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Sustainable Urban Landscapes in Hot–Dry Regions: Climate-Adaptive Courtyards

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Abstract: In hot and arid environments, courtyards are essential architectural elements that significantly contribute to microclimate regulation and enhanced thermal comfort. Beyond providing protection against environmental severities, these spaces elevate the standards of livability and sustainability in urban design. The traditional landscape of Mardin, Turkey, exemplifying such challenges, takes center stage in this study, where courtyards hold a prominent role in architectural composition. Facilitated by the ENVI-met software, the evaluation process herein comprehensively analyzes four representative courtyard case studies in Mardin. Key parameters, including air temperature, humidity, predicted mean vote (PMV), and wind speed, are considered to gain a nuanced understanding of their thermal dynamics. The initial evaluation of existing conditions reveals varying thermal comfort levels, with higher PMV values indicating discomfort in the courtyards, underscoring the need for interventions to enhance their microclimate regulation and resilience to climate change challenges. This study aims to enhance our comprehension of the relationship between courtyards and microclimate regulation, particularly in hot–dry regions. By examining the design principles and passive strategies of courtyards, this research identifies effective approaches for optimizing courtyard design, aiming to create sustainable and comfortable living environments.

Keywords: courtyard; passive design strategies; microclimate regulation; thermal comfort; ENVI-met; hot–dry climates; traditional Mardin houses; thermal environment simulation

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1. Introduction

A courtyard, defined as 'an enclosed area surrounded by a building or wall and exposed to the sky', is a common architectural element used to create open spaces between the outdoors and indoors, often located in the center of a building or surrounded by walls or groups of buildings [1]. The design and structure of buildings featuring courtyards have historically been influenced by a blend of social norms, environmental considerations, and cultural preferences, including the need for privacy or the pursuit of social interaction [2–4]. The consistent use of courtyards across different cultures highlights their role as an effective strategy for coping with various climatic conditions, demonstrating their widespread functionality and appeal. By utilizing this specific form as part of a passive design strategy, it becomes possible to create a microclimate that can effectively regulate and optimize critical environmental variables such as air circulation, solar heat gain, thermal comfort, and moisture levels, all of which play a vital role in enhancing the overall environmental performance and sustainability of a building [5–7]. In this regard, climate-responsive courtyards serve as highly functional open spaces that address environmental requirements by responding to local climatic conditions and providing comfortable living environments throughout the year [8].

For centuries, inhabitants of hot–dry regions have developed a deep understanding of the land and its resources [9]. Hence, they have learned to adapt by developing specialized

skills and knowledge that allow them to cope with such challenging environments. This traditional approach has thus become a cornerstone of passive architectural strategies [10], with the use of vegetation in courtyards emphasized to regulate indoor temperature and sunlight exposure efficiently.

Courtyards are designed to partially control natural forces, contributing significantly to the aesthetics and functionality of living environments [11,12]. As illustrated in Figure 1, during the summer season, courtyards can provide shading to the facades of surrounding buildings, in turn protecting the courtyard from intense solar radiation. This not only keeps the buildings cooler, but also reduces the need for air conditioning and other cooling measures, thereby lowering energy consumption and costs. Similarly, during the winter season, courtyards can admit the winter sun and provide a degree of protection from harsh weather and climate events.

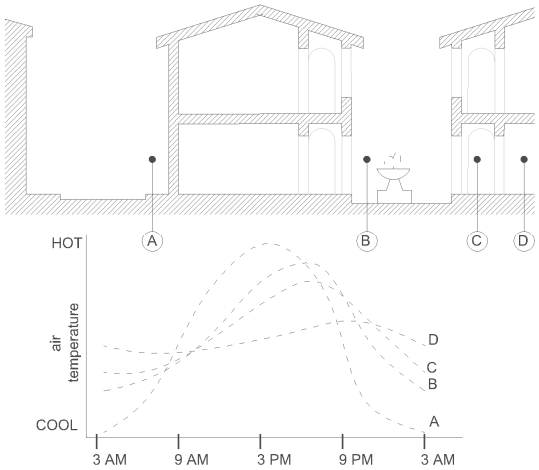


Figure 1. The distribution of temperature in the street, courtyard, and surrounding areas in hot weather. Drawing by author after Reynolds, 2002 [11].

Courtyards can be seen any part of the world; however, their effectiveness is related to how far environmental conditions are considered in the design process, in addition to architectural design, building function, and users' needs, as well as maintenance and management. In the utilization of courtyards, the building form, openings, materials, and the selection of natural elements collectively play a significant role in creating comfortable and sustainable built environments. A well-designed courtyard can provide natural ventilation, daylight, and thermal mass through the strategic use of sunlight, wind, and shade. This reduces reliance on energy-intensive mechanical systems such as air conditioning and artificial lighting, while also enhancing the health and well-being of building occupants. In arid and semi-arid regions, the strategic incorporation of certain plant species and natural materials into courtyards plays a crucial role in preserving environmental balance and fostering sustainable development. However, in other climates, the humidity and cooling effects of these natural components are not required [13]. In this regard, courtyards can be varied in their interpretation to fulfill the demands of a region and its residents, as well as to provide preferable thermal conditions.

The courtyard design is considered appropriate for all climate regions; however, it is particularly well-suited for hot climatic regions, whereas its benefits may be restricted in moderate or cold regions [14]. These outdoor spaces have been used to alter environmental conditions by providing shaded areas to residents that protect them from the harsh effects of the sun, wind, and dust, while also allowing them to engage in various outdoor activities [15]. This study investigates how courtyards influence microclimate regulation in hot–dry regions, focusing on Mardin in southeastern Turkey. It identifies design strategies to enhance thermal comfort and energy efficiency, and address climate change challenges effectively. By doing so, it aspires to contribute to the creation of more resilient and sustainable built environments that prioritize human comfort and well-being. The research

question that guides this study is as follows: What is the potential impact of passive design strategies on improving the microclimate conditions of courtyards in hot–dry climates?

2. Materials and Methods

This study's methodology encompasses several stages, as summarized in Figure 2. The study begins with a comprehensive literature review, followed by a description of on-site data collection. Following this, passive design strategies are developed for specifically chosen courtyards in the case study of Mardin, Turkey. These strategies are tailored to address the unique social functions, distributions, architectural features, and natural factors of the courtyards, considering the constraints of heritage conservation. The approach emphasizes minimal intervention, using Nature-based Solutions (NBS) and passive design to adapt urban areas to climate change scenarios, particularly focusing on heat peaks in hot, dry climates. The effectiveness of these strategies is then evaluated through simulations using the ENVI-met software (version 5.5), allowing for a detailed assessment of environmental improvements and a comparison with comfort thresholds. This multifaceted methodology aims to enhance the environmental performance and livability of urban spaces, particularly within the selected courtyards.

