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RESEARCH

Projection of bioclimatic patterns via CMIP6 in the Southeast Region of Türkiye: A guidance for adaptation strategies for climate policy

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Abstract Over the past three decades, global urbanization and climate change have caused significant differences in climate conditions between urban and rural environments. The effects of global warming affect the climatic values in the urban area. The bioclimatic comfort in an area effectively chooses a site regarding the urban quality of life and activities. This study aims to predict the temporal and spatial changes of the bioclimatic comfort zones of Gaziantep province in terms of climate comfort in the context of long-term global scenarios. The future climate simulation maps were produced and analyzed comparing comfort conditions according to Shared Socioeconomic Pathways (SSPs) 245 and 585 scenarios of the Intergovernmental Panel on Climate Change's (IPCC) Coupled Model Intercomparison Project (CMIP) Phase 6 (CMIP6). Spatio-temporal changes in temperature, humidity, and bioclimatic comfort areas were analyzed to inform these efforts according to Thom's discomfort index (DI) and effective temperature-taking wind velocity (ET*v*). The current situation of bioclimatic comfort areas to examine their synergy under extreme hot weather throughout the province and their possible concerns in 2040, 2060, 2080, and 2100 were modeled using ArcGIS 10.8 software. SSP585/2100 will create hot (84%) areas, according to DI, and warm (29%) areas, according to ET*v*. The spatial results of the research are discussed, and some strategies are produced in terms of urban planning, design, and engineering.

Keywords Adaptation strategies · Climate change · IPCC · Land use planning · Sustainable development goals

Introduction

The climate crisis is a critical global development facing humanity, affecting cities in a multidimensional and complex way (Amoak et al., 2022; Jabareen, 2013). While changes in climate parameters threaten settlements, cities are held responsible for more than 75% of global greenhouse gas emissions and 24% of global emissions from road transport (Frumkin & Haines, 2019; Giles-Corti et al., 2022). Surface biophysical differentiations, land use land cover (LULC) changes (Estoque et al., 2017; Naikoo et al., 2022), industrialization, and activities carried out to meet the needs of people increase greenhouse gas emissions and fuel the process, following exponential growth. Prudent decision-makers argue that

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4.5% of the world's countries are carbon neutral and that most countries aim to achieve this by 2070 (Chen et al., 2022; Nugroho et al., 2023). The ineffectiveness of mitigation strategies, the acceptance of change, and vulnerability prevention goals caused countries to develop their adaptation targets. Interest in urban climate studies is increasing since a more significant part of the world's population lives in cities and is therefore affected by the climatic changes in these areas (Aslam & Rana, 2022; Ren et al., 2022).

Changing climate values contain many risks: food and water insecurity (Behnassi et al., 2021; Phillips et al., 2020), unstable temperature, and precipitation values (O'Brien & Wolf, 2010; Bady, 2014; Coccolo et al., 2016), exposure to extreme weather events such as flooding, heavy precipitation, and strong winds that result in material and moral losses (Ha, 2022; IPCC, 2021; Istanbullu et al., 2023; Pörtner et al, 2019). Research frontiers in the urban heat island (UHI), which emerges differently from the regional climate in urban areas, means that urban environments have a warmer thermal structure than the surrounding natural areas (Al-Atroush et al., 2022; Marando et al., 2022; Potchter & Ben-Shalom, 2013; Susca et al., 2022; Wang et al., 2022). UHI and bioclimatically unsuitable values uniquely threaten public health and strongly reduce the quality of lifestyle regarding heat sensitivity (Karimi et al., 2023). Areas that are not suitable for thermal comfort can cause heart and respiratory diseases (Durmowicz et al., 1997) and psychological disorders and may pose a life threat in more fragile age groups (Liu et al., 2022). Previous studies have reported that heat waves are associated with increased mortality from respiratory diseases (Cheng et al., 2020; Wang et al., 2023). Societies try to bring the values of the area to the range where people can feel comfortable by using various energy sources to increase the quality of life, work efficiently, and maintain their health (Isinkaralar et al., 2023a). They use a variety of energy sources to heat, cool, or produce moisture (Hesaraki & Huda, 2022). The effort to bring the field's values into conformity entails severe costs. Unfortunately, the energy used for this purpose initiates a process that triggers the increase in emissions.

Conceptual framework

Several studies have proposed the impact of climate-responsive design at particular scales in Table 1. While a few studies have highlighted the effect of climate on building energy (Jafarpur & Berardi, 2021; Nguyen et al., 2021), few have addressed climate change in terms of indoor thermal comfort (Ismail et al., 2021). Some studies aim at the current evaluation of bioclimatic comfort (Daneshvar et al., 2013; Svensson et al., 2003). While some studies have focused on the effect of bioclimatic comfort, which changes with the impact of climate, on urban planning (Isinkaralar, 2023a), none of the studies has presented inferences about the plans of cities and which land cover will be affected.

Literature gap and research question

In this impasse of a global challenge, concrete indicators experienced require effective management of the crisis. Global mean sea levels are expected to rise by 0.43–0.84 m by 2100 (IPCC, 2019). Therefore, there are solid spatial repercussions of change. More recently, the climate crisis is one of the vital concerns facing urban planning today. Due to the multi-disciplinary nature of urban planning, it is the responsibility of urban design professionals to apply knowledge from other disciplines, such as urban climatology, to urban design from city scale to building scale. Especially in developing countries, because of the magnitude of spatial changes, it is necessary to focus on climate adaptation strategies. As a precaution, passive heating and cooling strategies are the integrated approach to producing thermally comfortable indoor and outdoor spaces without energy (Mahdavi et al., 2023). In another example, Mahmoud and Abdallah (2022) developed passive strategies for thermal comfort in school courtyards. Santamouris (2016) has recently revealed that high-rise enclosed buildings affect thermal efficiency. Some studies model the effects of climate on urban thermal comfort (Isinkaralar, 2023b). Therefore, passive strategies can be produced from the building scale to urban design, from the urban scale to the regional scale (Mohammad et al., 2021; Mohammadzadeh et al., 2023). In this context, the research focuses on the spatial analysis of future outdoor bioclimatic change based on climate scenarios and developing passive strategies. The 2100 estimates aim to identify existing and planned land cover and human settlements at risk by emphasizing the speculative. The main research questions are as follows:

Table 1 Recent background of the study

No	Article	Location	Context	Key results
1	Jafarpur & Berardi (2021)	Canada	Effects of climate changes on building energy	The impacts of climate change on building energy use as well as heating and cooling loads
2	Latha et al. (2015)	-	Building materials that provide thermal comfort in workplaces	Using it as a passive method has benefits such as energy savings and efficiency.
3	Yao et al. (2018)	Yangtze River Valley	Impact of passive measures on thermal comfort and energy savings	Passive measures can significantly extend heating/non-cooling demand time and peak load demand
4	Hadavi & Pasdarshahri (2021)	Tarbiat Modares University	Effects of urban configuration and density on urban climate and building system energy consumption	16.4% energy saving for rooftop units is achieved by reducing urban compactness
5	Nguyen et al. (2021)	Plaschem tower	Performance of office buildings under the influence of climate change	Climate change impact assessment using sampling and simulation-based optimization method
6	Rathore et al. (2020)	-	One-year comparative analysis of the indoor thermal profile of buildings	Significant reduction in indoor peak temperature and thermal amplitude observed
7	Ismail et al. (2021)	England	The impact of climate change on the energy performance of buildings	Highly insulated prefab buildings can potentially have a lower base temperature for degree-days of heating
8	Amaripadath et al. (2023)		The role of humidity as an indoor thermal comfort parameter in humid climates	The effects of humidity cannot be ignored when indoor thermal comfort is considered.
9	Asfour (2020)	Suudi Arabistan	Daylight and energy performances of courtyard and atrium buildings considering the hot climate	Courtyard/atrium buildings demonstrated equivalent to daylight and energy performance
10	Daemei et al. (2019)	Rasht, Iran	Passive design strategies	Strategies to improve indoor thermal comfort with humid climate indicators
11	Isinkaralar (2023a)	Kocaeli, Türkiye	Estimation of temporal and spatial changes of bioclimatic comfort zones in terms of climate comfort	According to the pessimistic scenario, hot areas will form in 2100.
12	Daneshvar et al. (2013)	Iran	Evaluation of bioclimatic comfort conditions	Thermal comfort conditions were not observed in July and August in summer.
13	Svensson et al. (2003)	Göteborg, İsveç	A proposal for a method for generating large-scale bioclimatic maps	The model uses a GIS application that makes it non-static.

RQ$_1$: Are urban growth areas consistent with bioclimatic suitability over time?

RQ$_2$: What are the critical measures for urban design and climate-sensitive strategies for risky areas?

Methodology

The study area is Gaziantep province of Türkiye. The modeling methodology is divided into three sections: (1) data collection, (2) scenario selection, and (3) bioclimatic change modeling in Fig. 1. The data collection step gathers all the necessary data to develop the distribution of current bioclimatic comfort zones and the data for 2020 to be used in future forecasts. Data that can be used to calculate bioclimatic comfort zones are provided, and pre-processing them to be recorded in a numeric format was carried out in this step. While determining the scenarios from the WorldClim 2.1 database, a moderate approach (SSP 245 presents a moderate scenario reflecting RCP 4.5 reflecting RCP 8.5) and the worst possible scenario (SSP 585) were used in the model as commonly preferred (Goyal et al., 2023). The change of bioclimatic comfort zones at intervals of 20 years until 2100 is simulated spatially.

Study area

The Gaziantep province, which is located in the southeast region of Türkiye within latitudes N 37° 3′ 58.392″ and longitudes E 37° 22′ 59.952″, is the 6th largest city in the country in Fig. 2. Mediterranean, temperate climate dominates, summers are hot and dry; however, winters are not very cold, and precipitation is very unstable.

Data collection

Discomfort index (DI) and effective temperature-taking wind velocity (ETv) bioclimatic comfort methods were used in the study, as it was comprehensively formulated in the bioclimatic change modeling section. The temperature, humidity, and wind speed data required for these calculations were obtained from 15 stations belonging to the General Directorate of Meteorology Institution as yearly averages. Data from the WorldClim v2.1 project, which can predict future descriptive variables, has been reclassified. By choosing two different socioeconomic paths (SSP), data were organized to create a model at intervals of 20 years until 2100, the end of the century we are in. Bioclimatic comfort maps for the present and the database to be used in forecasts were created using ArcGIS 10.8 software.

