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ARTICLE / ARAŞTIRMA

Bioclimatic and Vernacular Approaches in Hot and Aride Climate at Urban Scale: A Comparison on M'Zab and Yazd Valleys

Kentsel Ölçekte Sıcak ve Kurak İklimlerde Biyoklimatik ve Verneküler Yaklaşımlar: M'Zab ve Yazd Vadileri Üzerine Bir Karşılaştırma

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ABSTRACT

In recent decades, bioclimatic architecture has become a highly discussed topic among researchers and architects who mainly aim to harmoniously integrate architecture with the environment and even the climate to ensure human comfort and well-being. Although this topic generates a keen interest in discussions, it is important to confirm the use of this approach by examining the achievements of our predecessors, particularly in vernacular architecture. In this article, we aim to explore the link between vernacular architecture and the bioclimatic approach, highlighting two masterpieces on the architectural and urban level: The M'zab Valley in Algeria and the Yazd Valley in Iran. These two cities, listed as UNESCO World Heritage Sites, demonstrate a remarkable adaptation of local societies to hot and arid climatic challenges. By conducting a comparative study, we notice striking similarities such as a compact urban fabric, minimization of vegetation, introverted architecture, narrow streets, compact fabric…etc. From this study, we explore how these ancient cities were able to integrate sustainable solutions on the architectural and urban level to be able to integrate with the immediate environment. We also find nuances that emerge, especially in the way each city finds solutions according to the particularity of its site. These two vernacular examples showcase the bioclimatic factors used in ancient cities. Based on the main factors of the two approaches, bioclimatic and vernacular, this study aims to highlight the understanding of the environmental aspects of ancient cities and their know-how, with the aim of preserving them and using them in future constructions. This comparison allowed us to confirm that both approaches emphasize the deliberate use of local

ÖZ

Son yıllarda, biyoklimatik mimarlık, başta insan konforu ve refahını sağlamak amacıyla mimari çevreyi iklimle uyumlu bir şekilde bütünleştirmeyi amaçlayan araştırmacılar arasında oldukça tartışılan bir konu haline gelmiştir. Bu makalede, vernaküler mimari ile biyoklimatik yaklaşım arasındaki bağlantının kurulması amaçlanmıştır. Bu bağlantı Cezayir'deki M'zab Vadisi ve İran'daki Yazd Vadisi olmak üzere iki örnek üzerinden tartışılarak ortaya konmuştur. Bu şehirler, yerel toplumların sıcak ve kurak iklim zorluklarına karşı gösterdiği olağanüstü uyumu göstermektedir. Bu iki yer arasında karşılaştırma yapıldığında, kentsel doku, bitki örtüsünün minimuma indirilmesi, içe dönük mimari, dar sokaklar, yoğun doku gibi dikkat çekici benzerlikler gözlemlenmiştir. Bu çalışmada, geleneksel kentlerin, çevreleriyle uyum sağlayabilmek için ürettikleri sürdürülebilir çözümleri mimari ve kentsel düzeye nasıl entegre ettikleri incelenmiştir. Biyoklimatik ve vernaküler yaklaşımların ana faktörlerine dayanan bu çalışma, geleneksel kentlerin çevresel yönlerinin ve yerel bilgi birikimlerinin anlaşılmasını vurgulamayı amaçlamakta olup, bunların gelecekte korunması ve bu bilgilerin kullanılmasını hedeflemiştir. Bu karşılaştırma, her iki yaklaşımın da yerel kaynakların bilinçli bir şekilde kullanılmasına, hâkim iklime uyum sağlanmasına ve insan konforunu sağlamak amacıyla doğa ile mükemmel bir şekilde uyumlu bir yapılı çevre yaratılmasına vurgu yapıldığını doğrulamaya olanak sağlamıştır. Böylece, vernaküler mimarinin, yaşayanların ihtiyaçlarını karşılayabilen, konfor ve refah sağlayan ve çevreye uyum sağlayan bir biyoklimatik mimari olduğu göstermiştir. Ayrıca vernaküler mimarinin biyoklimatik yaklaşımları

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resources, the need to adapt to the prevailing climate and the creation of a built environment that integrates perfectly with nature to ensure human comfort. Thus, we can affirm that vernacular architecture is a bioclimatic architecture which has been able to meet the needs of the inhabitants, provide comfort and well-being, and has been able to integrate into its environment while respecting it.

Keywords: Bioclimatic; hot-arid climate; M'Zab Valley (Algeria); Yazd Valley (Iran); vernacular.

kentte yapılacak yeni düzenlemelerde önemli bir tasarım yöntemi ortaya koymaktadır. Bu açıdan M'Zab Vadisi (Cezayir), Yazd Vadisi (Iran) üzerine yapılan çalışma Cezayir ve Iran kentleri için veri sağlamanın yanında kurak iklim bölgeleri için mimari ve kentsel düzeye sürdürülebilir çözümleri nasıl ürettikleri bağlamında bir öğreti veya yöntem sağlaması açısından önemlidir.

Anahtar sözcükler: Biyoklimatik; sıcak-kurak iklim; M'Zab Vadisi (Cezayir); Yazd Vadisi (Iran); Vernaküler.

1. Introduction

In contemporary discourse, we notice a great interest by urban planning, architecture, and urban studies professionals to integrate the principles of vernacular architecture into modern frameworks and sustainable design practices. This is mainly due to the increasing population growth and urbanization, which has brought negative challenges such as environmental resource depletion, climate change, and sustainability issues in urban areas.

The bioclimatic approach seems to be a very relevant solution to address these issues. This method explains the reasons in detail and the way to construct buildings and arrange spaces taking into account the particularities of the natural climate. It aims to increase energy efficiency as well as to form optimal indoor environments by acting on the judicious use of natural light, ventilation, and local climatic conditions. In this way, it not only conserves energy but also enhances the standards of living and creates a wholesome urban ecology. Hence, the necessity for a bioclimatic understanding has even more been accentuated in current day debates, as it takes center stage in climate change mitigation efforts and promotes sustainable urban ecosystems.

The evolution of sedentary human communities has given rise to vernacular architecture, an approach that is part of traditional values that emphasize the environmental, social, and economic aspects of society (Ghisleni, 2020). This form of design represents a local or regional building philosophy, using traditional materials and resources specific to the local environment. With a diverse range of forms, materials, and techniques adapted to climate, morphology, and societal needs, vernacular architecture draws on historical experience, offering a wealth of knowledge for innovative solutions that integrate bioclimatic considerations while preserving cultural identity (Genovese & Zoure, 2023).

Bioclimatic (or sustainable) architecture represents an alternative approach that takes account of local climatic conditions and uses various passive solar technologies to improve energy efficiency and user comfort. Often inspired by vernacular architecture, it analyses traditional construction methods in the context of climate and culture, in search of architectural and constructive solutions. The introduction of bioclimatic architecture may involve the concept of bioclimatic urban planning, which includes the design of streets with deliberate solar orientations and the strategic placement of green spaces to create environments that promote comfort in public spaces. This comfort is achieved by integrating not only architectural elements but also vegetation (Manzano-Agugliaro, et al, 2015).

The cultural heritage of the M'Zab Valley in Algeria and the Yazd Valley in Iran gives an insight into these two societies, which have faced very similar climatic environments and helps them understand their ancestors' ingenuity. Both of them, also inscribed as UNESCO World Heritage Areas, dramatically illustrate how local buildings have been designed to suit the hot dry desert climates. A more extensive view discloses awe inspiring Uniformities, which include urban concentration, low dependence on green cover and architectural extraversion in inverse proportion. Much attention has been devoted both to the M'zab valley and the Yazd valley, yet most investigations concern architectural issues leaving aside the urban scale.

In this study, we aim to investigate the bioclimatic aspects of these two cases of vernacular architecture in the context of the urban scale. In particular, it is aimed to make a comparison by identifying the urban strategies produced in the context of bioclimatic and vernacular tendencies embodied in the traditional architecture of Iran and Algeria. In this context, the study provides data for contemporary cities in terms of sustainability by revealing the bioclimatic and vernacular knowledge that exists at the urban scale in traditional cities.

2. Methodology

In this study, the first step was conducting literature analysis, particularly focusing on academic reviews about vernacular and bioclimatic approaches especially in hot and arid climates. In the second step, the application of these two approaches in studies about traditional cities of Algeria and Iran was investigated, examining the urban and architectural characteristics. In the third step, the case study analyzed the mentioning location, topography and climatic conditions of the selected sites. After that, the interaction between bioclimatic and vernacular approaches in the case study was explored, analyzing key aspects such as urban fabric and bioclimatic design, street and orientation strategies, water management system, vegetation integration, and architectural features. Lastly, a comparison section between this two case studies in both urban and architectural scales was provided (Fig. 1).

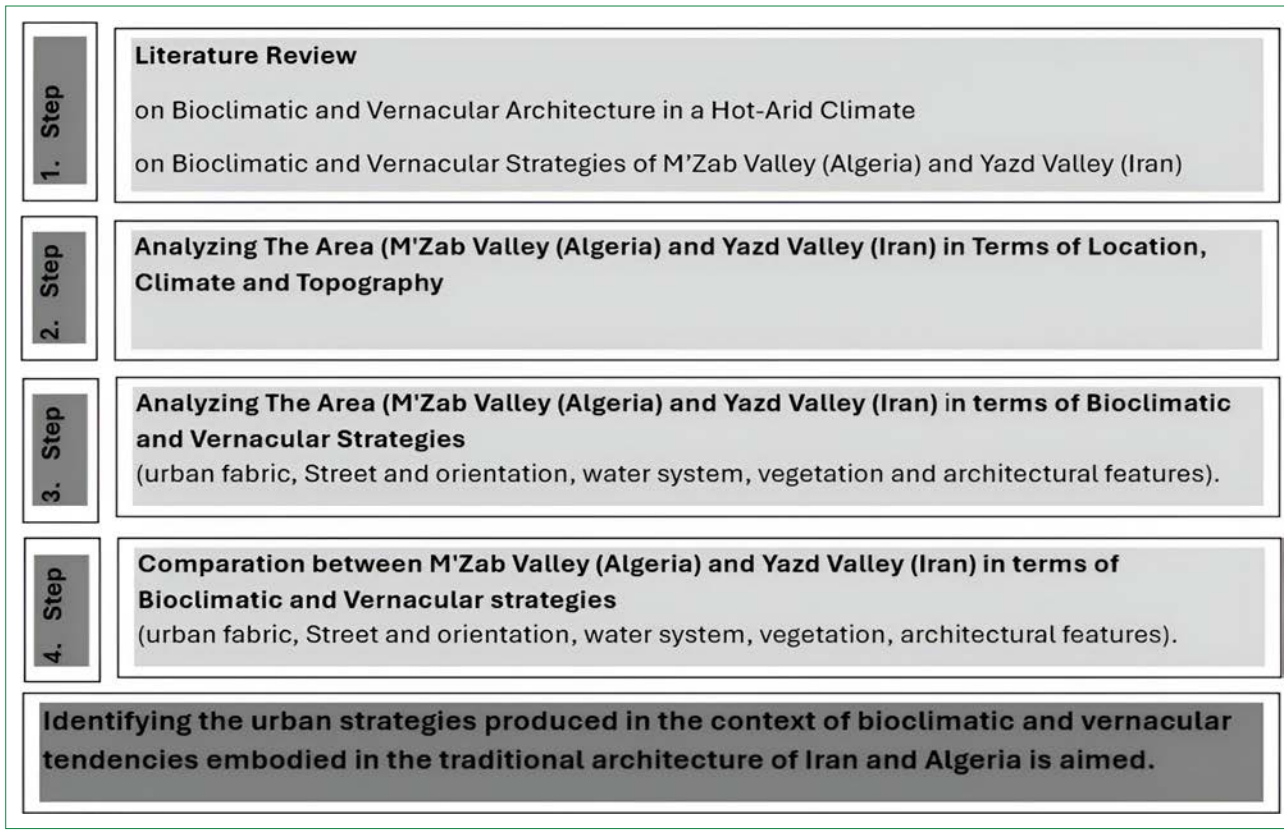

Figure 1. Model of study.