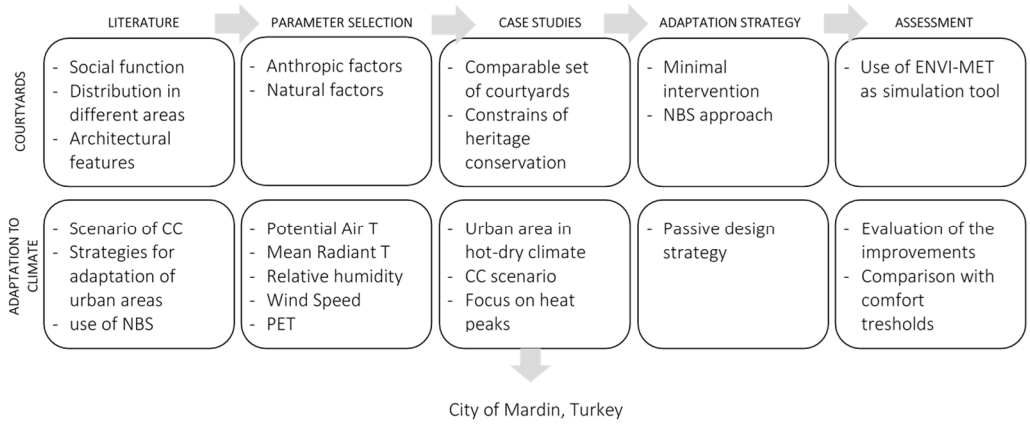


Figure 2. Workflow diagram of the research methodology.

2.1. Microclimate Regulation of Courtyards

Central to this research is the exploration of parameters that influence the microclimate regulation potential of courtyards. This includes an in-depth analysis of morphological factors, such as form, orientation, and surface-to-volume ratio [16,17]; architectural considerations, like material selection, window placement, and shading mechanisms [18–20]; and environmental aspects encompassing vegetation, water features, and spatial relation to surrounding buildings [21–23]. These parameters, summarized in Table 1, are crucial for devising strategies to optimize courtyard designs to improve microclimatic conditions and enhance the well-being of users [13,24].

2.2. Case Study: Mardin, Turkey

Mardin is one of the cities in the Southeast Anatolian Region of Turkey, and is located in the historical region of Mesopotamia, between the Euphrates and Tigris rivers, just north of the border with Syria and just west of the border with Iraq. Mardin, like many other settlements in Upper Mesopotamia, has hosted various cultures for thousands of years due to its historical significance as a hub for trade relationships and transitions, which has led to a diverse ethnic and cultural presence [25]. It stands out as a remarkable city exhibiting a rich cultural heritage, as well as preserving various cultures, religions, and traditional harmony over the years due to its strategic location between Mesopotamia and Anatolia, where the first civilizations emerged [26].

Table 1. Factors affecting microclimate regulation.

Anthropic Factors	Morphological	• Courtyard form • Orientation • Building height • Aspect ratio and Solar Shadow Index
	Architectural	• Materials • Window placement • Shading devices
	Environmental	• Materials • Vegetation • Water elements
Natural Factors	Environmental	• Air temperature • Humidity • Natural ventilation • Solar radiation

The city has a characteristic architectural and urban morphology. This spatial configuration not only showcases the city's layered and consolidated experience in overcoming climatic challenges, but also contributed to the recognition of Mardin on the UNESCO World Heritage Tentative List in 2000, under the name "Mardin Cultural Landscape" [27]. The preservation of Mardin's architectural and urban fabric, amidst its role as an active cultural and commercial nucleus, highlights its pivotal role in the discourse on sustainable urbanism and climate-adaptive design within arid regions.

The urban area of Mardin, as shown in Figures 3 and 4, is located on the southern slope of a mountain. This means that it is open to both the sun and the hot desert wind, while the high mountains in the north prevent cold air masses from entering the region [25]. When it comes to the winter season, the air gets extremely cold in Mardin, which is a high-pressure area due to the mountains, and strong winds are encountered.



Figure 3. General view of historic Mardin, Turkey (by authors).

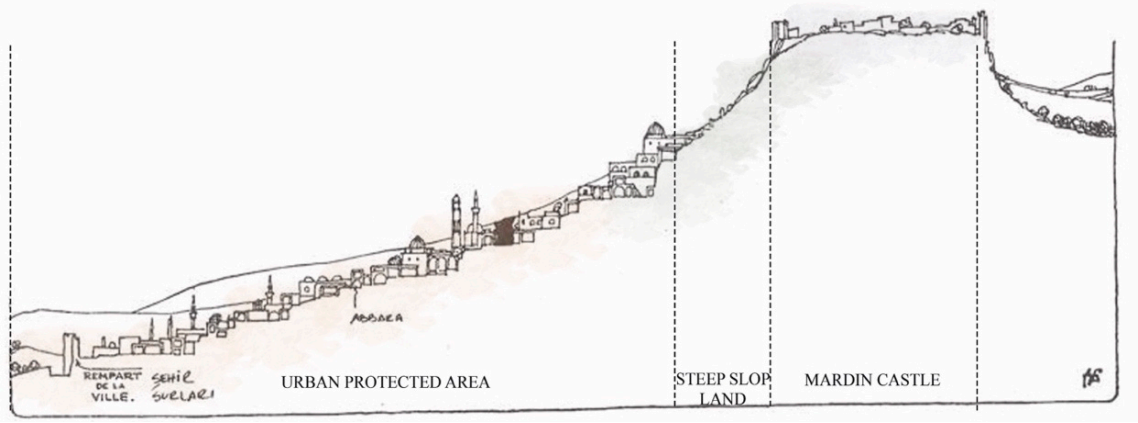


Figure 4. Mardin city sections, drawn by Albert Gabriel in the 1930s [28].

The houses feature enclosed, open, and semi-open spaces that are characteristic of spatial design, with each unit supported by a structural system of walls, columns, and arches that connect to each other through vaults [29,30]. As shown in Figure 5, the dwellings are built in a stepped arrangement, with each house higher up the hill than the one in front of it, ensuring that each house receives adequate sunlight and ventilation. The primary facades of Mardin houses face south and receive direct sunlight throughout the day. While the southern orientations of buildings can potentially introduce challenges related to heat gain, this can still be effectively managed through proper design strategies. The south-facing slope provides the benefit of protecting the housing from winter winds, and ensures that refreshing night breezes can reach all homes on the sloped terrain during summer, as opposed to flat terrain, where buildings can block each other and hinder the sensation of a breeze [31].

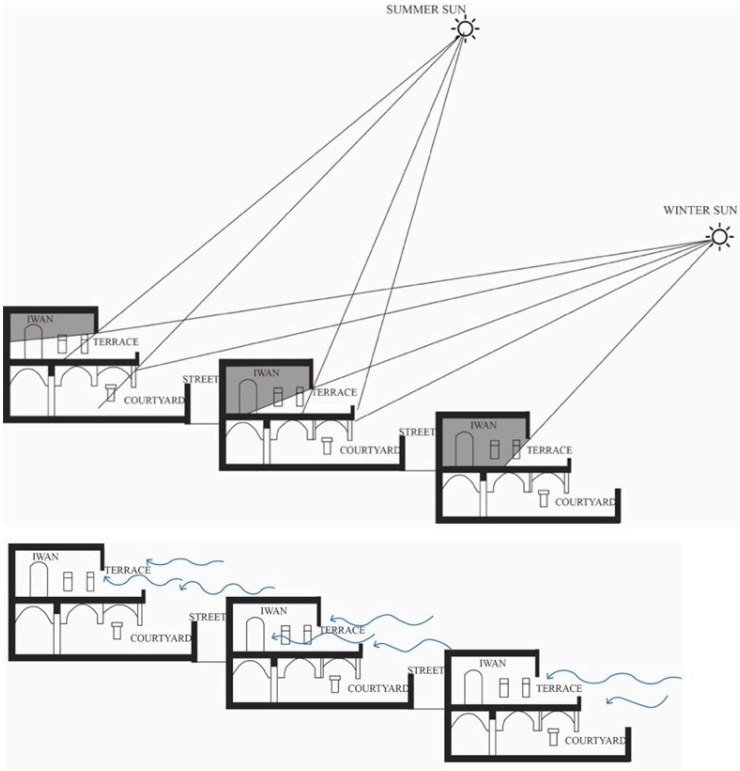


Figure 5. Relationship between daylight and shade under different sun positions (**above**), and wind flow scheme (**below**) in Mardin's traditional houses [31].