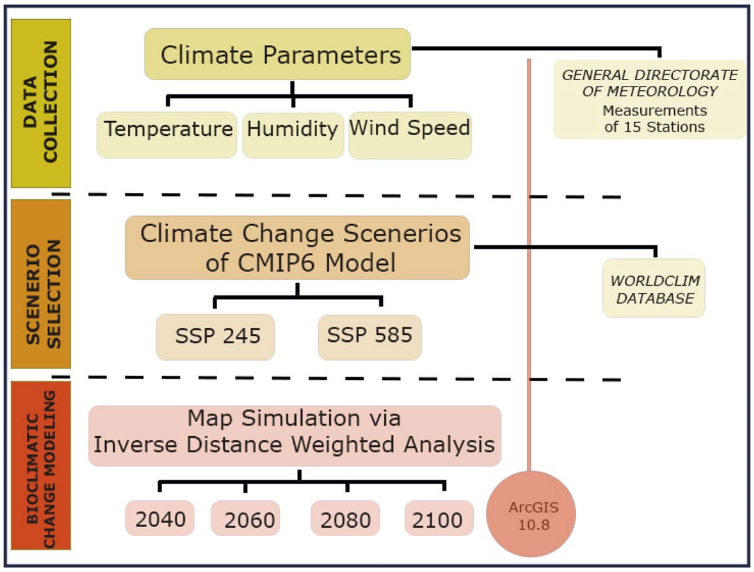
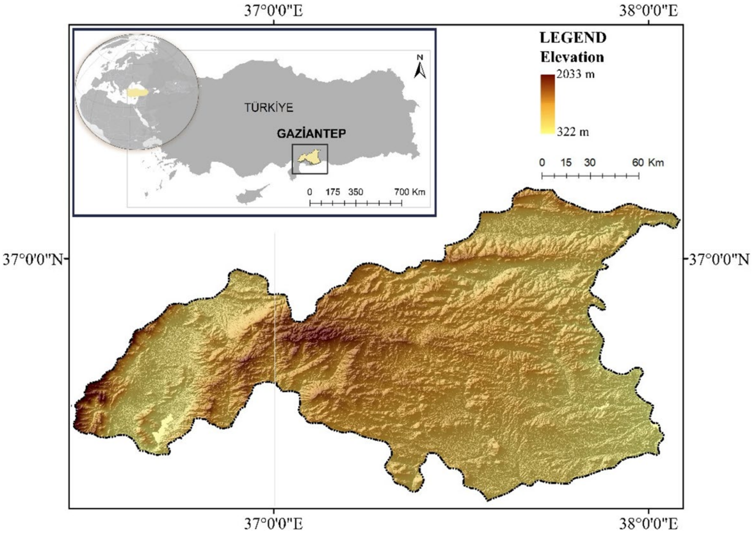
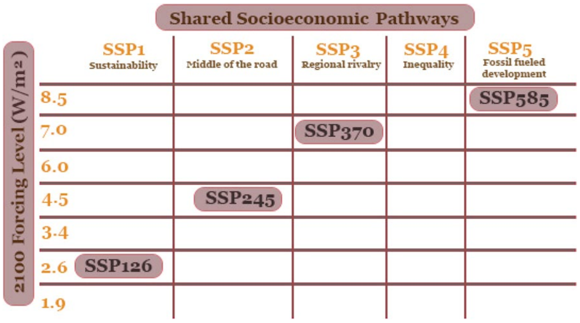


Fig. 1 Methodology to modeling bioclimatic comfort change up to 2100

Fig. 2 The location and topography of the study area





	SSP1 Sustainability	SSP2 Middle of the road	SSP3 Regional rivalry	SSP4 Inequality	SSP5 Fossil fueled development
8.5					SSP585
7.0			SSP370		
6.0					
4.5		SSP245			
3.4					
2.6	SSP126				
1.9					

Fig. 3 Shared socioeconomic pathways

Scenario selection

The Coupled Model Inter-comparison Project Phase 5 (CMIP5) has been used in previous research. The project aims to produce models based on the study of climate predictability and measures against bad weather conditions. However, it was thought that CMIP5 ignored some points, so CMIP6 was developed after CMIP5. Thus, model deviations due to climate uncertainties were formulated in scenarios, and answers were sought. Among the four scenarios within the scope of the project in Fig. 3 (O'Neill et al., 2017), SSP 126, SSP245, and SSP585 are among the most preferred. Chou et al. (2021) selected them in their research on the effect of extreme weather events on rice production, and Bai et al. (2021) on wheat production. Isinkaralar (2023c) preferred a climate-sensitive scenario approach in urban growth modelling. Sadhwani and Eldho (2023) preferred using it to achieve river water estimation. In this study, the effect of a moderate (SSP 245) and a pessimistic (SSP 585) approach was investigated spatially.

Bioclimatic comfort change modeling

Various indexes determine the level of comfort in terms of bioclimatic conditions. Thom discomfort index (DI) (Thom, 1959) and ETv were chosen in this study. It offers the opportunity to interpret the determined indexes and similar parameters with different calculation techniques. However, there is the potential for comparison with each other. DI is a widely preferred index to interpret outdoor thermal comfort using ambient temperature and relative humidity. After all layers were organized at a spatial resolution of 1 × 1 km, the calculation was made according to the formula as in Eq. 1 (Giles & Balafoutis, 1990):

$$DI = \left(T_{dbt}\right) - 0.55[1 - (0.01)(RH)] * \left[T_{dbt} - 14.5\right] \tag{1}$$

where DI is the temperature-humidity index (discomfort empirical index), T_{dbt} is the dry bulb temperature (°C), RH is the relative humidity (%), and v is the wind speed (m/s).

The following formula in Eq. 2 is used for effective temperature taking wind velocity (ETv) (Lucena et al., 2016):

$$ET_v = 37 - \left[\frac{(37 - T_{dbt}) * (1.76 + 1.05v)}{(0.68 - 0.0014RH + 1)}\right] - (0.29) * (T_{dbt}) * \left[1 - \frac{RH}{100}\right] \quad (2)$$

The interpretation of the index value obtained after the calculations was made according to Fig. 4. Evaluation of the indexes has been classified in an advanced manner in various studies (de Freitas & Grigorieva, 2015). There are four categories in the field according to DI and six categories according to ET*v*.

All of the models were made using ArcGIS 10.8 application as in Eq. 3:

$$z(x_o) = \frac{\sum_{i=1}^{n} z(x_i).d_{i0}^{-r}}{\sum_{i=1}^{n} d_{i0}^{-r}} \quad (3)$$

where the location X_0 where the estimations are made is a function of neighbor measurements n [$z(X_{0i})$ and i=1, 2, …, n]; r is the top that determines the assigned range of each of the observations, and d is the distance separating the observation location X_i from the prediction location X_0.