3. Material

The relation between vernacular and bioclimatic approach: George Gilbert Scott was the first to make popular the vernacular style of architecture in 1857 (Fellahi, 2017). This theory embodies the history of specific regions, cultures, societies, religions and tends to nature. Its primary aim is to design the structures, which do not contradict but complement the nature and do not disturb the local way of life, while making use of available resources to the full extent possible. There is an inclination towards the use of local materials and the modification of construction methods to suit the climatic conditions of the location. The vernacular architecture is most pronounced in the case of all traditional structures found in numerous geographic locations, revealing a clear-cut style that is characteristic of that area. These establishments comprise of materials manipulated and polished from the immediate environment, without ignoring the past, present and possible future interactions of the climate, culture, technologies, and geographic enclosures. Now, such an approach is being critically examined by architects and urban designers in regard to modern models, which emphasizes the necessity of the principles of sustainable design (Coch, 1998; Manzano-Agugliaro, Sabio-Ortega, García-Cruz, & G.Montoya, 2015; Karabag & Fellahi, 2017; Salkinia, Grecoa, & Lucentea, 2017; Beqqal, Saaid, & Chaoui, 2021; Genovese & Zoure, 2023).

On the other hand, it was in 1963 that contemporary architectural design was redefined with the advent of the bioclimatism concept developed by Aladar and Victor Olgyay (Beqqal et al, 2021). These reshaped notions of architectural design, as it focused largely on practical issues such as energy efficient and sustainable designs. This is a conceptualization approach that takes into account several factors such as climatic conditions, building placement, urban design, airflow and use of natural heat light due to the sun. Bioclimatic Architecture turns out to be architecture with nature, rather than simply providing a building as shelter to its dwellers. Such methods include sensitive design to architectural elements based on local climate and renewable resources, all which emphasize encouraging sustainable construction and combating global warming effects. Whether it is a single-storey house in the temperate regions utilizing passive solar heating or a multi-storey commercial building located in the high rainfall tropics using natural air flow for cooling, principles of bioclimatic design are unbounded and practical (Manzano-Agugliaro, Sabio-Ortega, García-Cruz, & G.Montoya, 2015; Salkinia, Grecoa, & Lucentea, 2017; Tamba, Kamsu-Foguem, Diourte, Alhouseini, & Habbadi, 2017; Beqqal, Saaid, & Chaoui, 2021; El Fadar & Elaouzy, 2022; Genovese & Zoure, 2023).

The connection between the vernacular and bioclimatic strategies is based on their commonality and success in en-

hancing each other. There are some architectural features that observe historical, geographical, social, religious and ecological elements more than just constructions. The major objective of this type of architecture is to produce a built environment that co-exists with nature, whereby there is respect to customs and optimal uses of resources. There is a focus on the employment of place specific materials and the modification of the technology according to local bioclimatic climate. On another aspect, bioclimatic architecture also aims at promoting the natural environment by achieving sustainable structures but this time focuses more on energy saving features and devices. A number of factors include the internal climate of the building, the direction at which the building is facing, the planning of the site, the provision of air movement and passive solar systems in developing the structure provided that it helps in the comfort of the users. Going by the two systems of architecture advances, vernacular connotes an architecture that possesses bioclimatic features. They stress the appropriate use of region's materials, embrace the external weather, and strive to construct buildings in the most natural manner possible. Vernacular architecture offers explorations and incursion that are necessary for the sustenance of modernism urban structure.

As part of understanding how bioclimatic and vernacular approaches are related to each other, a literature search which contained many relevant scientific studies was performed. The paper 'Review of Bioclimatic Architecture Strategies for Achieving Thermal Comfort' by Manzano-Agugliaro et al. (2015) concludes that some bioclimatic construction schemes tend to be transferred from country to country provided they are first adopted in a particular country with similar climatic characteristics. Coch (1998) studied the vernacular architecture work entitled Bioclimatism in Vernacular Architecture and claimed that since time immemorial people have lived in different places and climates which imposed various strains on them. The study points to the need to incorporate such anthropocentric design strategies into the architecture of today's world as they are lessons learned in the making of balanced and sustainable spaces.

Salkinia et al. (2017), in their article 'Towards Adaptive Residential Buildings: Traditional and Contemporary Scenarios in Bioclimatic Design' (the case of Aleppo), argue that the conventional dense urban tissue is very often an efficient design in many aspects and can indeed promote the thermal quality of buildings while minimizing urbanism concerns.

It is also found in the thesis of Beqqal, et al. (2021) 'At the Dawn of the Sustainable Moroccan Modernism: Bioclimatic Approach in Early GAMMA Group's Architecture' that architect turned to the concept of native buildings. These concepts, however, were employed not only in the service of making contextual architecture but also in investigating their abilities in terms of bioclimatic realizability. The aim was to produce a new way of conceptualizing contemporary architecture that would be both satisfying and respectful towards the environment.

The contributions from these various studies enhance our comprehension of the scope for integration between bioclimatic and vernacular strategies in designing energy conscious architecture.

These locations were chosen as case studies for the paper because of the distinctive urban and architectural features they possess that are found in the city of M'zab Valley in Algeria and in Yazd – Iran. These ideal places show the unique coexistence of traditionalism with environmental conservation. The M'zab and Yazd case studies discuss the historically conscious architecture around the adaptable solutions developed by societies to sustain themselves in particular ecologies over time.

These choices are driven by cultural heritage and the principles of their propagation. Yazd and the M'zab confer good examples of how communities have been able to grow alongside their environment and will provide lessons towards addressing the issues faced by sustainable urban development today. This analysis has the intention to demonstrate how certain traditional practices can be adapted in a modern context so as to come up with green technologies in design.

In Western and Eastern Algeria, as well as Iranians themselves, vernacular architecture was manifested through the installation of different components and techniques in both the building and planning levels. Looking at the available literature regarding these areas, it is noted that most of the performed research concentrates on architectural rather than on urban strategies. We will thus center on urban strategies for the comparison. At times there is a need to delimit these two activities where urban strategies would refer to things beyond just the occupation of a given space or activity within a building. This is because strategies are inclusive of plans and other resolutions that are arrived at prior to the onset of actual building.

These strategies draw upon a variety of distinctive urban components with the primary aim of attaining perfect amalgamation with the surrounding environment (Table 1).

3.1. Case Study

The M'Zab valley and the city of Yazd are approximately 600 km south of the Mediterranean Sea. They are both located in hot, arid regions. They share similar climatic conditions, such as low rainfall, high temperatures, and low humidity. The M'zab is a natural region of the northern Sahara Desert in Ghardaïa Province, Algeria. It is located 600 km south of Algiers. The M'Zab valley stretches across the Hamada plateau, with altitudes ranging from 300 to 800 metres, and extends

Table 1. Some studies about vernacular architecture in Algeria and Iran through the bioclimatic approach

Region	Author	Findings
ALGERIA	Mestoul, 2009	• In the study conducted specifically for the city of Timimoun, on-site measurements of climatic parameters were carried out to evaluate summer comfort in the city.
	Karabag & Fellahi, 2017	• This article highlights the sustainable features of traditional housing design in Algeria and draws attention to changes in the country's-built environment. It evaluates the degree of sustainable practices by examining Algeria's different climatic zones and traditional architectural methods.
	Rais & Tendero Caballero 2019	• This study examines the bioclimatic aspect in vernacular structure by examining M'zab traditional architecture. It is being investigated how the energy performance of this architecture is achieved and whether the same principles can be used in the construction of a contemporary energy efficient building.
	Amieur et al, 2022	• This study examines the microclimate in the city of Ghardaïa in the hot and arid regions. Hot summers in the city cause serious discomfort, especially for risk groups. Vegetation plays an important role in mitigating Heat Islands impacts.
	Arigue et, al., 2023	• This study examines the thermal performance of a ventilated mask wall used in low-income housing designed to adapt to the hot desert climate in Ghardaia, Algeria. Ventilated mask wall is a facade system that can work effectively in hot climates.
IRAN	Kashani, 2013	• Examined the city of Yazd in terms of environmental sustainability. It addressed factors such as climate, renewable energy, water consumption, open spaces, waste reduction and sustainable building materials.
	Jamei et, al., 2016	• Reviews studies on urban greening and design at the pedestrian level to increase thermal comfort in cities. These strategies can be applied in the early stages of urban planning and can directly affect the microclimate
	Sahebzadeh et, al., 2017	• It deals with the evolution of local architectural development in the Yazd and Sistan regions of Iran. This text highlights how this architecture maintains sustainability while adapting to the environmental and cultural context. The study explores the factors that shape the architecture of these regions and the reasons for the existence of these factors, examining various elements and techniques such as texture and orientation, materials and wind catchers.
	Güleç et al., 2020	• Research focused on the orientation of city streets relative to sun and wind. Yazd was examined in terms of sustainability criteria, and it was stated that it is a remarkable city with its streets that provide natural air conditioning systems in hot weather conditions.

for 25 km (Fellahi, 2017). The City of Yazd is located in the middle of the Iranian plateau, 270 km southeast of Isfahan, close to the Spice and Silk Roads (ICOMOS,2016) with altitudes ranging from 750 to 1500 metres (Maassoumi, Mahmoodi, & Bagheri, 2020) (Fig. 2).

M'zab reasoning for constructing ksours within the boundaries of the province of Ghardaïa is directly related with the specific geomorphological features of the region. Every ksar commands a vantage position on a rocky summit rising above the valley affording both protection and environmental considerations (Adad & Mazzouz, 2013). A high-altitude positioning eases the defensive surveillance of the surrounding area from possible danger. This disposition depicts the producers' fears about the safety of the people. On the contrary, such a construction of a settlement at an elevated area encourages conservation of water and good agricultural lands free from the 'yellow soil and water' – which could hinder farming activities (Bensalah, et al, 2017) (Fig. 3).

The emergence and development of the historic core of Yazd within the city walls mostly relied on the features of the natural environment, such as climate, land suitability for construction, and the direction of underground water (Rahbarianyazd, 2021). All settlements in the historic part of the city had direct or, at least, appropriate access to waterways, known as

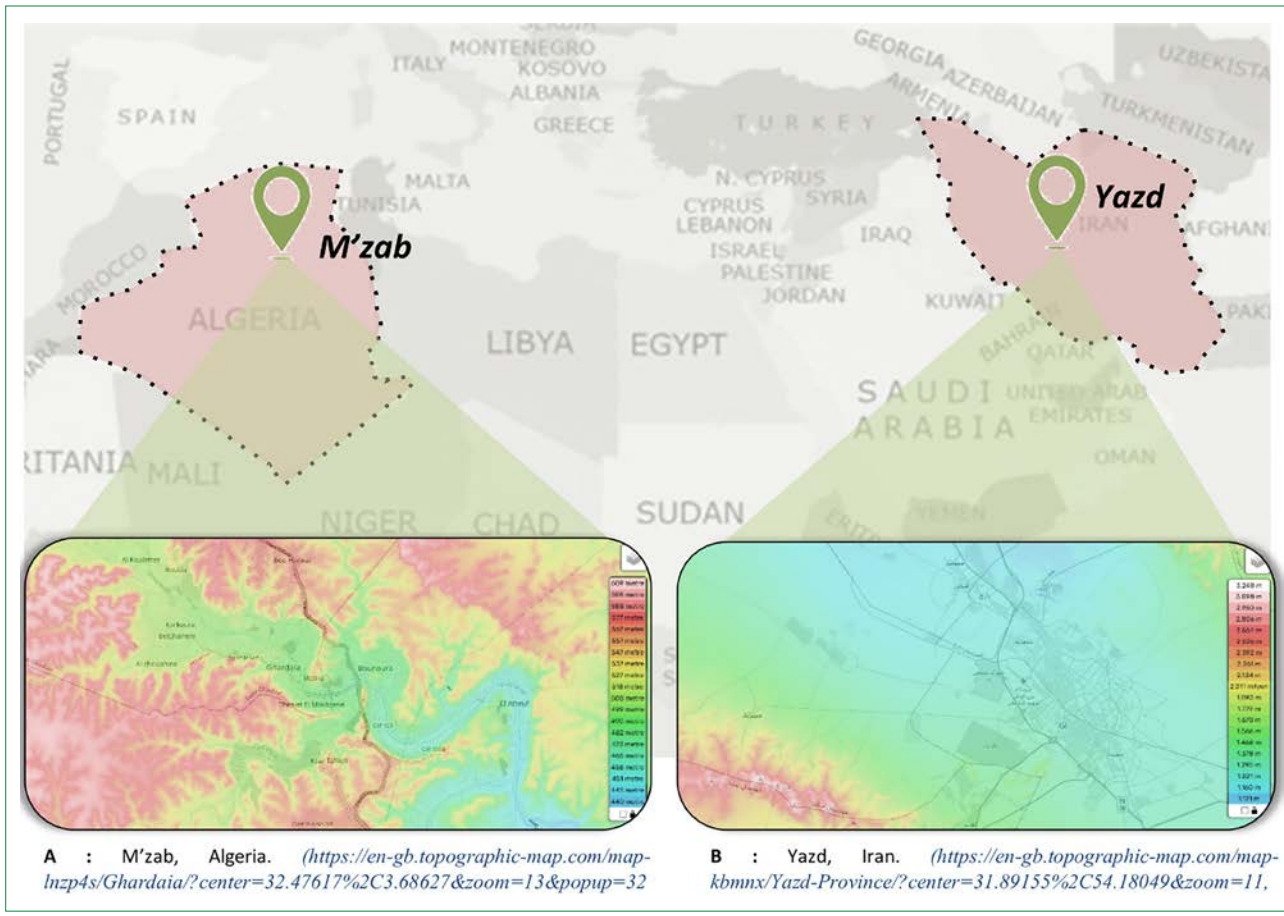

Figure 2. Geographical location and topography of Yazd and M'zab (source, modified by author).