Turkey's Southeast Anatolia Region, encompassing Mardin and its neighboring provinces, is among the areas most severely impacted by drought resulting from climate change [32]. The area is renowned for its semi-arid climate, characterized by minimal annual rainfall, substantial variations in temperature throughout the day, low humidity, and cold winters. However, because of climate change, the region's rainfall and snowfall have decreased even further. This drop in precipitation has resulted in a severe drought in the area. In addition, annual temperature increase will be higher in Mardin compared to other cities in Turkey, and seasonal projections clearly indicate that the temperature increase in summer will be higher than in winter [32]. In other words, the region is currently experiencing the impacts of aridity and high temperatures, especially during the summer season, and this will intensify due to climate change, as shown in Figure 6. Furthermore, increasing temperatures and decreasing rainfall will result in excessive evaporation and water scarcity, and ultimately lead to desert-like conditions [33].

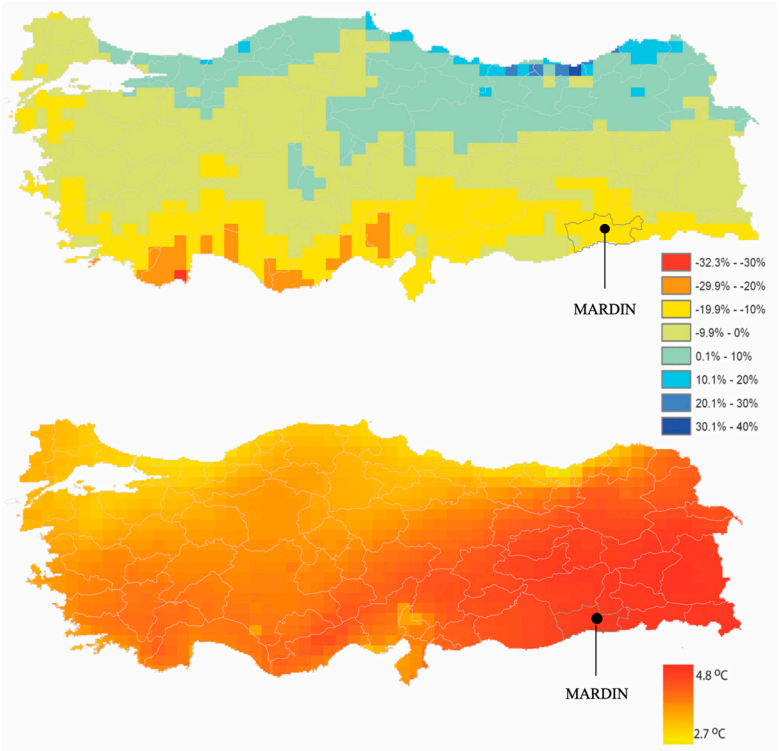


Figure 6. Precipitation (**top**) and temperature (**bottom**) change maps for Turkey with the ECHAM5 global climate model A2 scenario simulation. These changes reflect the differences in the 2070–2099 period from the 1961–1990 period [32].

This in-depth study and understanding of the case study of Mardin provides grounds to further investigate the architectural and environmental effectiveness of courtyards, and explore design strategies to maximize their role in microclimate regulation. By enhancing thermal comfort and minimizing energy consumption, this study underscores the importance of courtyard design in promoting sustainable living. It posits that optimizing courtyard layouts is crucial not only for enhancing environmental sustainability, but also for safeguarding and adapting rich architectural and urban legacies against the backdrop of climate change.

2.3. Data Collection

The knowledge derived from the literature review on courtyard design and on the specific context of Mardin was further complemented with field visits to empirically observe the multitude of parameters that significantly influence microclimate regulation within

courtyards. For the purpose of this study, the aspects reported in Table 2 were considered and recorded during the site visit.

Table 2. An evaluation of microclimate parameters in the courtyards of Mardin houses based on data collected from 14 visited courtyards.

Morphological Factors	Courtyard form Building height Orientation Aspect ratio and Solar Shadow Index	• Square, rectangular, 'L', and 'U' • 1-2-3-4 floors • South orientation • It varies depending on the house
Architectural Factors	Materials Building openings Shading devices	• Limestone • Small openings • Presence of canopy in some cases
Environmental Factors	Neighborhood buildings Vegetation Water elements	• High proximity • Moderately • Moderately

The morphological aspects assessed include courtyard form, which predominantly manifests as a square, rectangular, 'L', or 'U' shape, alongside a range of building heights from one to four floors. The aspect ratio (see Equation (1)) in architecture describes the proportion between a structure or architectural space's contained volume and its outer surface area. This ratio affects the amount of heat gain or loss, ventilation needs, and insulation requirements, making it an important consideration when designing energy-efficient buildings. The Solar Shadow Index (see Equation (2)) is another critical factor impacting a building's exposure to sunlight and shade, which in turn influence thermal performance and energy efficiency [11].

$$\text{Aspect ratio} = \frac{\text{Area of courtyard floor}}{(\text{Average height of surrounding walls})^2} \quad (1)$$

$$\text{Solar Shadow Index} = \frac{\text{South wall height}}{\text{North} - \text{south floor width}} \quad (2)$$

The use of limestone is noted for its thermal properties, coupled with the strategic placement of small window openings and the occasional presence of canopies as shading devices. These all contribute to the passive cooling strategies employed in Mardin's courtyards. Environmental factors further influence the microclimate, with moderate vegetation presence, a rare incorporation of water elements, and a high proximity to surrounding buildings characterizing the local courtyard settings. This detailed examination underscores the intrinsic relationship between courtyard design and microclimate adaptation in Mardin, illustrating how traditional architectural practices are aligned with environmental sustainability and comfort.

As reported in Figure 7, during the site visit conducted on May 2023, 14 traditional houses were examined. These houses exhibited diverse characteristics, allowing for a preliminary comparison and the selection of 4 cases to proceed with further analysis. The choice of 4 courtyards out of 14 based on their attributes was undertaken to maximize the comparability between them. We selected only U-shaped spaces with variations in floor height, different vegetation types, and incorporated water elements. This selection enables a comprehensive examination of different design elements and their respective impacts on microclimate regulation within courtyards in Mardin, as reported in Table 3.



Figure 7. Locations of 14 examined courtyards (represented with lighter red) in Mardin old town, with the focus on 4 courtyards (represented with darker red) selected during the site visit conducted on 30 May 2023 by authors.

Table 3. Observations on the physical and environmental characteristics of the selected courtyards.

