (g/kg)	2.82 (g/kg) 2.95 (g/kg)
time 12:00	Min Max	2.91 (g/kg) 3.25 (g/kg)	3.03 (g/kg) 3.24 (g/kg)	3.05 (g/kg) 3.24 (g/kg)
time 17:00	Min Max	2.56 (g/kg) 2.67 (g/kg)	2.56 (g/kg) 2.67 (g/kg)	2.56 (g/kg) 2.66 (g/kg)

Mean radiant temperature

The results demonstrated that the main factor affecting urban geometry in creating suitable thermal comfort conditions is the mean radiant temperature .In this research, mean radiant temperature as the main criterion has been emphasized and analyzed deeper.The mean radiation temperature in thermal comfort is the energy we apply to the environment to withstand temperatures below the comfort temperature. The standard average radiant temperature in ASHRAE 2010-2015 is between 16 °C and 28 °C. According to the program output at 12 o'clock, The mean radiant temperature ranges from 11.62 to 20.98 degrees Celsius. The mean radiant temperature is shown in table 16 in different times.

Table 16. Mean radiant temperature Simulation

		Courtyard model	Linear model	Singular model
time 8:00	Min Max	3.85 °C 14.11 °C	3.85 °C 14.66 °C	3.84 °C 14.48 °C
time 12:00	Min Max	11.97 °C 20.96 °C	11.98 °C 20.82 °C	11.62 °C 20.11 °C
time 17:00	Min Max	5.28 °C 9.63 °C	6.79 °C 9.68 °C	7.42 °C 9.65 °C

Discussion

According to previous studies, various strategies can be used to improve thermal comforts for humans, such as changes in block shapes, building typology, street design, vegetation, and others [16, 17, 19, 20]. The positive effect of building and block shape has been observed in other outdoor thermal comfort studies [15, 18, 22]. For outdoor thermal comfort in the New Aswan area of Cairo, at the block level, enclosure extent and area ratio were the most important factors [22]. In this study, quantitative techniques were used to analyze the effects of block shape on the outdoor thermal comfort of residents in the cold-dry climate of Tabriz. The ENVI-met tool (4.4.6) was used to simulate three selected models. This research analyzed the comfort performance of three types of urban blocks in Tabriz city. The main purpose of the research was to clarify the effect of building form and geometry on outdoor thermal comfort for Tabriz dwellings based on the Ashrea thermal comfort standards. Contrary to previous studies, our study introduced a completely different layout to achieve outdoor thermal comfort due to different situations and climatic conditions.

One of the variables that impact the quality of thermal comfort is air temperature. The findings show that results are nearly similar to each other during the reference day; however, the maximum air temperature is higher in the courtyard model. Another variable that impacts the quality of thermal comfort is wind speed and direction. In winter seasons, as the wind speed increases the outdoor thermal comfort of individuals decreased. According to ENVI-met simulations in Table 9 and 10, the wind speed in the courtyard model is relatively low, however, the results for singular block form exposes the highest speed of wind in chosen very time. Overall, the results of the research showed that the shape of the blocks has a direct impact on wind flow and, thus, thermal comfort. Among the three models of liner, singular and courtyard, the courtyard model has a lower wind speed than the others, and residents could present outdoors without being exposed to Tabriz's cold winter winds. The three chosen models indicated that the findings were similar; nevertheless, each of them performed better in one of the factors; for example, results of wind analysis demonstrated that the courtyard model, performs better than the other models. In PMV analysis, the singular model performed better, whereas for temperature analysis, both the courtyard model and singular model showed well performance. Winter was chosen for simulation in this study, and firstly the courtyard model and secondly singular model has the highest effect in the winter in order to achieve outdoor thermal comfort for individuals.

Conclusion

This research analyzed the comfort performance of three types of urban blocks in Tabriz city. The main purpose of the research was to clarify the effect of building form on outdoor thermal comfort for Tabriz dwellings based on the Ashrea thermal comfort standards. The form of buildings has a direct impact on the wind environment of the residential area. The courtyard model has a lower wind speed than the others, and residents can be outside without being exposed to Tabriz's cold winter winds. Ecological design approach by making changes in morphology and urban structure can be effective in micro-climatic conditions and in addition to increasing energy efficiency in urban issues, it can increase the presence of space users by providing the required thermal comfort. In other words, climate-compatible urban planning can lead to the guidance of form by perceiving climatic parameters as the guiding structure, and the urban form, when affected by wind, radiation, etc. The shape and texture of the city created under this model provide climatic comfort for the citizens. In fact, by applying changes in the spatial, physical, and environmental dimensions of the city form as well as manipulating the geometric properties of urban blocks, space can be created that provides thermal comfort for all seasons. This study has shown that the purposeful design of block form can have a beneficial and decisive influence on the use and conservation of the outdoor environment.

Finally, some issues are recommended to be explored in future research. To further explore the courtyard as an optimal urban shape, examining the impacts of different orientations and ratios (length and width, height and width) on outdoor thermal comfort is recommended. To obtain more accurate information, another parameter that plays a vital role in outdoor thermal comfort is the green vegetation. It is recommended that the effects of density and vegetation on outdoor thermal comfort be investigated.

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Data availability statement. The data used to support the findings of this research are available upon request from the corresponding author. ENVI_met outputs could find with this DOI: 10.6084/m9.figshare.28204712

Ethical standards. The research meets all ethical guidelines.

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