Results and discussion

This section presents the findings of a study aimed at understanding the impact of climate change on climate parameters and the change in bioclimatic comfort zones.

Overview of the climate parameters change

Table 2 shows climate parameters for climate scenarios that the average wind speed observed in the area today has a value of 0.65 m/s. In 2100, these values decreased to 0.5 compared to SSP245 and SSP 585. Average humidity values are estimated to be 58.5% in 2020, 54.5% according to SSP 245/2100, and 48.5%

Fig. 4 Interpretation scale of index values (a classification of DI; **b** classification of ET*v*)

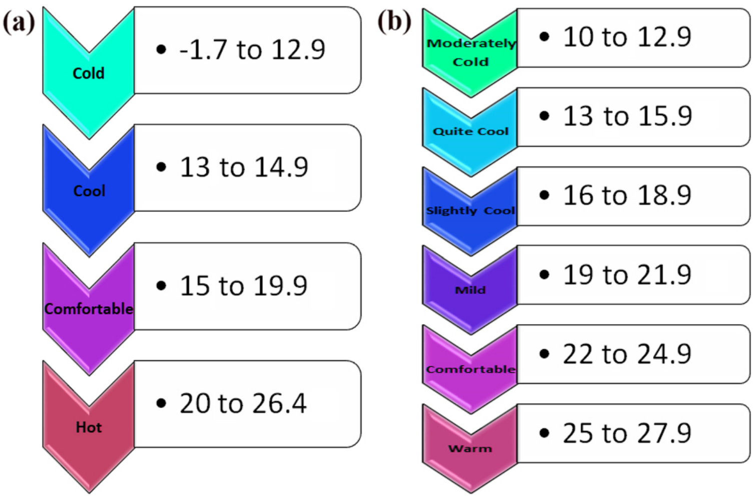


Table 2 Characterization of the climate scenarios based on the climate parameters

Climate scenario	2020	SSP 245/2100	SSP 585/2100
Mean outdoor wind speed (m/s)	0.65	0.5	0.5
Min outdoor wind speed (m/s)	0.4	0.2	0.2
Max outdoor wind speed (m/s)	0.9	0.8	0.8
Mean outdoor relative humidity (%)	58.5	54.5	48.5
Min outdoor relative humidity (%)	55	51	43
Max outdoor relative humidity (%)	62	58	54
Mean outdoor temperature (°C)	13.5	17.5	20.5
Min outdoor temperature (°C)	8	12	15
Max outdoor temperature (°C)	19	23	26

according to SSP 585/2100. Today, the average temperature values of the area are measured as 13.5 °C. However, it is predicted to be 17.5 °C according to SSP 245/2100 and 20.5 °C according to SSP 585/2100.

A graphical display of climate change parameters is in Fig. 5. Currently, a large part of the area (53%) has a wind speed of 0.5–0.6 m/s. While it drops to 0.3–0.4 m/s wind speed in 59% of SSP245/2080, it reaches 61% in SSP245/2100 and 62% in SSP585/2040. The lowest wind speed observed in the area, 0.2–0.3 m/s, gets 35% in SSP585/2100. Humidity values of the region have a share of 66% in the range of 56–60% and 34% in the field of 61–64% in 2020. Areas in the 51–55% range in SSP245/2040 constitute 71% of the total area. According to SSP585/2040, these range values include 79%. Our findings highlight that in SSP585/2100, humidity values in the range of 43–45%, which are not present in the area, will begin to be seen and constitute 11% of the site. The most common (60%) humidity values in SSP585/2100 are predicted to be 46–50%. Average temperature values are generally (80%) in the range of 16–20 °C in 2020. Another interesting finding in SSP245/2040, this rate reaches 97% while the share of areas in the 11–15 °C range decreases. According to SSP245/2100, temperature ranges of 21–25 °C, which is not present in the area today, will begin to form and have a 53% share. In the predictions of SSP585/2080, there will not be a range of 11–15 °C covering an area of 20% today, whereas the range of 21–25 °C will reach 94%, while areas with a temperature of 25–26 °C will begin to be followed with a rate of 4% in the province. Temperature is crucial in climate change, land use, and land cover. Many researchers performed multiple climate change scenarios between species distribution and climate variables by Liao et al. (2020), Krausmann et al. (2020), Molotoks et al. (2021), and Isinkaralar et al. (2023b). Wang et al. (2021) showed the impact of climate change on species distribution and richness using 19 bioclimatic variables via *Akebia* taxa. Their potential distributions and future conditions were compared under the SSP5-8.5 climate scenario, which correlated variables affected by temperature, precipitation, and multicollinearity. Similarly, Jiang et al. (2020) simulated future climate scenarios of musk deer geographical distribution using bioclimatic variables. Moreover, researchers tried to remove the prediction uncertainty and their distribution response to future climate. In addition to temperature-based climate change models, distribution, and sustainability of living things, estimates were made in indoor environments' energy consumption and calculations. Yang and Cui (2019) reviewed the SSPs-RCPs-SPAs framework climate change scenario for the sustainable environment such as land use, water resource, energy, and ecosystem. Chakraborty et al. (2021) also performed the prediction of cooling energy consumption in buildings using local climate data (dry bulb air and dew point temperature, relative humidity, etc.) by CMIP6. They determined prototype residents for correlation analysis and time-series decomposition.