House		Building Form	Orientation	Aspect Ratio	Solar Shadow Index	Floor N.	Water	Vegetation
	Case 1 Şahtana Mansion	U form	South–north	7.31	0.31	2	No	-Chinese elm (*Ulmus parvifolia*) -Tea rose (*Rosa hybrida*) -Taiwanese photinia (*Photinia serratifolia*) -Oriental Arborvitae tree (*Platycladus orientalis*) -Japanese pieris (*Pieris japonica*)
	Case 2 Tatlıdede Mansion	U form	South–north	2.78	0.67	3	No	-China rose (*Rosa Chinensis*)
	Case 3 Ensari Mansion	U form	South–north	1.68	0.58	3	Fountain	-Oriental Arborvitae tree (*Platycladus orientalis*) -Johnny jump up plant (*Viola tricolor*) -Peppermint (*Mentha piperita*)
	Case 4 Mansion at Tekeli District	U form	South–north	3.95	0.34	2	No	-Mulberry tree (*Morus*) -Common hawthorn (*Crataegus monogyna*)

The investigation on the thermal efficacy of the courtyards primarily integrated climatic data, utilizing meteorological measurements obtained from stations in Mardin. This

approach provided comprehensive insights into critical climatic variables, i.e., temperature, humidity, wind speed, and solar radiation, which are fundamental for delineating microclimate conditions and their seasonal shifts. Specifically, analytical emphasis on the dates of 21 June and 14 August was chosen due to their distinct meteorological characteristics, as 21 June corresponds to the summer solstice, characterized by the year's longest daylight duration and the zenith of solar exposure, while August 14th is historically recognized for recording Mardin's peak temperature, symbolizing extreme thermal conditions. The aim of this methodological approach was to enable a nuanced exploration of courtyard design's thermal comfort under diverse and challenging climatic conditions, offering insights into the architectural adaptations necessary for mitigating the impacts of thermal extremes.

2.4. Microclimate Simulations

Considering courtyards' efficacy in microclimate regulation, the adoption of further strategies could boost their thermal performance, especially in the face of climate change. Our objective was to investigate the influence of various design strategies on the thermal performance of the courtyards. The four selected courtyards were subjected to different design interventions and strategies to assess their effectiveness using the ENVI-met software. By simulating these interventions, the thermal performance of the courtyards was thoroughly examined [34,35]. Our aim was to identify design strategies that can optimize microclimate regulation within courtyards and hence improve thermal comfort for occupants.

ENVI-met, which is widely used in the study of urban microclimates, is designed to analyze microclimates by simulating interactions between buildings, soil, vegetation, and air through the fundamental laws of fluids and thermodynamics [36]. This software utilizes climatic data and some building information to simulate microclimates, providing valuable data on temperature, humidity, airflow, and other relevant parameters. It enables the analysis of various spatial scales, ranging from small areas like courtyards to entire cities, to establish sustainable and resilient living conditions. In the study, simulations were carried out using the ENVI-met 5.5 software. ENVI-met stands out due to its comprehensive consideration of factors like longwave radiation fluxes, local wind profiles, reciprocity between buildings, and environmental effects, making it a preferred choice in environmental modeling among software such as CitySim Pro, RayMan, and Grasshopper plug-ins Ladybug Tools [37,38]. The main reasons for choosing this program were its user-friendly interface, low input demands, and minimal time requirements.

The simulations incorporated various parameters, i.e., PMV (predicted mean vote), relative humidity, potential air temperature, mean radiant temperature, and wind speed. By evaluating these factors, we aimed to assess the occupants' perceived comfort levels and identify potential areas for improvement in the microclimate regulation of the courtyards in Mardin. As reported in Table 4, PMV and PET (physiologically equivalent temperature) serve as critical indices in the realm of microclimate analysis, offering insights into human thermal comfort by accounting for a range of factors such as air temperature, humidity, air velocity, and personal characteristics, including clothing insulation and metabolic rate.

These indices, utilized within the ENVI-met simulation framework for evaluating thermal comfort in Mardin's courtyards, facilitate a comprehensive assessment of environmental conditions and their impact on human comfort. While the PMV index predicts the normalized thermal comfort of a large group of people exposed to similar environmental conditions, the PET index takes into account the detailed thermo-physiological aspects and energy balance of the human body in relation to climatic conditions [39]. Through the application of these simulations, this study endeavors not only to quantify the perceived comfort levels of courtyard occupants in Mardin, but also to pinpoint strategies for optimizing microclimate control, thereby enhancing the overall comfort and livability of these traditional architectural spaces.

Table 4. Thermal sensations according to PMV and PET values [39].

PMV	PET (°C)	Thermal Perception	Grade of Physiological Stress
<−3.5	<4	Very cold	Extreme cold stress
−3.5–−2.5	4–8	Cold	Strong cold stress
−2.5–−1.5	8–13	Cool	Moderate cold stress
−1.5–−0.5	13–18	Slightly cool	Slight cold stress
−0.5–0.5	18–23	Comfortable	No thermal stress
0.5–1.5	23–29	Slightly warm	Slight heat stress
1.5–2.5	29–35	Warm	Moderate heat stress
2.5–3.5	35–41	Hot	Strong heat stress
>3.5	>41	Very hot	Extreme heat stress

During the utilization of the ENVI-met software, several assumptions were made to overcome limitations and ensure a feasible simulation process. These assumptions influenced the methodology and outcomes of the study:

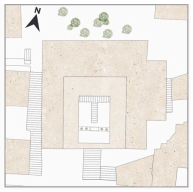
- The simulation area was limited to a smaller section of the actual environment by defining a frame of 50 × 50 × 40 units around each courtyard, with grid dimensions of 1.5 × 1.5 × 3 m. This modeling approach constrained the integration of surrounding built environments in the simulation.
- The simulations focused solely on the relationship between building density and voids within the urban fabric.
- Semi-open spaces, arches, and building apertures were excluded from the modeling process due to constraints in the simulation framework.
- The absence of some existing plants in the program led to the selection of plants with similar characteristics and sizes instead.
- An individual's perception of comfort in a courtyard environment can be considerably influenced by variables including age, gender, dress preferences, and personal thermal sensitivity. A 35-year-old male with average clothing was chosen as the representative occupant for the PMV calculations. While this selection provides a basis for assessing thermal comfort, it may not fully encompass the diverse range of occupants and their preferences.

3. Passive Design Strategies in Mardin

While there are various passive design strategies available to improve the microclimate of courtyards [14,40–42], this study specifically focuses on the integration of a range of vegetation and water elements, such as pools and fountains. With a concerted focus on maintaining congruence with the established traditional elements endemic to the urban milieu and the cultural heritage protected by UNESCO recognition [43], this research endeavors to cultivate a seamless continuum, thereby enriching the architectural landscape. Potential design interventions include the selection of appropriate plant species that are well-adapted to the local climate, requiring minimal maintenance. The dimensions of a courtyard critically impact the formulation of design strategies. Larger courtyards afford sufficient space to integrate a combination of water features and vegetation, thereby harnessing the synergistic benefits of evaporative cooling and shading. In contrast, smaller courtyards necessitate a more focused and deliberate approach due to spatial limitations. In such instances, designers must prioritize either the implementation of water features, such as water-spraying pools or fountains, or the incorporation of vegetation, such as tall trees with broad leaves, to optimize thermal comfort. In conclusion, developing a comfortable and sustainable microclimate can be achieved while taking into consideration courtyard-specific qualities and restrictions by customizing design interventions. This

customized approach was applied to the four selected courtyards, introducing appropriate interventions for each of them. These interventions are summarized in Table 5 below.

Table 5. Implementing passive design strategies on the selected courtyards.