Qanats. Due to the topographic state of the city and the flow of surface water originating in the southern heights toward the North (Petruccioli, 1989) (Fig. 4).

The M'zab area is characterized by cold winters with north-westerly winds, south-westerly ones during the spring season, which tend to be dusty, and Sirocco, a south wind, which is extremely hot and blows throughout the summer (URL 5). In connection with Sirocco in the Ghardaia regions, there are about 11 days/year on average between May and September (URL 3).

The city of Yazd can be considered the extreme heat-nest city which is situated north of the gulf coast of the Persian region. The temperature's range in both makes equivalent from -5°C in the month of January to 50°C in the month of July with an annual mean carried out of 21 degrees Celsius and 60mm of a downpour. Differences in meteorological parameters can show up during the summer months, with the day and night temperature differences going over 20 degrees Celsius (Soleymanpour, et al, 2015). The dominant winds of Yazd, Iran are North-West and North-East (Boloorchi & Eghtesadi, 2013).

The climatic data established for the M'zab and Ghardaia regions in Algeria indicates a change of winds and very high temperatures accompanied by scanty moist levels. In the M'zab, the prevailing winds are north-westerly in cold winters, south-westerly in spring, often laden with sand particles, and the Sirocco, a very hot southerly wind, which blows for much of the summer (URL 5). As Sirocco wind is associated with intense heat, 'Sirocco' wind also affects the climatic conditions drastically in the summer months (URL 3). Temperature varies between 21.05 degrees in January and 45.65 degrees in July, where the coldest month and the hottest month vary by a range of 40 degrees (Oulad & Labed, 2021). Rainfall is very low with September being the rainy month with 16.6 mm while July is the driest month with only 2.1 mm (Oulad & Labed, 2021).

In relative terms, both temperatures in Yazd, Iran, spacious part located north of the coast of the Persian Gulf are between -5 degrees in January and 50 degrees in July, with an annual rate of 21 degrees centigrade. Precipitation levels are slightly higher at 60 mm annually. Last but not least, the temperature can be seen on the map varied within hot seasons especially 20 degrees in between the day and night (Soleymanpour, et al, 2015). The wind direction in Yazd is primarily North-West and North-East (Boloorchi & Eghtesadi, 2013).

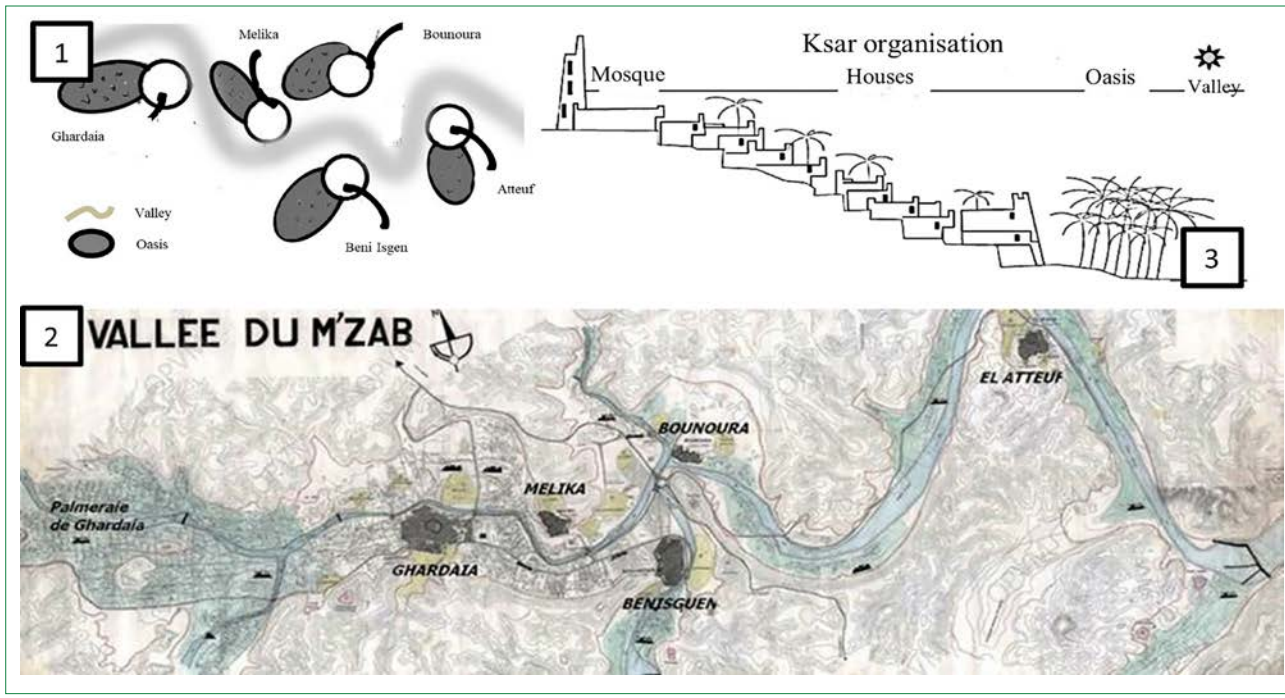

Figure 3. The logic of implementation of the ksours of Ghardaia (sources: 1: Bensalah, Yousfi, Menaa, & Bougattoucha, 2018, modified by author; 2: http://www.opvm.dz, consulted on 17-10-2024; 3: author).

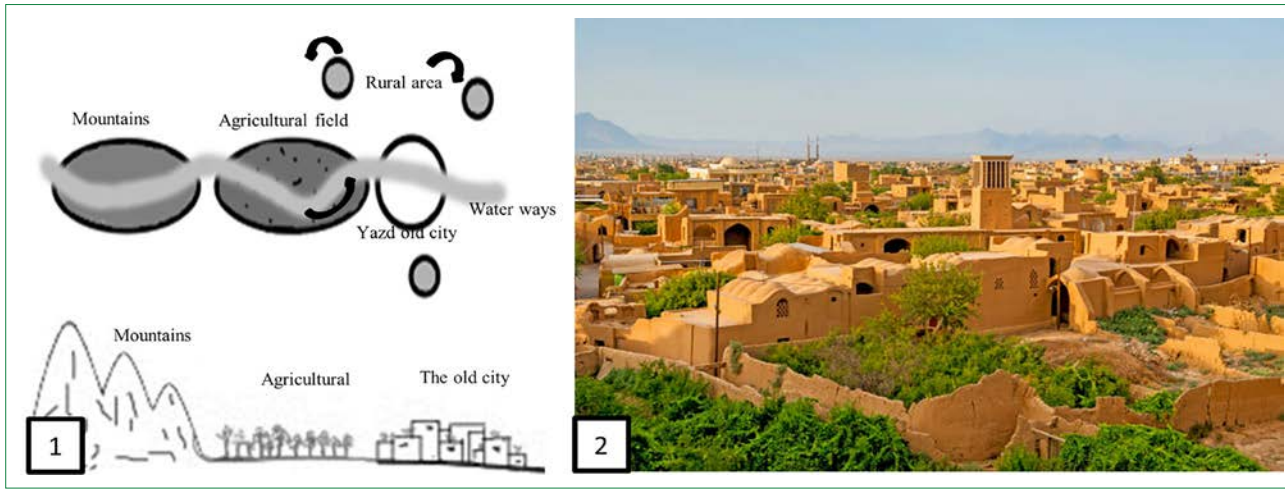

Figure 4. The logic of implementation of the Old City of Yazd (sources: 1: author; 2: https://image.hurimg.com/i/hurriyet/75/770x0/64cca1124e3fe01558b9dc01.jpg, consulted on 11-01-2024).

In general, both latitudes show great temperature extremes with most parts exhibiting marked seasonal cycles, low rainfall and winds influencing the climate. On the other hand, Ghardaia is very hot and arid where a hot wind known as the Sirocco carries sand but in Yazd follows the same pattern of high temperatures, but the rainfall is much lesser and apex yaw differs (Fig. 5).

After carrying out an exhaustive review of previous accounts on the cities of Mzad and Yazd, the acquired data underwent a thorough visual exploration, although it focused more on the urban scale instead of the architectural scale, in order to evaluate their bioclimatic approaches. This in-depth study reveals the nature of bioclimatic vernacular architecture in a hot arid region.

3.2. Analyzing of the Bioclimatic Effect of Urban Planning-urban Organization

This research will investigate bioclimatic interactions in urban regions within a macroscopic to a microscopic viewpoint. A number of visual analysis methods will be applied to read different aspects of this approach. It analyzes some topics as

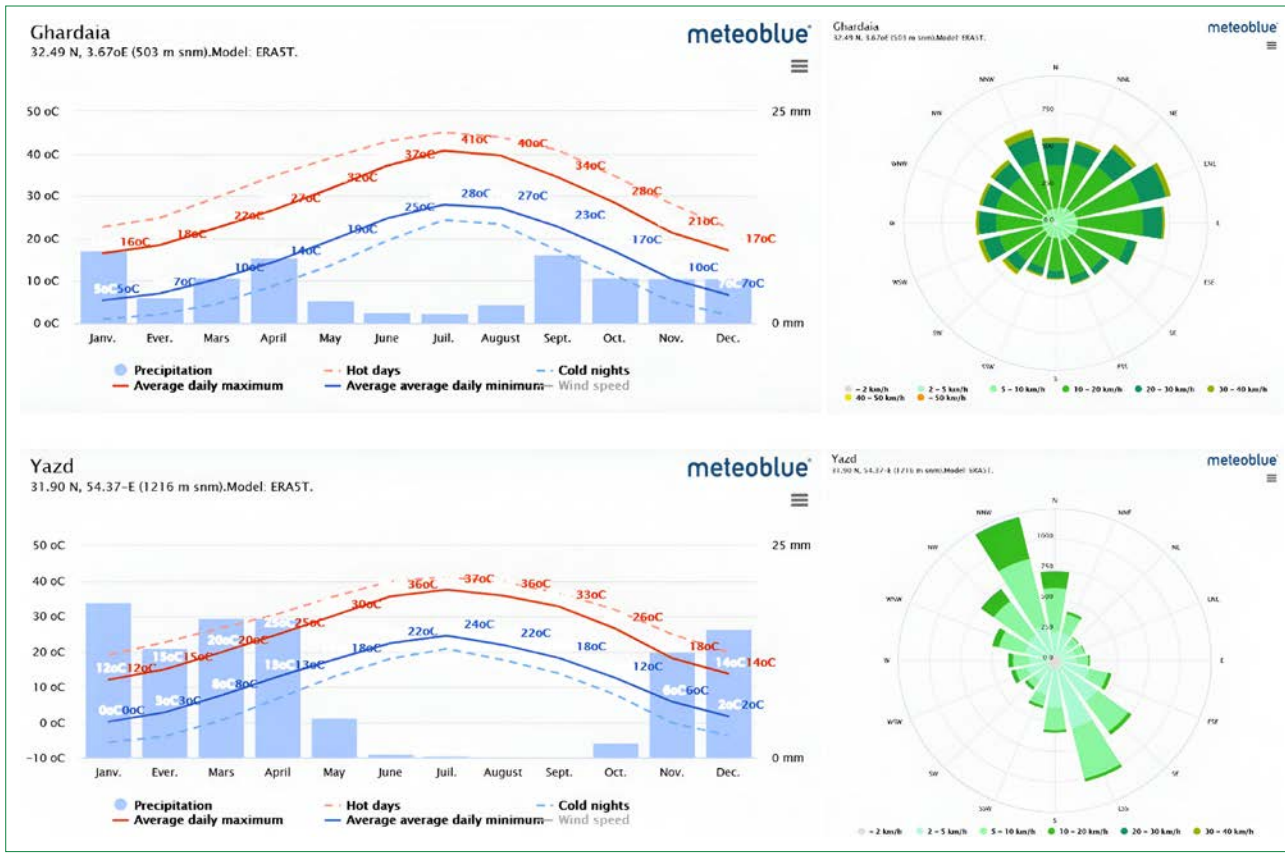

Figure 5. Monthly variation of rainfall an wind in case in Mzab and Yazd (sources: URL5).

urban fabrics-bioclimatic relation, streets and orientations, water systems, architectural features.