Modeling of bioclimatic comfort

The change of bioclimatic comfort areas within the scope of two different indexes and according to two different scenarios is given in Table 3, and spatial analysis of the site is in Figs. 6 and 7. According to DI, cool zones constitute the largest (50%) area today. As such, SSP245/2040 cool areas decrease to 17%, decreasing to 1% in SSP245/2100. These areas have turned into comfortable regions with a rate of 98%, according to SSP245/2100. In SSP585/2100, on the other hand, comfortable areas are also decreasing and constitute 16%. Broadly, hot areas that do not exist in the area have started to occur with a rate of 30% in SSP585/2080 and have a share of 84% in SSP585/2100.

According to the classification of ET*v*, almost all (84%) of today's areas are in the mild category. When the SSP245/2100 comes, the shaft areas are reduced to 8%. On the other hand, comfortable areas reach 91%. According to SSP 585, in 2060, mild areas will decrease to 26%, while mild regions will have a share of 73%. In SSP585/2100, on the other hand, warm areas that do not exist occur for the first time. These areas make up 29% of them.

Outdoor thermal comfort studies were conducted by several researchers using simulating possible climate changes (Hamed et al., 2023). Although the effects of rising temperature can also be seen in the interior. The increasing mean temperature has caused cooling to satisfy occupants' thermal comfort with active technologies (Karimi et al., 2020). For example, Bugenings and Kamari (2022) reviewed to

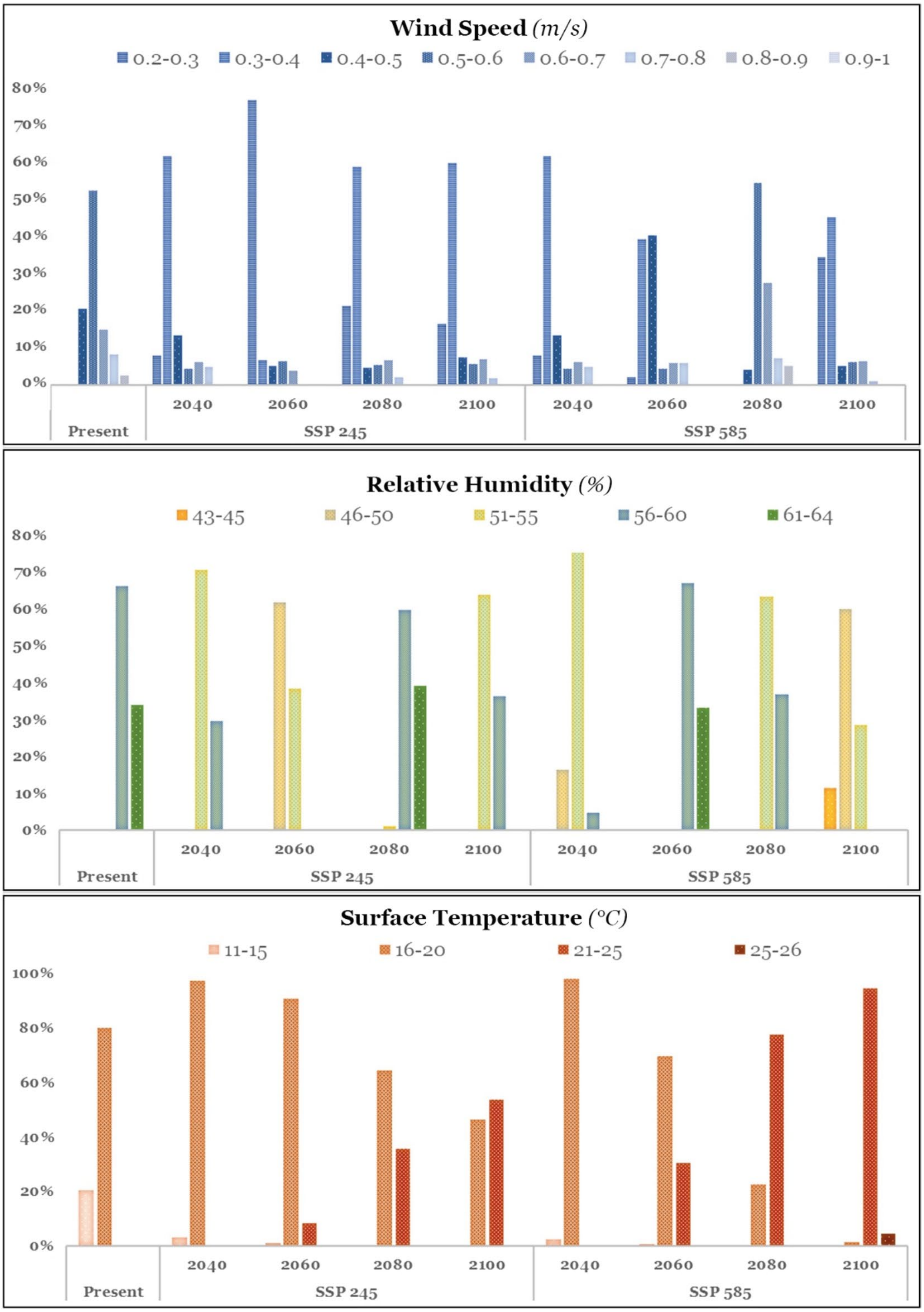


Fig. 5 Graphical display of climate change parameters

Table 3 The percentages (%) of the current and future status of bioclimatic comfort maps under the SSP 245 and SSP 585 scenarios