	Existing Plan	Proposal Plan	Interventions
Case 1 Şahtana Mansion			Additional water elements Additional field maple
Case 2 Tatlidede Mansion			Additional wild cherry
Case 3 Ensari Mansion			Additional wild cherry
Case 4 Mansion at Tekeli District			Additional water elements

Despite its limitations, this study utilized ENVI-met to conduct thermal simulations and evaluate the microclimate regulation within Mardin's courtyards. First, each case study was modelled through the software, taking into account the topography, as shown in Figure 8. The evaluation process prioritized the two hottest days in Mardin, specifically 14 August and 21 June. The former represents the hottest day recorded in recent years based on meteorological data, while the latter is the longest day of the year. Simulations were executed at noon when the sun was at its highest in the sky, ensuring maximum solar exposure.

The analysis of these two days revealed that, on 14 August, the courtyards experienced significantly higher levels of thermal discomfort than on 21 June. Consequently, the assessment was focused on 14 August, comparing current conditions with the proposed passive design strategies to mitigate thermal discomfort.

In addition to the meteorological data of the selected dates for simulation, ENVI-met needs other input variables that require accuracy for precise simulation results. The location and coordinates of a selected site can be chosen on the software directly; in this study, Mardin (37.31° N, 40.74° E) was selected. A grid size of 1.5 m was used in the modeling process to ensure a high level of precision for each grid. While the soil type and pavement material were chosen from the material library available in the software, special attention was given to customizing the building material selection (i.e., limestone), considering its crucial role as an effective passive design strategy within each site. Lastly, simulations started at 5 a.m. and extended until 5 p.m. (12 h in total) to evaluate the effect of sunlight.

This time frame allowed to analyze the changing microclimatic conditions throughout daytime hours. All the input variables used for the simulations are reported in Table 6.

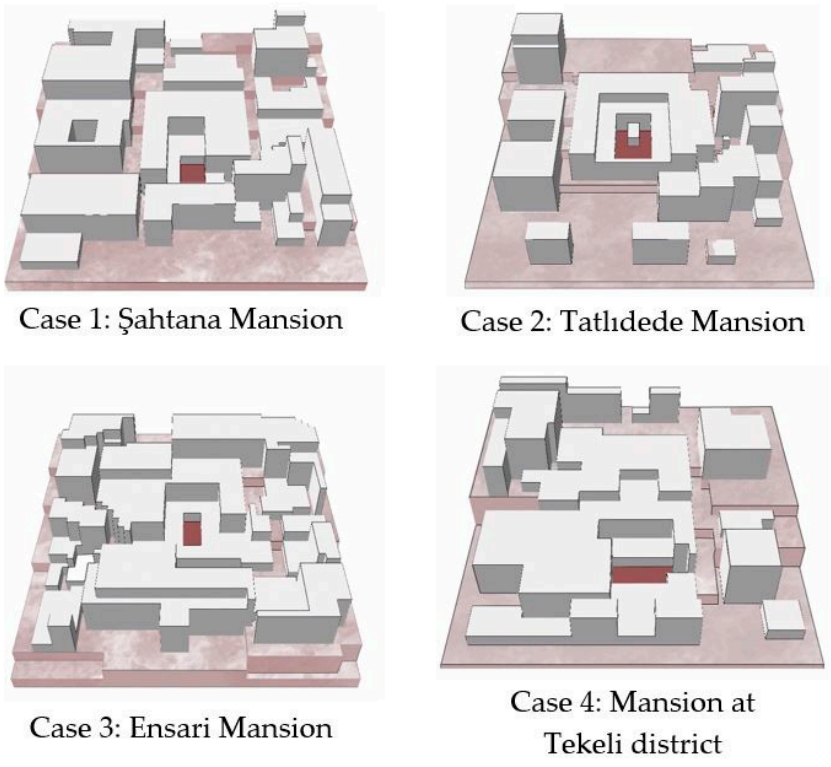


Figure 8. Modelling of selected courtyards using ENVI-met.

Table 6. Input variables on ENVI-met for selected case studies.

Variable	Input
Location	Mardin (37.31° N, 40.74° E)
Model geometry (number of cells of grid)	50 × 50 × 40
Cell dimensions	1.5 × 1.5 × 3 m
Wall/roof material	Limestone
Soil type	Loamy soil
Pavement material	Concrete pavement light
Simulation days	21 June 2022, 14 August 2022
Simulation starting time	05:00:00
Total simulation time	12 h

4. Results

The investigation of four different courtyards via ENVI-met simulations produced results on existing and proposed conditions based on the microclimate. In the initial phases, case 1, characterized by a larger aspect ratio, exhibited inferior thermal conditions, potentially attributed to its increased exposure to sunlight compared to the other cases. Case 4 demonstrated the highest level of thermal comfort compared to the others. This could potentially be attributed to a combination of factors, such as the use of vegetation and water elements, as well as a smaller aspect ratio. As shown in Table 7, after implementing minor passive design strategies, improvements were observed in thermal comfort and microclimate regulation for all case studies, although they remained relatively minor. The implementation of design strategies in the case studies resulted in lowered potential air temperature, mean radiant temperature, and PMV, coupled with heightened relative humidity and wind speed values. In other words, the courtyard's lush vegetation and

water features facilitated shade, improved evaporative cooling, and reduced temperature overall. The numerical results are reported in Table 8. The complete summary of the simulated results before and after the proposed interventions is reported as Appendix A.

Table 7. Predicted mean vote (PMV) of selected courtyards based on simulations on 14 August 2022 at 12 p.m. (with extreme temperature that year). The initial PMV is depicted in the first row, the PMV after the interventions is in the middle, and the comparison between the initial and proposed conditions is in the last row.

	Case 1 Şahtana Mansion	Case 2 Tatlıdede Mansion	Case 3 Ensari Mansion	Case 4 Mansion—Teker District
14 August 2022 12 p.m. PMV Existing above 5.50 5.00 to 5.50 4.50 to 5.00 4.00 to 4.50 3.50 to 4.00 3.00 to 3.50 2.50 to 3.00 2.00 to 2.50 below 2.00				
14 August 2022 12 p.m. PMV Proposal above 5.50 5.00 to 5.50 4.50 to 5.00 4.00 to 4.50 3.50 to 4.00 3.00 to 3.50 2.50 to 3.00 2.00 to 2.50 below 2.00				
14 August 2022 12 p.m. PMV Comparison above -0.31 -0.51 to -0.31 -0.71 to -0.51 -0.90 to -0.71 -1.10 to -0.90 -1.30 to -1.10 -1.50 to -1.30 -1.70 to -1.50 below -1.70				

Table 8. Maximum difference results of the selected courtyard simulations considering potential air temperature (ΔT_{PA}), mean radiant temperature (ΔT_{MR}), relative humidity (ΔRH), and wind speed (ΔWs), with a focus on predicted mean vote (ΔPMV).