3.2.1. Urban Fabrics-bioclimatic Relation

M'zab town is shaped like an irregular concentric oval. The Ksour, notable for their distinctive architecture and spatial layout, are structured around the juxtaposition of the sacred and profane (including the mosque and cemetery, as well as the market and residential areas) and the dynamic interplay between the internal and external components that define both the family dwellings and the wider urban landscape (Bouchair, et al, 2013).

As 'Universelle Algérie' (2006) points out, the central presence of a mosque, the existence of a lively market (souk), and the complex labyrinth are the old nuclei adhering to a logical organization. This logic of organization of urban space aims to an introversion of the inhabited space and makes the home protected from any insolation or effect of noise and climatic pollution (Gueliane, 2017) (Fig. 6).

Yazd's urban fabric is characterized by its dense and compact nature. The old town was surrounded by walls (Petruccioli, 1989). The cohesion of the townscape is derived from a well-ordered space created through consistent dimensions among the urban elements, emphasizing a sense of volumetric unity.

The layouts of both the walled city and the old city exhibit irregularities, resembling a labyrinthine arrangement that unfolds in a radial concentric development of the urban area. The old core is located in the northern part of the old town, and because the desert moves from the north-eastern side of it, expansion has always occurred towards the southeast and southwest where more comfortable humidity is found. This land is favorable to agriculture and planting (Petruccioli, 1989) (Fig. 7).

3.2.2. Streets and Orientations

The settlements of Algeria tend to have a close-set cell shaped hierarchy in design, and the settlements are fortified with walls to protect them from strong winds and sandstorms. This arrangement reduces the area of outside walls further contributing to the cool climate (Gueliane, 2017). Free standing edifice adds more costs with energy use whereas roofed organized formations with unsheathed roofs are cost effective (Bouchair, et al, 2013). Urban ventilation is a non-prior concern in regimes characterized by hot and dry temperatures during the day hours. Design strategies address urban dust pollution while creating conflicts between the orientation of streets with respect to the sun and dust.

Urban form adapted to hot dry climates consists of many narrow winding streets and alleys which all help in shad-

Figure 6. Plan of the urban fabric showing the radio concentric development of the ksar of Ghardaïa (sources: 1: Ammar Bouchair, 2004, 2: URL7).

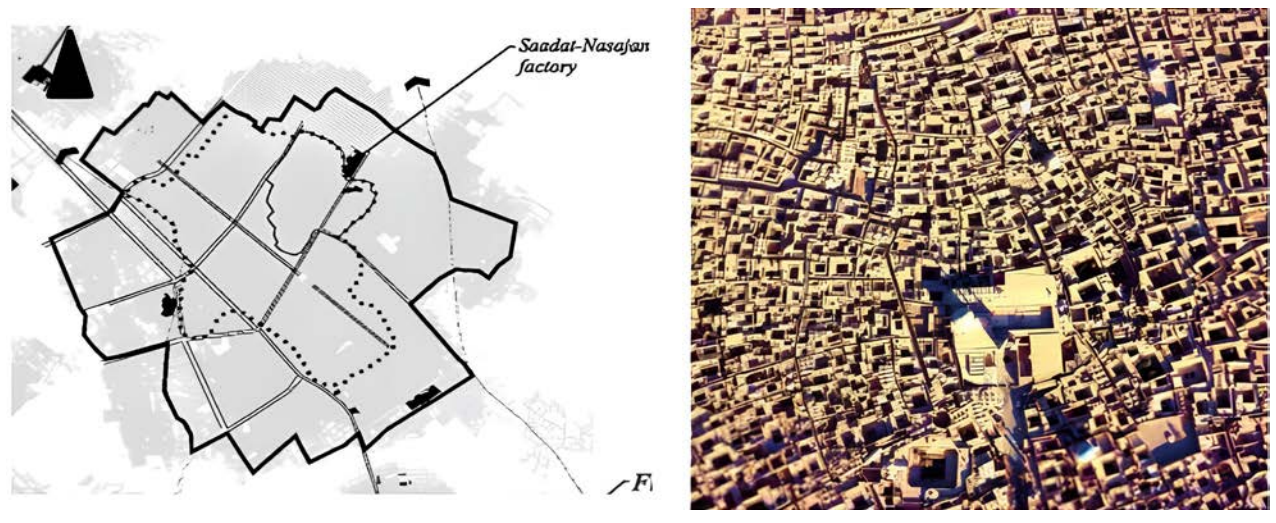

Figure 7. Plan of the urban fabric showing the radio concentric development of the old city of Yazd (sources: 1: URL8, 2: URL9).

ing. This provides warmth and comfort in cold nights. It is optimum for the thermal comfort of pedestrians as no measures to protect them from rain are put in place; this is usually provided by the building features such as canopies, colonnades, or tree cover on the sidewalk. Narrow alleys are important in the hot dry climate as they facilitate the retention of the cool air that settles down at night due to the venture prisms thus enhancing cooling. Shelter is also provided for the occupants by the design of the buildings as certain shapes provide resistance against the strong winds and force the movement of air inside the building. Walkways are patterned in elliptical and spoke like patterns having smaller widths towards the apex and broadening towards the base of the zone (Fig. 8).

The layout of Yazd's streets is configured at an angle of 45 degrees (NE-SW) to reduce the effect of warm northwest wind and periodic sand and dust storms. In this case, urban blocks align with this axis or perpendicular to it, which serves to the benefit of wind breeze for the comfort of the occupants (Güleç Özer, et al, 2020). The design features a compact and thick texture with inconspicuous and long streets, which leads to lower energy usage. These narrow urban passages also help eliminate dense desert heat and dry winds within the oasis. High walls are built along the narrow streets of Yazd with shaded pavements discouraging heat from the ground. The orientation of 45° towards the north helps the Inkas geothermically in the sense that these sunlight-variated walls act as surfaces prone to wind and thus ensure adequate shading for almost the entire day from morning to evening (Güleç Özer, et al, 2020). Also, humid air is trapped in narrow spaces between the buildings because of the narrow alleyways.

All over the urban area, there are some scattered Sabats, roofs over the passageways, which help to 'break' the sky-

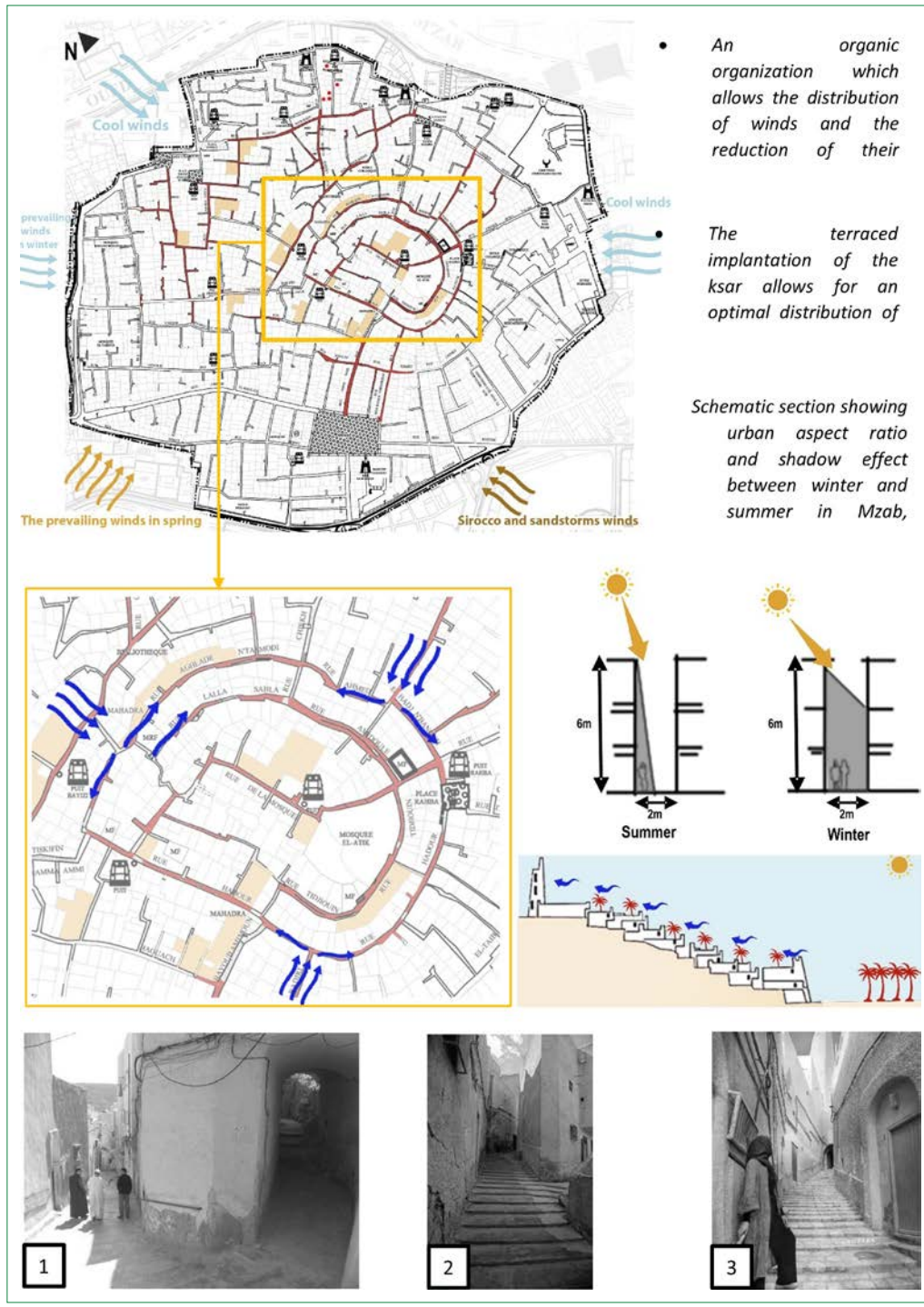

Figure 8. Summary diagrams of the urban organization of the ksour of Mzab for better outdoor comfort, Ghardaïa (sources: 1: URL10, 2: URL11, 3: URL12).

line and connectivity of the space. These passages are beneficial to the users because in summer they help to cool the users while winter provides warmth (Güleç Özer, et al, 2020). Moreover, such facilities also link the buildings, making them more stable and adding ease of movement for users (Fig. 9).