Index and scenario		Class	Years				
			Present (2020)	2040	2060	2080	2100
DI	SSP 245	Cold	5%	1%	0%	0%	0%
		Cool	50%	17%	16%	2%	1%
		Comfortable	45%	82%	84%	98%	99%
		Hot	0%	0%	0%	0%	0%
	SSP 585	Cold	5%	1%	0%	0%	0%
		Cool	50%	13%	3%	0%	0%
		Comfortable	45%	86%	97%	69%	16%
		Hot	0%	0%	0%	31%	84%
ET*v*	SSP 245	Moderately cold	0%	0%	0%	0%	0%
		Quite cool	1%	2%	1%	1%	0%
		Slightly cool	15%	50%	17%	10%	1%
		Mild	84%	48%	82%	89%	8%
		Comfortable	0%	0%	0%	0%	91%
		Warm	0%	0%	0%	0%	0%
	SSP 585	Moderately cold	0%	0%	0%	0%	0%
		Quite cool	1%	1%	0%	0%	0%
		Slightly cool	15%	14%	1%	1%	0%
		Mild	84%	85%	26%	23%	1%
		Comfortable	0%	0%	73%	76%	70%
		Warm	0%	0%	0%	0%	29%

identify climate change effects on bioclimatic architecture-based buildings in Denmark. Instead of the energy-requiring coolers used in general, some structures do not require energy due to the different architecture of the buildings. Hadi Pour et al. (2019) used the time series on a larger scale to define bioclimatic comfort zones under annual and seasonal climatic indicators in different climatic zones of Iran.

Analysis in terms of the existing land cover and master plan

The land cover classification of the CORINE Land Cover Level 1 located within the provincial borders is in Fig. 8. The lands used for agricultural purposes throughout the area cover a large extent. The city center is elevated in the center of the province compared to its immediate surroundings. Forest land classification represents a minimal region in