Courtyard	ΔT_{PA} (°C)	ΔT_{MR} (°C)	ΔRH (%)	ΔWs (m/s)	ΔPMV
Case 1 Şahtana Mansion	−0.09	−15.31	%0.12	%0.01	**−0.77**
Case 2 Tatlıdede Mansion	−0.10	−20.08	%0.17	%0.01	**−1.02**
Case 3 Ensari Mansion	−0.07	−16.34	%0.14	%0.01	**−0.88**
Case 4 Mansion at Teker district	−0.15	−24.50	%0.33	%0.01	**−1.66**

The main considerations on the results reported in Tables 7 and 8 can be summarized as follows:

- In the 12 h simulation conducted, the analysis was primarily focused on the results at 12:00 p.m., as this is when sunlight reaches its peak intensity with the steepest angle of incidence.
- The research mainly focuses on PMV because the initial investigation into the existing conditions revealed varying thermal comfort levels, with high PMV values indicating discomfort in the courtyards. Although the table includes parameters such as humidity, wind speed, temperature, and PMV, PMV is highlighted in bold because it is a comprehensive parameter that addresses the thermal comfort of users. Essentially, PMV is a combination of these other parameters, and thus serves as a key indicator of overall thermal comfort. The initial investigation into the existing conditions revealed varying thermal comfort levels, with high PMV values indicating discomfort in the courtyards.
- Along with the incorporation of passive design strategies, significant improvements in the thermal comfort and microclimate regulation of the courtyards were obtained, as evidenced by the selected case studies, and visible in Tables 7 and 8.
- Passive design strategies can significantly reduce PMV values and provide better thermal conditions for all case studies, as shown in Table 8. However, the simulation results indicate that excessive heat stress may still be observed, and it may be necessary to incorporate additional strategies.
- The proposed interventions produce an improvement in the outdoor microclimate conditions. However, the simulated outdoor conditions do not adequately achieve desired comfort levels. The adoption of a minimally invasive approach to intervention due to the historical context and the heritage preservation constraints may explain the limited visibility of benefits. This highlights a significant challenge in adapting historical areas: the current scope of allowable interventions is insufficient.

5. Conclusions

This study addresses the microclimate regulation potential of courtyards in hot–dry regions, specifically focusing on the city of Mardin, Turkey. While the existing literature underscores the effectiveness of courtyards as passive design elements, there remains a paucity of research on optimizing their performance under evolving climatic conditions and utilizing advanced simulation tools like ENVI-met.

Despite certain interventions providing improvements, the necessity of minimal interventions to preserve the historical context limited the extent of these improvements. As a result, the ideal PMV values indicated in Table 4 could not be achieved according to the simulation results, indicating that these improvements did not meet anticipated levels. This underscores a fundamental tension between the imperatives of conservation and the urgency of adaptation within the broader context of recognizing the intrinsic value of cultural heritage in enhancing urban resilience and community preparedness. Urban environments must navigate the dual pressures of conserving historical integrity and adapting to climate change, necessitating a delicate balance between these occasionally conflicting goals. The preservation of cultural heritage not only enhances urban resilience and community preparedness, but also serves as a crucial asset for future adaptation strategies.

This study demonstrates that courtyards enhance thermal comfort and mitigate the adverse effects (e.g., excessive solar radiation, high temperatures, wind exposure) of harsh climates. Thermal simulations using ENVI-met revealed that the incorporation of vegetation and water elements improved thermal conditions within the selected courtyards. However, while ENVI-met is effective for measuring outdoor microclimates, its limitations in small-scale areas may have affected the accuracy of the results. The outcomes were likely influenced by modeling only a limited portion of the context, using similar rather than precise plant species, and omitting critical details such as building openings and semi-open spaces. This conclusion is fully consistent with the results provided by other scholars [36].

Given the software's limitations in delivering precise results, it is crucial to incorporate additional verification methods, such as field measurements, to validate the effectiveness

of implemented strategies and enhance the reliability of research findings. These findings provide critical insights for architects and designers aiming to create sustainable and comfortable living environments in hot–dry regions. By adopting the design principles and strategies outlined in this study, the performance and adaptability of courtyards can be significantly improved, thus contributing to the resilience of buildings in response to climate change. Future research should explore additional passive design strategies, such as integrating shade structures like pergolas, to further enhance thermal performance. Additionally, comparative studies evaluating the accuracy and reliability of various simulation tools, including EnergyPlus and IESVE, are recommended to advance the field of courtyard microclimate analysis. Addressing these research directions will enhance our understanding of courtyard design and simulation, ultimately leading to the development of more effective and sustainable architectural solutions.

Furthermore, while this study primarily addresses the thermal comfort within courtyards, it opens the door for future research to investigate the impact on indoor thermal comfort. Understanding how courtyards influence the internal environments of adjacent buildings can offer a more holistic approach to passive cooling strategies, ultimately contributing to the overall energy efficiency and comfort of the entire building complex.

Author Contributions: Conceptualization, J.N.T., H.B.U. and M.S.L.; methodology, J.N.T., H.B.U. and M.S.L.; software, H.B.U.; validation, J.N.T., M.S.L. and O.O.; formal analysis, H.B.U.; investigation, H.B.U.; resources, H.B.U.; data curation, H.B.U.; writing—original draft preparation, H.B.U.; writing—review and editing, J.N.T., M.S.L. and O.O.; visualization, H.B.U.; supervision, J.N.T.; project administration, J.N.T.; funding acquisition, J.N.T. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

The simulations focused on evaluating essential variables such as air temperature, relative humidity, wind speed, PMV, and MRT. For each case study, twenty maps were generated to visually represent different variables. These maps included the existing conditions on 21 June, the existing conditions on 14 August, as well as proposal and comparison maps for August 14th. In the final step, comparison maps were generated for analysis and to evaluate the difference between the existing and proposed conditions.

Table A1. Process of simulating Şahtana Mansion through ENVI-met.

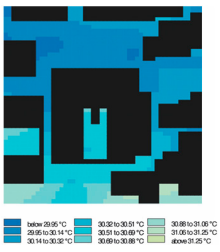
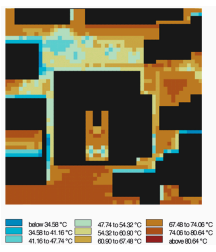
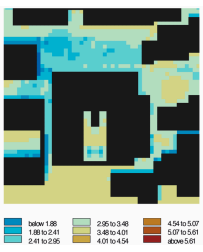
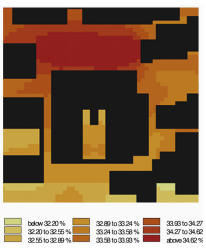
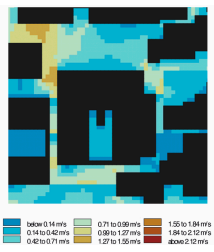
Case 1 Şahtana Mansion	Potential Air Temperature	Mean Radiant Temperature	Pmv	Relative Humidity	Wind Speed
21 June 2022 at 12 p.m. Existing					