3.2.3. Water Systems

Situated in an arid environment with little water, the M'Zab valley Water's supply in the region relies on two key methods. The first method involves wells and wadi floodwaters. This water serves the dual purpose of irrigating gardens and

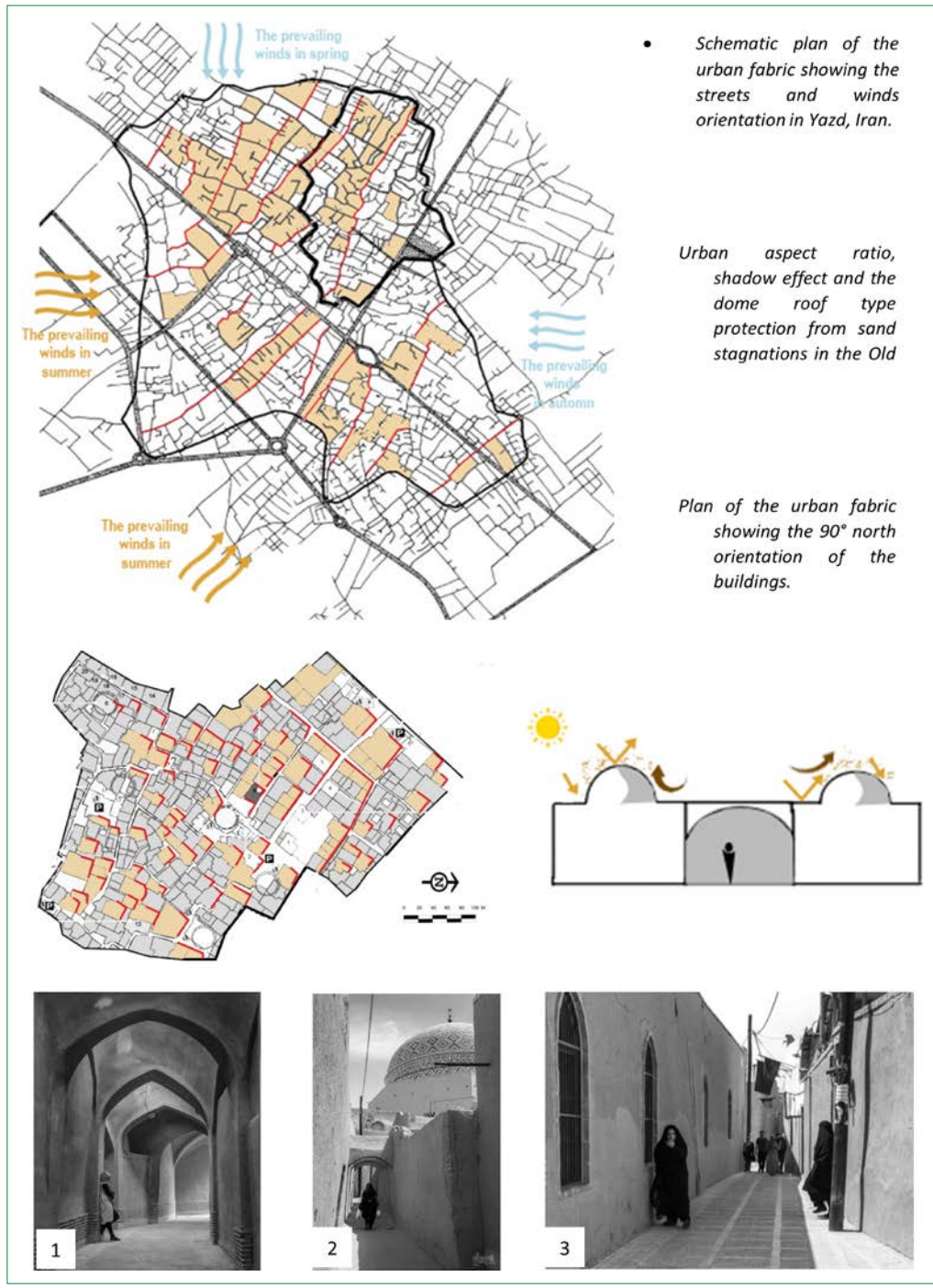

Figure 9. Summary diagrams of the urban organization of the Old city of Yazd for better outdoor comfort, Iran (sources: 1: URL13, 2: URL14, 3: URL15).

meeting the needs of the residents. The second method involves harnessing rainwater to alleviate water shortages. The Mozabites have ingeniously developed a hydraulic system to capture even minimal water flows from neighboring regions, utilizing gravity to enhance their water collection efficiency (Bensalah, et al, 2017). This sophisticated system stands out for its precise and rational management. Comprising multiple water retention dams, water extraction wells, canal paths and underground canals guide the water to the palm groves. The distribution network in these canals extends up to three or four kilometers from the retention structure. Remarkably, this ancient water management structure, dating back to the 14th century, remains fully functional to this day (URL 3) (Fig. 10).

The sophisticated hydraulic system consists of various components such as reservoirs, minor barriers, irrigation, and drainage systems, rasfates (water reservoirs) or catchment tanks, and wide water wells all made in a way that allows the administration of the right amounts of water for the irrigation of the palm trees within each garden. Since its inception, the management of this complex system has been in the hands of a group of experts who are called 'Oumanas' in reference to their expert history in management and this has been evident to the protection and functional management of the system (URL 3).

The other defining factor, which explains Yazd's sustenance over the years, is the creation of the remarkable qanat system, a vertical shaft system which is a hundred years Old Iranian technology. Qanats are horizontal, slightly graded tunnels that convey groundwater derived from underground aquifers using the force of gravity for agricultural purposes. It is prudent to note that this type of water distribution system is designed with several shafts to facilitate construction and maintenance of the system, and it conserves groundwater resources (URL 16).

Today, the majority of modern deep wells are available, yet some of the central provinces of Iran, including Yazd, are still making use of qanat structures. These underground canals, where thousands of water wells are connected, provide the most water to irrigate farmlands. Remains of old qanats, which existed in the 5th and 6th century, can be witnessed in the old districts of Yazd and its surroundings (Abouei, 2006) (Fig. 11).

3.2.4. Vegetation

In M'zab, The Palm Groves, strategically positioned near cities, are much more than just agricultural areas. They represent real summer towns, with a network of hydraulic works including dams, underground galleries, wells, artificial streams, and seguia canals (URL 3). These arrangements not only allow the irrigation of crops, but also the creation of a refreshing environment during the hot seasons (Bensalah, et al, 2017). In addition, trees absorb carbon dioxide, emit oxygen, and contribute to urban air quality through evapotranspiration and dust filtration. Furthermore, these trees act as natural barriers against sand-laden winds, thus corresponding to the deposition of sand on structure such as palm groves, houses, and alleys (Bouchair, et al, 2013).

The Yazd city was designed in a compact way that has a different climatic solution to create a comfortable environment for its inhabitants such as reducing direct sunlight exposure and maximizing the shadow coverage in the alleys and urban spaces (Deljou & Bahmanyaran, 2021). The city has found an effective solution to high temperatures within its urban fabric by using agricultural land and orchards outside its boundaries. In addition to the climatic benefits, this land has played a crucial role in meeting the population's food needs. Thanks to the productivity of this land, the city has demonstrated its resilience, meeting its needs in a self-sufficient manner over the centuries (Deljou & Bahmanyaran, 2021) (Fig. 12).

3.2.5. Architectural Features

Mzab houses are in an area where temperatures can be extreme, so they are designed holistically to meet the climatic needs of the region, using several elements such as the central patio, terraces, strategic openings, and specific practices to regulate temperature and humidity.

A covered central patio is in the Mozabite house and plays a versatile role. It provides minimal overhead lighting for the ground-floor rooms and acts as a climate regulator (Bouchair, et al, 2013; Aydeniz, 2016; Gueliane, 2017). It is also used for ventilation, being covered by a wire mesh called 'chbek' (Aydeniz, 2016; Gueliane, 2017). This is left covered during the day to block the sun's rays, and open at night to allow warm air to escape and fresh air to enter (Gueliane, 2017) (Fig. 13).

Rooftop terraces are used in summer for sleeping and are often partitioned to form separate open-air rooms (Aydeniz, 2016). They offer space to take advantage of temperature differences at night (Bousquet, 2013; Aydeniz, 2016). Ikomar space is opened southeastward to be protected from the hot sun in summer (Aydeniz, 2017) (Fig. 14).

The design of the openings used is called 'ayn eddar' or 'the eye of the house', which plays a crucial role in lighting the first floor thanks to their strategic positioning (Aydeniz, 2016). The amount of light available in the courtyard varies according to the southeast orientation of the house, favoring abundant light in the morning (Aydeniz, 2016). This also provides protection from the hot sun in summer, while providing warmth in winter. The openings are positioned at the top of the wall and face each other, the one through which air enters being smaller than the one exiting (Bouchair, et al, 2013; Gueliane, 2017). This ensures optimum air circulation and minimizes solar gain to prevent overheating inside. Air circulation is encouraged by strategically positioned openings, and the thermosiphon system is activated by opening the chebeq to allow cooler outside air to enter (Degrigny, 2014; Gueliane, 2017) (Fig. 15).

Although Mozabites have no sophisticated humidification system, they use porous water jars in front of air inlets during hot spells to absorb heat and cool the air (Gueliane, 2017). The entire architectural system is designed to create a comfortable internal atmosphere without resorting to energy-intensive heating or air conditioning systems, highlighting the ingenuity of Mzab residents in the face of extreme climatic conditions.

The materials used are extracted on site, contributing to the harmony of the built structure with its location, both in

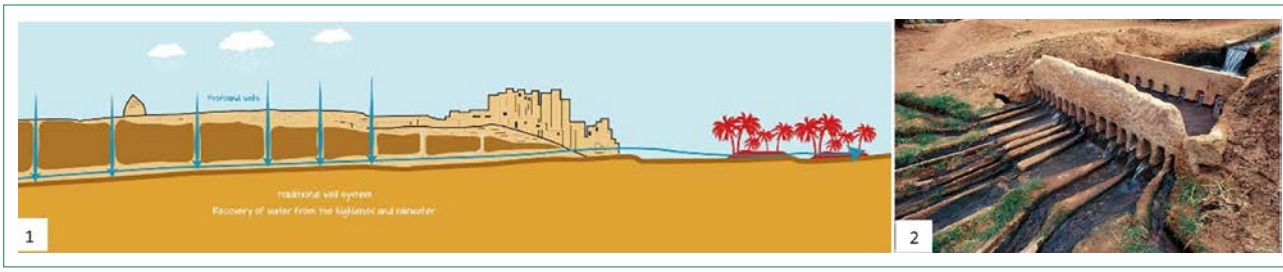

Figure 10. Water recovery system in the Algerian oases Foggara (sources: 1: Souami et al, 2023, 2: Btash, 2022).

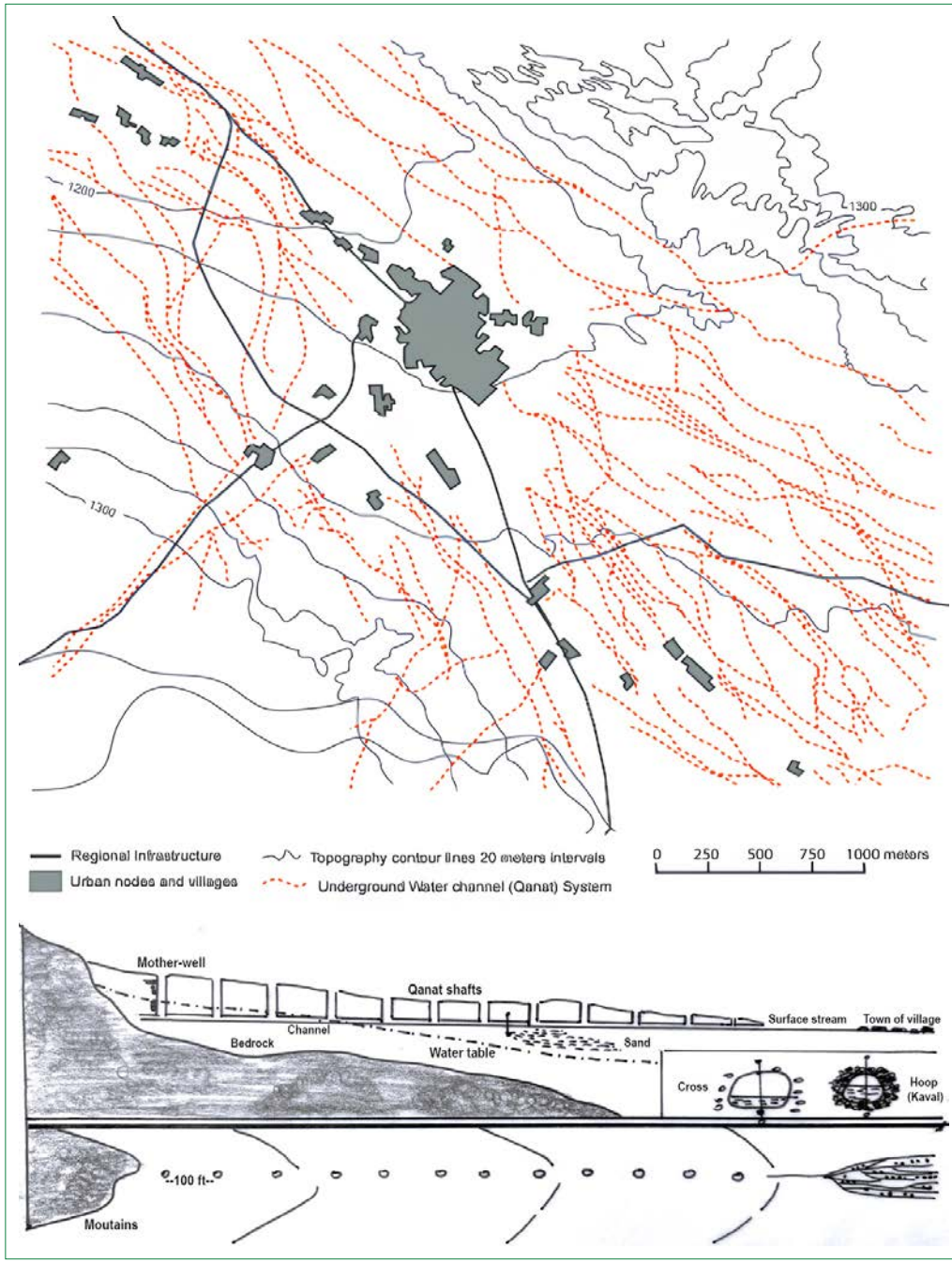

Figure 11. Qanat of the old city of Yazd (sources: 1: Tabrizian, 2010, 2: Abouei, 2006).