the province's west. Regarding bioclimatic classification, it is predicted that the areas at risk in the DI and ET*v* categories will generally be effective in forest and agricultural regions far from settlements. On the other hand, it has been determined that the city limits the development points. Using bioclimatic comfort zones as a basic analysis in determining the urban growth boundaries (UGBs) in spatial decisions is critical.

Industrial areas to the east of the city, residential development areas to the southeast of the town, and rural settlements to the east and west of the city center are bioclimatically threatened in Fig. 9. However, it has been determined that the agricultural lands in the west and east of the area and the pastures in the south pose a risk. Urban development along eastern arterials is not recommended for growth. Although forest lands form a threshold in the west of the area, bioclimatically, the development in the western region can be directed by determining the UGBs.

Guidance for planning, design, and engineering

The comfort zones change at intervals of 20 years according to two different indexes in the field. It is an inevitable process that extreme weather events will increase due to climate change. As a complex system, it is normal for there to be uncertainties about urban climate. In addition, modeling studies must start from certain assumptions. However,

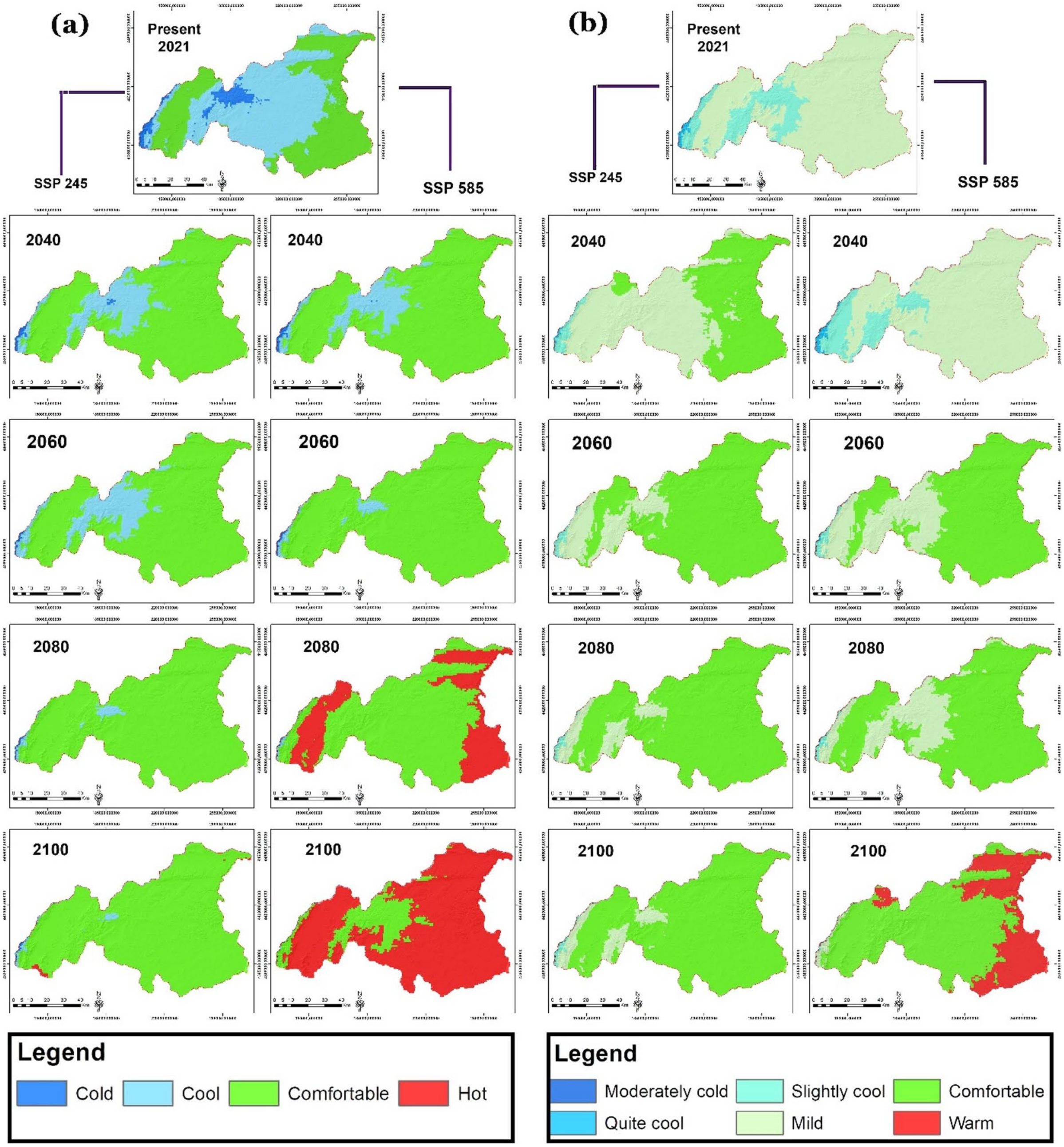
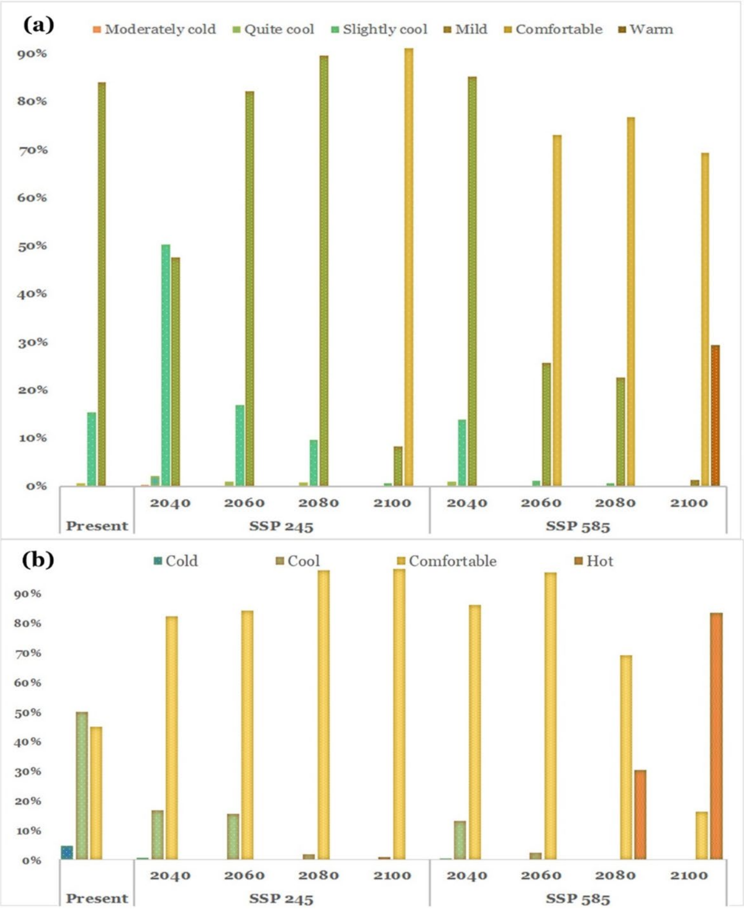