Table A1. *Cont.*

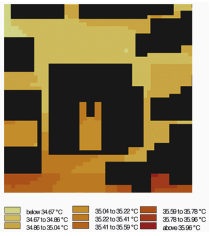
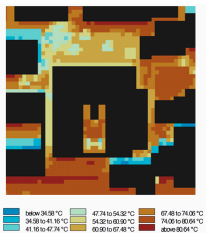
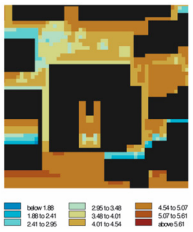
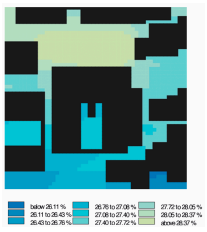
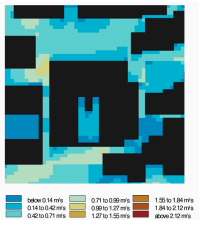
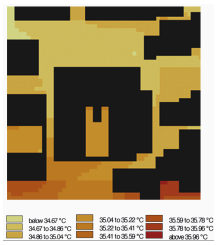
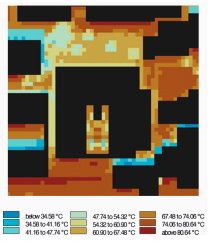
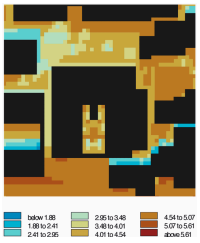
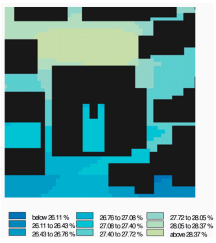
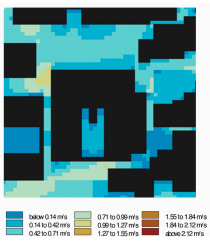
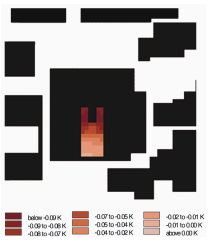
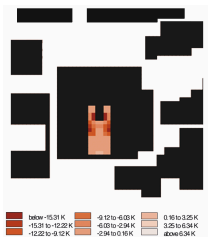
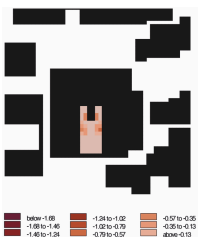
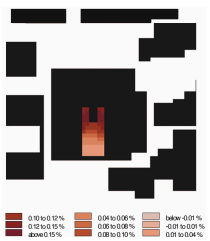
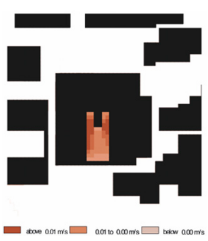
Case 1 Şahtana Mansion	Potential Air Temperature	Mean Radiant Temperature	Pmv	Relative Humidity	Wind Speed
14 August 2022 at 12 p.m. Existing					
14 August 2022 at 12 p.m. Proposal					
14 August 2022 at 12 p.m. Comparision					

Table A2. Process of simulating Tatlıdede Mansion through ENVI-met.

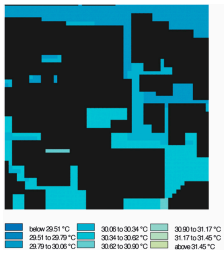
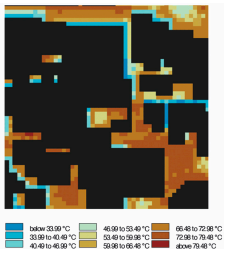
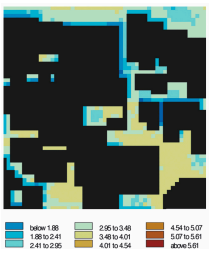
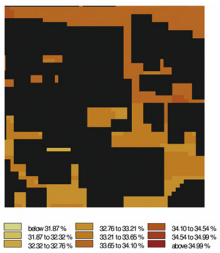
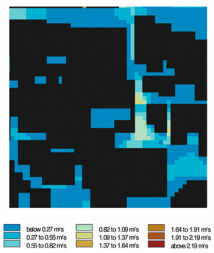
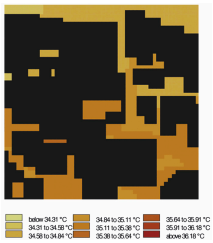
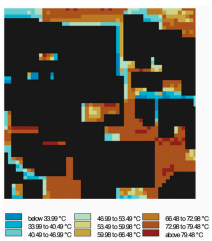
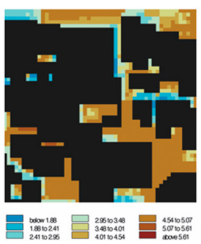
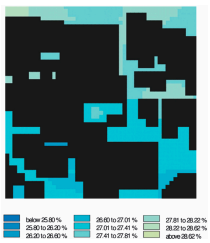
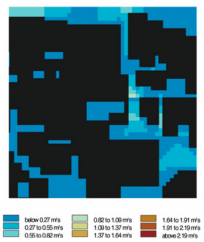
Case 2 Tatlideede Mansion	Potential Air Temperature	Mean Radiant Temperature	Pmv (Predicted Mean Vote)	Relative Humidity	Wind Speed
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14 August 2022 at 12 p.m. Existing					

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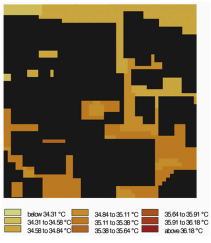
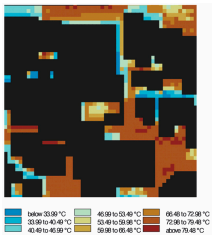
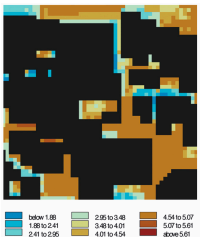
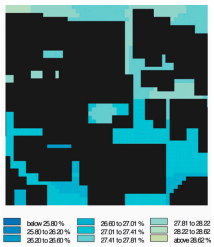
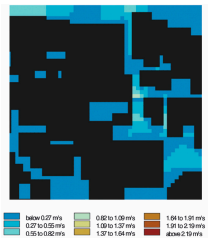
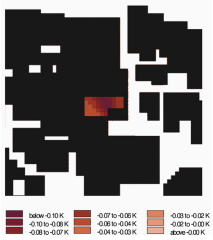
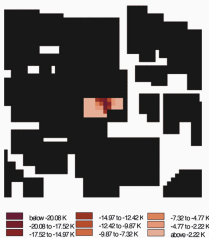
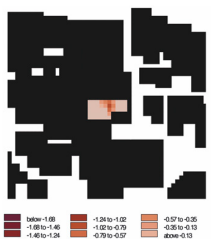
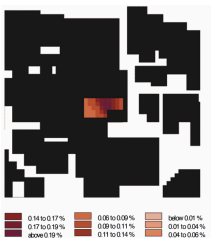
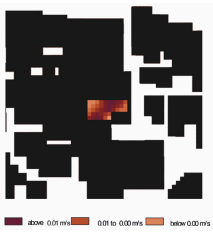
Case 2 Tatlideede Mansion	Potential Air Temperature	Mean Radiant Temperature	Pmv (Predicted Mean Vote)	Relative Humidity	Wind Speed
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14 August 2022 at 12 p.m. Comparision					

Table A3. Process of simulating Ensari Mansion through ENVI-met.