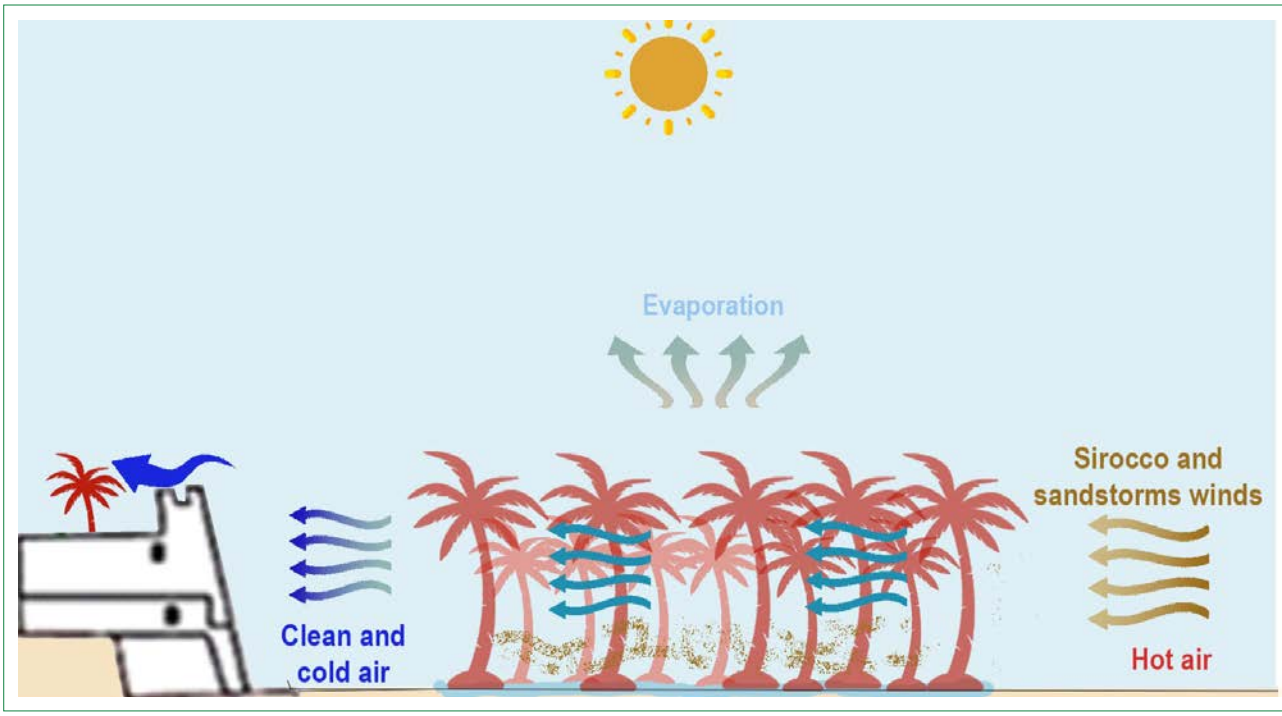

Figure 12. Palm grove system of Mzab ksour (source: Author).

terms of color and climate. What is more, these materials do not require any industrial treatment, which reduces pollution and health risks. The main building material is limestone, quarried from the valley site and used for various structural elements without extensive processing. Bricks made from local clay, sometimes mixed with straw, are also used, offering a recyclable and energy-efficient alternative (Gueliane, 2017). Timchent, a regional plaster derived from locally sourced gypsum, is used both as a plaster and as a binder. Despite certain drawbacks, such as the need for wood as a fuel and the depletion of gypsum deposits, the overall construction process minimizes environmental impact (OPVM). In the context of the M'zab settlements, dead palm wood is used for roofing, in keeping with the belief that living trees support the inhabitants (Aydeniz, 2016). Lime mortar, sand dunes and dates contribute to the exterior finish, providing shade and preventing overheating.

The vernacular houses of Yazd have specific spatial components, including courtyards, entrances (Hashti), short roofs, sitting porches, corridors (Tarme or Dalan), swimming pools, gardens (Hoz and Baghche), and salons (Saloon) (Kashani, 2013). In addition, these components are designed to maximize potential heat in winter and decrease it in summer and focus on environmental sustainability.

The houses in Yazd consist of two main parts: a summer zone and a winter zone. The orientation of the main part of the house is towards the northeast. In summer, the shaded summer zone is the main living space, while the winter zone, located opposite the courtyard, provides access to sunlight for warmth (Keshtkaran, 2011) (Fig. 16).

Courtyards play a very important role in the architecture of houses in Yazd. They act as a central space surrounded by rooms, providing protection from extreme weather conditions such as heat in summer, cold in winter, and sandstorms in desert regions (Keshtkaran, 2011). The courses are considered a valuable design model, minimizing exposure to the elements (Kashani, 2013).

The number of windows opening to the outside is minimized to prevent the penetration of unfavorable climatic elements. Windows and openings are often placed high on walls or ceilings to avoid dust and excessive sunlight. The introverted organization of the house allows most of the windows to open onto the central courtyard, thus providing a more favorable environment (Keshtkaran, 2011).

In Yazd the system of natural ventilation is assured by towers, which work on two basic principles. These structures, known as 'air traps', are designed to capture favorable winds, such as the Isfahan wind, and use them to regulate the indoor climate. Additionally, the summer section of the houses is placed so that its backs are to the south, which helps prevent excessive heat (Keshtkaran, 2011). In addition to air traps, some homes incorporate ponds, plants, or small backyard gardens to create evaporative cooling (Soleymanpour, et al, 2015). Air traps direct cool, moist air into the home, creating a pleasant environment. In summer, the

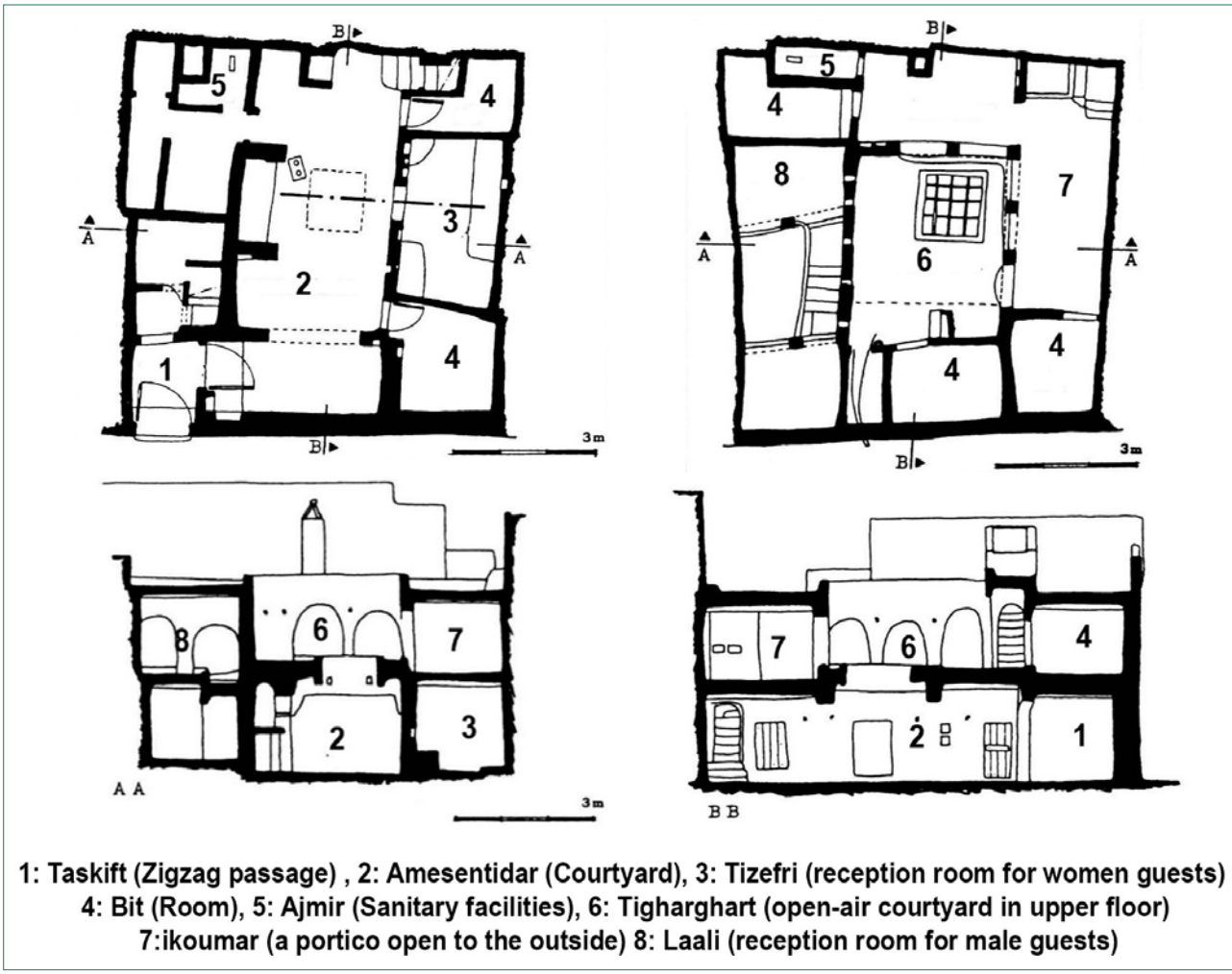

Figure 13. Holistic architectural presentation of typical mozabite house: Plans, sections, and axonometry (Bousquet, 2013).

air trap captures cold night winds, maintaining a cool interior during the morning (Keshtkaran, 2011).

When there is no wind from outside, the towers act as solar chimneys, creating a vacuum effect due to the difference in internal and external temperature. This facilitates the circulation of warm air during the day and cold air at night. Although this ideal synchronization does not always occur, these wind towers play a very important role in the natural ventilation of space (Kavraz, 2017).

They are used to direct wind already moving through the house, providing natural cooling without electricity consumption. The design and height of the wind catchers are adapted to the needs of each family (Kashani, 2013; Soleymanpour, et al, 2015). They draw in clean air and expel dirty air from the building by taking advantage of the movement of air from high pressure to low pressure (Kavraz, 2017) (Fig. 17).

Besides being commonly used in construction, wind towers are also integrated into other structures, such as water reservoirs. In regions with dry climates, their design, linked to water, contributes to increasing local humidity. This goes beyond their functional purpose and gives wind towers cultural, aesthetic, and social significance in Yazd (Kavraz, 2017) (Fig. 18).