Fig. 6 Spatial modeling of bioclimatic zones changes: **a** DI and **b** ET*v*

various trends provide us with clues. Based on this, we need guiding and precautionary measures. In a world where heat waves are growing, critical contributions of spatial planning, urban design, and building design are needed (Karimi et al., 2022). Based on spatial zoning decisions, the passive heating/cooling approach is a handy tool for energy efficiency in buildings to provide thermal comfort. Outdoor conditions affect the thermal comfort indoors. Therefore, starting from bioclimatic comfort zones, strategies for thermal comfort levels in buildings should be produced.

Fig. 7 Graphical change of bioclimatic zones: **a** DI. **b** ET*v*



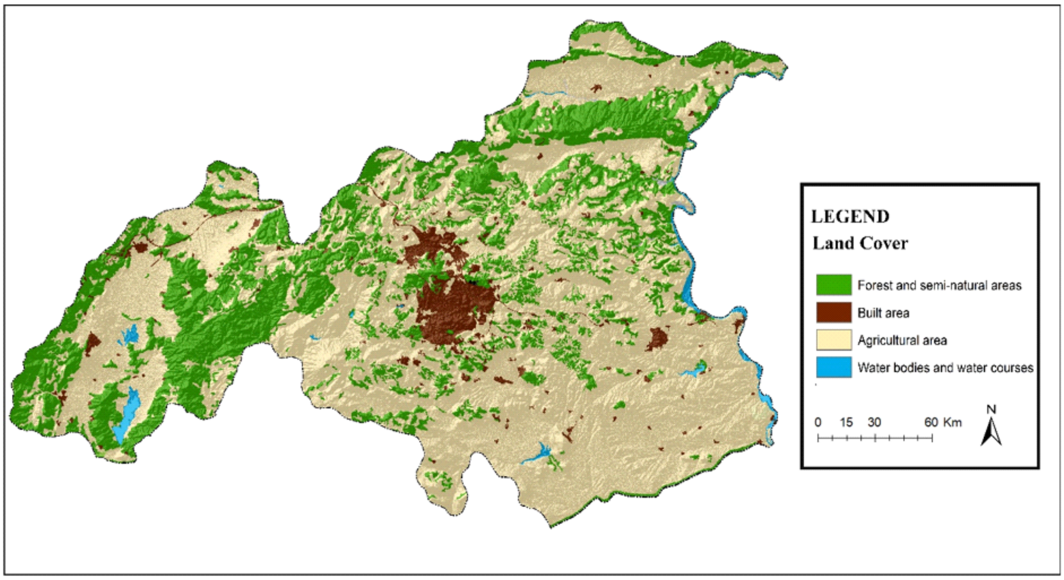


Fig. 8 The land cover of the city

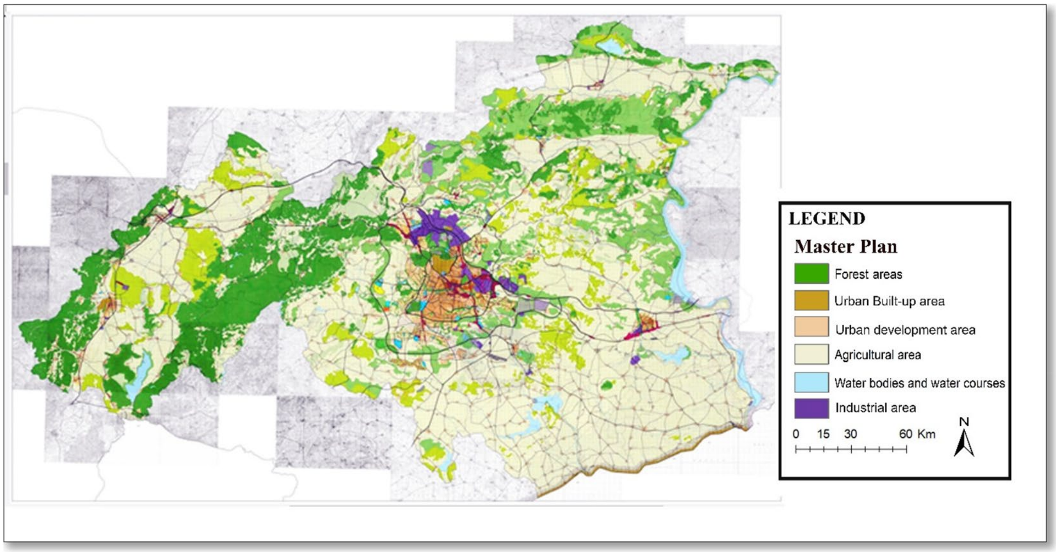


Fig. 9 The master plan of the city

Effective management of urban growth and land use

Urban growth, which requires new development areas, triggers negative dynamics such as land degradation (Seifollahi-Aghmiuni et al., 2022), infrastructure costs (Vermeiren et al., 2022), administrative difficulties (Yi et al., 2022), and transportation costs (Singh et al., 2022). It is critical that urban growth does not stray away from several strategies:

- First of all, it is necessary to take urban planning beyond traditional analyses. Today's technology can provide more analytical and comprehensive information sets (Falah et al., 2020). When making decisions, anticipated future conditions should be added to the analysis instead of today's conditions.
- In practice, the subject of study is a complex issue that must be managed collaboratively by various experts, including urban planners, climate scientists, architects, environmental scientists, health professionals, and policy makers. Collaboration networks need to be developed systematically.
- Significant investments and transportation arteries are among the decisions that ignite urban growth. Bioclimatic comfort analyses should not be ignored while making decisions for large projects. Determining comfortable areas as the direction of urban growth will reduce future consumption.
- The importance of planning the green system in urban land cover is more serious in regions that are more sensitive in terms of bioclimatic comfort. Warmer areas that move away from the comfortable situation through urban air corridors should be cooled by taking into account the prevailing winds. Land use decisions, such as the orientation of residential areas and the effective use of water surfaces, should be made more sensitively.
- The risks in the produced particle and local zoning plan decisions can be read from the spatial maps of comfort areas.
- Since an optimum thermal environment in shopping centers affects customer satisfaction and purchasing behavior, energy use for heating and cooling is relatively high (Yi & Kang, 2019; Zhao et al., 2022). Therefore, more comprehensive thermal comfort analyses in the location selection of urban land uses of similar character will provide energy savings. In this context, thermal measures such as the orientation and angle of the buildings with respect to the sun, the selection of suitable materials in terms of insulation, and the use of double glazing and insulating glass should be kept in the foreground.

- Locating work areas in comfortable areas will affect production efficiency and the city economy. Bioclimatic comfort analyzes should be taken into consideration in interventions to be made in urban work areas such as office areas and industrial areas.

Social sustainable development and public health

Another dimension of thermal comfort perception is to manage the exposure of the social structure in the city to areas that are/are not bioclimatically comfortable. In this respect, the basic perspective may be as follows:

- Parallel to these findings, population densities should be kept as low as possible in areas where bioclimatically critical thresholds are exceeded in hot climate regions. In other words, keeping the energy consumed to reach the thermal ranges at the building scale, regardless of the area, is a significant reduction method with sensitivity analysis.
- The social groups addressed by urban land uses may differ. Environmental scholars Baquero and Forcada (2022) showed that adults felt warmer and were less tolerant in the same ecological conditions as older people. Accordingly, spatial planning of urban living spaces and working areas in a comfortable way in terms of bioclimatic is critical for public health.
- Since the usage rate of urban activities that are located in an area that is not bioclimatically suitable will be low, social interaction and economic activities will be affected. Therefore, its contribution to the socio-economic dimension is critical.

Conclusion

This research presents a perspective that directs the building design based on the effect of the climate crisis on thermal comfort in urban outdoor spaces. Turning to the importance of the spatial planning approach, where outdoor conditions are comfortable, reduces energy use for heating and cooling and prepares the necessary infrastructure for passive design strategies. The research results draw attention to the urban zones where precautions should be taken in building design. From our perspectives, the research deals with the change due to climate change in terms of bioclimatic comfort in urban space, based on scenarios. Different urban growth forecasting methods such as artificial neural networks and Markov chains can be integrated into the subject in future studies. The article provided spatial classification using DI and ETv. It can be improved by comparing various indexes. Comprehensive analyses of areas with high bioclimatic change at the local scale can enrich measures. Short and long-term actions can be planned for sectors. The effects of the change on plant and animal species can be examined. Energy-saving models can be developed by producing indexes with approaches to be developed with various disciplines. All proposed strategies have the potential to create an infrastructure in the context of log-term sustainable, resilient and adaptable cities in the kontext of urbaan environments and the quality of life for residents. Additionally, strategies are guiding in reducing the impact of UHI. In future studies, the methodology of this research may provide new perspectives.

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Data availability The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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