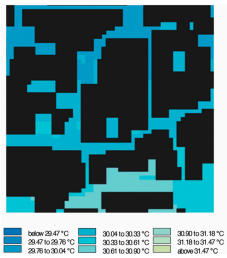
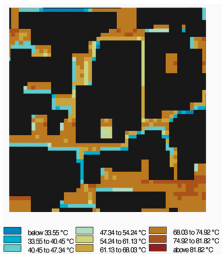
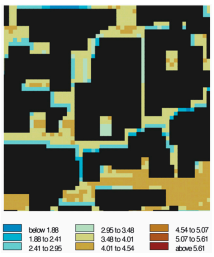
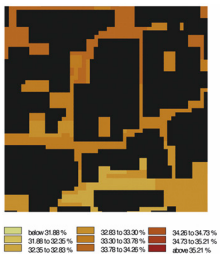
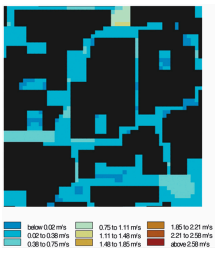
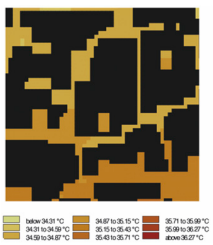
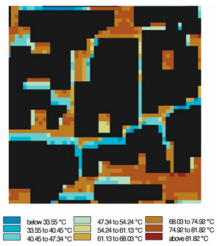
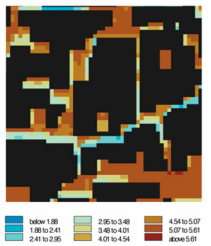
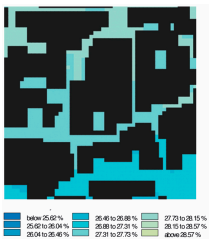
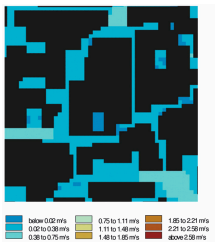
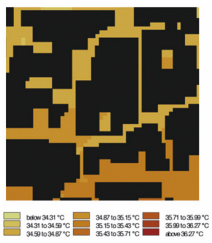
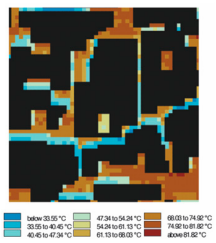
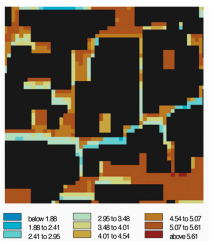
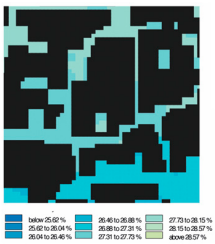
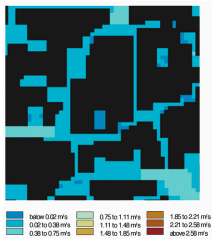
Case 3 Ensari Mansion	Potential Air Temperature	Mean Radiant Temperature	Pmv (Predicted Mean Vote)	Relative Humidity	Wind Speed
21 June 2022 at 12 p.m. Existing					
14 August 2022 at 12 p.m. Existing					
14 August 2022 at 12 p.m. Proposal					

Table A3. *Cont.*

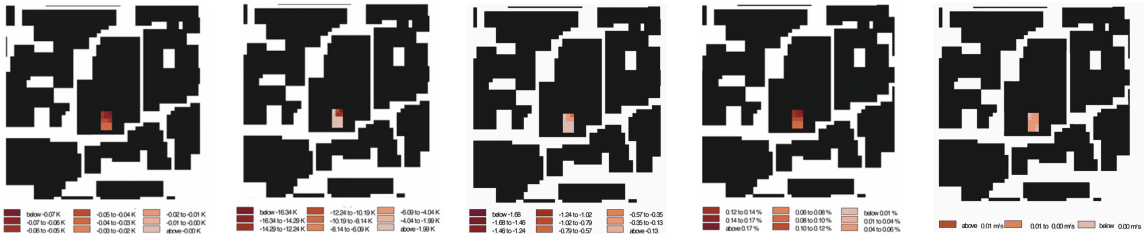
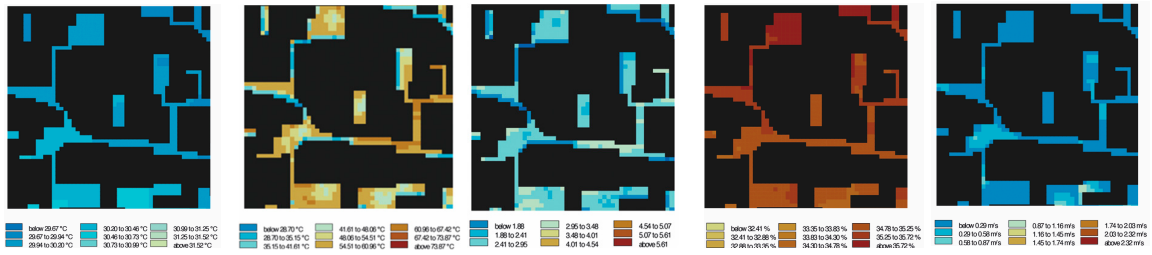
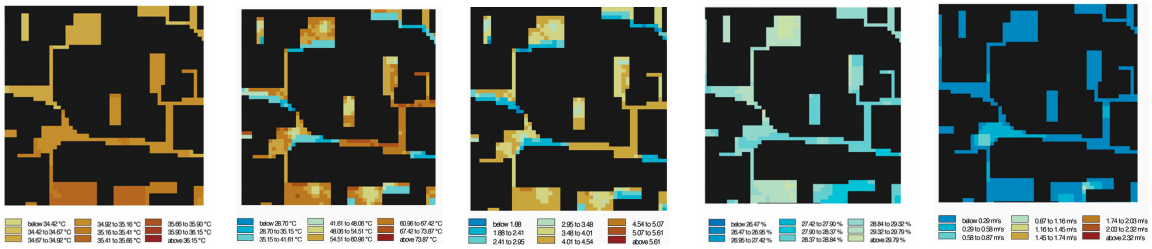
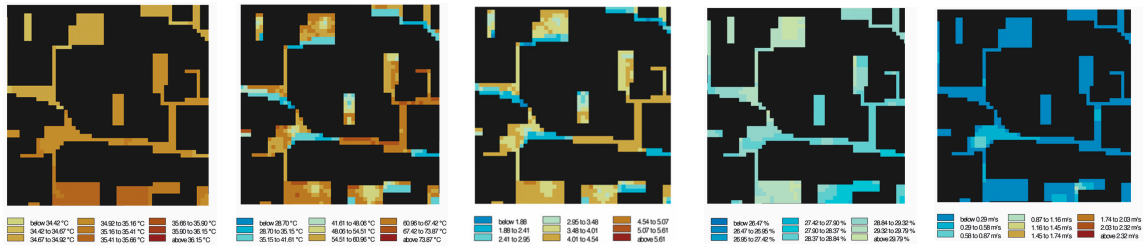
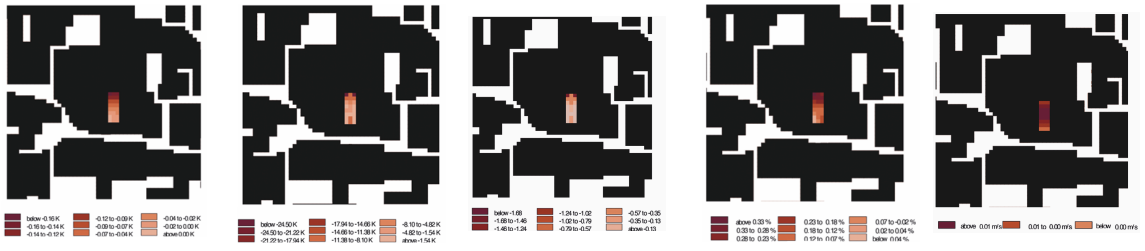
Case 3 Ensari Mansion	Potential Air Temperature	Mean Radiant Temperature	Pmv (Predicted Mean Vote)	Relative Humidity	Wind Speed
14 August 2022 at 12 p.m. Comparision					

Table A4. Process of simulating Mansion at Tekeli district through ENVI-met.

Case 4 Mansion at Tekeli District	Potential Air Temperature	Mean Radiant Temperature	Pmv (Predicted Mean Vote)	Relative Humidity	Wind Speed
21 June 2022 at 12 p.m. Existing					
14 August 2022 at 12 p.m. Existing					
14 August 2022 at 12 p.m. Proposal					
14 August 2022 at 12 p.m. Comparision					

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