Situated in a region known for its distinct architectural and environmental significance, the ancient city of Yazd is integrating solutions to the prevailing problems such as the shortage of timber and its severe weather conditions. Construction materials, especially mud brick, play a significant role in building construction as they are effective and durable in the desert environment as well as being able to retain thermal energy for long periods preventing rapid outward radiation of heat and thus suitable for very hot climatic conditions (Keshtkaran, 2011; Sahebzadeh, et al, 2017). In the construction of the city, there is a more complex system of construction that includes walls, arches, vaults, and domes, as well as decorative parts, such as glazed bricks, ceramic tiles, and plaster (ICOMOS, 2016).

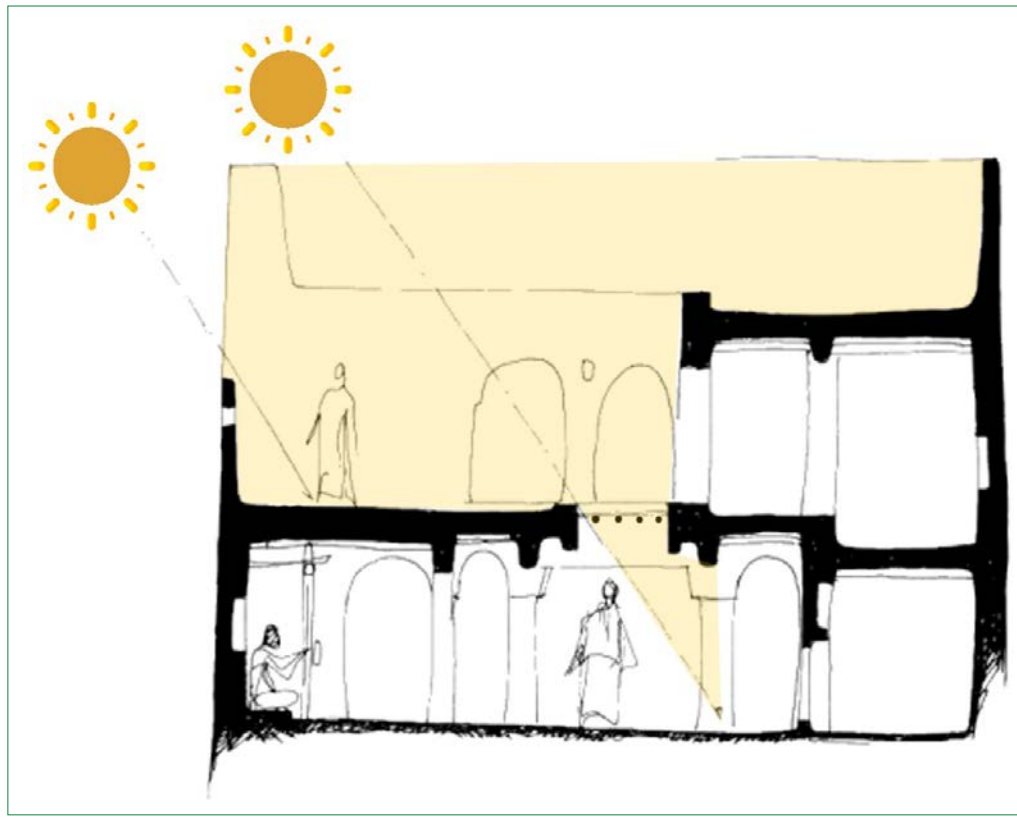

Figure 14. Section through a traditional house in the Mzab Valley showing the used of the terrase and the lighting of the dwelling (Rezaei, 2021).

4. Results and Discussions

Having analyzed the results, we now turn to a detailed discussion of these findings. Environmental and socio-cultural factors have a very strong effect on the design of towns and traditional houses in hot and arid climates, as the case for the Mzab and the city of Yazd. Geography and topography are environmental elements that impact architectural and urban organization. Likewise, the impact of climate is the major factor influencing the materials, form, and orientation of ancient cities. The biggest issue in the design of traditional houses and towns was the use of natural resources such as wind, sun, and rain to adapt to the climate and ensure optimal comfort for the residents of the city, placing this approach in a bioclimatic perspective.

The city of M'zab and the city of Yazd are two optimal examples that represent human know-how and genius in traditional cities, responding to harsh climatic conditions. They have been able to provide innovative solutions for integration and adaptation both on an urban level and on an architectural level. There are points of similarity due to climatic conditions and Islamic culture, such as the patio. However, each of them has brought specificity by using different techniques depending on the available means, but their main goal remains to ensure optimal comfort and to improve living conditions by creating a healthy and natural environment.

A compact and radio concentric urban fabric with narrow and winding streets and alleys provides shade, thus contributing to thermal comfort and better ventilation. The exploitation of aerodynamic principles in construction, which protect against prevailing winds and ensure smooth circulation, is implemented. A joint commitment is the use of sophisticated water management systems, which use gravity for greater efficiency and serve both to irrigate gardens and meet the needs of residents. A city that has been resilient and self-sufficient over the centuries, exploiting agricultural land and orchards beyond its borders to effectively combat high temperatures, represents a point of urban similarity.

In every home in Yazd and Mzab, a courtyard or a patio is almost always present. It acts as a buffer for extreme climatic conditions and also allows for cross ventilation. Here we find a strategic positioning of the openings for the purpose of air circulation with little sun penetration where overheating is avoided. This is also noted in the design of both types of houses where external windows number is limited in order to protect the interiors from unfavorable external conditions. These features illustrate that control of climatization is taken to another level, as well as cooling techniques, showing remarkable devotion to living green. The use of local unprocessed materials in construction is yet a clear indication of

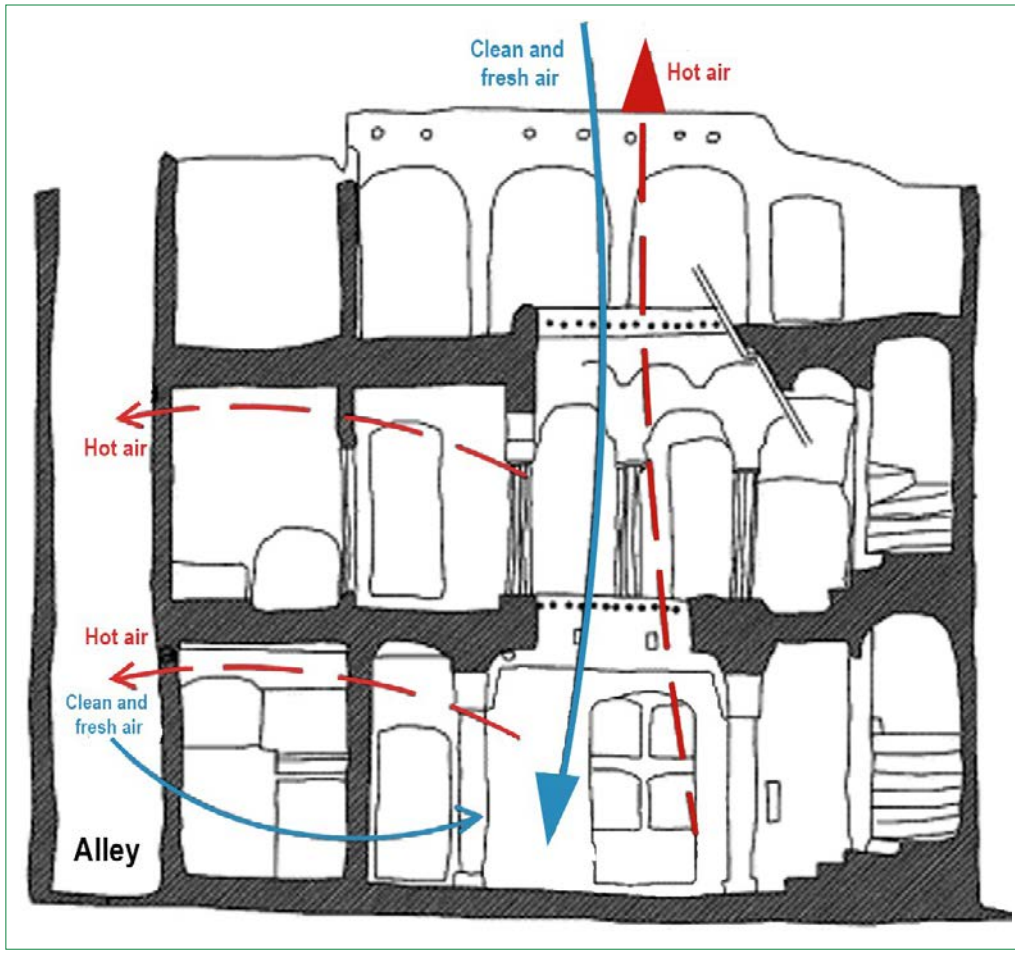

Figure 15. Vertical section through a typical courtyard in M'zab Settlements (Bouchair A., 2004).

their simplicity, eco-friendliness and architectural integration with the environment that brings about similar aspects architecturally. However, despite this similarity, there also exist several differences between the two cities reflecting their geographic, topographic, or climatic integration differently. To begin with, although the radio concentric development has taken place in the city of Yazd, it does not appear to be retained to this day, but rather the urban space has developed into a more geometric one. The case of Mzab is characterized by the fact that no significant modern boulevards were built inside the old city and instead an expansion of the city limits took place, with the old city preserved. This variation is apparent in ksour construction because the ksour in question are situated a top a ridge as opposed to in Yazd.

Despite these points of similarity, there are several points of difference between the two cities, representing their varying approaches to ensuring geographic, topographical, or climatic integration. First, although the city of Yazd has experienced radio concentric development, it has failed to maintain this pattern until today and has instead evolved towards a more geometric urban fabric. The addition of large boulevards inside the old town unlike in Mzab where the old town was preserved and an extramural expansion was carried out, highlights this difference. This difference is explained by the strategic positions of the ksour, which develop on a ridge, which is not the case in Yazd.

Secondly, both cities played a very intelligent role in protecting themselves against the prevailing winds and sandstorms each in their way. We notice a difference in the orientation, the dimensioning, the shape of the roofs, and the size of the houses. For example, the use of mixed terrace and dome roofs in Yazd provided protection from the sun and avoided the stagnation of sand on the roofs. In the case of Mzab, this problem was solved by a very compact urban plan, a stepped layout of the site, and the presence of palm groves, which acted as regulators for a refreshing microclimate and a buffer space for sand winds.

Architecturally, the wind-catchers, the swimming pools, and the vegetation in the patio, as well as the subdivision of summer and winter spaces in Yazd, represented their side, demonstrating the know-how of the inhabitants to ensure optimal interior comfort. Whether through better

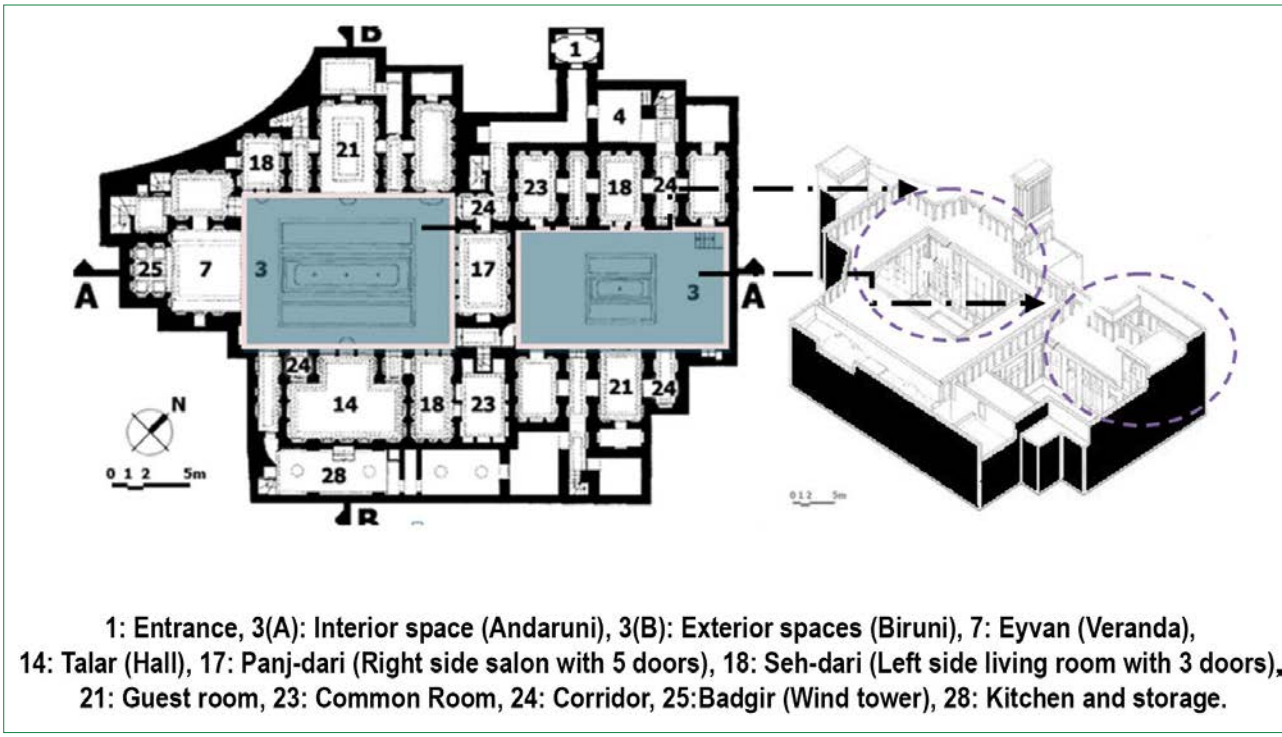

Figure 16. Ground floor plan of Yazd dwelling showing the courtyard design and seasonal subdivision (Kashani, 2013; Nejadriahi, 2015; Bondarabady & Khavarian-Garm, 2018).

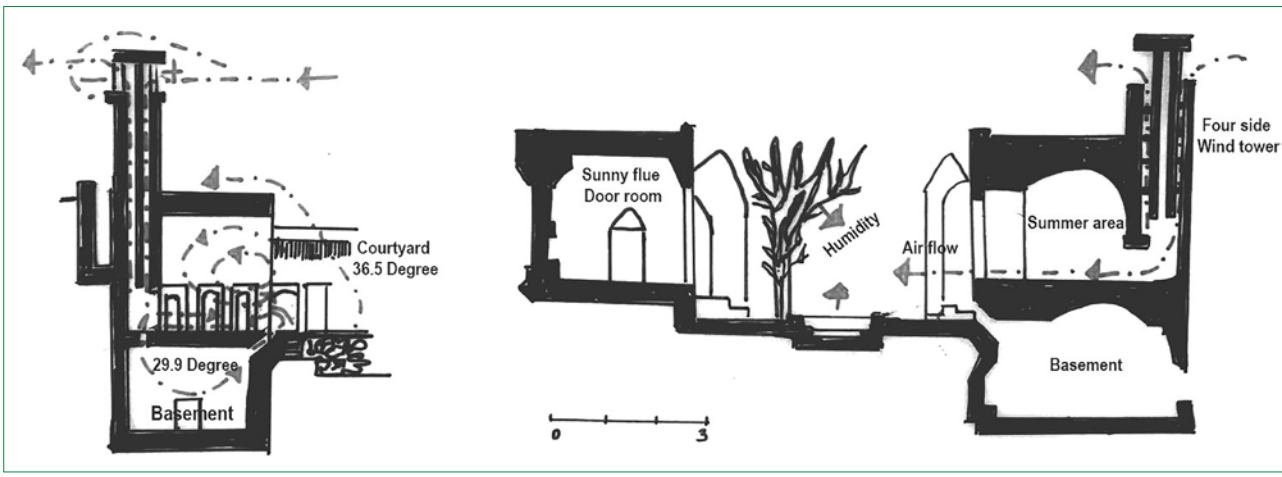

Figure 17. Vertical section through an Air traps and ventilation system and a typical courtyard in Yazd houses (Keshtkaran, 2011).

ventilation, better lighting, or better humidification, these elements contributed to the quality of life of residents. The architecture of the Mzab was more modest and simpler in comparison to Yazd, but despite this, they were able to ensure better interior conditions through the chebeq, the terraces, the opening of the doors for ventilation, and the jars for humidification.

Finally, it can be said that these disparities in the architecture and organization of space are a product of not simply the environment but the specific socio and cultural histories of the regions. Although both cities contain certain Islamic cultural elements, their different historical developments result in different architectural and urban planning strategies (Table 2).

5. Conclusion

It can be concluded that the study of bioclimatic factors in the architectural development of rural cities has the history and principles of sustainable design that are so inherent in the culture and environment where the practice of architec-

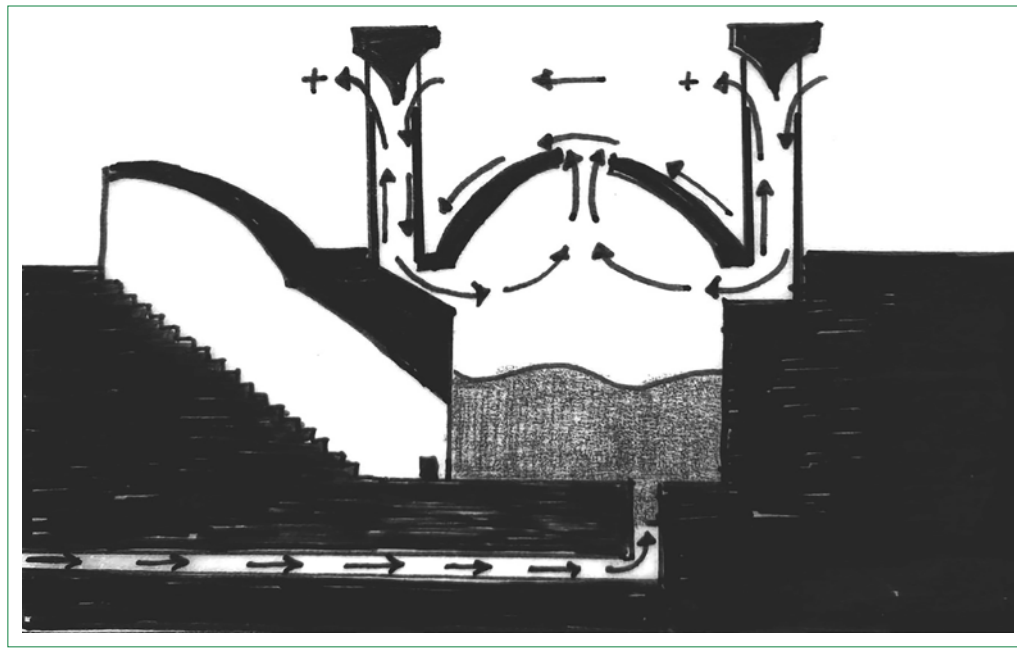

Figure 18. Water tank and ventilation system assured by wind tower (Kavraz, 2017).

ture exists. In the case studies of M'zab and Yazd, we have learned great lessons on how these cities have succeeded for years and decades, offering successful and true models of reconstruction that serve modern urbanists today.

In this regard, it explains how health has been addressed in various studies regardless of the time and place whereas it is maintained that bioclimatic principles have alleviated this problem. According to Manzano-Agugliaro et al. (2015), there is no restriction even limiting the use of these strategies to appeal to certain geographical areas as such regions are highly likely to have comparable climatic characteristics. Also, Coch (1998) talks of wearing out of such structures advocating for their use in architectural vernacular structures, above all, due to their emphatically and practical modernism.

On the one hand, however, our research demonstrates that there are certain limitations with respect to the scope of bioclimatic principles. As stated by Olgyay (1963), some solutions are effective everywhere, but adjustments to the climate and the culture of the place in question must be made. This issue is further complicated by Hammad and Abu-Hijleh's (2010) work on passive cooling strategies for contemporary buildings, which explores the difficulties of combining age-old strategies with modern-day lifestyles and technologies.

Bioclimatic urban design principles at the levels of the orientation and width of streets, the role of vegetation and urban fabric, and other elements are demonstrated in the case studies of M'zab and Yazd. These measures not only increase the comfort of the inhabitants but also support the environmental sustainability and resilience of the inhabitants and the cities to stress factors.

Furthermore, the conclusions from extra studies emphasize cultural architecture as a key factor for future enhancement. Rais (2019) affirms that traditional architectures are survivable in any culture, and that is why solutions put forth here can be enhanced further. In the same way, Kashani (2013) points out the need to look at contemporary buildings in relation to their climates by using architecture that incorporates principles of environmentalism in building design, especially those bearing vernacular designs, which are warm and clean.

In principle, the two temporal eras unity calls for a bioclimatic urban design model. Drawing on positive and negative aspects of places such as the country of M'zab and the city of Yazd as examples, we can find a way to a more responsible, evolutionary, and balanced planning today with regard to existing cities that will serve their populations – both contemporary and prospective. Also, the comparison of cases M'zab and Yazd shows that urbanism is also about climate and sociocultural context. Bioclimatically similar, the two cities studied in this research have noticeable differences in their built environment and urban planning; such differences illustrate the flexibility of an ecologically sound design. Analysis of such variations helps to appreciate the best practices in the given context while recognizing the overarching reality of bioclimatic practices. In comparing M'zab and Yazd, we can extract help for urban design applicable to other portions of the world, adding to the timeline of urban sustainability through various civilizations.

Table 2. Similarities and differences between M'zab and Yazd settlements both in urban and architectural scale

	Differences		Similarities
	Mzab	**Yazd**	
Urban features			
Implementation	• Decentralized system (self-sufficiency) • Small multiple ksur • Surrounded by oasis	• Centralization • Single center city • Surrounded by rural area	• Adaptation to geomorphological landscape • Defensive considerationin urban planning • Climate and enviromental influence
Urban space	• Placed on high rock pinnacles	• Surrounded by walls	• Strategic placement for defuse • Irregular concentric oval shapes • Central mosque presence • Market integration • Introverted urban space
Orientation	• North-west/south-east orientation	• °45 north east/south West orientation	• Dense and compact urban arrangement • Protection against sandy winds and dust • Aerodynamic construction forms
Streets	• Shaded area	• Roofed alleys (sabats) • Mixed roofs (terraces and domes) • Retention of fresh night air	• Narrow and winding streets and alleys • Improved ventilation
Water system	• Minimal water system (foggara)	• Qanat system • Water from deep underground aquifers from mountains	• Sophisticated water management system • İrrigation and resident needs • Long-standing water system
Vegetation	• Sparses greenery (oais)	• Large garden areas	• Effective solution to high temperatures
Architecture features			
Courtyard	• Courtyards with chbek netting	• Courtyards are open area	• Courtyards for ventilation and climate regulation
Opening	• Thermosiphon system • For huminification porous water jars	• Wind catcher • For huminification gardens and ponds	• Strategic openings facilitate air circulation minimize solar gain
Season	• Roof terraces for summer slepping	• Two courtyards for winter and summer	• Use of shaded spaces • Consideration of tempeture variations
Materials	• Limestone, local clay brides, timchent, dead palm wood	• Adobe, glazed fired bricks, tiles stucco and wood	• Local reusable and ecofriendly materials • Excellent thermal capacity

There are opportunities for future studies to analyze the sustainability measures in practice and the innovative ideas which are present in these cities or any other such climatic vernacular cities. Evaluating the current bioclimatic strategies in place and the modifications or innovations that have been made considering the prevailing latest conditions would also help diversify the discussion of sustainable urbanism.

Ethics committee approval: As this study does not involve direct human participation or data that requires ethics committee approval, approval from the ethics committee was not obtained.

Informed consent: All participants were informed about the purpose and scope of the study, and written informed consent was obtained in accordance with ethical principles.

Conflict of interest: The authors declare that there are no financial or personal conflicts of interest related to this study.

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Use of artificial intelligence (AI): No AI-based writing or editing tools were used at any stage of this study.

Authorship contributions: Research/project coordination – D.Y.Y.; Conceptualisation – D.Y.Y., H.S.; Research design and structuring – D.Y.Y., H.S.; Methodology – D.Y.Y.; Data sources and documentation – H.S.; Data collection and/or processing – H.S.; Data analysis and/or interpretation – H.S.; Mapping/visualisation – H.S.; Literature review – H.S.; Writing – original draft – H.S.; Writing – review and editing – D.Y.Y., H.S.

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